MINERAL RESOURCES OF THE APPALACHIAN REGION

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

GEOLOGICAL SURVEY PROFESSIONAL PAPER 580

Mineral Resources of the Appalachian Region

By THE U.S. GEOLOGICAL SURVEY *and* THE U.S. BUREAU OF MINES

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A compilation of information on the
mineral resources, mineral industry,
and geology of the Appalachian Region

U.S. DEPARTMENT OF THE INTERIOR
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MINERAL RESOURCES OF THE APPALACHIAN REGION

By THE U.S. GEOLOGICAL SURVEY and the U.S. BUREAU OF MINES

ABSTRACT

The Appalachian Region, also called Appalachia, extends from southern New York to northern Alabama and Georgia; it includes all of West Virginia and parts of New York, Pennsylvania, Ohio, Maryland, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, and Alabama, an area of 185,000 square miles having a population of 17.3 million. The region is rich in minerals and other natural resources. In the mid-20th-century, Appalachia has a rather low per capita income, a large rural population, high unemployment, and a limited industrial complex. In recognition of the need to solve the social and economic problems, the Federal Government has initiated a program of study and development of the region under Public Law 89–4, of which this study of mineral resources is a part.

The mineral resources of the Appalachian Region have played a vital role in the industrial development and economic growth of the eastern United States. The huge deposits of anthracite and bituminous coal were the principal sources of the Nation's energy during the 18th and early part of the 19th centuries. The abundance and wide distribution of coking coals, iron ores, and fluxing stone gave rise to the important iron and steel centers in and near the region. The oil industry was born in the Appalachian Region, and for many years Pennsylvania, Ohio, and West Virginia were the most important oil-producing States in the Nation. Appalachian clay, sand, feldspar, salines, and a few other mineral commodities have long been utilized by eastern industry. Some of the most beautiful and extensively mined marble in the United States has come from the Appalachian Region. Presently, nearly one-fourth of domestic zinc is produced in the region.

This report evaluates the mineral resources of Appalachia in terms of their geologic setting and distribution, availability, and use, and discusses the past, present, and future roles of the mineral industry. It was prepared by 67 specialists of the U.S. Geological Survey and the U.S. Bureau of Mines. The report consists of three main parts: The introductory part describes the geography and physiography of Appalachia, discusses causes and effects of the current lagging economy in much of the region, and evaluates the mineral industry. This part is followed by a discussion of geology that provides the background for understanding the distribution and relative abundance of mineral commodities; the influence of geology on engineering works is also discussed. The main part of the report consists of 50 sections which deal, in summary form, with history, production, geology, and resources of each mineral commodity that has been produced or that potentially may be produced in Appalachia.

The mineral commodities are: (1) Fuels and related organic materials—asphalt, coal, oil shale, peat, petroleum, and natural gas; (2) construction materials—cement, clay, crushed stone, dimension stone, gypsum, anhydrite, clay and shale for lightweight aggregate, vermiculite, lime, limestone, dolomite, roofing granules, sand, and gravel; (3) nonmetals—abrasives, arsenic, asbestos, barite, feldspar, phosphate rock, fluorspar, gem stones, graphite, kyanite, sillimanite, lithium and beryllium minerals, mica, olivine, brine, rock salt, silica, sulfur, strontium minerals, talc, soapstone, pyrophyllite, sericite schist, and zircon; and (4) metals—bauxite and aluminous clay (for alumina or aluminum), cadmium, chromium, cobalt, nickel, copper, gold, iron ore, manganese, niobium, tantalum, silver, thorium, rare-earth metals, tin, titanium, tungsten, uranium, vanadium, zinc, and lead.

In 1964, total production of mineral commodities in Appalachia was about $2.5 billion, of which bituminous coal, valued at $1.64 billion, was by far the most important. Twelve other mineral commodities accounted for an additional $816 million: (1) petroleum and natural gas ($187 million), (2) crushed stone ($145 million), (3) anthracite coal ($144 million), (4) cement ($142 million), (5) sand and gravel ($50 million), (6) zinc ($37 million), (7) lime ($29 million), (8) clay ($28 million), (9) salines ($19 million), (10) dimension stone ($18 million), (11) copper ($9 million), (12) iron ore ($8 million). Eighteen other mineral commodities accounted for the remaining $32 million.

The fuel resources could support a much larger production. Bituminous and anthracite coal resources have been extensively studied and are well known; they are probably larger than those of any other area of comparable size in the world, Production of petroleum and natural gas also could be increased, but extensive geologic study is required in order to evaluate the total resources. Oil shale deposits, considered to be low grade by present standards, are very large and represent a resource for the future. Peat resources of northern Appalachia are probably large enough to sustain a manyfold increase in production for several decades.

Resources of many construction materials are virtually inexhaustible. Among the most important are limestone and dolomite for general-purpose crushed stone and cement, clay and shale for brick, tile, and lightweight aggregate, sand and gravel, and attractive marble, sandstone, granite, and limestone for dimension stone. Because these materials are used chiefly close to the source, expanded production will logically follow industrial and economic growth of the Appalachian and surrounding market areas.

Resources of nonmetals and industrial minerals such as high-calcium limestone, high-purity silica, high-grade clay, feldspar, mica, salt, and olivine are large, and these materials can be utilized to a much greater extent than at present. Others such as asbestos, barite, kyanite, sillimanite, and talc (including soapstone and sericite schist), occurring in moderate to large amounts, require additional study.

The only Appalachian metal having a large production in terms of national consumption is zinc, and only this metal can be expected to have a greatly increased production within the next decade or two, and continue to be important nationally. The rather small production of lead will increase with zinc output. The potential for finding new low-grade, but economic, copper-bearing sulfide deposits is good, and their exploitation would result in substantial increase in copper and sulfur output.

Even though the Appalachian Region has had a long history of mineral prospecting, many of its mineral resources are still imperfectly known, and systematic exploration is needed to assess their future potential. The following are among the most urgent: A search should be made for deep petroleum and natural gas, which are virtually unknown because production to date has been from shallow fields. The distribution and quality of high-grade silica, limestone, clay, and salines should be determined. The ultramafic rocks of southeastern Appalachia should be studied to evaluate their resources of olivine, asbestos, and vermiculite. Zinc deposits and massive copper-bearing sulfide deposits should be investigated to determine ore controls that will aid in the search for hidden ore bodies.

INTRODUCTION

The Geological Survey and the Bureau of Mines initated in 1965 a special examination and analysis of the distribution, magnitude, and economic significance of the region's mineral resources. The results of this study, which was undertaken with the advice and help of appropriate State geological and mining agencies, are presented in this report.

The Appalachian Region as defined in Public Law 89–4, March 9, 1965, extends through a 12-State region from southern New York to northern Alabama and Georgia; it includes all of West Virginia and parts of New York, Pennsylvania, Ohio, Maryland, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, and Alabama (pl. 1). The region also is known as Appalachia and is so referred to throughout this report. It is mainly a dissected mountainous and highland area; it covers some 185,000 square miles and has 17.3 million inhabitants (1960 census). Low income and unemployment are serious problems in many parts of the region, and their effects are not only disadvantageous to the people of Appalachia but costly to the Nation. Regional economic development of Appalachia has therefore been adopted as a national program of high priority. The present study contributes a foundation of resource data to this program that should serve to stimulate and guide development of resource-based industries.

This report summarizes information on the geology, mineral resources, and minerals industry of the Appalachian Region, giving special attention to appraising the mineral resources and assessing the role of the minerals industry in the future. It is mainly a compilation and synthesis of data available in many published and unpublished reports (see "References cited" at end of report), supplemented by the firsthand knowledge of those who collaborated in its preparation. As far as possible the report is written in nontechnical language, so that it may be of use to officials and businessmen interested in development of mineral-resource-based industries as well as to engineers and geologists who are directly concerned with mineral exploration and mining. Because it is a summary of a vast amount of information on this classic geological region, the report also should be of interest to the student and teacher.

Preparation of a report on a region as large and as diverse geologically as Appalachia required the cooperation of many persons and agencies other than the authors themselves. Thor H. Kiilsgaard of the Geological Survey and Robert B. McCormick of the Bureau of Mines were in charge of the overall project. George E. Ericksen was the principal coordinator and editor of the report; Robert A. Laurence assisted in its assembly and contributed from his rich store of firsthand knowledge of the Appalachian Region. Editorial and coordination assistance also was given by Alfred J. Bodenlos, Dennis P. Cox, Alice E. French, and Robert A. Weeks, all of the Geological Survey. The "Mineral Commodities" sections and a few of the other sections were reviewed by the following State Geologists and staffs of State agencies, who also contributed valuable information and advice: Philip E. LaMoreaux, State Geologist, and Otis M. Clarke, Jr., Thomas J. Joiner, Thornton L. Neathery, Thomas A. Simpson, W. Everett Smith, and Michael W. Szabo, Geological Survey of Alabama; A. S. Furcron, Director, and J. H. Auvil and James W. Smith, Department of Mines, Mining and Geology of Georgia; Wallace W. Hagan, Director and State Geologist, and Preston McGrain and Edward N. Wilson, Kentucky Geological Survey; Kenneth N. Weaver, Director, and Emergy T. Cleaves, and Jonathan Edwards, Jr., Maryland Geological Survey; John G. Broughton, State Geologist, and James F. Davis and Karen J. Lukas, Geological Survey, State Museum and Science Service of New York; Stephen G. Conrad, State Geologist, Division of Mineral Resources of North Carolina; Ralph J. Bernhagen, Chief, and Horace R. Collins, Karl V. Hoover, and David K. Webb, Jr., Ohio Division of Geological Survey; Arthur A. Socolow, State Geologist, and Bernard J. O'Neill and Davis M. Lapham, Bureau of Topographic and Geologic Survey of Pennsylvania; Henry S. Johnson, Jr., State Geologist, Division of Geology of South Carolina; W. D. Hardeman, State Geologist, and Stuart W. Maher, Division of Geology of Tennessee; James L. Calver,

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APPALACHIA: PROBLEMS AND OPPORTUNITIES

By V. E. McKelvey, U.S. Geological Survey

Appalachia has the mineral resources to support extensive industrial and urban development. Its rich and widespread deposits of coal and other sources of energy, its diverse resources of metalliferous, chemical, ceramic, and construction minerals, and its abundant water supplies are the physical ingredients for a wide range of industrial activities. These resources form the potential nucleus for accelerated economic development and growth.

Currently, the mineral industry of Appalachia is sometimes identified as the source of some of its gravest economic and social problems rather than as the key to its future economic growth, and technological changes affecting coal mining and marketing have indeed brought about widespread unemployment and loss of local income in Appalachia. Much of Appalachia's current mineral production is marketed outside the region, and if this pattern were to continue, even expanded mineral production would do little to spark economic development in Appalachia itself. The root of a new prosperity for Appalachia lies not in increased mineral production in itself, but in increased internal use of energy and raw materials in value-adding industries.

This section identifies some of the origins of Appalachia's economic distress, outlines the role minerals can play in economic development, and points to some of the opportunities for mineral-based economic development. As in the remainder of the volume, the emphasis is on the role of mineral resources in economic development; other aspects of the problem, some of which are of equal or greater importance, are treated only briefly or not at all. This neglect arises not from lack of awareness of the importance of other phases of the development problem, but from attention to the central purpose of the volume. The broader problems are summarized in the report of the President's Appalachian Regional Commission (1964).

A note of caution should be sounded here concerning the limitations in treating Appalachia as a unit, and in generalizing about its problems and opportunities (see also President's Appalachian Regional Comm., 1964, p. xv-xviii). Appalachia is not homogeneous in the distribution and nature of its resources or in its present state of development. Parts of Appalachia are prosperous, and some of its cities are industrial centers already pyramiding a wide variety of manufacturing and related activities from the local resource base. Opportunities for economic growth therefore differ in extent and character from one area to another. Moreover, Appalachia is not a closed or unified economy. Economic problems and needs for a given area are likely to be more closely linked to problems and needs in surrounding areas than to those in other parts of Appalachia. Nevertheless, urban and industrial growth will benefit all parts of Appalachia, and it is the thesis of this volume that mineral resources are available to serve as the base for expanded industrial development throughout the region.

SOME OF THE PROBLEMS AND THEIR ORIGIN

THE RESOURCE-WEALTH PARADOX IN APPALACHIA

The economic status of nations has sometimes been expressed in terms of the "haves" and the "have nots." The economically affluent nations supposedly have been those with a rich natural-resource base, whereas the poor nations supposedly have been those without abundant resources. Considered under this concept, Appalachia is a paradox, for it has abundant resources of some of the most valuable kinds—fuels, minerals, water, forests, wildlife, and scenery—and yet its average per capita income is only about 68 percent of the national average per capita income. By the "have" and "have not" economic theory, the extent to which Appalachia's resources have been exploited, that is, the extensive past production of coal, timber, and a few other resources, should have made the area wealthy indeed.

The fact that production of these valuable resources in Appalachia has not resulted in a faster rate of economic growth has been disillusioning to many, and has led some to conclude that Appalachia's future must be built on some other base. Coal, for example, seems to be considered by some to be a liability now rather than an asset, for many of the ills of Appalachia—a substantial part of its unemployment problem, and the damage to land, water, and scenery arising from strip mining and acid mine drainage—are directly identified with the coal industry. Instead of envisioning coal as the source of power for industrialization within Appalachia, some of the disillusioned think only of covering it up, of sealing existing mines, and forgetting the coal as soon as the remaining scars of the industry will allow.

The have-have not concept is no longer widely held, for economic development is now understood to be influenced and controlled by many other factors besides natural resources (for example, see Hirschman, 1958). Still, natural resources—together with the human resources necessary to exploit them constructively and imaginatively—do form the basis of economic development. Why, then, did they not do so in Appalachia?

THE WEAKNESS OF AN EXTRACTIVE ECONOMY

This question is complex, and the answer to it has many parts. Principal among them, however, is that the resource industries of Appalachia were extractive, not only in the sense that the materials were removed from the ground, but also in the sense that they were exported from the region and used elsewhere. To quote from the analysis of the President's Appalachian Regional Commission (1964, p. 20): "Where a society depends primarily on the extraction of natural resources for its income and employment—as did the people of Appalachia—it is extremely important that a high proportion of wealth created by extraction be reinvested locally in other activities. The relatively low proportion of native capital did not produce such a reinvestment in large sections of the region. Much of the wealth produced by coal and timber was seldom seen locally. It went down stream with the great hardwood logs; it rode out on rails with the coal cars; it was mailed between distant cities as royalty checks to nonresident operators who had bought rights to the land for 50 cents or a dollar an acre. Even the wages of local miners returned to faraway stockholders via company houses and company stores." Appalachia's resource industries were few and highly specialized, forming the one- or two- "crop" economy that received the full brunt of fluctuations and changes in the outside market.

Even so, Appalachia's resource industries did produce great wealth—elsewhere. Although Appalachia itself has only seven major cities with populations of more than 100,000 the surrounding region, which includes the great metropolitan areas of New York, Philadelphia, Cleveland, Cincinnati, Buffalo, Baltimore, Washington, and Atlanta, contains 30 cities of more than 100,000 people within 100 miles of Appalachia's boundaries. Appalachia's coal, and to an important extent its oil and gas also, provided the greater part of the energy that supported the industrial growth of the eastern United States, and in this and other ways Appalachia has played the part of a resource truck-garden to the surrounding region.

ROUGH TERRAIN AS A DETERRENT TO DEVELOPMENT

With superabundance of timber and coal, Appalachia served as a source of supply for the surrounding region, but why did it not also develop industrially itself? Why did investment in manufacturing concentrate in surrounding areas? Some industrial capital was invested in Appalachia, of course, in Pittsburgh and a few other areas that not only had local access to key mineral resources but that were located close to the border of the region on favorable transportation routes. But compared to the adjacent region, most of Appalachia's rough terrain is a formidable barrier to access and transportation and an inhospitable setting for town and plant development and even for farming. Nearly all of Appalachia is hilly or mountainous; in very few localities is more than 20 percent of the land gently sloping or is the local relief less than 500 feet. Appalachia was therefore literally bypassed by the bulk of the people and enterprises in a developing America in favor of surrounding areas. From the start, then, the principal demand and market for Appalachia's resources grew in the surrounding region. The centers of industrial activity that did develop in Appalachia were close to its margins, oriented to the needs of the denser population centers in adjacent areas.

CURRENT STATUS

The Appalachian economy is now changing. Coal mining and agriculture have been displaced by manufacturing and services as the dominant activities of the bulk of the population. Nevertheless, the original sources of Appalachia's economic underdevelopment continue to be heavy contributors to it: its mineral crop is still relatively specialized, and the bulk of it is mined for export. With an urban population of only 47.5 percent, compared with 72 percent for the rest of the United States, Appalachia remains weak in the high-income producing activities that characterize the U.S. economy as a whole. The tower of income derived from the use of Appalachia's energy and raw materials is therefore still building up elsewhere.

The terrain in Appalachia also remains an obstacle to regional development, but with the bulldozer to open the way for the highway and to level the ground for the plant, terrain is not as formidable an obstacle as it was. Moreover, since rising affluence has allowed increasing numbers of people to enjoy the luxury of leisure time and natural beauty, Appalachia's rugged terrain has become an economic asset as an attraction for tourists and sportsmen. However, tourism and recreation alone will not raise the income of Appalachia's comparatively large population to a satisfactory level, but as new and expanding sources of income they will help. With an already rich resource base broadened by new values and with more efficient and cheaper means of molding and taming its terrain, Appalachia has a high potential for economic growth.

SOME PRINCIPLES OF ECONOMIC DEVELOPMENT

RAW MATERIALS, ENERGY, AND INGENUITY AS THE BASIC INGREDIENTS OF WEALTH

Many diverse factors play a part in economic development, but resource utilization is one of the most important. In order to show its essential role and at the same time to show its broad relation to some of the other factors on which a high level of living is based, the fundamental factors that determine level of living are briefly discussed. If we think of level of living as the amount of goods and services consumed, this level is plainly low if the average individual has to exert much time and great physical effort to satisfy his minimum needs for food, clothing, warmth, and shelter; and the level is high if he can obtain luxuries as well as necessities at the expenditure of little time and effort. This principle means that the more raw materials (for example, water, fibers, and materials for making tools and dwellings) easily available, the higher the potential level of living. It takes work, however, to gather and use these materials effectively, and over the millenia man has found many ways of getting this work done for him; he has thus reduced the effort required to satisfy his needs and wants. Animate energy—man and domesticated animals—was used first for this purpose, but the greatest gains have come from discovery of means to utilize inanimate energy—that is, power from wind, water, and especially fossil fuels.

The widespread use of inanimate energy, especially as it is used to power machines, is, of course, the most important tangible basis for the high level of living enjoyed by many western countries today for it makes possible the production and consumption of large quantities of goods and services without much physical effort. The essence of this wealth, however, is something less tangible—namely, human ingenuity, defined in the broad sense as the collective ability of a group to obtain, distribute, and use raw materials and energy efficiently. Summing all this up, we can say that a group's total consumption of goods and services is a function of the use it makes of all kinds of raw materials, all kinds of energy, and all kinds of ingenuity (McKelvey, 1959). The amount available for the individual, of course, decreases roughly with the number of people that must share the total. Expressed in the form of a simple equation, the relation among these factors is approximately:

$$L=\frac{R \times E \times I}{P}$$

where L is the level of living of the average person, R is the total useful consumption of all kinds of raw materials by the society, E the total useful consumption of all forms of energy, I the total useful consumption of all kinds of ingenuity (socioeconomic ingenuity as well as technologic ingenuity), and P the total number of people who must share the society's product. This equation is conceptual rather than operable, because specific values cannot be assigned to some of its components; moreover, R and E are not wholly independent of I, for the constructive use made of natural resources (and even their very magnitude) is in large part a function of human ingenuity. Nevertheless the expression serves to broadly identify human activities and the intelligent use of resources as the essential elements of income, and it brings out another important point: there is a certain flexibility in the composition of the income-producing mix, for the use of a larger amount of one element will offset the use of a smaller amount of another in a given instance. It is no surprise, of course, to find that there is more than one route to wealth, for many countries and communities do indeed draw on different combinations of skills and resources to produce comparable incomes. In spite of this flexibility, however, there is a remarkably consistent relation among the countries of the world between their consumption of energy and metals and their level of living, and the high-income economies are almost entirely those built around extensive use of machines and advanced technology.

Although the basic elements of income are those broadly described in this equation, their mere existence or availability in a country is nothing more than a potential. To be of benefit to the level of living, they must be constructively used. For example, mineral resources must be found and mined; and if they are mined, they must be used by the country or traded directly or indirectly for things it does not have. Stated differently, resources undiscovered and unused are of no benefit to the level of living, and ores and fuels extracted and exposed from an underdeveloped region or country yield to the local population only a small proportion of the ultimate value derived from their use.

ROLE OF CAPITAL

An extremely important part of the constructive use of materials, energy, and ingenuity is the formation, accumulation, and use of capital, consisting not only of produced goods but also productive agents—improved land, tools and machines, factories and buildings, transportation and communication systems, power stations, knowledge, training, and so on. Capital is the very essence of productive capacity, and in terms of the conceptual equation above it should be understood that R, E, and I each include a component of capital that must increase to improve the return or income derived from a given input of materials, energy, and human activity. Capital is formed from natural and human resources, and time is required for its accumulation. It can be transferred from one area to another by physical transport or by money exchange, however, and its investment (that is, the introduction of productive agents) in a given region or industry is literally an investment in improved productive capacity with the expectation of increased production and efficiency. Its effects on income are apparent not only in the differences in income between industrialized and nonindustrialized countries, in which productive agents are used in conspicuously different degrees, but also within the industrialized countries. In the different regions of the United States and within individual industries, for example, there is a direct relation between the capital-labor ratio and income per worker (Perloff and others, 1960, p. 105, 603).

The high role of capital in economic development and growth should not obscure the fundamental importance of raw resources both as they are consumed directly and as they are used to form new capital and replace old. As previously mentioned, among the countries of the world, and in individual countries over their history, there is an almost straight-line relation between per capita income and consumption of steel, energy, and other key commodities. Much of this consumption goes into the formation of productive agents, and although these agents wear out in time and have to be replaced, some evidence in the United States and other developed countries indicates that as the capital inventory reaches a substantial size, the rate of increase in per capita consumption of energy and materials diminishes somewhat. Technologic advances that increase the technical efficiency in the use of energy and materials have a similar effect, and combined with growth in capital inventory they help increase the income derived from a given input of raw resources. But however the ratio may change, increase in input of raw resources is vital to economic development and growth.

THE VALUE OF INDIGENOUS RESOURCES

It is worth emphasizing that the level of income in a given society is related to the consumption or utilization of R, E, and I, and not to their production in that society. It is in the use of these basic ingredients that their full value is realized and, as previously mentioned, a tower of income many times higher than their value in the raw state develops as they are progressively transformed and utilized. These basic ingredients are truly the acorns from which big oaks grow and thus they can be imported if they are not available locally. Each region or nation has to satisfy some of its needs from imports, and some countries without substantial indigenous resources import the bulk of their supplies and are able to derive a high income from their use.

The lack of indigenous natural resources is therefore not an overwhelming obstacle to economic development, but their availability is a tremendous asset. Minerals and fuels are expensive to transport and if those used in large volume are available near the point of use, substantial savings result; other factors being the same, the products made from them can be sold at a lower cost and can compete for markets over a wider area. A going community able to draw on local resources not only satisfies its own needs at lower cost but may be able to parlay its savings into expanded production of manufactured goods for a regional or foreign market.

There is a still greater advantage in indigenous resources to a developing region, stemming from the multiplier effect of new industry. Any new industry in an area has a backward-linked multiplier effect, for it is inevitably trailed by service and supply enterprises that create additional employment and add to the economic activities of the area. Some industries, however, also have a forward-linked multiplier effect, for they set the stage for the development of a succession of other industries that use their products. Primary resource industries—mining, oil and gas production, agriculture—are mainly forward linked; final manufacturing industries, such as clothing manufacture, are mainly backward linked; and intermediate manufacturing industries—such as iron and steel, petroleum refining, and chemical manufacture—have both a forward and backward linkage (H. B. Chenery and T. Watanabe, in Hirschman, 1958, p. 106).

Backward-linked industries may have a strong effect on economic development. If they are located in a given area in advance of the development of other industries (as they may be if the existing population is sufficiently large), they establish a firm local demand for supplies and services, and thus create a strong incentive to develop local industry (see Hirschman, 1958, p. 109 for argument for backward-linked industry as stimulants to economic development). Forward-linked industry does not establish local demand (except in a small way as noted above) but instead creates supply, a less certain attraction to new enterprise than firm demand, but an element with a far greater potential multiplier effect per unit of initial investment or employment. A hosiery and a coal industry will both stimulate backward-linked industry, but under favorable circumstances the coal industry may also form the base for an iron and steel industry, a chemical industry, and a train of others (Perloff and others, 1960, p. 94–97).

The "favorable circumstances" under which a resource may attract manufacturing and related industries to the region are broadly those in which access to inputs at competitive costs is more important for the higher industries than access to markets for their outputs (Perloff and others, 1960, p. 75). The availability of the resource is therefore often an important and positive factor working on behalf of the industrial development of a region.

The advantages of indigenous resources multiply where the assemblage of available minerals is diverse and especially where it includes low-cost mineral fuels or hydropower. If cheap energy is not available, valuable minerals are likely to be shipped elsewhere for processing as well as fabrication; but if cheap energy is available, economies result from local processing, and the combined availability of refined materials and energy adds incentive for local development of manufacturing industries. Historically, heavy industry has tended to develop in the vicinity of sources of cheap energy, and although improvements in energy transport make this factor less critical than it was formerly, areas with cheap local sources still have an edge in supporting a manufacturing industry. For developing regions, this edge may make the difference between an easy and a difficult road to economic growth.

THE TOWER OF INCOME IN AN INDUSTRIAL SOCIETY

Examination of the sources of income in the United States shows the part that various activities play in producing income in an industrial society. The contribution from major sources in 1960 is shown in table 1.

Table 1 shows that the direct income from the production of raw materials is comparatively small; in particular, the income from mining (including oil and gas) and agriculture is only 5.4 percent of the total. A substantial part of the total, however, comes from the manufacturing, construction, and communication industries that use minerals and fuels as raw materials; without these industries most of the other income-producing activities could not exist. Modern agriculture itself may be counted as one of the industrial activities dependent on minerals and fuels, for inanimate energy, machines, and mineral-derived fertilizers and insecticides are now its essence.

TABLE 1.—*Sources of U.S. national income (1960)*

[Source: U.S. Bur. Census, 1965, p. 330]

	Percent
Agriculture, forestry, and fisheries	[1] 4.1
Mining	1.3
Contract construction	5.4
Manufacturing	[2] 29.2
Wholesale and retail trade	16.6
Transportation	4.3
Communications and public utilities	[3] 3.9
Finance, insurance, and real estate	10.3
Services	11.9
Government and rest of world	13.0
	100.0

[1] About one-third of total from livestock and about a tenth from forest products.

[2] About two-thirds from industries based on minerals.

[3] About half from electric and gas utilities.

The great bulk of the United States national income is earned in activities that are essentially urban rather than rural, and this is true of other developed countries also. There is a direct relation between per capita income and per capita consumption of energy among the countries of the world, but there is an inverse relation between per capita income and the percentage of the population engaged in agriculture. The level of living enjoyed in the United States is one attainable only by a machine-based economy.

MINERALS UTILIZED BY AN INDUSTRIAL SOCIETY

The common popular concept of mineral resources tends to overemphasize the importance of minerals like gold, gems, and oil and to overlook the fundamental importance of more prosaic resources such as water and construction materials. It may be informative, therefore, to examine briefly the complex of raw materials that are actually used by a modern industrial society such as the United States which has an extremely broad and diversified economy. It should be understood, however, that the pattern of use of raw materials in the United States is not the only one that will support a high level of living.

The relative values of the main classes of raw materials are shown in table 2. These data show clearly that the value of agricultural and forest products far exceeds that of minerals, even in an industrial society. The data also show the vital role that minerals play in the economy, for whereas the per capita consumption of nonmineral raw materials has not changed much, the increase in the per capita consumption of minerals in the period 1900–1960 is closely parallel to the rise in per capita income over the same period. In other words, the level of living in the United States has risen somewhat in proportion to increased consumption of minerals and fuels.

Table 3, which focuses more closely on the minerals consumed in the United States, shows the relative values of the main classes of minerals produced and consumed in the United States in 1960. Note that fuels far outrank metals and nonmetals in their value, that nonmetallic minerals outrank metals and that imports of nonmetals are relatively small, whereas imports of metals are relatively large. Some of these data are amplified in table 4, which lists the principal groups of mineral commodities consumed in the United States. About 40 minerals are consumed in amounts annually valued at $20 million or more, and an additional 100-150 are consumed in lesser amounts.

TABLE 2.—*Per capita consumption of raw materials in the United States*

[Source: Comsumption data from Spencer (1964, table A4, p. 94). Population and per capita gross national product from U.S. Bur. Census (1965, p. 5, 327)]

	1900		1960	
	Value, in 1958 constant dollars	Percent of total	Value, in 1958 constant dollars	Percent of total
Agricultural materials	166.2	70.4	179.8	57.2
Fishery and wildlife products	3.7	1.5	4.9	1.6
Forest products	37.2	15.7	18.4	5.9
Subtotal	207.1	87.6	203.1	64.7
Minerals, except gold	29.2	12.4	109.9	35.3
Total	236.4	100.0	313.0	100.0
Per capita gross national product	$747		$2,704	
Total population	76,094,000		180,684,000	

TABLE 3.—*Production and apparent consumption of minerals in the United States in 1960, in millions of 1958 dollars*

[Source: Spencer (1964, table A11, p. 107)]

	Production	Imports	Exports	Apparent consumption
Fuels	12,571	2,111	442	14,240
Nonmetals	2,813	326	152	2,987
Metals, except gold	1,615	1,663	677	2,601
Total	16,999	4,100	1,271	19,828

TABLE 4.—*Value of apparent consumption of minerals (except gold) in the United States in 1960*

[Source: Spencer (1964, table A11, p. 107)]

	Value in millions of 1958 constant dollars	Percent of total
Mineral fuels:		
Coal	2,089	10.5
Crude oil	9,785	49.4
Natural gas	1,568	7.9
Natural gas liquids	798	4.0
Subtotal	14,240	71.8
Ferrous metals:		
Iron	816	4.1
Manganese	219	1.1
Tungsten	50	.3
Others	237	1.2
Subtotal	1,322	6.7
Nonferrous metals:		
Silver	61	.3
Copper	622	3.1
Lead	144	.7
Zinc	118	.6
Bauxite	108	.5
Others	227	1.2
Subtotal	1,280	6.4
Construction materials:		
Dimension stone	68	.3
Crushed and broken stone	1,000	5.1
Sand and gravel	708	3.6
Fire clay	49	.2
Common clay and shale	45	.2
Gypsum	50	.3
Others	97	.5
Subtotal	2,017	10.2
Chemicals:		
Potash	100	.5
Phosphate rock	85	.4
Sulfur and pyrite	164	.8
Others	359	1.8
Subtotal	708	3.5
Other nonmetals:		
Abrasives	51	.3
Others	210	1.1
Subtotal	261	1.4
Total, all minerals	19,828	100.0

The total value of mineral construction materials used in the United States—that is, common minerals such as stone and sand and gravel that many people don't even think of as mineral resources—is greater than that of iron and ferro-alloy metals (table 4), and far more valuable than the precious metals. Soil, water, and construction materials, of course, are the most essential raw materials for any society, be its base industrial or agrarian, for they are the source of the basic necessities of food, clothing, and shelter. However, transportation costs are high compared to unit value, and it is impractical to transport them long distances.

Important as construction materials and other nonmetals are, the key resources for industrialization are nonetheless metals and fuels, used for machines powered by inanimate energy. The significance of the use of inanimate energy may be illustrated by comparing the cost of the physical work it will do with that which can be done by human efforts. For example, a gallon of gasoline burned in a conventional gasoline engine produces about 8 horsepower hours, which is as much energy as can be produced by 25 laborers working an 8-hour shift on a food intake of 3,500 calories per day. The fuel cost alone, at a gasoline price of $0.25 per gallon, is equivalent to buying labor at about 1 cent per man day (Slichter, 1959, p. 368). Defining a high level of living as the condition in which man's needs and wants for shelter, warmth, food, clothing, transportation and so on are fulfilled with little expenditure of energy on his part, it is easy to see that the high level of living of industrial societies is founded more on the use of large quantities of inanimate energy than anything save ingenuity itself.

To summarize these observations, an industrial society utilizes a wide variety of resources. The most essential ones for a country or region to have within its own boundaries are usable soil, water, and construction materials, for they are difficult, if not impossible, to import. Metals, fuels, and chemicals are essential for industry, but no region is or can hope to be self-sufficient with respect to all of these materials. The fewer that have to be imported, however, the better, and a wide resource base may give a region an advantage in attracting the investment capital needed to begin or expand industrial development, especially if low-cost energy is available.

ROAD TO ECONOMIC DEVELOPMENT IN APPALACHIA

From this brief outline of the principles of economic development and the structure of a high-income producing economy, the road to further economic development in Appalachia becomes clear. Appalachia must expand and diversify its industry and to do so it must increase its internal utilization of energy and minerals as the base for manufacturing, and take maximum advantage of indigenous resources, both to reduce manufacturing costs and increase the competitiveness of its products and to attract investment capital to the region. And it must make imaginative and extensive use of the topographic map and the bulldozer to select and develop construction sites and transportation systems that will mitigate if not remove the drawbacks of its terrain.

Among the component steps necessary for Appalachian development, terrain mitigation and development of cheap electric power are among the most critical, and neither will take place without a concerted effort to bring them about. As previously mentioned, the difficulty of natural access to Appalachia and its rough terrain have hindered urban development. Advances in technology now make victory over these handicaps possible at fairly low cost, but they remain nevertheless as obstacles that will have to be deliberately attacked. The needs of existing and potential Appalachian industrial complexes for cheap access to local raw materials and markets are especially critical, and probably will not only require the new highway systems already planned, but improved transport systems of other kinds as well.

The existing pattern of power manufacture and utilization is almost as firmly set as the terrain, and concerted effort will be required to establish a new one. With manufacturing well developed in the surrounding regions, the natural tendency is to continue to design Appalachia's coal industry for energy export, and it will take bold steps, perhaps better described as bold gambles, to make cheap power internally available for new manufacturing industries. In the key steps of terrain mitigation and internal power utilization, as well as in many others, the public authorities and public-spirited organizations at national, State, and local levels will have to work together to set the stage for a new pattern of urban development, manufacturing, and trade.

Very large capital investment will be required for new or expanded mines, mills, plants, cities, transportation systems and other elements of an industrialized Appalachia. Much of the required capital will have to come from outside Appalachia, as is nearly always true of regional development, but because it should yield viable, self-sustaining industrial enterprise, the capital requirements should be met without difficulty.

ALTERNATE ROUTE TO AN ADEQUATE LEVEL OF LIVING

There is only one route to economic development in Appalachia, but there is an alternate route to higher level of living for its people, namely continuing out-migration to achieve a population level that can be supported by existing industries (including the extractive ones) plus an expanded tourist and recreation industry. The tourist industry almost certainly will expand considerably and should contribute importantly to economic growth in Appalachia. In itself, however, or with existing industry, it will not support Appalachia's comparatively large population (six times that of Utah and Colorado, which together are of comparable size and have well-developed tourist industries) at an acceptable level.

At other periods of history, out-migration has been taken as the solution to a similar situation in other countries (for example, Ireland and Sweden) and in other regions of the United States. At both the regional and national levels, this solution is not considered an acceptable one for Appalachia, and in view of

Appalachia's rich natural resources it would indeed be a mistake not to develop its full potential. Appalachia has the resources to support a larger population than it has now at a higher level of living and to contribute importantly to national economic growth.

It should be noted that it is out-migration, not the development and use of Appalachia's touristic and recreational resources, that is an alternative to greater industrialization. Growth of Appalachian industry will bring about urbanization, reduce the rural population, and open the way for fuller development and use of the region's scenic and recreational resources.

OPPORTUNITIES FOR MINERAL-BASED INDUSTRY IN APPALACHIA

The opportunities for new and expanded manufacturing based on indigenous mineral resources in Appalachia are both diverse and bright. Several of the minerals most important to industrial development are already being produced in Appalachia (fig. 1) and, as will be shown in subsequent sections of this report, the known resources of many of the commodities that underpin manufacturing, construction, and transportation are adequate to support expanded production. There is in addition a substantial potential for new discoveries of these and other mineral resources that could further diversify the base for industry in many parts of the region. Full realization of Appalachia's resource potential will require a far better knowledge of its geology than is available now and considerable advance in many phases of mineral technology. Work in these areas should be accelerated now; however, presently known and minable deposits are ample to support industrial development in many parts of Appalachia.

In examining the opportunities for industrial development, Appalachia must be considered in terms of component regions and the areas surrounding them. Appalachian products will compete in areas adjacent to their manufacture both inside and outside its boundaries. The magnitude of the outside market that Appalachian products could hope to capture has not been determined, but it is worth noting that there is now within Appalachia a deficiency in retail sales of $4 billion a year, measured on a per capita basis, compared to the rest of the United States. This sum is a gauge of the size of the retail market that new income in Appalachia would generate, and a substantial part of this market should be captured by new or expanded Appalachian industry.

Detailed analysis of potential markets in and near Appalachia has not yet been made, but something of the industrial potential that Appalachia's mineral resources might support are briefly indicated here in terms of major groups of commodities. Detailed information on the production, distribution and resources of individual minerals is presented later in the "Mineral Commodities" sections of this report.

COAL

In its rich and widely distributed coal resources, Appalachia has one of the Nation's—in fact, the world's—largest sources of cheap energy. Coal is available for direct use as a source of heat for those industries that require that form of energy; it can be converted to liquid and gaseous hydrocarbons; and, most important, it can be converted to electric power marketable in Appalachia at lower prices than are obtainable in most other areas. It is this potential for the widespread production of cheap power that holds the most promise for industrial expansion in Appalachia and, along with improved access, development of power deserves the greatest emphasis.

The wide availability of cheap electric power in Appalachia would be an attraction to almost any kind of manufacturing industry, but it would be particularly important to secondary (fabricating) industries that utilize materials mined or refined within the region—primary metals, chemicals, and the like. Such industries are already developing in Appalachia—for example, employment in the fabricated metals industries has increased relatively more in Appalachia than elsewhere in the United States since 1950—and much of the secondary industry that now exists in Appalachia is of this type. Increased availability of cheap power would thus set the stage for the value-adding activities so important in building the tower of income on the home base.

Large mine-mouth thermal power stations would seem essential to new sources of cheap power. Mine-mouth plants are already being considered for long-distance power transmission, and plants in Appalachia prepared to serve external and internal markets would involve less capital risk than those for internal markets alone.

Whereas electric power is stressed as the base for a diversified manufacturing industry, its importance, along with coal for direct use, in primary, high-energy consuming industries is also of fundamental importance. The steel industry has its origin mainly in the local availability of cheap coal of high quality. The aluminum plants built in recent years in the Ohio Valley and in Pennsylvania also use cheap energy, a factor that evidently offsets the costs of importing the bulk of their raw materials and exporting their products. High-energy consuming industries that utilize other kinds of raw materials available in Appa-

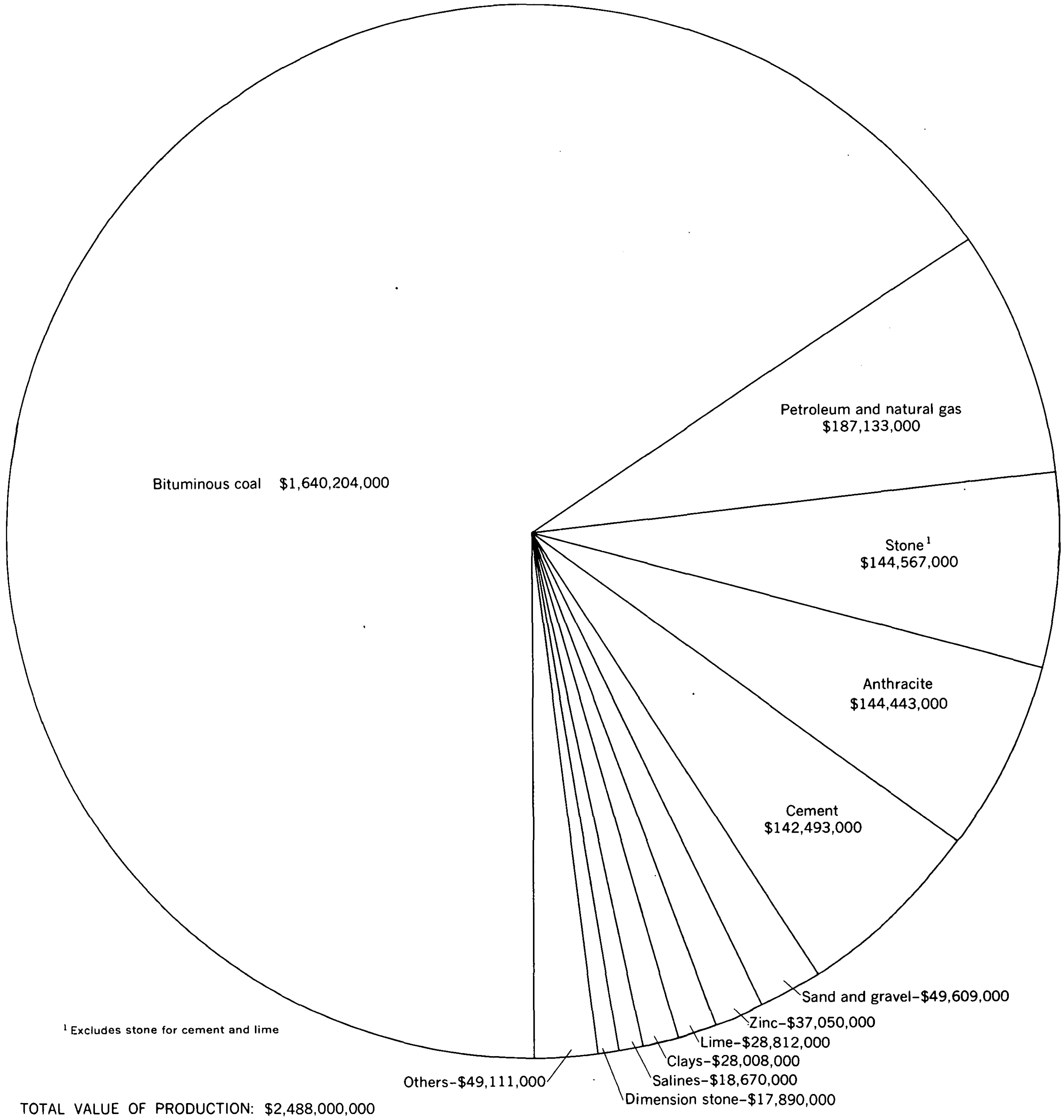

FIGURE 1.—Mineral commodities produced in the Appalachian Region in 1964 (values shown in 1958 constant dollars). Source: U.S. Bureau of Mines.

lachia—the glass and ceramic industries, cement, some of the chemical and petrochemical industries, and base-metals refining—have added reason to locate or expand in Appalachia.

Recent advances in the conversion of coal to gasoline make it probable that coal-conversion plants will be built in Appalachia within the next decade or so. Such plants would help generate new local industry. To be commercially practical, coal-gasoline refineries will have to be in the range of 30,000–100,000 barrels a day and may require an annual coal production of 3–12 million tons per plant (Fumich, 1966). They will produce a substantial byproduct of low-volatile char, which may be good fuel for thermal power generation, or furnish raw material for manufacture of a variety of chemicals. Coal-gasoline refineries could be the nucleus of a whole new industrial complex, attracting a variety of primary and secondary satellite industries.

Unfortunately, much of the promise outlined here for Appalachian coal does not apply to anthracite, an industry still marketing much of its product to the household sector. Anthracite does not have the liquid- or gas-conversion potential of bituminous coal, and for several reasons it is not strongly competitive in outside markets for power manufacture. Its prime market for the future seems to be mainly in the manufacture of power, particularly for industrial use in and close to the anthracite region of Pennsylvania.

OIL AND GAS

The oil and gas industry is Appalachia's second largest in the minerals field and, as described by Meyer and Edgerton in the section on "Petroleum and Natural Gas" (p. 145), the prospects for additional discoveries in unmetamorphosed Paleozoic rocks are bright. For many years, exploration in much of Appalachia has been undertaken at only a low level; new geologic and geophysical exploration methods successful elsewhere have been little used, and drilling has been limited almost entirely to shallow depths.

Search for oil and gas should be intensified in Appalachia and if it proves successful the resulting new production could profoundly affect Appalachia's economy as it has and does elsewhere. Important discoveries in certain areas might have an adverse affect on the development of the coal-conversion industry but, with future demands for liquid fuels expected to increase by at least 50 percent by 1980, the two industries should be able to coexist in the region as a whole.

Extensive oil shale deposits in Appalachia—chiefly in Kentucky, Tennessee, and Alabama—are also important potential sources of oil and gas, as well as a number of coproduct elements, including uranium and sulfur. These deposits are not competitive now with other sources, but they could be exploited at prices not much higher than those prevailing now and their availability adds tremendous depth to Appalachia's energy potential.

WATER

Appalachia is blessed with abundant and widely distributed supplies of water (Schneider and others, 1965), one of the presently limiting resources elsewhere in the expansion of urban, industrial, and recreational activities. Better water management, particularly to control floods, mine drainage, and industrial wastes is already needed in Appalachia, and even more care will have to be taken to see that urban and industrial growth do not further poison runoff. These problems should yield to intelligent planning and management, however, and the abundance of Appalachia's water resources constitutes one of its main attractions for new and expanded industry.

CONSTRUCTION MATERIALS

Sand and gravel, stone, other rocks and minerals and cement, used mainly for construction, now make up Appalachia's third largest group of mineral industries. Usable deposits are scattered throughout Appalachia and are extensive enough to support greatly expanded highway, industrial, and urban construction in and adjacent to all parts of the region. Most of these materials have such low unit value that it is impractical to transport them long distances, but Appalachia's own needs for new construction are so great that the industry should grow rapidly. Indigenous resources are adequate to support increased production also of some higher value materials such as roofing granules, lightweight aggregate, marble, and terrazzo.

CERAMICS, GLASS, AND REFRACTORIES

Clay, glass sand, feldspar, kyanite, sillimanite, olivine, and other raw materials for ceramics and related products are abundant in Appalachia; they already support the region's fourth largest group of mineral-based industries. Most of these industries use substantial amounts of energy, and the wide availability of raw materials and fuels sets the stage for new centers of manufacture in many parts of the region. Most of the manufactured ceramic products are now exported, but economic growth in Appalachia should provide a growing internal market for them.

CHEMICAL MINERALS

A rich variety of chemical raw materials—salt, brine, high-calcium limestone, barite, sulfur from smelter gas, and others—are already exploited in parts of Appalachia, and many are widely enough distributed to support new centers for the manufacture of chemicals and other products derived from them. Many of the chemical industries are high-energy consumers, and the availability of cheap energy in proximity to raw materials provides a natural setting for the growth of these industries.

FERROUS AND BASE METALS

Iron ore has been produced in several areas in Appalachia, but the chief production has come from the Clinton ores of the Birmingham area. Much of the better ore there has already been mined, and local production is declining as higher grade imports become available. There are some prospects, however, for discoveries of new ore bodies or for improved technology that would permit fuller use of the known

Clinton ores, and these prospects need to be further investigated. Brown iron ores of Tertiary age in southwest Georgia, some 40 miles south of Appalachia, are already being mined and may be extensive enough to warrant development of a steel industry there.

In spite of the fact that most of the iron ore comes from other sources, an important part of the U.S. steel industry is located in Appalachia because of the availability of good coking coal. Although some new plants in eastern United States are being built elsewhere, the Appalachian industry appears to be well rooted and can be expected to expand as the needs of the region it now serves increase.

Production of base metals in Appalachia has a long history and a bright future. Massive copper-bearing sulfide deposits at Ducktown, Tenn., almost certainly have other analogues in southern Appalachia, and low grade red-beds type deposits in Pennsylvania deserve exploration. The East Tennessee zinc district is one of the largest in the world, and the prospects for discovery of new lead and zinc sulfide deposits here and elsewhere in Appalachia are excellent.

With world demand for sulfur straining present sources, there is growing interest in pyrite as a source of sulfur. Sulfur has been produced from sulfides in this region in the past, and several large pyrite and pyrrhotite deposits, some of which carry recoverable amounts of other metals, are already known. Most of the large sulfide deposits that crop out have probably been found, but there is much favorable ground to be probed at depth by modern exploration tools and methods. Pyrite in coal is another possible source of byproduct sulfur.

Base metals, as well as most of the other minerals produced in Appalachia, have largely been exported in the past, often in raw form. The challenge to a developing Appalachia will be to carry refining and fabrication of these metals to higher stages in Appalachia.

OTHER MINERALS

Many other mineral commodities have been produced in Appalachia, and still others are part of its resource potential. Among these are abrasives, peat for use as a soil conditioner, lime, barite, asbestos, talc, zircon, and gold. A deposit of zircon and ilmenite-bearing sandstone found a few years ago in Cocke County, Tenn., for example, is high grade by world standards and might become an important producer. Gold has a long history of past production in southern Appalachia, based on relatively primitive methods of prospecting and mining, and still has an unexplored potential.

CONCLUSION

If this section seems to be an optimistic description of the possibilities for economic development in Appalachia, it is because that is its very purpose. The industrial economy's high tower of income is literally built from sand and clay—and a host of other prosaic ingredients that are worthless in their raw state. But before these raw materials are taken from the ground, their possible presence has to be recognized and the conviction must form that something useful can be done with them. Economic development generates from the desire for economic change and betterment, linked to intelligent but nevertheless optimistic, imaginative, and venturesome enterprise. The grist for the development mill comes from the earth, but it is the human activities that make the mill turn.

Grist is readily available in Appalachia but its abundance obviously has not led to full development. Terrain was the initial inhibitor of development, and remains a hindrance. Accumulated damage to land and water from mining and acid mine drainage is extensive, and its repair will add to the development costs. Educational levels need to be bettered and part of the working force must be retrained. Even though these and other obstacles to economic development are large, they are not insurmountable. Technologic advances that have made terrain mitigation feasible coupled with Appalachia's rich natural-resource base are the makings of a viable, self-sustaining productive economy in Appalachia, and accelerated economic development is a realistic goal.

THE MINERAL INDUSTRY

INTRODUCTION

The vast supplies of certain mineral resources, particularly coal, played an important role in the early settlement of the Appalachian Region. Recent shifts in consumption patterns, markets, and population and increased mechanization have, however, reduced employment in mining although the mineral industries still comprise a substantial part of the economy.

Much of the Appalachian economy has long centered around coal mining, and the rise and decline of the Appalachian economy can be written as a history of the coal industry. Many Appalachian communities were almost entirely dependent upon the earnings of men employed by coal companies. The dislocations caused by the loss of traditional coal markets, coupled with the industry's mechanical revolution, has had severe consequences for many of these communities.

The economic problems of Appalachia cannot be understood, nor can an appraisal of the mineral resources of Appalachia be successful, without an understanding of the past and possible future economic ramifications of mineral development. It is for such an understanding that this part of the report has been prepared.

HISTORY OF THE MINERAL ECONOMY

By Robert D. Thomson, Donald J. Frendzel, and
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FUELS

The early history of the mineral industry in Appalachia is essentially that of fuels. Both the U.S. coal and petroleum industries were born in this region, and they continue to be its largest mineral industries.

Prior to and immediately following the American Revolution, coal was primarily used locally for domestic fuel, brickmaking, and blacksmithing. This situation changed with the advent of the steam engine, the construction of canals such as the Erie and the Schuylkill, and the building of the railroads. Coal output increased substantially around the middle of the 19th century as the new modes of transportation gave additional impetus to the industry, not only as a consumer but as a means to new markets.

The petroleum industry developed during the latter part of the 19th century. The first well drilled exclusively for oil on the North American Continent was completed by Edwin L. Drake, a railroad conductor from Connecticut, in August 1859 near Titusville, Pa. The discovery of oil here led to subsequent development of oil fields in Pennsylvania, New York, Ohio, West Virginia, Kentucky, and Tennessee before the end of the century.

By the beginning of the 20th century, the efficiency of coal production, together with the proximity of the coal deposits to the most heavily populated and industrialized parts of the United States, had made coal preeminent in the energy market. Coal was consistently responsible for 70 percent of the total energy derived from mineral fuels and waterpower until 1920 when petroleum products began to make the first significant inroads into the heating and transportation markets.

In the late 1920's, improvements in steel metallurgy and pipeline-welding techniques permitted the economic and safe transportation of natural gas under high pressure. This technological advance resulted in shipment of gas into Appalachia and surrounding areas, and gas began to make an impact on traditional coal markets because of its competitive advantages in cost, cleanliness, and high-heat efficiency.

Such inroads caused drastic losses in the anthracite domestic space-heating markets, traditionally the largest outlet for this fuel. Less serious losses occurred in bituminous coal retail deliveries and railroad markets. The losses in these traditional markets were counterbalanced somewhat by increased shipments to industrial facilities, electric-utility companies, and by exports. Nevertheless, the bituminous coal and anthracite industries both declined in relative importance to the Appalachian mineral economy. In 1945, fuels represented approximately 87 percent of the total value of Appalachian mineral production (see table 5); by 1964 they had dropped to 80 percent.

During the 1945–64 period, total mineral production in the United States increased at an average annual

TABLE 5.—*Principal mineral production of the Appalachian Region, 1945–64*

[Source: U.S. Bur. Mines. Values in thousands of 1958 constant dollars]

Year	Fuels				Nonmetals					Metals			Total mineral production [2]	
	Bituminous coal	Anthracite	Petroleum, natural gas, and natural gas liquids	Total	Sand and gravel	Stone [1]	Clays	Salines	Total	Lead	Zinc	Total	Appalachia	Appalachian States
1945	1, 767, 347	424, 094	264, 738	2, 456, 179	17, 732	41, 671	13, 574	6, 424	79, 401	974	15, 038	16, 012	[3] 2, 837, 396	2, 990, 776
1946	1, 864, 990	536, 821	245, 310	2, 647, 121	24, 909	45, 741	18, 770	6, 626	96, 046	1, 279	13, 122	14, 401	[3] 3, 066, 445	3, 413, 499
1947	2, 515, 449	497, 783	251, 030	3, 264, 262	27, 893	57, 545	19, 983	7, 691	113, 112	1, 332	14, 008	15, 340	[3] 3, 772, 245	4, 047, 376
1948	2, 730, 324	539, 663	235, 670	3, 505, 657	30, 134	68, 633	21, 130	7, 813	127, 710	1, 951	13, 995	15, 946	[3] 4, 057, 455	4, 450, 371
1949	1, 900, 743	410, 466	215, 816	2, 527, 025	26, 820	70, 654	18, 453	8, 004	123, 931	1, 300	12, 680	13, 980	[3] 2, 963, 711	3, 374, 832
1950	2, 206, 176	445, 652	224, 934	2, 876, 762	31, 106	78, 075	21, 098	9, 587	139, 866	1, 036	15, 429	16, 465	[3] 3, 373, 560	3, 870, 333
1951	2, 203, 029	430, 022	221, 607	2, 854, 658	35, 830	80, 574	31, 363	10, 271	158, 038	561	17, 764	18, 325	[3] 3, 369, 591	3, 932, 341
1952	1, 881, 813	396, 566	216, 604	2, 494, 983	33, 183	75, 107	29, 363	10, 503	148, 156	1, 286	17, 897	19, 183	2, 816, 533	3, 558, 591
1953	1, 875, 649	314, 666	215, 329	2, 405, 644	33, 726	86, 643	22, 870	11, 307	154, 546	777	13, 448	14, 225	2, 760, 446	3, 558, 068
1954	1, 462, 215	264, 715	225, 060	1, 951, 990	36, 358	102, 193	23, 540	15, 682	177, 773	1, 274	10, 942	12, 216	2, 303, 618	3, 134, 098
1955	1, 789, 488	221, 352	196, 973	2, 207, 813	38, 431	108, 713	30, 616	17, 891	195, 651	973	15, 671	16, 644	2, 628, 562	3, 600, 660
1956	2, 031, 176	246, 860	217, 031	2, 495, 067	35, 460	118, 502	40, 654	17, 436	212, 052	1, 006	18, 746	19, 752	2, 946, 071	3, 988, 941
1957	2, 044, 659	229, 038	212, 004	2, 485, 701	35, 247	118, 659	36, 343	16, 020	206, 269	914	18, 156	19, 070	2, 906, 959	3, 932, 952
1958	1, 546, 392	186, 281	186, 859	1, 919, 532	41, 125	118, 514	26, 865	16, 492	202, 996	687	15, 804	16, 491	2, 398, 253	3, 284, 395
1959	1, 479, 442	167, 176	198, 417	1, 845, 035	44, 100	127, 066	29, 328	16, 725	217, 219	628	23, 622	24, 250	2, 325, 724	3, 435, 454
1960	1, 463, 792	143, 290	206, 987	1, 814, 069	42, 529	136, 431	29, 659	16, 984	225, 603	499	26, 702	27, 201	2, 210, 229	3, 414, 038
1961	1, 373, 961	136, 781	204, 878	1, 715, 620	41, 878	141, 749	25, 923	17, 100	226, 650	764	23, 868	24, 632	2, 158, 343	3, 311, 018
1962	1, 417, 294	130, 279	197, 949	1, 745, 522	46, 195	152, 057	22, 822	18, 511	239, 585	751	21, 008	21, 759	2, 220, 487	3, 409, 625
1963	1, 520, 684	149, 272	196, 406	1, 866, 362	47, 449	160, 546	26, 484	18, 176	252, 655	753	26, 943	27, 696	2, 350, 665	3, 598, 339
1964	1, 640, 204	144, 443	187, 133	1, 971, 780	49, 609	166, 150	28, 008	18, 670	262, 437	1, 005	37, 050	38, 055	[3] 2, 488, 000	3, 837, 357

[1] Excludes limestone used for cement and lime, 1945–53.
[2] Includes all mineral production, not just the total of items shown.
[3] Partly estimated.

rate of 3.8 percent, gross national product rose 3.2 percent per year, and national energy consumption increased a total of 57 percent. Energy derived from oil and gas rose 173 percent and that from bituminous coal declined 23 percent. On the other hand, within Appalachia, coal represented 89 percent of the value of mineral fuels produced in 1945 and 91 percent in 1964. During this period the national coal industry sustained the complete loss of railroads as a consumer of coal and the nearly complete loss of the home-heating market. The home-heating market may be indirectly recaptured because of the advent of electric space heating, which may result in the burning of more coal to generate electricity. Use of coal by the electric-utility industry has increased markedly. Presumably, the national situation is analogous to that in Appalachia because the region's coal mines produced more than 70 percent of national output throughout the 1945–64 period.

The only important growth in the Appalachian bituminous coal market in recent years has been for the manufacture of electric power. The tonnage of bituminous coal consumed by electric utilities increased from 72 million tons in 1945 to 223 million tons in 1964.

In spite of this increase, the overall consequence of the competitive factors outlined above has been a decline in Appalachian coal output from a high of 469 million tons in 1947 to 287 million tons in 1961. Under the stimulus of this decline, innovations have occurred in the mining, processing, transporting, and marketing of bituminous coal. Greater mechanization and automation of production and processing have resulted in increased productivity and lower employment which, together with an improvement in the overall economy, led to a production increase to 351 million tons by 1964. Coal-mine employment, however, has continued to decline.

Continuous-mining machines, in recent years, have won increasing acceptance by the industry. Machines now cut, load, and convey coal to the mine mouth, much reducing labor requirements. The growth of machine mining is illustrated by the fact that less than 1 percent of the total U.S. underground production of coal was mined by continuous-mining machines in 1950, whereas 39 percent was so mined in 1964. Of the total underground production, 96 percent is mechanically cut and 87 percent is mechanically loaded.

Strip-mine production has also increased as a result of the development of larger and improved stripping and drilling equipment and trucks. The trend has been toward power shovels and dragline excavators with large dipper and bucket capacities. Approximately 19 percent of the total coal mined in Appalachia in 1964 was produced from stripping operations.

The average output per man-day in Appalachian strip mines is about double that of underground mines. In 1964, average labor productivity in Appalachian underground mines ranged from a low of 2 tons per man-day in Georgia to a high of 15 tons in West Virginia. Average strip-mine output per man-day, on the other hand, ranged from a low of 20 tons in Pennsylvania to a high of 50 tons in Kentucky.

The market losses and technologic innovations have resulted in a decline in total U.S. employment in bituminous coal mining from a peak of 705,000 in 1923 to 129,000 in 1964, and most of it took place in Appalachia. The decline has caused serious social and economic problems.

The competitive advantages in transportation held by other fuels (petroleum and natural gas) have recently forced the development of new concepts of coal transportation such as the coal-slurry pipeline, the "unitrain," and the mine-mouth powerplant. The coal slurry pipeline, which operated between Cadiz, and Cleveland, Ohio, transported a mix of coal and water in much the same manner as crude petroleum. To meet this competition, the railroads devised the unitized train and thereby lowered rail freight rates. When unitized trains were introduced, the slurry pipeline operation ceased. The mine-mouth powerplant concept utilizes coal as a fuel to produce electricity at the mine, and thus eliminates the need for long-distance coal transport. High-voltage transmission may prove less costly than the transportation of an energy equivalent of coal and may further increase the use of Appalachian bituminous coal for electric power generation.

The anthracite industry has not been as fortunate. In 1950, anthracite accounted for 34 percent, fuel oil for 55 percent, and natural gas for 9 percent of total fuels consumed (calculated on Btu content) in major anthracite sales areas. Comparative data for 1964 indicated a market decline for anthracite to 8 percent of the total and a rise of fuel oil and natural gas to 64 and 28 percent, respectively. The tonnage of anthracite consumed in these markets decreased from 33 million tons in 1950 to 13 million tons in 1964. The chief components in this decline were retail dealer deliveries, mainly for home heating, and consumption by electric utilities. Retail dealer deliveries (not including sales in the producing region) decreased from 13 million tons in 1955 to 3 million tons in 1964, while consumption by electric utilities fell from 3 million tons to 2 million during the same period.

The loss of anthracite markets is reflected in a decline in employment from a peak of 180,000 in 1914, to 13,144 in 1964; the net decrease of 167,000 employees has had a drastic effect on the local economy. During the 1945–64 period alone, employment decreased 59,698.

NONMETALS AND CONSTRUCTION MATERIALS

The critical role which the mineral fuels have played in the decline of the Appalachian mineral industry should not obscure the growth of the nonmetallic minerals and construction materials industries. Although a variety of materials are produced, stone (crushed stone, dimension stone, and cement limestone) and sand and gravel are the most important in terms of dollar value, and have tripled their share of the mineral economy since 1945. Production of nonmetallics and construction materials increased at an annual rate of 4.9 percent. Stone and sand and gravel increased annually at the rate of 6.2 percent and 3.3 percent, respectively.

The production history of the crushed stone industry in Appalachia is one of overall growth, with occasional decreases in output that coincide with the national industry trend. Production rose from 24 million short tons valued at $37 million (in 1958 constant dollars) in 1945 to an output of 92 million tons valued at $148 million (1958 constant dollars) in 1964. During the 1945–64 period, the crushed stone quarries in Appalachia accounted for 13 percent of national production and 15 percent of the value.

Several factors have stimulated the growth in the demand for crushed stone. Increasing national population has brought about the need for more roads, buildings, factories, and other facilities requiring crushed stone as concrete aggregate. Greater construction activity and the declining use of dimension stone also have increased the demand for crushed stone used in manufacturing cement. The growth demand for steel has contributed to the increased demand for metallurgical limestone, there has also been a growing use of crushed limestone to neutralize acid soils and thus boost farm productivity.

Similarly, the growth in population and construction activity have spurred the growth of the sand and gravel industry. Appalachian sand and gravel output increased from 12 million tons valued at $18 million (in 1958 constant dollars) in 1945 to an all-time high of 31 million tons with a value of $50 million (in 1958 constant dollars) in 1964. Appalachian sand and gravel constituted 4 percent and 7 percent of national production and value, respectively, during the 1945–64 period.

METALS

Iron ore, copper, gold, and zinc are the only metal commodities that have been produced in Appalachia in significant quantities. Of these, only zinc is now produced in large amounts. Iron ore of Appalachia was an important factor in the development of the early iron and steel industry of the United States, but in 1964 Appalachian iron ore was being utilized only at Birmingham, Ala. Copper has been produced at many mines of which those of the Ducktown district of Tennessee, opened in 1843, are the only ones that continued to produce into the 1960's. Substantial amounts of gold were produced in the late 19th century and early 20th century when the rich deposits were mined out. In 1964 only a small amount of gold was produced as byproduct of the Ducktown copper ores.

CURRENT MINERAL ECONOMY

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Of the 373 counties in Appalachia, 327 produced $2.5 billion (current dollars) of mineral raw materials in 1964; this total was 64 percent of the value of mineral output of the 12 Appalachian States and 12 percent of the United States total (table 6). The counties

TABLE 6.—*Value of 1964 mineral production in the Appalachian Region and Appalachian States*

[Source: U.S. Bur. Mines]

State	Appalachian part		Total State		Appalachian part, as percent of—	
	Counties	Value (millions of current dollars)	Counties	Value (millions of current dollars)	Total counties	Total value
Alabama	33	$189.1	67	$235.7	49	80
Georgia	35	29.4	159	128.0	22	23
Kentucky	49	209.8	120	444.4	41	47
Maryland	3	15.5	24	73.9	13	21
New York	13	28.2	62	288.4	21	10
North Carolina	29	14.2	100	56.5	29	25
Ohio	28	178.3	88	454.9	32	39
Pennsylvania	52	681.2	67	902.0	78	76
South Carolina	6	5.3	46	38.7	13	14
Tennessee	49	125.1	95	174.0	52	72
Virginia	21	166.1	98	237.4	21	70
West Virginia	55	822.7	55	822.7	100	100
Total	373	[1] 2,464.9	981	3,856.6	38	64

[1] Preliminary.

which supplied this output and the commodities produced are shown in table 7.

Although the output of most mineral commodities in Appalachia was small in terms of the national mineral economy, that of a few commodities was of national significance. In 1964, Appalachia supplied 98 percent of the value of anthracite produced in the United States, 76 percent of the bituminous coal, 52 percent of the fire clay, 24 percent of the zinc, and 21 percent of the dimension stone (table 8).

TABLE 7.—*Minerals produced in the Appalachian Region in 1964, by States and Counties*

Source: U.S. Bur. Mines]

State, county	*Minerals produced, in order of value*
Alabama:	
Bibb	Coal, limestone.
Blount	Iron ore, cement, fire clay, limestone, coal.
Calhoun	Fire clay, limestone, miscellaneous clay, iron ore.
Cherokee	Sand and gravel, iron ore.
Chilton	Sand and gravel.
Cleburne	Do.
Colbert	Limestone, native asphalt.
Cullman	Limestone, coal.
De Kalb	Limestone.
Elmore	Sand and gravel.
Etowah	Limestone, coal, sand and gravel, fire clay.
Franklin	Iron ore, limestone, sand and gravel, fire clay.
Jackson	Coal, limestone.
Jefferson	Coal, cement, iron ore, limestone, miscellaneous clay, sandstone, fire clay.
Limestone	Limestone.
Madison	Limestone, miscellaneous clay.
Marion	Coal, kaolin.
Marshall	Limestone, sandstone.
Morgan	Limestone, sand and gravel.
Randolph	Mica.
St. Clair	Cement, limestone, fire clay, miscellaneous clay, coal.
Shelby	Cement, lime, limestone, coal, miscellaneous clay.
Talladega	Marble, limestone, talc, iron ore.
Tuscaloosa	Coal, iron ore, sand and gravel, limestone.
Walker	Coal, fire clay, miscellaneous clay.
Winston	Coal.
Georgia:	
Bartow	Barite, slate, limestone, iron ore, iron oxide pigments.
Chattooga	Marble.
Cherokee	Mica, sand and gravel.
Dade	Limestone.
Douglas	Granite.
Fannin	Limestone.
Floyd	Limestone, miscellaneous clay, bauxite, kaolin.
Forsyth	Granite.
Franklin	Sand and gravel.
Gilmer	Marble.
Gordon	Miscellaneous clay.
Gwinnett	Granite, sand and gravel.
Hall	Granite.
Madison	Do.
Murray	Talc, soapstone.
Pickens	Marble, sandstone.
Polk	Cement, slate, miscellaneous clay, iron ore, sandstone.
Rabun	Granite.
Walker	Limestone, coal.
Whitfield	Limestone.
Kentucky: [1]	
Adair	Limestone.
Bath	Petroleum.
Bell	Coal, petroleum.
Boyd	Coal, miscellaneous clay, petroleum.
Breathitt	Coal, petroleum.
Carter	Limestone, fire clay, coal.
Casey	Limestone, petroleum.
Clay	Coal.
Clinton	Petroleum, limestone, coal.
Cumberland	Petroleum, limestone.
Elliott	Petroleum, coal.
Estill	Petroleum, limestone.
Fleming	Limestone.
Floyd	Coal, petroleum.
Garrard	Limestone.
Green	Petroleum, limestone.
Greenup	Fire clay, petroleum.
Harlan	Coal, limestone.
Jackson	Coal, limestone, petroleum.
Johnson	Petroleum, coal.
Knott	Coal, petroleum.
Knox	Do.
Laurel	Coal, limestone, petroleum.
Lawrence	Petroleum, coal.
Lee	Petroleum, limestone, coal.
Leslie	Coal, petroleum.
Letcher	Coal, limestone, petroleum.
Lincoln	Petroleum.
McCreary	Coal, petroleum.
Madison	Limestone.
Magoffin	Petroleum, coal.
Martin	Coal, petroleum.
Menifee	Limestone, petroleum.
Monroe	Do.
Montgomery	Limestone.
Morgan	Limestone, coal, petroleum.
Owsley	Coal, petroleum.
Perry	Do.
Pike	Coal, petroleum, limestone, sand and gravel.
Powell	Petroleum, limestone, miscellaneous clay.
Pulaski	Limestone, coal.
Rockcastle	Do.

See footnotes at end of table.

TABLE 7.—*Minerals produced in the Appalachian Region in 1964, by States and Counties*—Continued

State, county	*Minerals produced, in order of value*
Kentucky—Continued	
Rowan	Fire clay, limestone, miscellaneous clay.
Russell	Petroleum.
Wayne	Coal, limestone, petroleum.
Whitley	Coal, petroleum, miscellaneous clay.
Wolfe	Petroleum, coal.
Maryland:	
Allegany	Coal, sand and gravel, stone, clays.
Garrett	Coal, natural gas, stone, sand and gravel, peat.
Washington	Cement, stone, clays, potassium salts.
New York:[2]	
Allegany	Sand and gravel.
Broome	Sand and gravel, stone, clays.
Cattaraugus	Sand and gravel, peat.
Chautauqua	Sand and gravel.
Chemung	Do.
Chenango	Do.
Cortland	Do.
Delaware	Stone, sand and gravel.
Otsego	Do.
Schuyler	Salt, sand and gravel.
Steuben	Sand and gravel.
Tioga	Do.
Tompkins	Salt, stone, sand and gravel.
North Carolina:	
Alexander	Sand and gravel.
Ashe	Do.
Avery	Kaolin, mica, sand and gravel.
Buncombe	Sand and gravel, granite.
Burke	Sand and gravel.
Caldwell	Granite, sand and gravel.
Cherokee	Marble, granite, talc, sand and gravel.
Davie	Sand and gravel.
Forsyth	Granite, sand and gravel.
Haywood	Sand and gravel.
Henderson	Limestone, granite, miscellaneous clay.
Jackson	Olivine, granite.
McDowell	Sand and gravel, feldspar.
Macon	Granite, sand and gravel.
Madison	Sand and gravel, feldspar.
Mitchell	Feldspar, mica, sandstone, sand and gravel.
Polk	Granite, sand and gravel.
Rutherford	Sand and gravel.
Stokes	Miscellaneous clay, sand and gravel.
Surry	Granite, traprock, sand and gravel.
Swain	Limestone, granite.
Watauga	Sand and gravel, granite.
Wilkes	Granite, sand and gravel.
Yadkin	Do.
Yancey	Mica, olivine, sand and gravel, feldspar, asbestos.
Ohio:	
Adams	Stone.
Athens	Coal, stone, clays, sand and gravel.
Ohio—Continued	
Belmont	Coal, stone.
Brown	Stone, sand and gravel.
Carroll	Coal, clays, sand and gravel, stone.
Coshocton	Coal, stone, sand and gravel.
Gallia	Coal, stone, sand and gravel, clays.
Guernsey	Coal, stone.
Harrison	Coal, stone, clays.
Highland	Stone, sand and gravel, clays.
Hocking	Coal, clays.
Holmes	Coal, stone, clays, sand and gravel.
Jackson	Coal, clays, stone.
Jefferson	Coal, clays.
Lawrence	Cement, stone, coal, clays, sand and gravel.
Meigs	Coal, sand and gravel, salt.
Monroe	Sand and gravel, stone.
Morgan	Coal, stone, sand and gravel.
Muskingum	Cement, stone, coal, sand and gravel, clays.
Noble	Coal, stone, clays.
Perry	Coal, sand and gravel, clays, stone.
Pike	Sand and gravel, stone.
Ross	Do.
Scioto	Stone, clays, sand and gravel.
Tuscarawas	Coal, clays, sand and gravel, stone.
Vinton	Coal, stone.
Washington	Sand and gravel, abrasives.
Pennsylvania:[3]	
Allegheny	Coal, cement, clays, sand and gravel, stone, iron ore (pigment material).
Armstrong	Coal, clays, sand and gravel, stone, lime.
Beaver	Coal, sand and gravel, clays.
Bedford	Stone, coal, lime.
Blair	Stone, coal, clays, sand and gravel.
Bradford	Sand and gravel, coal.
Butler	Coal, cement, stone, lime, sand and gravel, clays.
Cambria	Coal, clays, stone, sand and gravel, iron ore (pigment material).
Cameron	Coal.
Carbon	Coal, stone, sand and gravel.
Centre	Lime, stone, coal, clays.
Clarion	Coal, stone, clays, sand and gravel.
Clearfield	Coal, clays, sand and gravel.
Clinton	Coal, clays, stone, sand and gravel.
Columbia	Coal, sand and gravel, clays, peat.
Crawford	Sand and gravel.
Elk	Coal, sand and gravel, stone.
Erie	Sand and gravel, peat.
Fayette	Coal, stone, clays, sand and gravel.
Forest	Sand and gravel.
Fulton	Stone, sand and gravel.
Greene	Coal, clays.
Huntingdon	Sand and gravel, stone, coal, clays.
Indiana	Coal, clays.
Jefferson	Coal, clays, stone, sand and gravel.
Juniata	Stone, lime.

See footnotes at end of table.

TABLE 7.—*Minerals produced in the Appalachian Region in 1964, by States and Counties*—Continued

State, county	Minerals produced, in order of value
Pennsylvania—Continued	
Lackawanna	Coal, sand and gravel stone, peat.
Lawrence	Cement, stone, coal, clays, sand and gravel, peat.
Luzerne	Coal, sand and gravel, stone, peat, clays.
Lycoming	Stone, sand and gravel, coal, tripoli.
McKean	Clays, coal, stone, sand and gravel.
Mercer	Coal, sand and gravel, stone.
Mifflin	Sand and gravel, stone, lime.
Monroe	Stone, sand and gravel, clays.
Montour	Stone, sand and gravel.
Northumberland.	Coal, clays, stone, lime.
Perry	Stone.
Potter	Stone.
Schuylkill	Coal, stone, sand and gravel, clays.
Snyder	Sand and gravel, stone, coal, lime.
Somerset	Coal, clays, stone, sand and gravel.
Sullivan	Coal.
Susquehanna	Stone.
Tioga	Coal, sand and gravel, stone.
Union	Stone.
Venango	Coal, sand and gravel.
Warren	Sand and gravel.
Washington	Coal, stone.
Wayne	Stone, sand and gravel, peat, coal.
Westmoreland	Coal, sand and gravel, stone, lime.
Wyoming	Sand and gravel, stone.
South Carolina:	
Anderson	Granite.
Cherokee	Limestone, sand and gravel, barite, miscellaneous clays.
Greenville	Granite, sand and gravel.
Pickens	Do.
Spartanburg	Granite, feldspar, sand and gravel.
Tennessee: [2]	
Anderson	Coal, limestone, miscellaneous clay.
Bledsoe	Coal.
Blount	Marble, limestone.
Bradley	Limestone, sand and gravel.
Campbell	Coal, limestone, sandstone.
Carter	Limestone.
Claiborne	Coal, limestone.
Clay	Limestone.
Cocke	Do.
Coffee	Do.
Cumberland	Sandstone, limestone, sand and gravel, coal.
Fentress	Limestone, coal, sandstone.
Franklin	Cement, limestone, sandstone, sand and gravel, miscellaneous clay.
Grainger	Marble.
Greene	Limestone, sand and gravel.
Grundy	Coal, sand and gravel, limestone.
Hamblen	Limestone.
Hamilton	Cement, limestone, sand and gravel, coal, miscellaneous clay.

TABLE 7.—*Minerals produced in the Appalachian Region in 1964, by States and Counties*—Continued

State, county	Minerals produced, in order of value
Tennessee—Continued	
Hancock	Zinc, limestone.
Hawkins	Limestone.
Jefferson	Zinc, limestone.
Johnson	Limestone.
Knox	Cement, zinc, limestone, marble, lime, sand and gravel, miscellaneous clay.
Loudon	Barite, sand and gravel, miscellaneous clay.
McMinn	Barite, limestone.
Macon	Limestone.
Marion	Cement, coal, limestone.
Meigs	Limestone.
Monroe	Limestone, sand and gravel, barite.
Morgan	Coal.
Overton	Limestone, coal.
Polk	Copper, pyrites, zinc, silver, sand and gravel, gold.
Putnam	Coal, limestone, sand and gravel.
Rhea	Limestone, coal.
Roane	Limestone.
Scott	Coal.
Sequatchie	Limestone, coal.
Sevier	Limestone, sand and gravel.
Sullivan	Cement, limestone, miscellaneous clay.
Unicoi	Sand and gravel, limestone.
Union	Marble, limestone.
Van Buren	Coal.
Warren	Limestone.
Washington	Limestone, miscellaneous clay.
White	Limestone.
Virginia:	
Alleghany	Stone.
Bland	Do.
Botetourt	Cement, stone, clays.
Buchanan	Coal, natural gas.
Craig	Sand and gravel.
Dickenson	Coal, natural gas, sand and gravel.
Giles	Lime, stone.
Grayson	Stone.
Highland	Do.
Lee	Coal, stone, petroleum.
Pulaski	Stone, iron ore (pigment material).
Russell	Coal, stone, clays.
Scott	Stone, coal.
Smyth	Lime, salt, stone, sand and gravel, clays.
Tazewell	Stone, coal, lime, clays, natural gas.
Washington	Stone, gypsum, sand and gravel.
Wise	Coal, stone, sand and gravel.
Wythe	Zinc, stone, lead, sand and gravel.
West Virginia: [3]	
Barbour	Coal.
Berkeley	Cement, stone, lime, clays.
Boone	Coal.
Braxton	Coal, stone.
Brooke	Coal, sand and gravel.
Cabell	Sand and gravel, clays.

See footnotes at end of table.

TABLE 7.—*Minerals produced in the Appalachian Region in 1964, by States and Counties*—Continued

State, county	*Minerals produced, in order of value*
West Virginia—Continued	
Clay	Coal.
Doddridge	Stone.
Fayette	Coal.
Gilmer	Do.
Grant	Coal, stone.
Greenbrier	Do.
Hancock	Clays, sand and gravel, coal.
Hardy	Stone.
Harrison	Coal, stone.
Jefferson	Stone, lime.
Kanawha	Coal, salt, clays, stone, calcium-magnesium chloride.
Lewis	Coal, stone, clays.
Lincoln	Coal, sand and gravel.
Logan	Coal.
McDowell	Do.
Marion	Do.
Marshall	Coal, salt.
Mason	Coal, sand and gravel.
Mercer	Coal, stone, clays.
Mineral	Stone, coal.
Mingo	Coal.
Monongalia	Coal, stone, sand and gravel.
Morgan	Sand and gravel.
Nicholas	Coal, stone.
Ohio	Coal, sand and gravel.
Pendleton	Stone.
Pleasants	Salt.
Pocahontas	Coal, stone, sand and gravel.
Preston	Coal, stone.
Putnam	Coal.
Raleigh	Coal, stone, sand and gravel.
Randolph	Coal, stone.
Taylor	Coal, clays.
Tucker	Coal, stone, sand and gravel.
Tyler	Sand and gravel, salt.
Upshur	Coal, stone.
Wayne	Coal.
Webster	Do.
Wetzel	Sand and gravel.
Wood	Do.
Wyoming	Coal, sand and gravel.

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[1] Other than natural gas and natural gas liquids for which data are unavailable.
[2] Other than petroleum and natural gas for which data are unavailable.
[3] Other than petroleum, natural gas, and natural gas liquids for which data are unavailable.

TABLE 8.—*Comparison of Appalachian output with national output of selected mineral commodities in 1964*

[Source: U.S. Bur. Mines]

Commodity	Appalachia		United States		Percent Appalachia	
	Quantity (thousands of short tons)	Value (thousands of 1958 constant dollars)	Quantity (thousands of short tons)	Value (thousands of 1958 constant dollars)	Quantity	Value
Coal:						
Anthracite	16, 246	144, 443	17, 184	147, 905	96	98
Bituminous	350, 513	1, 640, 204	486, 998	2, 154, 754	72	76
Zinc	137	37, 050	575	155, 526	24	24
Sand and Gravel	31, 053	49, 609	868, 779	889, 622	4	6
Stone:						
Crushed [1]	91, 706	148, 260	703, 231	1, 002, 172	13	15
Dimension [2]	340	17, 890	2, 336	86, 910	15	21
Clay:						
Fire	3, 622	21, 324	8, 549	40, 788	42	52
Miscellaneous	4, 488	6, 217	38, 125	46, 718	12	13

[1] Excludes shell.
[2] Excludes slate and dimension trap rock.

The bulk of the $2.5 billion of minerals produced in Appalachia in 1964 was composed of relatively few commodities; the four most important represent 87 percent of the total value as shown below:

Commodity	*Value (1958 constant dollars)*	*Percent of total*
Bituminous coal	1, 640, 204, 000	67
Petroleum	187, 133, 000	7
Stone	166, 150, 000	7
Anthracite	144, 443, 000	6
Total	2, 137, 930, 000	87

Mineral fuels constituted 80 percent of the total value of 1964 Appalachia output. Mineral construction materials, such as sand, gravel, clay, and stone, were next in importance with 10 percent. The remainder comprised other commodities including metals, although zinc was the only metallic element produced in nationally significant amounts in Appalachia in 1964. This output was principally from Tennessee and represented 24 percent of the national total. Tennessee was the leading zinc-producing State in the country.

The production of several commodities originating in the Appalachian States, but not necessarily from the Appalachian parts of those States, ranks among the highest in the Nation. All anthracite production in 1964 originated in Pennsylvania and of the 10 leading bituminous-coal-producing States, 7 were Appalachian. West Virginia ranked first nationally with 29 percent of the quantity produced, all of which was from Appalachia. Kentucky was second, Pennsylvania third, Ohio fifth, Virginia sixth, Alabama eighth, and Tennessee ninth.

In the output of stone (crushed and dimension), Pennsylvania was the largest producer in the United States in 1964, and Ohio ranked fifth. New York was the leading Appalachian sand and gravel producing State, ranking third nationally; Ohio was fourth. In the output of clay, Georgia ranked first nationally, providing 31 percent of the total value of clay sold or used, whereas Pennsylvania was second and Ohio third.

In addition to mineral raw materials, Appalachia contains many large primary mineral-processing complexes, the most important of which involve iron and steel. All or part of the Pittsburgh, Valley (Youngstown), Upper Ohio River (Wheeling), South Ohio River, and Southern iron and steel districts lie within Appalachia. Of 239 blast furnaces producing pig iron and ferroalloys in the United States at the beginning of 1965, 70 percent were in Appalachian States and 37 percent were in Appalachian counties. Table 9 shows the distribution of these blast furnaces.

TABLE 9.—*Appalachian blast furnaces, January 1, 1965*

[Source: American Iron and Steel Institute, 1964]

State	Total in State	Total in Appalachia
Alabama	19	19
Kentucky	3	3
Maryland	10	----------
New York	15	----------
Ohio	49	8
Pennsylvania	63	52
Tennessee	3	2
Virginia	2	----------
West Virginia	4	4
Total	168	88

All the pig iron output of Alabama, Kentucky, and West Virginia, as well as a substantial part of the output of Tennessee and Pennsylvania, comes from Appalachia. More than 55 percent of total national pig iron production in 1964 was from Appalachia; Pennsylvania alone furnished one-fourth of the national total.

Vast quantities of mineral raw materials are needed to support this industry. The iron ore consumed, however, originates from outside of Appalachia, except for a small amount produced and consumed in the Birmingham, Ala., area. Other mineral raw materials essential to the manufacture of pig iron, principally coal and limestone, are for the most part from Appalachian deposits. The ready availability of high-quality coking coal and limestone were principal reasons for locating iron and steel complexes in the Appalachian area.

The manufacture of cement and lime also consumes large quantities of nonmetallic minerals, principally limestone. In 1964 there were 23 portland cement plants and 31 lime plants operating in Appalachia, distributed as follows:

State	*Portland cement plants*		*Lime plants*	
	Total	*Appalachia*	*Total*	*Appalachia*
Alabama	8	6	6	6
Georgia	3	1	0	0
Kentucky	1	0	0	0
Maryland	3	1	3	0
New York	12	0	2	0
North Carolina	1	0	0	0
Ohio	10	3	22	1
Pennsylvania	21	5	18	13
South Carolina	1	0	0	0
Tennessee	6	5	3	2
Virginia	3	1	9	6
West Virginia	1	1	3	3
Total	70	23	66	31

The 23 cement plants had a combined capacity of 49.5 million 376-lb barrels in 1964, or 10 percent of the national total. Pennsylvania had the largest capacity followed by Alabama, Tennessee, Ohio, West Virginia, Virginia, Maryland, and Georgia, in descending order. Capacity data are not available for the lime plants.

Shipments of lime from Appalachian plants in 1964 totaled 2.3 million short tons valued at $29 million; 44.1 million 376-lb barrels of cement valued at $143.2 million was shipped. Pennsylvania ranked first in the production of lime followed by Virginia and Alabama. Alabama led in cement output followed by Pennsylvania, Tennessee, Ohio, West Virginia, and Virginia.

The manufacture of coke is another of Appalachia's major primary mineral-consuming industries. In 1964, output of the Appalachian States (excluding New York and Maryland where all output is outside of Appalachia) totaled 33 million tons of oven coke valued at $569 million and 1.2 million tons of beehive coke valued at $19 million. These totals represented 54 percent of the domestic oven coke produced and all of the beehive coke, as shown in table 10. To achieve this output, some 49 million tons of coal valued at $396 million (all from Appalachian States) was carbonized at 62 plants.

TABLE 10.—*Coke production in selected Appalachian States, 1964*

[Source: Data from U.S. Bur. Mines, Minerals Yearbook, 1964]

State	Plants	Coke produced		Coal carbonized (short tons)	Origin of coal received [1]						
		Short tons	Value		Alabama	Kentucky	Pennsylvania	Tennessee	Virginia	West Virginia	Total
Oven coke: [2]											
Alabama	7	4,689,108	$85,549,979	6,365,139	5,825,074		37,988		24,634	709,428	6,597,124
Ohio	12	7,243,587	128,850,524	10,352,914		539,171	4,800,799		227,409	4,951,363	10,518,742
Pennsylvania	12	17,594,174	299,388,148	25,313,522		440,668	14,200,308		1,217,984	10,256,570	26,115,530
West Virginia	3	3,389,754	55,659,751	4,943,634			3,535,693		101,730	1,363,730	5,001,153
Kentucky Tennessee	2	(3)	(3)	(3)							
Total	36	32,916,623	$569,448,402	46,975,209	5,825,074	979,839	22,574,788		1,571,757	17,281,091	48,232,549
Beehive coke:											
Pennsylvania	18	561,777	7,571,657	914,405			914,405				914,405
Kentucky Virginia West Virginia	1 6 1	674,510	11,020,424	1,111,010		(4)			(4)	(4)	1,111,010
Total	26	1,236,287	18,592,081	2,025,415		(4)	914,405		(4)	(4)	2,025,415

[1] Origin of coal received at beehive-coke plants has been estimated as quantity of coal carbonized because no reported data are available. Traditionally, these plants are located at or near their source of supply.

[2] Oven coke also produced at three plants in New York and one in Maryland, none of which are in Appalachia.

[3] Data confidential, not included in total.

[4] Included in total.

RELATIONSHIP OF MINING TO OTHER ECONOMIC SECTORS

By ALBERT E. SCHRECK, EDWARD E. JOHNSON, and RICHARD FULLENBAUM, U.S. Bureau of Mines

While the importance of natural-resource-based industries has declined, the other segments of the Appalachian economy have been growing, as shown in table 11. This growth, with a few exceptions such as services, has occurred at a slower rate than the national average. Even in the services group the payroll has increased at a substantially slower rate than for the United States as a whole, although the rise in receipts and number of establishments entering this group has been close to or above the national growth rate.

In other businesses, where the increase in number of establishments has approached the U.S. average, the rise in sales and payrolls has been substantially less. In manufacturing, the payroll and value added have grown at a somewhat lower rate than for U.S. manufacturing, and even the increment in capital expenditures, which presumably will be the generator of future income, is somewhat less than the Nation as a whole experienced.

The low growth rates experienced by various industries in Appalachia have further contributed to the economic problems by inhibiting creation of sufficient new jobs to absorb those unemployed in the mining and agricultural industries. Had growth in other sectors of the Appalachian economy been near that of the national average, additional job opportunities would have been created for the region's unemployed.

Employment is generally considered a key indicator of economic activity inasmuch as a high level of employment is normally associated with a high level of income and output. Changes in the level of employment may be used as a barometer of regional economic activity, whereas changes in the patterns of employment indicate shifts in product demand, technology, and worker preference.

The latest comparable series of county employment statistics by industry indicate that the Appalachian area has undergone a period of economic and social transition. The economic base of the area has shifted from agriculture and mining to manufacturing and trade, as indicated in table 12. Between 1950 and 1960, population and labor force in Appalachia increased 2 percent while total employment declined slightly. Increases were registered by most other sectors of the economy, but these were insufficient to counteract the decline in employment in the resource industries. The major employers were manufacturing and miscellaneous industries which together accounted for two-thirds of the total labor force in 1960 compared with 60 percent in 1950.

Mining employment between 1950 and 1960 declined 56 percent and was 3 percent of the Appalachian labor force in 1960 compared with 8 percent in 1950. Coal-mining employment (table 13), which constitutes 80 percent of total mining employment, declined 60 percent during this same period.

The rate of increase or decrease of mineral production and attendant employment varies from region to region in Appalachia. In the metropolitan areas the impact of declining coal production has not been as serious as in the more rural areas where mining and a few mining-oriented industries were the principal employers. In the urban areas, when coal mining began to decrease, limited employment was available in other industries. However, in the more rural areas when mining declined, other supporting industries also declined, for they were generally dependent upon mining for their survival. Therefore there were fewer alternative job opportunities.

TABLE 11.—*Growth in the nonmineral sectors of the Appalachian economy and national economy, 1954–63*

[Data for each year and each separate heading are not necessarily comparable because of exclusion of confidential data. Source: U.S. Bur. Census. All monetary values in thousands of 1958 constant dollars]

	Appalachia				United States			
	1954	1958	1963	Percent change, 1954-63	1954	1958	1963	Percent change, 1954–63
Manufactures:[1]								
Establishments	21, 616	22, 114	21, 495	−1	286, 816	298, 453	304, 039	+6
Payroll	6, 186, 740	6, 731, 363	8, 656, 499	+40	67, 805, 657	73, 794, 693	99, 113, 850	+46
Value added	11, 574, 114	12, 658, 712	16, 338, 568	+41	125, 846, 923	141, 380, 886	189, 577, 291	+51
New capital expenditures	851, 374	982, 935	1, 083, 349	+27	8, 413, 402	9, 085, 245	11, 172, 874	+33
Retail trade:								
Establishments	168, 183	174, 381	167, 826	(2)	1, 721, 650	1, 794, 744	1, 707, 931	−1
Sales	14, 792, 619	15, 655, 884	18, 250, 128	+23	182, 953, 284	200, 370, 378	243, 224, 970	+33
Payroll	1, 406, 905	1, 538, 609	1, 829, 579	+30	19, 589, 040	21, 674, 669	27, 521, 460	+40
Wholesale trade:								
Establishments	16, 477	18, 719	20, 036	+22	252, 318	287, 043	308, 177	+22
Sales	12, 223, 168	14, 285, 641	15, 962, 012	+31	252, 577, 457	285, 726, 904	356, 952, 206	+41
Payroll	634, 395	721, 917	923, 747	+46	11, 863, 489	13, 244, 008	18, 028, 525	+52
Selected services trade:								
Establishments	62, 194	76, 197	86, 651	+39	785, 589	979, 195	1, 061, 673	+35
Receipts	1, 327, 701	1, 663, 695	2, 300, 399	+73	25, 281, 858	32, 505, 593	44, 407, 916	+76
Payroll	355, 069	432, 573	551, 383	+55	7, 024, 495	9, 045, 596	12, 143, 337	+73

[1] 1963 data are preliminary.
[2] Less than ½ percent decrease.

TABLE 12.—*Population and composition of labor force in the Appalachian Region, 1950 and 1960*

[Source: U.S. Bur. Census]

	Alabama		Georgia		Kentucky		Maryland		New York	
	1950	1960	1950	1960	1950	1960	1950	1960	1950	1960
Population	1, 820, 039	1, 946, 133	619, 766	675, 024	1, 072, 750	922, 150	189, 701	195, 808	894, 786	976, 448
Labor force	633, 590	677, 558	227, 221	252, 534	301, 366	245, 322	69, 845	71, 537	358, 280	383, 208
Unemployed ... percent	4. 4	5. 9	3. 9	4. 8	3. 6	8. 6	8. 0	7. 9	4. 6	5. 2
Mining ... do	4. 3	1. 6	. 7	. 6	19. 3	11. 1	2. 2	1. 0	. 5	. 3
Agriculture ... do	19. 7	7. 1	23. 3	8. 2	32. 0	17. 7	7. 5	4. 8	11. 7	7. 1
Manufactures ... do	23. 9	28. 2	34. 1	39. 6	7. 8	12. 8	28. 6	28. 6	23. 7	34. 0
Retail trade ... do	12. 2	13. 6	10. 5	12. 1	9. 2	12. 6	14. 1	14. 2	13. 6	12. 8
Wholesale trade ... do	2. 3	2. 6	1. 5	2. 2	1. 4	1. 6	2. 3	2. 4	2. 5	2. 0
Other ... do	33. 2	41. 0	26. 0	32. 5	26. 7	35. 6	37. 3	41. 4	43. 4	38. 6

	North Carolina		Ohio		Pennsylvania		South Carolina	
	1950	1960	1950	1960	1950	1960	1950	1960
Population	881, 560	939, 742	1, 035, 058	1, 119, 555	5, 784, 652	5, 930, 784	523, 265	586, 523
Labor force	316, 920	353, 489	362, 454	381, 647	2, 172, 557	2, 190, 287	210, 928	238, 169
Unemployed ... percent	3. 2	4. 4	4. 7	7. 3	6. 2	7. 9	3. 6	3. 6
Mining ... do	. 5	. 5	6. 3	2. 9	8. 6	2. 7	. 1	. 2
Agriculture ... do	21. 4	9. 5	16. 3	7. 8	4. 6	2. 9	12. 6	4. 3
Manufactures ... do	30. 9	37. 3	25. 5	29. 7	31. 1	33. 2	39. 0	42. 2
Retail trade ... do	11. 2	11. 7	13. 6	14. 3	13. 5	13. 0	12. 0	12. 2
Wholesale trade ... do	1. 6	1. 9	2. 1	1. 9	2. 4	2. 5	2. 0	2. 4
Other ... do	31. 2	34. 7	31. 5	36. 1	33. 6	37. 8	30. 7	35. 1

	Tennessee		Virginia		West Virginia		Total	
	1950	1960	1950	1960	1950	1960	1950	1960
Population	1, 520, 588	1, 599, 152	540, 675	509, 705	2, 005, 552	1, 860, 421	16, 888, 392	17, 261, 445
Labor force	518, 262	568, 078	165, 841	160, 670	659, 613	587, 232	5, 996, 877	6, 109, 731
Unemployment ... percent	4. 5	6. 0	4. 0	6. 9	4. 8	8. 3	5. 0	6. 8
Mining ... do	2. 5	1. 3	15. 9	10. 5	20. 4	10. 1	7. 9	3. 3
Agriculture ... do	19. 6	9. 5	21. 7	11. 7	9. 3	4. 0	12. 9	6. 2
Manufactures ... do	24. 6	29. 0	18. 1	23. 9	17. 9	21. 4	26. 4	30. 7
Retail trade ... do	12. 6	13. 2	10. 2	12. 5	12. 5	14. 1	12. 6	13. 1
Wholesale trade ... do	2. 2	2. 4	1. 3	1. 6	2. 3	2. 5	2. 2	2. 3
Other ... do	34. 0	38. 6	28. 8	32. 9	32. 8	39. 6	33. 0	37. 6

TABLE 13.—*Appalachian bituminous coal and lignite employment and productivity, 1947–64*

[Source: U.S. Bur. Mines]

	1947	1948	1949	1950	1951	1952	1953	1954	1955
Average number of men working daily:									
Alabama	20, 418	22, 523	21, 875	18, 363	13, 822	11, 800	10, 411	8, 217	8, 838
Georgia	57	45	45	45	45	44	25	16	25
Kentucky	54, 836	58, 820	59, 757	60, 698	51, 908	45, 237	39, 303	26, 626	31, 743
Maryland	2, 213	2, 005	1, 410	1, 326	712	633	595	383	561
Ohio	19, 944	20, 915	20, 052	18, 214	16, 249	14, 412	12, 244	10, 396	10, 374
Pennsylvania	103, 640	105, 810	99, 267	93, 181	84, 309	75, 908	68, 057	53, 135	47, 974
Tennessee	6, 385	6, 852	7, 002	6, 464	6, 514	6, 910	6, 372	4, 507	6, 397
Virginia	15, 914	17, 013	18, 122	17, 493	17, 500	17, 316	14, 640	12, 158	15, 202
West Virginia	114, 934	124, 952	124, 750	120, 888	111, 886	102, 996	88, 985	68, 011	66, 231
Total, Appalachia	338, 341	358, 935	352, 280	336, 672	302, 945	275, 256	240, 632	183, 449	187, 345
United States	419, 182	441, 631	433, 698	415, 582	372, 897	335, 217	293, 106	227, 397	225, 093
Percent in Appalachia	80. 7	81. 3	81. 2	81. 0	81. 2	82. 1	82. 1	80. 7	83. 2
Average tons per man per day:									
Alabama	3. 81	3. 77	3. 87	4. 31	5. 00	5. 53	6. 03	6. 54	6. 89
Georgia	3. 43	2. 24	3. 50	3. 50	3. 50	3. 50	3. 49	5. 19	2. 70
Kentucky	5. 25	5. 16	5. 22	5. 25	5. 61	5. 89	6. 47	7. 35	7. 54
Maryland	4. 85	4. 67	3. 97	4. 35	4. 53	4. 99	5. 22	6. 06	5. 60
Ohio	7. 11	8. 45	9. 34	10. 04	10. 21	11. 25	12. 35	14. 40	14. 65
Pennsylvania	5. 95	5. 76	5. 67	5. 95	6. 01	6. 24	6. 66	7. 71	8. 23
Tennessee	4. 69	4. 82	4. 26	4. 67	4. 90	5. 04	5. 50	7. 79	6. 79
Virginia	3. 83	4. 67	5. 10	5. 55	5. 80	6. 22	7. 06	7. 53	7. 38
West Virginia	6. 23	5. 92	6. 17	6. 41	6. 66	6. 97	7. 78	8. 86	9. 38
Average, Appalachia	5. 86	5. 68	5. 81	6. 63	6. 35	6. 70	7. 33	8. 45	8. 77
United States	6. 42	6. 26	6. 43	6. 77	7. 04	7. 47	8. 17	9. 47	9. 84

	1956	1957	1958	1959	1960	1961	1962	1963	1964
Average number of men working daily:									
Alabama	8, 439	8, 546	7, 179	6, 694	7, 405	6, 551	5, 961	5, 348	5, 421
Georgia	16	17	19	18	12	8	21	15	13
Kentucky	29, 891	30, 601	24, 439	21, 441	21, 738	19, 111	18, 356	19, 136	18, 039
Maryland	605	701	614	593	572	506	474	526	316
Ohio	10, 101	9, 598	8, 366	8, 488	8, 006	7, 278	7, 409	7, 232	7, 799
Pennsylvania	48, 325	46, 262	40, 203	36, 323	32, 651	27, 357	26, 209	26, 434	23, 349
Tennessee	6, 406	8, 229	5, 834	5, 238	4, 043	4, 657	4, 180	3, 170	3, 032
Virginia	15, 840	16, 693	15, 766	15, 634	13, 561	14, 021	12, 988	12, 343	9, 338
West Virginia	71, 996	71, 201	62, 437	53, 847	51, 062	43, 611	43, 763	44, 534	39, 308
Total, Appalachia	191, 619	191, 848	164, 857	148, 276	139, 410	123, 100	119, 361	118, 738	106, 615
United States	228, 163	228, 635	197, 402	179, 636	169, 400	150, 474	143, 822	141, 646	128, 698
Percent in Appalachia	84. 0	83. 9	83. 5	82. 5	82. 3	81. 8	83. 0	83. 8	82. 8
Average tons per man per day:									
Alabama	7. 29	7. 61	8. 40	8. 48	8. 66	9. 93	10. 81	11. 19	12. 16
Georgia	4. 29	3. 23	3. 20	2. 05	1. 84	2. 68	1. 75	2. 71	2. 70
Kentucky	8. 00	8. 42	9. 18	9. 61	10. 22	10. 73	11. 74	12. 29	13. 21
Maryland	6. 42	6. 78	6. 75	7. 46	8. 22	9. 06	10. 00	11. 77	15. 25
Ohio	14. 74	15. 68	16. 20	17. 09	18. 30	18. 86	19. 16	20. 69	18. 74
Pennsylvania	8. 58	8. 85	9. 38	9. 97	10. 68	11. 69	12. 45	13. 42	14. 43
Tennessee	7. 77	7. 91	8. 22	8. 06	8. 71	8. 86	10. 27	11. 47	10. 15
Virginia	8. 47	8. 39	8. 46	9. 80	9. 93	10. 71	10. 91	11. 94	14. 54
West Virginia	9. 65	10. 05	10. 66	11. 68	12. 07	12. 99	13. 57	14. 44	15. 31
Average, Appalachia	9. 20	9. 52	10. 06	10. 89	11. 37	12. 21	12. 91	13. 84	14. 72
United States	10. 28	10. 59	11. 33	12. 22	12. 83	13. 87	14. 72	15. 83	16. 84

Harlan, Leslie, and Letcher Counties in Kentucky and Wise County in Virginia are illustrative of areas where a declining economy accompanied a decline in mining. As shown in table 14, each of these counties has experienced a significant decline in total population between 1950 and 1960, coupled with a sharp rise in the proportion of older persons in the population and a drop in percent of population employed. Mining ranked first in the number of lost jobs. Virtually every other sector of the economy experienced a decline.

This drop in employment, resulting from increased productivity brought on by automation and improved mechanical mining methods, had a profound effect upon the Appalachian economy. The loss of thousands of mining jobs caused economic contraction to spread over much of the area and resulted in large outmigration, particularly from the coal mining regions of Pennsylvania and West Virginia.

The propensity to migrate appears to be a function of age, education, and skill, and consequently a large percentage of the older miners remained in the area. These miners form a large part of the chronic unemployed because they find it difficult to adjust to mechanization in the mining or manufacturing industries and because the number of jobs available to marginally skilled labor is insufficient.

The shift to mechanization not only reduced the size of the mining labor force, but also changed its composition. The average miner is becoming more skilled, and usually a more skilled worker requires more service and trade workers to support his needs. This requirement may partly explain the rise in the latter sectors of the economy.

ECONOMIC IMPACT OF THE MINERAL INDUSTRY

By Alvin Kaufman, U.S. Bureau of Mines

A useful tool in a discussion of the mining industry's impact on the Appalachian economy is input-output analysis. Such an analysis can be considered as an accounting system showing the shipments and purchases needed to support the economy at a given level. In effect, this system describes the economic relationship between the various parts of the economy. This analysis is accomplished by measuring both the purchases required from all other industries by a given industry in order to produce a dollar of output and the direct and indirect sales of that industry to all other industries. In preparing these input-output tables not only are direct purchases and sales traced, but purchases and sales required by secondary, tertiary, and other industries are also computed after eliminating duplication. For example, the coal industry has a direct requirement for timber; the timber producer needs saw blades, the saw-blade manufacturer needs steel, and so forth. The requirements to produce a dollar's worth of coal will, therefore, include forest products, manufactured steel products, and other materials (Wang and Kokat, 1966). Inasmuch as this total will include the requirements of all industries supplying the coal industry, as well as those supplying the suppliers, the total requirement will have a value larger than that of the coal industry's output.

Table 15 shows the total requirements for the coal and petroleum and natural gas industries and for minerals for the construction industries.

In preparing table 15 the national input-output coefficients were assumed to be relevant to Appalachia. In view of the substantial proportion of national output contributed by Appalachian coal, this assumption would appear to be logical for coal but because Appalachia's petroleum and natural gas and construction minerals make up a smaller part of the national output, the assumption may be less valid for these products.

The table indicates that $2.5 billion output from Appalachia's mines will generate $3.8 billion in total goods and services.

The total mining output also requires $615 million in manufactured products, primarily from such indus-

Table 14.—*Economic indicators, selected Appalachian counties*

[Source: U.S. Bur. Census]

	Kentucky						Virginia	
	Harlan County		Leslie County		Letcher County		Wise County	
	1950	1960	1950	1960	1950	1960	1950	1960
Population	71,751	51,107	15,537	10,941	39,522	30,102	56,336	43,579
Percent over 65	3.3	6.6	4.5	5.5	3.6	6.7	5.1	7.7
Total employment	18,554	10,972	3,718	1,660	8,972	6,054	14,647	10,181
Mining	10,741	4,039	1,274	788	5,306	2,857	6,373	3,518
Agriculture	607	112	1,005	20	772	77	736	250
Manufacturing	791	588	670	186	278	218	575	597
Retail trade	1,997	1,762	198	135	852	742	2,113	1,783
Wholesale trade	347	272	13	------------	63	84	403	299
Other	4,071	4,199	558	531	1,071	2,076	4,447	3,734

TABLE 15.—*Total requirements of Appalachian mining, 1958*

[Based on Goldman and others (1964, p. 26–29, table 3)]

Input industry group	Direct and indirect requirements for goods and services (million of dollars)			
	Coal	Petroleum and natural gas	Construction minerals	Total
Agriculture, forestry and fisheries	13.9	2.1	1.3	17.3
Mining	2,130.4	192.1	196.0	2,518.5
Construction	17.3	3.4	2.1	22.8
Manufacturing	521.3	21.9	72.1	615.3
Other	438.2	77.2	64.0	579.4
Total requirement	3,121.1	296.7	335.5	3,753.3

tries as iron and steel, chemicals, petroleum refining, rubber, and plastics. It would thus seem that the goods and services needed to produce Appalachia minerals are selective and that the Appalachian mining industry may be a rather minor market for the output of other industries. Consequently, it is unlikely that manufacturing industries dependent on mining as a customer will locate in Appalachia in significant numbers. There is a possibility, however, that those industries requiring the mineral raw materials produced in Appalachia will be attracted to the area. To evaluate this possibility, one must examine the output side, for output distribution is something of a measure of the inducement to other industries to locate in a given area because of the availability of the required raw materials. U.S. Department of Commerce data show that 23 percent of the coal, 5 percent of the petroleum and natural gas, and 7 percent of the construction materials are required by the ultimate consumer (such as coal burned for household use). The remainder is distributed to various processing or manufacturing industries for use in preparing other products. These mineral industries therefore apparently serve as an excellent attraction for mineral-based activities, providing other locational factors such as transportation are suitable.

Eighty-three percent of the petroleum and natural gas is required as an input by the petroleum-refining industry, and two-thirds of the construction materials are needed by the construction industry or stone and clay products manufacturers. Coal output is distributed between coal mining, primary iron and steel manufacture, electric-power generation, and miscellaneous producers. These industries may also attract others.

THE FUTURE: THE APPALACHIAN ECONOMY IN 1975

By BARBARA S. LLOYD, U.S. Bureau of Mines

Projections for the Appalachian economy shown in table 16 assume no change in circumstance or shift in trend, and thus are indicators of what may happen rather than indicators of what will happen. These projections demonstrate continuing growth in the area, although at rates considerably less than the average for the United States unless the trends are modified by some corrective actions.

TABLE 16.—*Projections of selected demographic, economic, and mineral data for the Appalachia Region for 1975, based on past trends*

[Source: U.S. Bur. Mines and U.S. Bur. Census]

	1960 (thousands)	1964 (thousands)	Projected growth rate (percent)	1975 (thousands)
Population	17,261	----------	0.3	17,942
Labor force	6,110	----------	.6	6,656
Employment	5,690	----------	.6	6,179
Mining employment	198	----------	−1.9	150
Coal employment	139	----------	−2.4	96
Minerals production:[1]				
1958 dollars	1,841,960	2,064,997	2.6	2,747,177
Sand and gravel:				
Short tons	27,939	31,053	3.3	45,050
1958 dollars	42,529	49,609	----------	71,967
Dimension stone:				
Short tons	330	340	5.4	605
1958 dollars	18,431	17,890	----------	31,834
Crushed stone:				
Short tons	72,000	91,706	4.3	150,000
1958 dollars	118,000	148,260	----------	242,490
Zinc:				
Short tons	104	137	2.8	185
1958 dollars	26,702	37,050	----------	50,031
Bituminous coal:				
Short tons	298,934	350,513	3.5	477,760
1958 dollars	1,463,792	1,640,204	----------	2,235,630
Anthracite:				
Short tons	18,052	16,246	−4.6	10,000
1958 dollars	143,290	144,443	----------	86,502
Fire clay:				
Short tons	4,344	3,622	−1.1	3,260
1958 dollars	23,380	21,324	----------	19,193
Miscellaneous clay:				
Short tons	4,658	4,488	3.3	6,880
1958 dollars	5,836	6,217	----------	9,530

[1] Total of items shown.

Accuracy of the projections for the Appalachian economy are limited by the data available. These estimates are not predictions and can change as the assumptions about future economic and technologic activities are modified. To place projections in proper perspective, it is necessary to discuss the methodology and assumptions used in their construction.

As a basis for the projections on mining production and employment, estimates of the population, labor force, and total employment in Appalachia for 1975 were prepared. The background data were from the Census of Population for 1950 and 1960 and from 1975 population projections by States made by the National Planning Association (1965; NPA). The State projections required several adjustments: (1) Because NPA population estimates were as of July 1 and Bureau of Census population as of April 1, the State estimates had to be adjusted to the April 1 date. (2) They also had to be adjusted to reflect only the Appalachia sectors of the State; this adjustment was accomplished by comparing the relative changes in population from 1950 to 1960 and using the Appalachia-to-State ratios for these years to make a reasonable projection for Appalachian population, labor force, and employment in 1975 on the basis of the NPA State forecasts for 1975.

The next step was to estimate output in 1975 of the major mineral commodities (sand and gravel, stone, bituminous and anthracite coal, clays, and zinc) in Appalachia. Data were available on production of these commodities for the period 1947–64 both for Appalachia and the United States; consequently, the forecasting approach was more direct. First, the relationship between past U.S. and Appalachian production was calculated. Then these relationships were applied to projections of U.S. production of these commodities (previously prepared by the U.S. Bureau of Mines) to derive the projected output for Appalachia.

In estimating total mining employment for Appalachia, the approach used was similar to that for estimating population, with the advantage that coal-mine employment data were available for 1947–64. Because coal employment historically has composed 70 percent of total mining employment in Appalachia, a more reliable trend could be established. A separate estimate was made for coal by projecting the productivity trend in this industry and applying it to the estimate of 1975 coal production previously made. By using this coal projection and the forecast of total Appalachian employment and comparing these two projections to the NPA forecasts for state total employment and state mining employment, the projection for total Appalachian mining employment was derived.

These methods and assumptions indicate that the regional population will grow at an annual rate substantially less than 1 percent as compared with a national estimated growth of 1.6 percent. Appalachian labor force and employment should grow at double the area-population rate. The U.S. labor force is expected to grow at approximately the same rate as its population. Insofar as Appalachia is concerned, the relationship between population and labor force implies that a larger percentage of the population in 1975 will be a part of the labor force.

Therefore, even without corrective action the overall Appalachian economy will experience a slow but steady growth. The extractive mineral industry is, however, expected to contribute a declining proportion of total regional income as is evident from the projected employment data which indicate that both overall mining employment and coal employment in particular will be declining, while total area employment is increasing. The value of mineral production (in constant dollars) is expected to increase between 1964 and 1975 because the output per man-hour will increase and only anthracite and fire clay will lose ground in absolute value of production. The estimated 33 percent increases over the 11-year period in the value of minerals production will, however, be less than the increase expected for the total Appalachian economy; a declining relative importance of the extractive mineral industries is thus indicated. Most of the economic growth in the region is expected to come from the manufacturing and service industries.

This shift away from dependence upon a mineral base reflects the growing maturity of the Appalachian economy. As income increases and as the economic system develops, the significance of the minerals industry relative to the total economy declines. The fact that this trend is already apparent in Appalachia indicates that the economy is becoming more diversified, more in line with the national economy, and less sensitive to changes in the demands for minerals.

GEOGRAPHY

By R. A. Weeks, R. D. Zahnizer, and G. L. Chute, U.S. Geological Survey

GENERAL

Appalachia, as defined legislatively, is an irregular shaped area of 185,000 square miles, extending from New York to Alabama. It is about 950 miles long from northeast to southwest and averages 250 miles in width, as shown in plate 1. It includes West Virginia, most of Pennsylvania, and parts of 10 other States. Most of the area is mountainous or hilly, and the major uplands of the eastern United States, collectively known as the Appalachian Highlands, are included within Appalachia. This area differs substantially from the surrounding region in geography and economic development.

The rough terrain limits the amount of arable land and provides barriers to access and through transportation routes; historically the area was bypassed during the settlement of the interior of the continent. Industrialization focused interest on the mineral and fuels resources of the Appalachian Highlands only after the rich farmlands of the Mississippi Valley had been settled. Settlement and development in earlier years followed the streams and valleys, then branched out to tap coal, oil, and a variety of mineral and rock products. Agrarian development has been limited to small tracts that vary substantially in fertility, and greatest emphasis has been on livestock, dairy products, and cash crops. Forests are extensive, and important wood-products industries have developed. Most towns are small, because of the limited population in their market areas.

The Appalachian Highlands are dissected by streams and rivers, most of which flow either into the Atlantic or into tributaries of the Mississippi River. A few streams flow to the Great Lakes, and some flow directly to the Gulf of Mexico. Summits along the drainage divide include the highest elevations in the eastern half of the United States. Many summits approach or exceed 6,000 feet, and Mount Mitchell, in North Carolina, is 6,684 feet high.

The pattern of hills, ridges, and mountains, together with their stream systems, depends on the nature of underlying rocks. Four distinctive patterns occur in the Appalachian Highlands, each designated as a physiographic province. The easternmost is the Blue Ridge, in part linear and elsewhere massive. The Valley and Ridge province to the west is characterized by long ridges separated by deep valleys; stream systems tend to be angular and of the type known as a trellis pattern. Next westward is the Appalachian Plateaus province, underlain by relatively flat-lying strata; stream patterns are dendritic. A small part of western Appalachia is in the Interior Low Plateaus province, where drainage is dendritic and in some areas is subterranean where it traverses limestone.

Surrounding these uplands are the Piedmont province on the southeast, the Coastal Plain province on the southwest, and the Central Lowland province on the northwest. The specific physiographic features characteristic of each province are described by Davies in the following section on "Physiography."

CLIMATE AND HYDROLOGY

As an interior upland mass, Appalachia has a climate distinct from that of surrounding areas. It is characterized by cooler temperatures and greater rainfall. Summer temperatures reach the mid-90's in the higher parts of the area and range as high as 109°F elsewhere. Winter minimum temperatures of record range from about —20°F in the north to a few degrees above zero in the south. Statistical averages conceal the extremes; average annual temperatures are about 50°F in the north and above 60°F in the south.

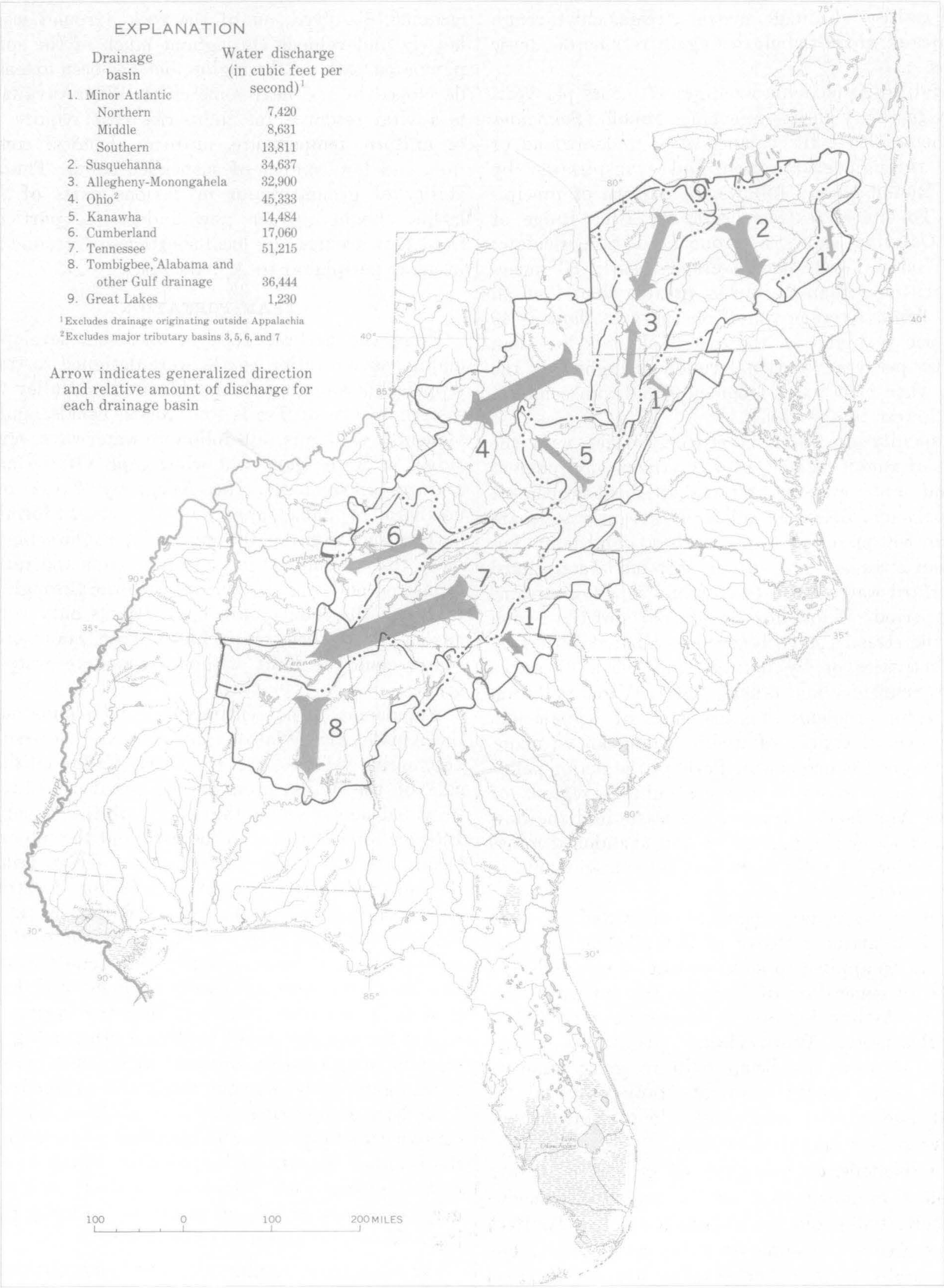
Precipitation averages about 47 inches annually, much above the national average for regions of comparable size. Most is derived from eastward-moving masses of air that lose their moisture as they are forced upward over the mountainous areas. High precipitation thus tends to occur along the western sides of mountain ranges, and distinct rain shadows are found east of them. The highest average annual rainfall, which occurs along the western side of the Blue Ridge in North Carolina and Georgia, is about 80 inches. Rainfall also increases from north to south, from an annual average of about 35 inches a year in New York and northern Pennsylvania to more than 55 inches in Alabama.

Precipitation is the source of an adequate supply of water reasonably well distributed between the growing and nongrowing seasons. Most summer rain falls during thunderstorms, which occur 30–35 days per year in the northern part of the region and as many as 60 days per year in Alabama. Thunderstorms may produce intense rainfall and cause crop damage and severe local flooding. Snowfall ranges from more than 100 inches in the higher elevations in the north, where individual storms may drop more than 20 inches of snow, to less than 3 inches in Alabama.

The large amount of surface water produced by precipitation moves seaward along well-developed stream systems toward the Atlantic and the Gulf of Mexico. In the highlands, streams are fast and narrow and move large amounts of water.

Stream systems flowing into the Atlantic originate in the Appalachian Plateaus in the north and in the Blue Ridge in the south. Their patterns and valley shapes reflect structure and relative resistance of underlying rocks. In headwaters, valleys are narrow and steep sided, broadening and flattening downstream, except where cutting through hard rock ridges. Stream patterns are dendritic in the plateaus and trellised in the Valley and Ridge province and in the Blue Ridge. After emerging from the uplands, streams flow in open valleys southeastward across the Piedmont and the Coastal Plain. Some streams descend as much as 2,000 feet in 3 miles as they emerge from the Blue Ridge. As they coalesce downstream, they develop into broad rivers with slower flow but greater total discharge. Discharges of major basins differ, as shown in figure 2.

Stream systems draining into the Gulf of Mexico via tributaries of the Mississippi River originate in the western part of the Appalachian Plateaus in the north and in the Valley and Ridge province in the south. Stream patterns and valley shapes reflect comparable control of underlying rocks. Most northern streams exhibit dendritic patterns and are deeply incised; in many places they flow more than 1,000 feet below the nearly flat but discontinuous plateau surface. Relief tends to be subdued in the northernmost part of Appalachia where glaciation modified the topography. Toward the south, streams may head in the Blue Ridge where drainage is dendritic or in the Great Valley on the east side of the Valley and Ridge province, where relief is low. The streams traverse northeast-trending hard-rock ridges through spectacular steep-sided water gaps and are fed by tributary streams that follow the interridge valleys. Beyond this



EXPLANATION

Drainage basin	Water discharge (in cubic feet per second)[1]
1. Minor Atlantic	
Northern	7,420
Middle	8,631
Southern	13,811
2. Susquehanna	34,637
3. Allegheny-Monongahela	32,900
4. Ohio[2]	45,333
5. Kanawha	14,484
6. Cumberland	17,060
7. Tennessee	51,215
8. Tombigbee, Alabama and other Gulf drainage	36,444
9. Great Lakes	1,230

[1] Excludes drainage originating outside Appalachia

[2] Excludes major tributary basins 3, 5, 6, and 7

Arrow indicates generalized direction and relative amount of discharge for each drainage basin

FIGURE 2.—Drainage basins and stream discharge in the Appalachian Region.

area of trellised drainage, master streams cut through the plateaus where tributaries again resume dendritic patterns.

Rainfall in Appalachia averages 47 inches per year. Twenty to thirty inches is surface runoff (Schneider and others, 1965); the balance seeps underground or is lost through evaporation and transpiration by plants. Runoff closely follows the pattern of precipitation. To cite an extreme case, the Blue Ridge of North Carolina shows a pronounced rain shadow; rainfall on its west flank averages nearly 80 inches per year, more than 25 inches greater than that on its east flank. Average runoff on the west flank is 40 inches per year and on the east flank it is less than 15 inches per year. Seasonal runoff is highest in the spring, when melt water from snow and rain combine, and is lowest in the fall.

The quality of water in streams varies with the amount of runoff as well as with stream environment and land- and water-use patterns. In about 90 percent of Appalachia, dissolved solids in stream waters are less than 300 ppm (parts per million), and most Appalachian streams have soft or only moderately hard water. Hard water is apt to be found in a few streams during periods of low flow and in parts of the region where the streams have been contaminated, either by man's activities or by natural infiltration of saline waters (Schneider and others, 1965). Water pollution may present problems in some parts of Appalachia, but the overall supply of usable water can be maintained by good management. Perhaps the major pollution of water exists in the coal-mining regions of northern Appalachia, where mine waste and the flow of ground water through active and abandoned mines adds a variety of solid and chemical contaminants to surface water.

In summary, a large amount of water of good quality is a major resource of Appalachia. This resource can be applied to development of new industry and also to generation of hydroelectric power, as described by Arthur Johnson in the section on "Water-power Resources." Thermoelectric plants using large amounts of water are being built in great numbers and this trend should continue. Many potential industrial and power sites exist along Appalachia's extensive stream and river systems.

Small to moderate quantities of ground water are available throughout most of the region (Schneider and others, 1965) and are abundant locally. Aquifers are the source of the water for many springs and seeps that maintain the base flow of many streams. In areas underlain by limestone, a good part of the drainage follows subterranean routes at various depths through channels dissolved out of the rock. Ground water is largely undeveloped throughout much of the sparsely populated parts of the region, but has been extensively developed in and near some cities. Where available it is a vital resource for industries that require water of uniform temperature, uniform chemical composition, and low content of suspended solids. The availability of ground water in various parts of Appalachia should attract new industries, particularly those that are meeting local shortages of ground water in areas peripheral to Appalachia.

TRANSPORTATION

From the earliest days of national development, major transportation routes were designed to traverse Appalachia and to link the Mississippi Valley to the eastern seaboard. Trails and roads, canals, and subsequently railroads, all followed waterways, crossing ridges at water gaps and wind gaps. Of the natural features encountered, the Allegheny Front of the northern Appalachians was the most formidable barrier and required the maximum engineering ingenuity to surmount its grade. Spur roads and railroads connected outlying settlements with the through-going routes as the country filled up. It was only with the advent of automotive vehicles that transportation routes could be built without regard to water-level grades.

Appalachia is not entirely hilly. Uplands such as the Appalachian Plateaus are relatively accessible by automotive vehicles, and the Great Valley on the east side of the Valley and Ridge province always has provided access along the length of the region. The Interior Low Plateaus to the west and the intervening basins and the areas bordering the Great Lakes on the north are fairly easy terrain for constructing transportation routes. The Ohio Valley below Pittsburgh always has been a natural corridor to the Mississippi Valley; more recently the Tennessee Valley has been developed by means of dams and locks to provide a southern waterway into the region. Even within the rougher areas, modern earth-moving equipment is being used to construct direct new routes and to straighten older sinuous roads and railroads.

Modern engineering also has made it possible to construct fuel pipelines and electrical powerlines across the roughest terrain of Appalachia. Pipelines supply many sections with petroleum products and natural gas, and transport oil and gas from the many producing fields of the region to refineries.

POPULATION, INDUSTRY, AND AGRICULTURE

The rugged terrain throughout much of Appalachia made the region generally more difficult to develop than the surrounding land of more subdued topography. Earliest settlements grew up around military and trading posts. The settlements at intersections of major transportation routes were on sites that naturally favored growth, especially where local sources of raw materials were at hand.

After nearly two centuries of national development, most of the region still is sparsely populated. According to the national census, the total population was 17,261,445 in 1960 (table 17). Figure 3 shows the distribution of population. Only 19 cities have populations greater than 50,000; only 7 of these have more than 100,000 inhabitants. Only Pittsburgh, with its population of 604,000, exceeds half a million people. In contrast, 30 additional cities of more than 100,000 lie within 100 miles of Appalachia's borders; they include the large metropolitan areas of New York City, Philadelphia, Baltimore, Washington, Cleveland, and Atlanta. The urban population of Appalachia is only 47.5 percent of its total population, whereas the national average is 72 percent. Within Appalachia are some of the most thoroughly rural areas in the United States. Although only 9 percent of the people live on farms, the major part of the population is scattered in many small towns. In some parts of the region as much as 90 percent of the population lives in open country or in villages and towns of less than 2,500 inhabitants.

TABLE 17.—*Population and area of the Appalachian Region by State*

State	Counties in Appalachia	Population		Area	
		1960 census	Percent of State total	Square miles	Percent of State total
Alabama	33	1,946,133	59.6	23,275	45.6
Georgia	35	675,024	17.1	10,934	18.6
Kentucky	49	922,150	30.0	16,945	41.9
Maryland	3	195,808	6.3	1,556	14.7
New York	13	976,448	5.8	11,233	22.7
North Carolina	29	939,742	20.6	11,921	22.6
Ohio	28	1,119,555	11.5	13,698	33.2
Pennsylvania	52	5,930,784	52.4	36,669	80.9
South Carolina	6	586,523	24.6	3,959	12.7
Tennessee	49	1,599,152	44.8	19,225	45.5
Virginia	21	509,705	12.8	9,371	23.0
West Virginia	55	1,860,421	100.0	24,181	100.0
Total	373	17,261,445	----------	182,967	----------

The 19 metropolitan areas of Appalachia listed in table 18 are dispersed throughout the region. Each has a unique combination of favorable transportation routes and local sources of materials or energy that

TABLE 18.—*Population centers of 50,000 or more in the Appalachian Region*

[Data adapted from Bogue and Beal (1961)]

City	State	Population (1960)		Additional cities of more than 10,000 included in area	Major products
		Central city	Standard metropolitan area		
Pittsburgh	Pa.	604,332	2,400,000	33	Steel, coal, coke, chemicals, glass, clay products, processed foods.
Birmingham	Ala.	340,887	635,000	4	Iron, steel, coal, coke, chemicals, textiles, machinery, aircraft.
Erie	Pa.	138,400	251,000	1	Steel, fabricated metals, machinery.
Chattanooga	Tenn.	130,009	238,000	2	Textiles, fabricated metals, wood products, chemicals, processed foods.
Knoxville	Tenn.	111,827	368,000	3	Textiles, fabricated metals.
Scranton	Pa.	111,443	235,000	2	Clothing, textiles, anthracite coal, fabricated metals, chemicals, leather goods.
Winston-Salem	N.C.	111,135	189,000	----------	Tobacco, textiles, furniture, electronic equipment.
Charleston	W. Va.	85,796	315,000	3	Chemicals, glass, coal.
Huntington	W. Va.	83,627	147,000	2	Nickel, steel, glass, shoes, tobacco, refractories, coke.
Binghamton	N.Y.	75,941	213,000	3	Shoes, leather goods, business machinery, photographic equipment.
Huntsville	Ala.	72,365	----------	----------	Textiles, processed foods.
Altoona	Pa.	69,407	137,000	----------	Machinery, processed foods, shoes, textiles, paper.
Greenville	S.C.	66,188	210,000	----------	Textiles, clothing, machinery, plastics.
Wilkes-Barre	Pa.	63,551	347,000	5	Anthracite coal, clothing, textiles, machinery, fabricated metals.
Tuscaloosa	Ala.	63,370	----------	----------	Fabricated metals, paper, rubber.
Asheville	N.C.	60,185	130,000	----------	Textiles, lumber, furniture, leather, machinery.
Gadsden	Ala.	58,088	----------	----------	Steel, rubber, textiles.
Johnstown	Pa.	53,949	281,000	----------	Steel, coal, machine tools, clay product, clothing.
Wheeling	W. Va.	53,400	358,000	5	Steel, coal, fabricated metals, chemicals, plastics, paints, glass.

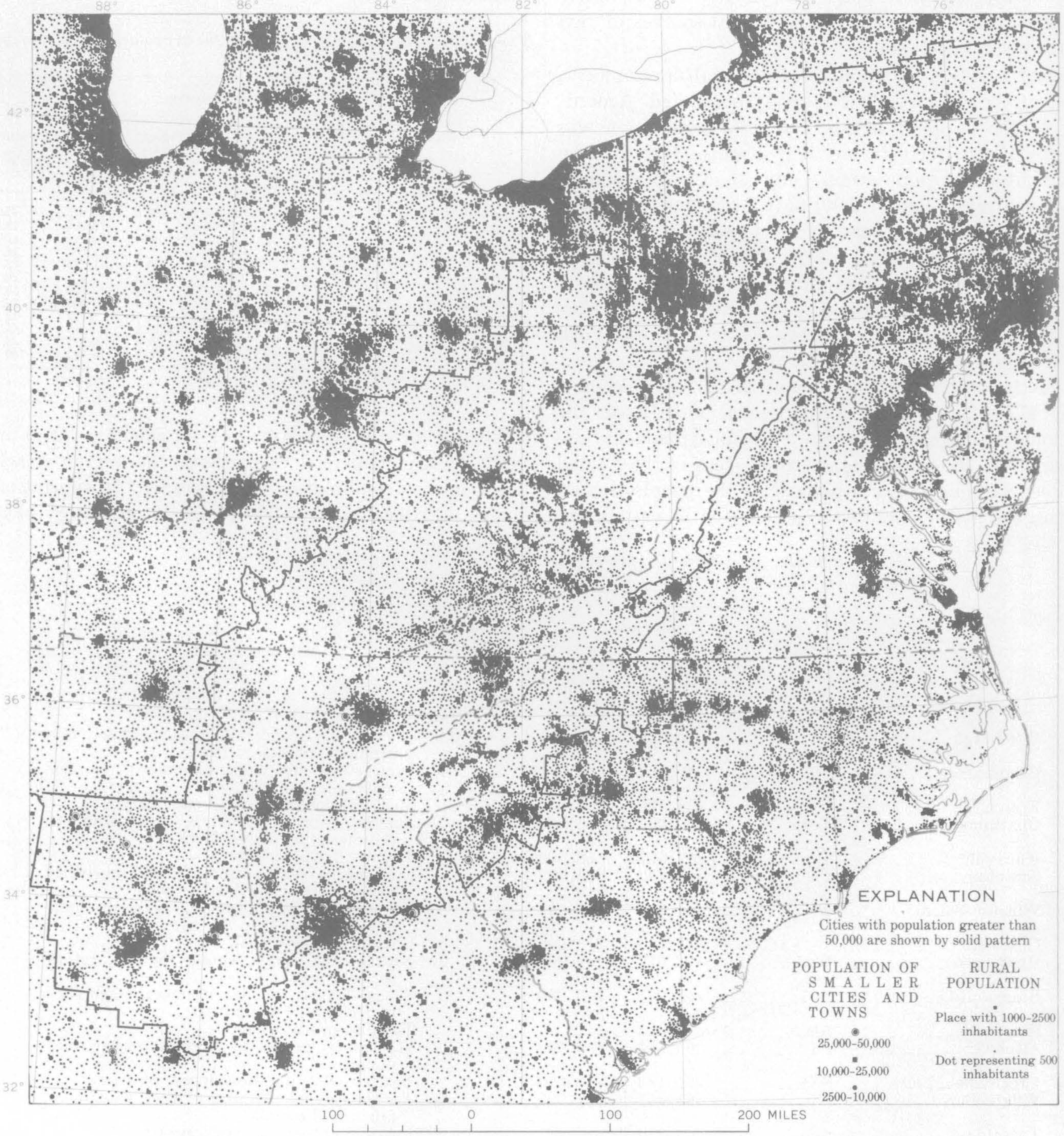


FIGURE 3.—Population density in the Appalachian Region and adjacent areas.

have served to augment its growth. Pittsburgh for example was founded as a fort at the junction of the Allegheny and Monongahela Rivers, it guarded the entrance to the Ohio Valley during the Colonial period and was a strategic objective in the struggle between the British and the French. After American independence, it was the major trading center of the upper Mississippi Valley and the portal for migration into the rich farm country to the west. Local iron ore, coal, and limestone provided the basis for an iron industry, and before the Civil War the city had grown to a population of about 100,000 inhabitants. The region has abundant high-grade coking coal, and subsequent growth of the city was based on construction of railroad nets to bring the rich Great Lakes iron ores to the coal country and to move manufactured products to consuming centers. Discovery of oil and gas in the surrounding region led to further diversification and growth.

Birmingham is another city whose growth was based on proximity to iron ore, limestone, and coal. Other metropolitan areas in Appalachia developed because of local availability of particular resources and favorable transportation routes. The region as a whole is especially endowed with abundant energy resources, both fossil fuels and water power, and much of the industry of Appalachia has been established either to use the energy or to transport fuels to internal and external markets.

Many smaller cities and towns have industries that produce for the immediate area and for the larger cities nearby. The population of most of these smaller industrial centers generally has not increased as rapidly as that of the metropolitan areas. The population of cities and towns in rural Appalachia has tended to decrease in recent years. The farm population decreased 12 percent from 1950 to 1960.

The topography of Appalachia has inhibited agricultural development because the hilly terrain inherently is difficult to cultivate, either by hand or mechanically, and soils tend to be thin and stony and subject to erosion. Consequently the extent of croplands in Appalachia is small in comparison to other areas in the conterminous United States. A conspicuous exception is the Great Valley, which is favored by low relief and rich soils that developed over limestone. Other smaller valleys floored by limestone throughout the region also have relatively high agricultural yields.

Much of the agriculture is a part-time activity of rural dwellers who also may be employed in various trades and services or in mining or manufacturing in nearby areas. Livestock production and dairy products are the major sources of farm income. Croplands devoted to hay and feed grains in general are in small fields along the valleys and lower slopes, and to a lesser extent along higher slopes. Almost two-thirds of the land is forested, the basis for a considerable industry in wood products.

In addition to livestock and dairy products, a variety of cash crops are grown in different areas, depending on soil, rainfall, and climate. Cotton and tobacco are grown in southern Appalachia and grains grow farther north. Fruits, vegetables, and other high-value small crops are grown for local markets.

PARKS AND RECREATION

As a sparsely settled mountainous area abounding in forests, streams, wildlife, game, and fish, Appalachia offers extensive recreational opportunities. Rolling green hills and spectacular ridges and water gaps contrast with the surrounding lowlands, and such scenic attractions bring thousands of tourists and campers into the region annually. Each season offers different attractions, from fishing in the spring to skiing in the winter.

Use of the region for recreational purposes came only with construction of road nets permitting families to roam at will through the hills and forests. Establishment of lodging facilities and campsites has attracted growing numbers of tourists.

In order to conserve some of the wilderness beauty, the Federal Government and each of the States have established parks, forest preserves, and wildlife refuges (fig. 4). Quasi-public and private land areas also are used for recreation where conservation tends to be practiced by owners. Total acreage of such protected areas is particularly large in the Blue Ridge of central and southern Appalachia (U.S. Natl. Park Service, 1964).

Appalachia's assets include the unique Appalachian Trail, a world-renowned hiking route.

The public and private parks and recreation facilities (table 19), serve for both educational and recreational purposes. The use of parks for educational purposes is often thought of in terms of groups, either organized or unorganized, primarily of school-age people. Parks offer the opportunity for studying the natural history, either at the amateur or professional level, of an area that has been relatively undisturbed. To cite only one example, Appalachia for many years has been a classic demonstration area for the training of geology students. Parks also attract people who only wish to observe natural beauty or to come and participate in sport activities offered by unspoiled nature.

FIGURE 4.—Existing and potential parks in the Appalachian Region.

TABLE 19.—*Public parks and recreation areas in the Appalachian Region*

[Area in acres]

	U.S. National Park Service		U.S. Forest Service		U.S. Fish and Wildlife Service		U.S. Corps of Engineers		Tenn. Valley Authority		State Parks	
	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area
Alabama	2	3,003	3	536,742	2	41,064	6	11,318	4	187,733	16	29,190
Georgia	1	8,190	1	680,327	2	96	2	85,191	3	12,025	17	10,194
Kentucky	1	10,679	2	458,523	----	----------	8	116,516	----	----------	12	12,353
Maryland	2	195	----	----------	----	----------	1	1,425	----	----------	6	2,864
New York	----	----------	----	----------	1	105	3	5,766	----	----------	12	65,922
North Carolina	2	309,256	3	922,275	1	121	----	----------	4	21,523	3	5,563
Ohio	1	68	1	106,129	1	72	1	1,359	----	----------	20	18,881
Pennsylvania	1	2	1	470,862	3	1,768	8	22,450	----	----------	51	117,393
South Carolina	1	1	1	341,624	1	104	----	----------	----	----------	5	12,760
Tennessee	4	238,694	1	594,770	1	58	2	81,015	15	357,913	10	38,377
Virginia	2	7,481	1	542,725	3	520	----	----------	1	2,155	3	7,070
West Virginia	2	473	2	903,878	3	216	2	6,380	----	----------	24	48,178
Total	19	578,042	16	5,557,855	18	44,124	33	331,420	27	581,349	179	368,745

	State Forest		State Fish and Game		State, Other		County Parks		Other		Total	
	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area	No.	Area
Alabama	1	240	----	----------	4	5,190	----	----------	5	704	43	815,184
Georgia	----	----------	10	177,322	4	42	----	----------	----	----------	40	973,387
Kentucky	5	266,322	1	4,000	----	----------	1	246	----	----------	30	629,041
Maryland	4	100,893	16	16,435	----	----------	1	1,934	----	----------	30	123,746
New York	11	223,686	10	27,518	----	----------	1	30	----	----------	38	323,027
North Carolina	----	----------	2	12,002	----	----------	----	----------	3	18,798	18	1,289,538
Ohio	15	147,549	22	28,178	16	2,154	----	----------	10	67,796	87	372,186
Pennsylvania	31	1,867,949	100	858,651	8	342	16	9,660	----	----------	219	3,349,077
South Carolina	----	----------	3	225	1	63	----	----------	----	----------	12	354,777
Tennessee	9	101,700	13	411,043	----	----------	15	3,112	18	3,008	88	1,829,690
Virginia	----	----------	3	20,060	1	1,633	----	----------	----	----------	14	581,644
West Virginia	9	78,857	29	99,652	----	----------	----	----------	2	2,029	73	1,139,663
Total	85	2,547,596	209	1,655,086	34	9,424	34	14,982	38	92,335	692	11,780,960

The use of public lands for education and recreation can be increased and their value for these purposes enhanced by greater dissemination of information about the natural habitat, including the geologic features. Guidebooks or tour guides for specific subjects or purposes are almost indispensable, particularly in large areas, for planning projects and selecting areas and subjects to be seen and routes to be followed. Outdoor or indoor displays of special subjects or phenomena are appropriate to some subjects and purposes, and descriptive signs and spot location signs are effective in calling attention to others.

STATUS OF TOPOGRAPHIC MAPPING

One of the primary requisites for study and development of the Appalachian Region and its resources is an accurate portrait of the land and its physical characteristics. An accepted standard for the basic portrait is the modern topographic map, which depicts the land in three dimensions. It shows the mountains and valleys, relief symbolized by contours, elevations at specific points, and the lakes and rivers as well as all manmade features, such as houses, bridges, dams, and towns and the roads and trails that join them. The topographic map provides an accurate base for recording the location and extent of the natural resources, and facilitates the study of highway routes.

Appalachia is one of the best mapped areas in the United States. As shown in figure 5, two-thirds of the area is covered by 7½-minute topographic quadrangle maps, about 40,000 square miles are in the current program for 7½-minute mapping, and all but 3,000 square miles of the remaining part is covered by maps published in the 15-minute series. The whole area is mapped in the 1:250,000 series (1 inch = 3.95 miles).

All of Appalachia within Ohio, Kentucky, Maryland, and Tennessee, is completely covered by published topographic maps in the 7½-minute series. Mapping projects in the current program will complete the 7½-minute coverage in New York and Virginia. In addition, the current program includes the completion of 7½-minute mapping for areas within the designated highway corridors. By 1968, most unmapped areas in Appalachia are expected to be added

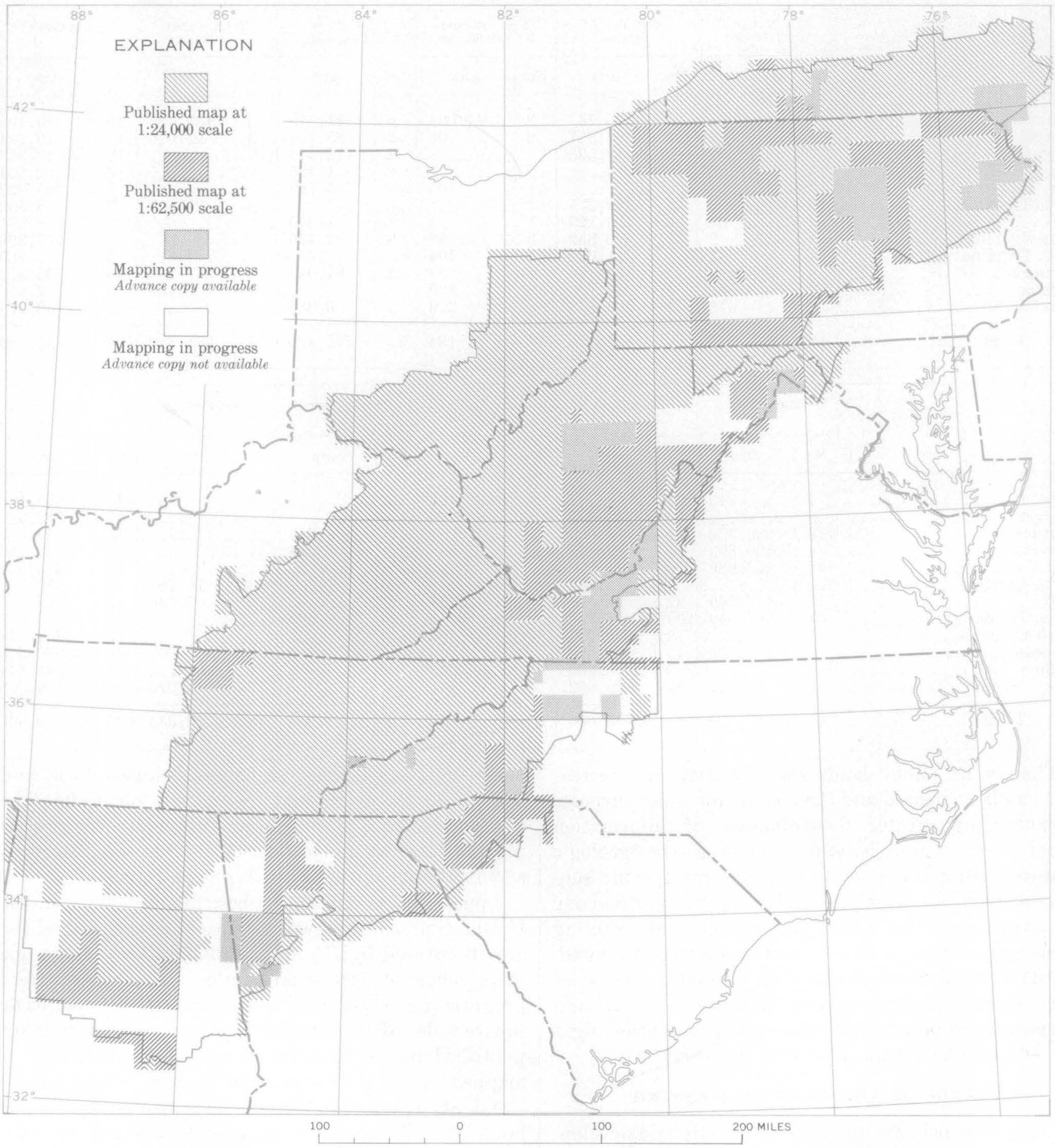


FIGURE 5.—Status of topographic mapping in the Appalachian Region.

to the mapping program, as well as resurveys at 7½-minute standards of some older 15-minute maps in areas selected for further development. Several older standard maps in potential growth areas are being revised; the 1:250,000 maps are also being updated. Therefore, current projects will complete the topographic mapping of Appalachia except for some 3,000 square miles in Alabama.

PHYSIOGRAPHY

By William E. Davies, U.S. Geological Survey

Appalachia, as an economic entity, is nearly coextensive with the Appalachian Highlands, one of the eight principal geographic divisions of the United States (Fenneman, 1938, p. 121; 6 *A*, *B*, table 20). Because Appalachia's boundaries were established in recognition of certain social and economic factors, the area of Appalachia overlaps slightly into two other major geographic areas—the relatively flat country of the Coastal Plain province in Alabama and the Interior Plains division in Ohio, Kentucky, Tennessee, and Alabama. The Appalachian Highlands extend northward into New England and easternmost Canada, and eastward beyond Appalachia in New York, Pennsylvania, Maryland, and Virginia.

Appalachia comprises part or all of seven physiographic provinces, four in the Appalachian Highlands and three in nearby lands of lower elevation and more gentle topography. Characteristics of these provinces are listed in table 20. Distinctive landforms have developed in each province, in large part depending on the structure and type of underlying rocks. Because the forces that have actively shaped the rocks have varied, the landforms in each province reflect the different periods of mountain building and crustal warping and the erosional forces of wind, water, ice, and gravity. The present landscape thus reflects the total geologic environment, past and present.

PHYSIOGRAPHIC PROVINCES

PIEDMONT

The eastern part of Appalachia in the Carolinas, Georgia, and east-central Alabama is in the Piedmont province. It is an upland of rolling hills with gentle slopes and relief generally less than 150 feet. Major steep-sided valleys, however, have been cut to depths of several hundred feet. Tributary valleys are generally broad with gently sloping sides. The expanse of rolling areas between deep streams is greatest in Alabama and Georgia where the upland extends for miles without interruption. Northwards in the Carolinas the relative amount of undissected upland diminishes, and steep-sided valleys are seldom more than a few miles apart.

Table 20.—*Rocks and landforms of the physiographic divisions of the Appalachian Region*

Province	*Landforms, relief, soils, and relation to bedrock structure*	*Principal rock units*
Appalachian Highlands division		
Piedmont	Rolling hills, gentle slopes, relief less than 150 feet. Residual soil, 50–120 feet thick, is widespread. Pattern of valleys and hills rarely coincides with bedrock structure.	Mainly Paleozoic metamorphic and igneous rocks. One small area of Triassic sedimentary rocks.
Blue Ridge	Mountains, steep slopes, relief 700–1,200 feet in north, 1,500–4,000 feet in Great Smoky Mountains. Soils thin to locally thick. Pattern of hills coincides with structure of resistant quartzite and conglomerate beds.	Lower Precambrian metamorphic and igneous rocks and upper Precambrian metavolcanic rock, Cambrian quartzite and conglomerate.
Valley and Ridge	Sandstone and conglomerate form ridges with steep slopes and relief 500–2,500 feet. Limestone, dolomite, and shale underlie broad valleys and areas of low rounded hills. Valley and ridge linear pattern controlled by structure of folded and faulted beds.	Folded and faulted sedimentary rocks of many types and of Cambrian through Pennsylvanian ages.
Appalachian Plateaus.	Dissected plateau, steep slopes, relief 500–1,500 feet. Soils generally thin except for thick glacial deposits in north. Drainage pattern is random or dendritic.	Predominantly flat-lying sandstone, siltstone, and shale but including conglomerate, coal and thin limestone beds. Devonian to Permian age.
Interior Plains division		
Interior Low Plateaus.	Gentle slopes, relief 50–200 feet. Soils thin, stony. Random drainage pattern.	Flat-lying sedimentary rocks of many types but limestone predominates. Mainly Ordovician to Mississippian in age but includes Pennsylvanian sandstones in eastern part.
Central Lowland	Gentle slopes, relief 50–200 feet, thin glacial deposits, variable soils, thicker than in Low Plateaus province.	Similar to above, in Appalachia part of province.
Atlantic Plain division		
Coastal Plain	Low hills, steep slopes and relief 100–250 feet.	Flat-lying poorly consolidated Cretaceous sandstone capping hills with rocks similar to Piedmont, Valley and Ridge, and Appalachian Plateaus exposed in stream valleys.

In Georgia and Alabama the upland surface is at an elevation of about 1,400 feet, except at the western edge where it rises to 1,800 feet along the foot of the Blue Ridge. The upland is crowned by rounded ridges and knobs, called monadnocks, that rise above the general level of the hilltops. These monadnocks are erosional remnants reflecting contrasts in weathering processes and the strength of underlying rocks. Stone Mountain, Ga., outside Appalachia, is one of the more notable monadnocks in the southern Piedmont.

In the Carolinas the monadnocks are of greater size and include extensive outlier ridges similar to spurs of the Blue Ridge. Some of these ridges rise about 1,500 feet above the rolling upland and are separated from one another by broad valleys and rolling uplands.

The rocks of the Piedmont are primarily granite, gneiss, schist, slate, and related metamorphic rocks.

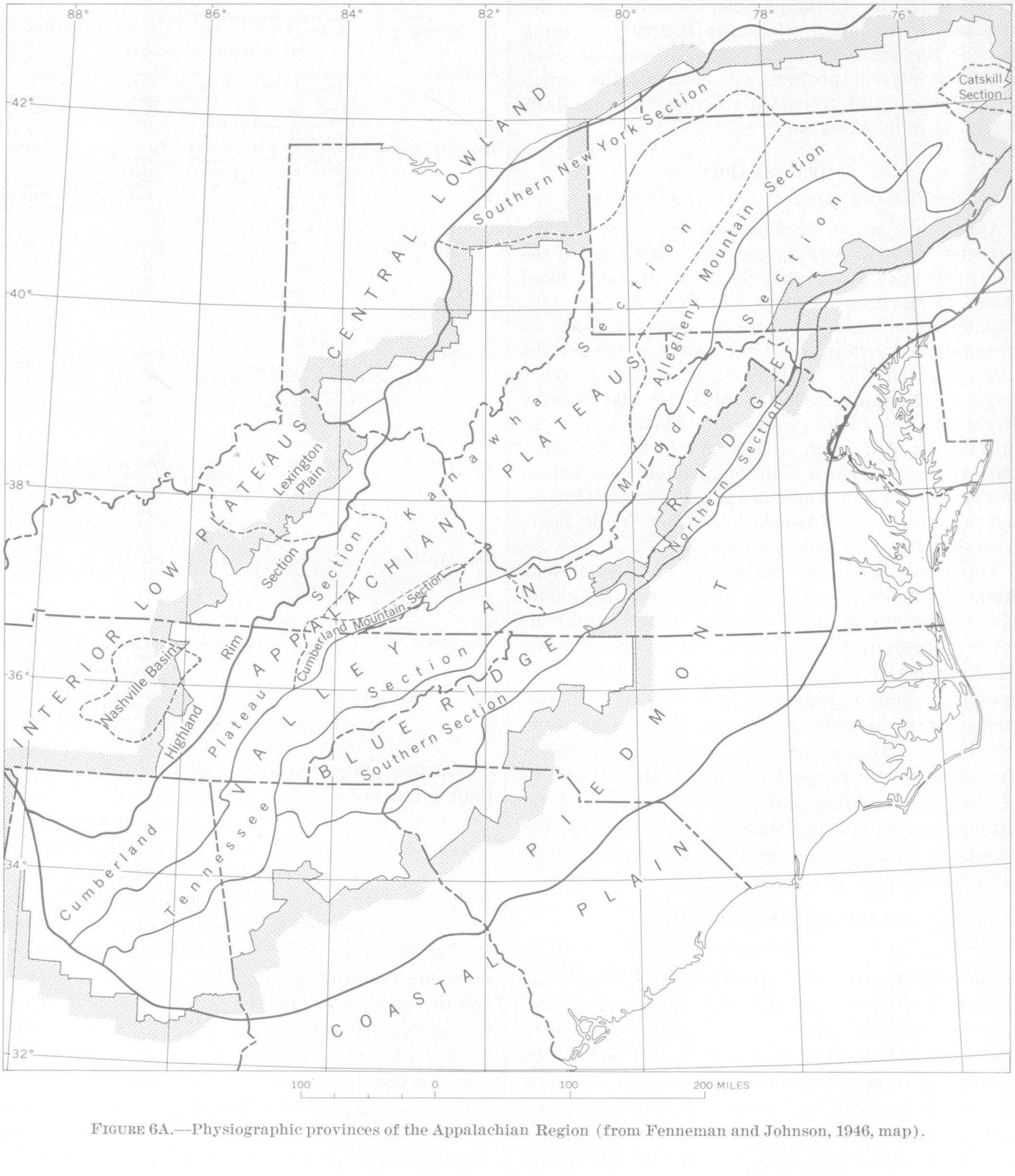


FIGURE 6A.—Physiographic provinces of the Appalachian Region (from Fenneman and Johnson, 1946, map).

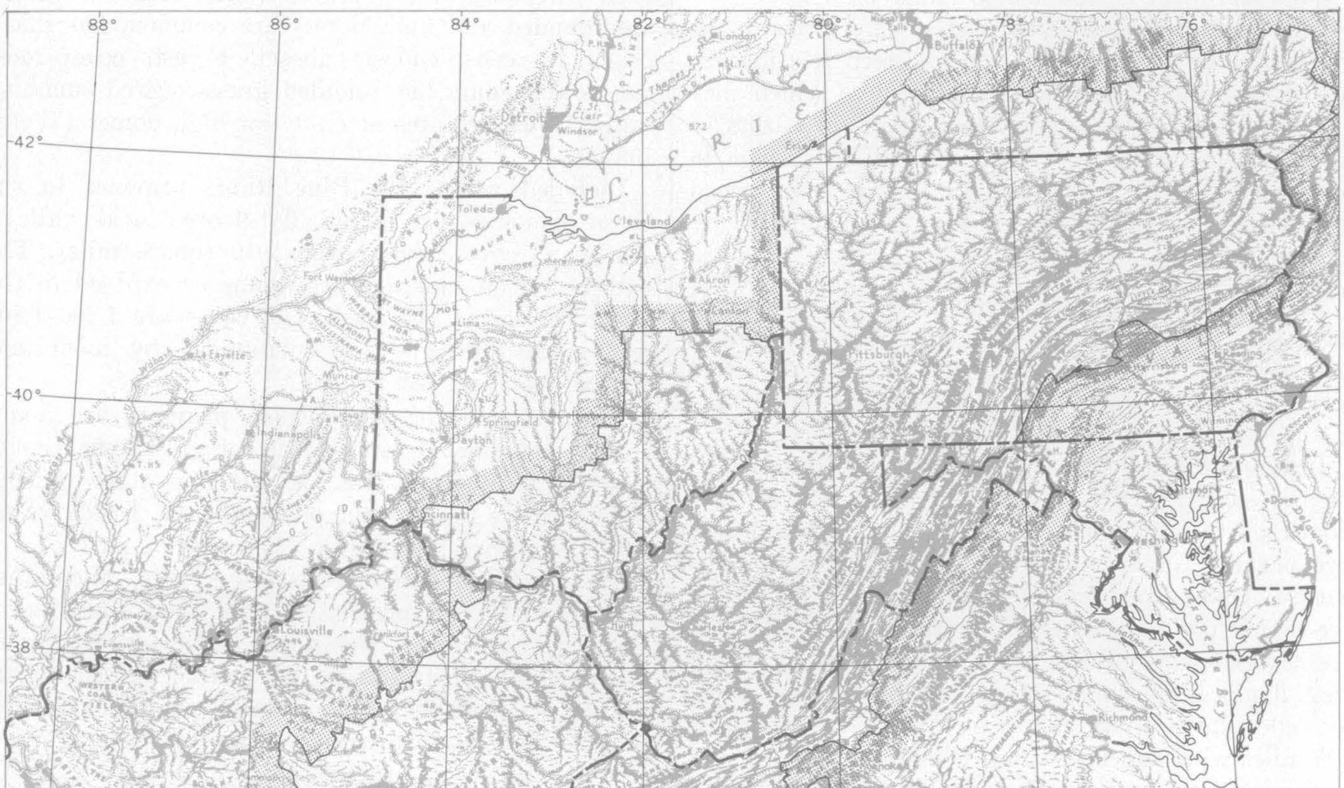


FIGURE 6B.—Landforms of the Appalachian Region (from Raisz, 1957).

Except in monadnocks the rocks are deeply weathered; the accumulation of soil and residual weathered material (saprolite) is as much as 120 feet thick.

The stream network and the other landforms in the Piedmont are located with little direct relationship to the types or structures of the rocks on which they are formed. The drainage system cuts across belts of granite, schist, and slate with no distinct change in pattern; similarly, the land surface is rarely in accord with beds of rock that lie under it.

BLUE RIDGE

The easternmost range of mountains in the Appalachian Highland is the Blue Ridge. These mountains rise abruptly from the Piedmont on the east and terminate with equal abruptness in the Great Valley to the west.

In Maryland the Blue Ridge consists of two parallel even-crested ridges rising to about 2,200 feet altitude. South of the Potomac the Blue Ridge continues as two parallel ridges; however, only the western one is within Appalachia. Angles of slope along the ridges are as much as 30°. Relief is 700–1,200 feet. The ridges are covered with forests, and on many parts of their west flanks large boulder fields extend from summits to valley floors. The valley separating the ridges is 1–2 miles wide and its surface is gently rolling.

Throughout most of Virginia the Blue Ridge is east of the borders of Appalachia. In this section it consists of a main high broad ridge with low peaks flanked by a broad band of spurs and foothills. Altitudes of the ridge crest range from 3,000 to slightly more than 5,000 feet; the spurs and foothills are 1,000–2,000 feet lower. Slopes on the flanks of the ridge and on the spurs are 30°–45°, and rocky cliffs as high as 400 feet are common. Most of the ridge and spurs are forested, but at high elevations open meadows interrupt the forest cover. A small part of the west flank of this part of the Blue Ridge is in Appalachia in Botetourt County, Va.

The Blue Ridge province is within Appalachia in southern Virginia, Tennessee, the Carolinas, and Georgia. In the Great Smoky Mountains in eastern Tennessee the province increases to a maximum width of 70 miles, and has 46 peaks and 41 miles of divide (6,400 acres) above the 6,000-foot level and 288 peaks and 300 miles of divide (54,000 acres) at 5,000–6,000 feet (Secretary of Agriculture, 1902, p. 20; Ayres and Ashe, 1905, p. 14). The main ridge is along the east side of the province; it is flanked on the west by many subordinate parallel ridges and spurs. On the east, several mountain masses form outliers close to the main ridge.

Although of great height, the Great Smoky Mountains largely consist of subdued landforms. Crags, bare cliffs, and talus slopes are rather scarce. Summits are rounded and high domes are common, but sharp peaks are conspicuously absent. Forests cover most ridges and spurs but rounded grass-covered summits, called balds, are present on a few high domes (Wells, 1937).

Included within the Blue Ridge province in the Great Smokies are broad flat-floored oval valleys, known as coves, that cover 5–10 square miles. The valleys are on limestone, the same as exposed in the Great Valley to the west. The coves are 1,200–1,800 feet in altitude and are surrounded by mountains several thousand feet higher.

The rocks in the Blue Ridge province are dominantly metamorphic and consist of greenstone (metabasalt), schist, and slate. Granite and other igneous rocks also are found throughout the area. In Maryland and West Virginia and in the western part of the Great Smokies, conglomerate, quartzite, and other bedded rocks are present. Where the bedded sedimentary rocks occur, the ridges reflect differences in resistance of various rocks to weathering. Elsewhere the direction of the major ridges and minor divides show little relation to the structure of the bedrock.

VALLEY AND RIDGE

West of the Blue Ridge a long narrow belt of mountains and parallel valleys, the Valley and Ridge province, forms a major part of the Appalachian Highlands. This mountainous belt is 1,200 miles long and is 80 miles wide in central Pennsylvania, 65 miles wide in Maryland, and 40 miles wide or less in Tennessee. The landforms are very closely related to the lithology and structure of the folded bedrock; the province is also known as the Folded Appalachians (Fenneman, 1938, p. 122). A characteristic of the entire province is the trellislike pattern of the streams, which occupy valleys carved from less resistant belts of rocks.

Along the eastern part of the Valley and Ridge province is the Great Valley, a rolling lowland formed on highly folded limestone, dolomite, and shale. Locally the valley is known as the Hagerstown Valley (Maryland) and Shenandoah Valley (West Virginia and Virginia). Although this lowland extends throughout the length of the province, it is outside Appalachia in Pennsylvania and northern Virginia.

In Maryland and West Virginia the Great Valley is 20 miles wide and is 500–800 feet above sea level. Slopes are gentle and relief is about 50–100 feet except where the Potomac River cuts across the valley. The river is bordered by steep slopes and cliffs extending

100–150 feet below the main level of the valley. Discontinuous short low ridges parallel the axis of the valley. Sinkholes, some as much as 300 feet in diameter and 10–30 feet deep, are a common part of the landscape that has developed on limestone, and in many areas the land surface is billowy where numerous shallow sinkholes coalesce. Underground drainage is extensive, and only trunk streams and major tributaries have water in them the year around.

From Roanoke, Va., southwest for 100 miles, the continuity of the Great Valley is disrupted by folds and faults. In this region the sandstone ridges that generally occur only in the western part of the Valley and Ridge province are present in many places as far east as the Blue Ridge, and the valley is reduced to a series of narrow valleys connecting broader areas of lowland.

South of Roanoke in southern Virginia and through Tennessee, Georgia, and Alabama, the Great Valley is a lowland 800–2,500 feet above sea level, in which are parallel ridges and knobs of resistant limestone and sandstone rising to several hundred feet above the general level of the valley. Karst topography is more conspicuous here than farther north. Steep-sided sinkholes, some more than 500 feet in diameter, are abundant. In the region of Maryville, Tenn., southeast of Knoxville, the Great Valley is a broad undulating lowland as shown in figure 7, underlain principally by shale. It is bordered on the east by the Chilhowee Mountains, a rugged area of basal Cambrian clastic rocks.

Along the east side of the Great Valley, abutting the lower flanks of the Blue Ridge, are extensive alluvial-fan deposits that have been dissected and reworked into terraces. Terraces a mile or two in width rise 300–700 feet above the level of the valley. Some deposits forming the terraces are more than 300 feet thick and consist of masses of residual clay overlain by sand and gravel. Similar deposits occur irregularly along the western side of the Great Valley.

The mountainous area west of the Great Valley consists of alternate long narrow even-crested ridges and narrow valleys that have been etched by erosion of alternating sequences of hard and soft rocks (fig. 8). As a general rule the major ridges are formed by prominent quartzitic sandstone that is prevalent throughout most of the Valley and Ridge province. The Tuscarora Sandstone and its equivalent, the Clinch Sandstone, along with other closely associated sandstone formations such as the Keefer Sandstone are at or near the base of the Silurian and make the majority of high ridges. The Pocono Formation at the base of the Mississippian and the Pottsville Formation in the lower part of the Pennsylvanian consist of hard sandstone and conglomerate that form the backbone of other high ridges. Subordinate ridges consist of the Oriskany sandstone (Lower Devonian) and various sandstones of the Upper Devonian. In central West Virginia and parts of Pennsylvania and Virginia, Middle Devonian limestone also forms ridges equal in size to those of the Oriskany.

The valleys and lower flanks of major ridges are underlain by shale and limestone. Valley floors contain rolling low hills. Hills formed of shale are generally well rounded and smooth; those formed of limestone are somewhat irregular. The valleys are generally cultivated and have little woodland, whereas most major ridges and more than half of the subordinate ridges are forested.

The ridges in the northern part of Appalachia are narrow and have very level crestlines that extend for miles between major stream crossings (water gaps). They have only a few wind gaps cutting slightly below their crests. Adjacent ridges are more or less parallel, although the system has numerous sharp zigzags, and many ridges unite to form very intricate patterns (Ashley, 1933, p. 12). The zigzags have formed where resistant beds wrap around the axes of plunging anticlines and synclines. Wind gaps are more numerous and larger north of the Potomac River than they are to the south. In the southern part of Appalachia the crests of ridges are less uniform, having alternating broad swales and low domes. Throughout all of Appalachia the subordinate ridges are cut by many streams, but the intervening crests are relatively smooth.

In the northern part of Appalachia the major ridges are 1,300–4,500 feet in altitude, with relief as much as 2,500 feet. The subordinate ridges are 1,000–1,500 feet lower in altitude and correspondingly lower in relief. The flanks of major ridges directly reflect the attitudes of stratified rocks, and slopes range from 15° to 45°. Cliffs along the strike fronts of ridges of quartzitic sandstone are extensive and are 30–150 feet high. Steep slopes and cliffs as much as 1,500 feet high are present in most water gaps cutting major ridges. Where the hard sandstone beds are vertical, spines of rocks rise 50–700 feet along the axes of ridges.

Extensive fields of talus and boulders devoid of vegetation lie along the flanks of major ridges, and in many areas the boulders, piled to a depth of 30 feet or more, form large rubble fields. These fields are extensive in Pennsylvania, but are less common southward and are rare south of Roanoke, Va.

In the southern part of the Valley and Ridge province within Appalachia, the major ridges are closely parallel and have fewer zigzags than do those to the

FIGURE 7.—Radar image of the Great Valley and Chilhowee Mountain, Tenn. Tennessee River southwest of Knoxville in upper left; Chilhowee Mountain, Great Smokies in lower right. Scale approximately 1:200,000 (distorted).

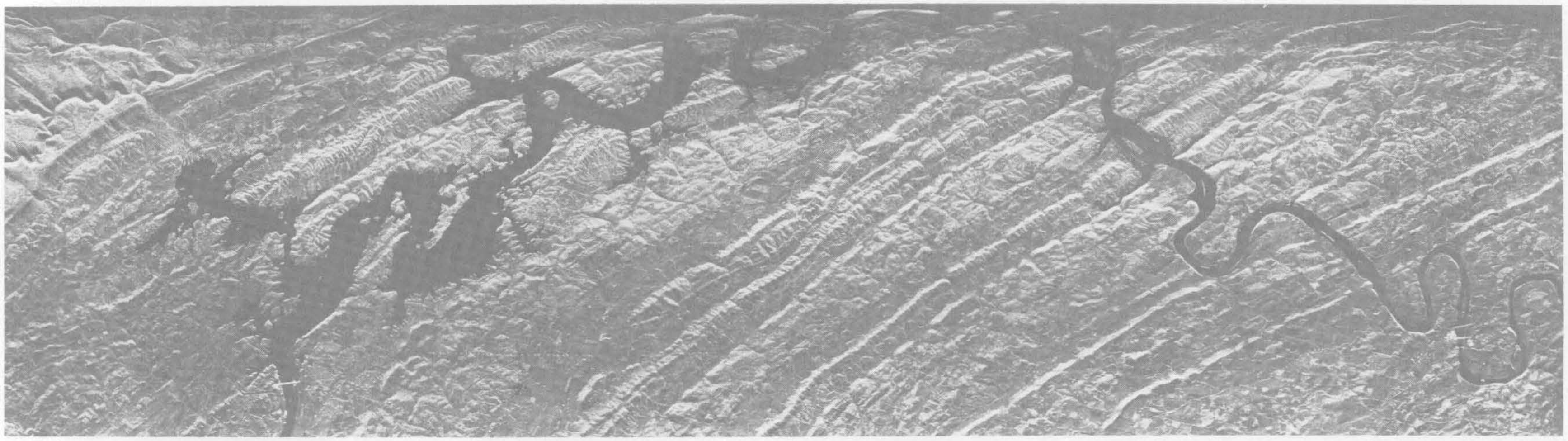


FIGURE 8.—Radar image showing typical Valley and Ridge topography at Kingston, Tenn. Watts Bar Dam on Tennessee River in lower left; city of Loudon in lower right. Scale about 1:280,000 (distorted).

north. The resistant rock layers have been brought to the surface repeatedly by extensive faulting. Altitudes are as much as 4,700 feet in the Roanoke area, but drop to 1,000 feet or less in the vicinity of Birmingham, Ala. Relief is 2,500 feet near Roanoke and drops to 500 feet in Alabama. Flanks of ridges are steep and are forest covered. Subordinate ridges are 400–1,000 feet lower than major ridges and are disrupted by many water gaps. Most of the subordinate ridges have woodlands on their summits and cultivated fields and pastures on their flanks.

APPALACHIAN PLATEAUS

Immediately west of and in sharp contrast with the Valley and Ridge province is a high upland dissected by many streams, the Appalachian Plateaus province (fig. 9). The contrast in landforms is a result of the abrupt change in rock structure, from highly folded in the Valley and Ridge to nearly horizontal or very gently dipping strata in the Appalachian Plateaus. There is a major change in stream patterns, the linear valleys and trellislike pattern of streams in the Valley and Ridge province giving way to incised wandering stream courses with dendritic pattern.

The eastern edge of the Appalachian Plateaus province is an escarpment that rises abruptly 1,000–3,000 feet above a valley that bounds it on the east. Maximum altitudes at this front are generally several hundred feet greater than those of the ridges in the Valley and Ridge province immediately to the east. This eastern ridge is the highest part of the Appalachian Plateaus. In Pennsylvania, altitudes range from 1,750 to about 3,000 feet, increasing to 4,800 feet in central West Virginia, and diminishing to 3,000 feet or less in Tennessee and to less than 1,000 feet in Alabama. Westward the altitude of the upland decreases to 900 feet in southwestern Ohio, 1,100–2,000 feet in east-central Kentucky and Tennessee, and 500 feet in northwestern Alabama.

Relief in the western part of the Appalachian Plateaus in central and southwest Pennsylvania, West Virginia, eastern Kentucky, and northern Tennessee is 500–1,500 feet. This area is carved into small steep-sided hills. Slopes of 45° are common, and steeper slopes, some vertical, prevail along the major rivers. The extreme dissection, high relief, and steep slopes have made it very difficult to build roads and railroads in this area.

The Allegheny Mountains (Ashley, 1933, p. 8), in the eastern part of the province in southern Pennsylvania, western Maryland, and northern West Virginia, are two broad low parallel ridges localized along gentle folds disrupting the normal westward dip of the stratified rocks. These ridges rise 500–1,200 feet above the upland. Their flanks slope 15° or less, and the crests are broad and level. A similar fold near and parallel to the front of the plateau has been

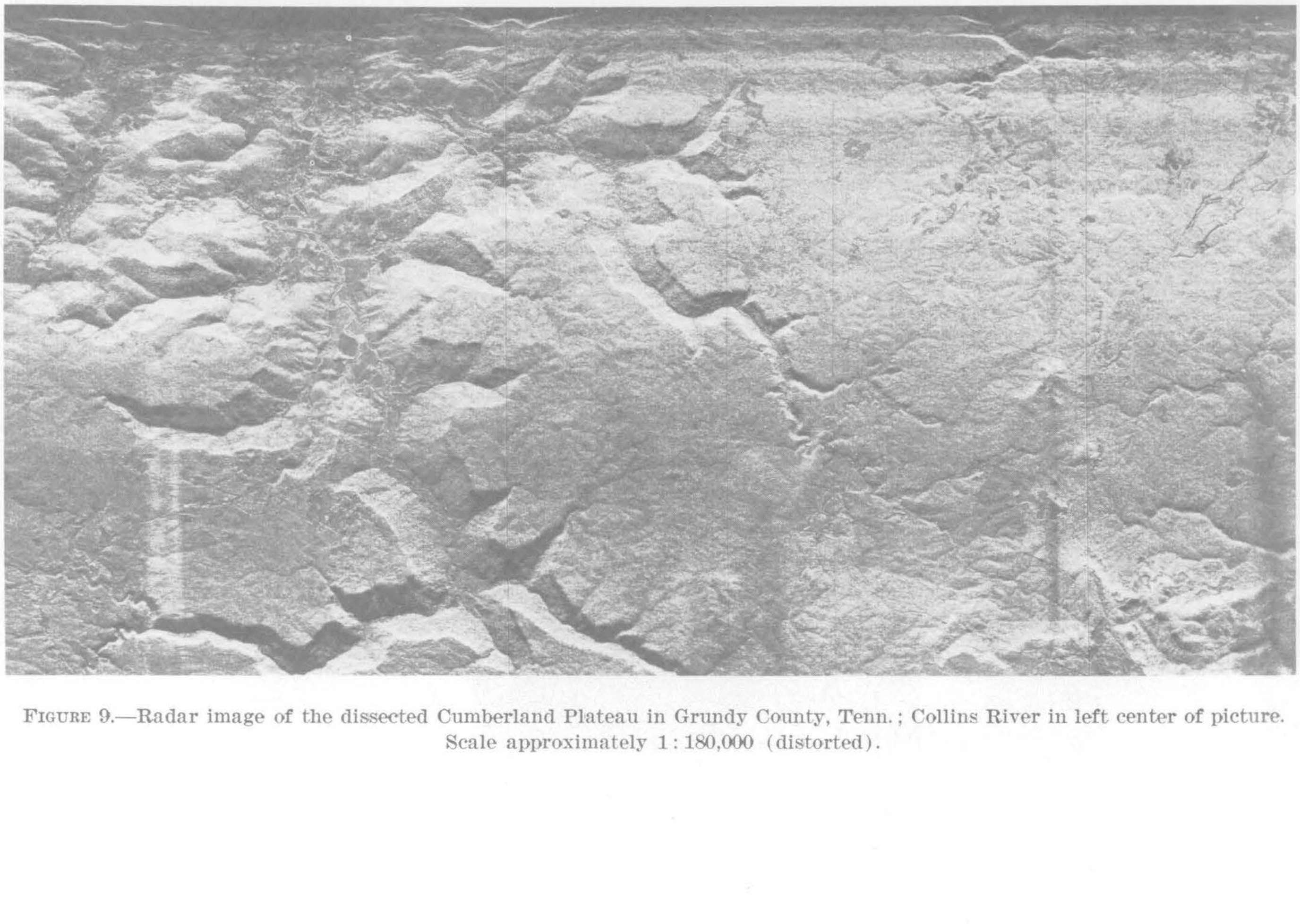


FIGURE 9.—Radar image of the dissected Cumberland Plateau in Grundy County, Tenn.; Collins River in left center of picture. Scale approximately 1:180,000 (distorted).

eroded to form the broad lowland of the Sequatchie Valley in central and southern Tennessee.

In northeastern and northwestern Pennsylvania and southern New York the upland surface has been glaciated. The glaciated section is at altitudes of 1,200–2,000 feet, and relief is generally 300–400 feet, although major valleys cutting it are as much as 800 feet deep. Glaciation rounded the ridges and filled major valleys with thick deposits of sand and gravel. As the result, old drainage systems were disrupted and extensive swamps and bogs developed.

Most of the Appalachian Plateaus province is underlain by rocks of Mississippian and Pennsylvanian age except in southwest Pennsylvania, northwest West Virginia, and adjacent parts of Ohio, where Permian rocks are present (plate 2). The rock formations typically are repetitious sequences of coal, shale, limestone, and sandstone.

Extensive karst areas occur where limestone is at the surface, as in parts of Kentucky, Tennessee, and southeastern West Virginia (fig. 19, p. 85).

INTERIOR LOW PLATEAUS

In southwestern Ohio, central Kentucky, Tennessee, and northwestern Alabama, the Appalachian Plateaus grade into the Interior Low Plateaus province. The actual boundary between these provinces is a low west-facing scrap formed by the Pennsylvanian rocks. West of this low scarp are nearly flat-lying shale and limestone of Mississippian age. The large segment of the Interior Low Plateaus in Appalachia is the Highland Rim. Altitudes are 1,100–1,300 feet in Kentucky and 700–1,100 feet in southern Tennessee and northwestern Alabama. Relief is low, exceeding 200 feet only along the valleys of major rivers. The upland is rolling and along the eastern edge has knobs that are capped by Pennsylvanian rocks, outliers of the Appalachian Plateaus. Karst landscape with deep sinkholes, long blind valleys, and large caves are extensive in the areas underlain by limestone (fig. 19).

In north-central Kentucky, north of Lincoln County, Appalachia laps over a small part of the Lexington Plain, and in Carthage County, Tenn., it includes a very small part of the Nashville Basin. These sections are underlain by nearly horizontal beds of lower and middle Paleozoic rocks, dominantly limestone and shale. The region has many conical knobs that stand as isolated hills separated by wide, flat valleys and lowlands. The knobs reach altitudes of 1,400 feet and have relief of 50–200 feet. The soil in the Appalachian part of the Lexington Plain and Nashville Basin is thin and poor.

CENTRAL LOWLAND AND COASTAL PLAIN

In southwestern Ohio, a small area of Appalachia lies within the Central Lowland province. The strata underlying the area are continuous with those of the adjacent Interior Low Plateaus but are covered with a thin mantle of glacial deposits. Soils tend to be thicker here than in the adjacent provinces and relief more subdued.

Along Lake Erie in New York and Pennsylvania a distinct low scarp separates the Appalachian Plateaus from the narrow terraced plain of the Central Lowland province which lies along the lake at an altitude of 575 feet with terrace levels as high as 780 feet.

The western and southern extremes of Appalachia in Alabama are within the inner part of the Coastal Plain province, known as the Fall Line Hills (Fenneman, 1938, p. 67). The hills are in a belt as much as 50 miles wide and are formed of Cretaceous sand. In northwestern Alabama, altitudes are more than 700 feet but southward they decrease to about 300 feet. The hills are bounded by many valleys 100–200 feet deep; in the central part of the belt, in western Alabama, valleys are 250 feet deep along major streams. Slopes as steep as 45° are common along valley sides and 5°–15° on the upland.

Because of the relief, many valleys cut through the Cretaceous deposits and expose deeply weathered Mississippian and Pennsylvanian sandstone, shale, and limestone in western Alabama and older Paleozoic rocks in the south-central part of the State.

Except for the geologic formations present, the Fall Line Hills bear closer resemblance to the adjacent mountain and plateau areas than to typical parts of the Coastal Plain adjacent to other parts of Appalachia, and most inhabitants of the region do not designate their region as Coastal Plain. The hills are mainly in woodland because of poor soil, rugged relief, and steep slopes.

DEVELOPMENT OF LANDFORMS

The pattern of landforms in the several physiographic provinces of Appalachia reflects a long geologic history. At the close of the Paleozoic Era the Appalachians were probably a high, massive mountain range. Erosion slowly cut away the weak rocks and formed the valleys, while the strong rocks remained as ridges. Because the rock strata are deformed, the location of ridge lines changed as lower parts of the inclined beds of rock were exposed. Since completion of major deformation and throughout most of its erosional history the Appalachian Highlands province has resembled the present landscape.

The origin of the even, concordant ridge tops and the wind and water gaps has been a challenge for geomorphologists studying Appalachia. One school of thought reflects classical theories developed by W. M. Davis (1889, 1890), which envisioned the Appalachian Highlands as being eroded to a near sea-level plain (peneplain) by the end of the Cretaceous. Rivers on this plain established southeastward courses unrelated to the bedrock structure. Subsequently the region was uplifted and the main rivers became entrenched. Erosion by tributary streams resulted in the etching of resistant beds into high-standing ridges. Several subsequent periods of widespread levelling in the early Tertiary were believed to have produced the concordant levels of subordinate ridges.

With the accumulation of geologic evidence over the last half century the concept of peneplains has been questioned, and some geomorphologists believe that the topography of Appalachia reflects systematic and continuous erosion by streams developing headwards from the Atlantic side of the highlands (Hack, 1965, p. 64–65).

In more recent times, Pleistocene glaciers covered much of the plateaus in New York, northern Pennsylvania, and Ohio. Landforms were smoothed by the ice, and valleys were widened and filled with morainal and outwash material. Repeated freezing and thawing accompanying the cold climate during glacial times caused rapid mechanical weathering of hard rocks, the broken material forming large fields of rubble. During the same period, large fans formed along the foot of major mountain ridges, and many river terraces were cut as streams eroded their older flood plains.

CAVERNS

Appalachia is noted as an area containing large and beautiful caves in the widely distributed limestone of the region. Almost 2,900 caves have been recorded. The most extensive cavern area in the eastern United States lies along the Great Valley (fig. 10); altogether about 1,500 caves are known in the Great Valley of Maryland, West Virginia, southern Virginia, Tennessee, and Alabama. To the west, in the mountainous part of the Valley and Ridge province, several hundred caves are found in many belts of limestone, and about 700 are known in the Appalachian Plateaus and the Interior Low Plateaus provinces. Contrary to popular opinion, most Appalachian caves are small; fewer than 300 are recorded as exceeding 500 feet in length. Very few of the caves contain stalactites, flowstone, and similar ornamentations. Large, well-ornamented caves number less than 50 in Appalachia, and barren or sparsely ornamented cavern passages are the rule.

Caves form as soluble material is removed from rocks by moving fluids. Movement of the fluids may be by slow percolation until a solution channel forms, usually along fractures, joints, or especially favorable horizons; once formed, the solution channel may continue to enlarge to form passageways. Slow percolation of small amounts of moisture toward the openings continues to dissolve mineral matter, and under some conditions this material may precipitate in a variety of forms collectively called speleothems.

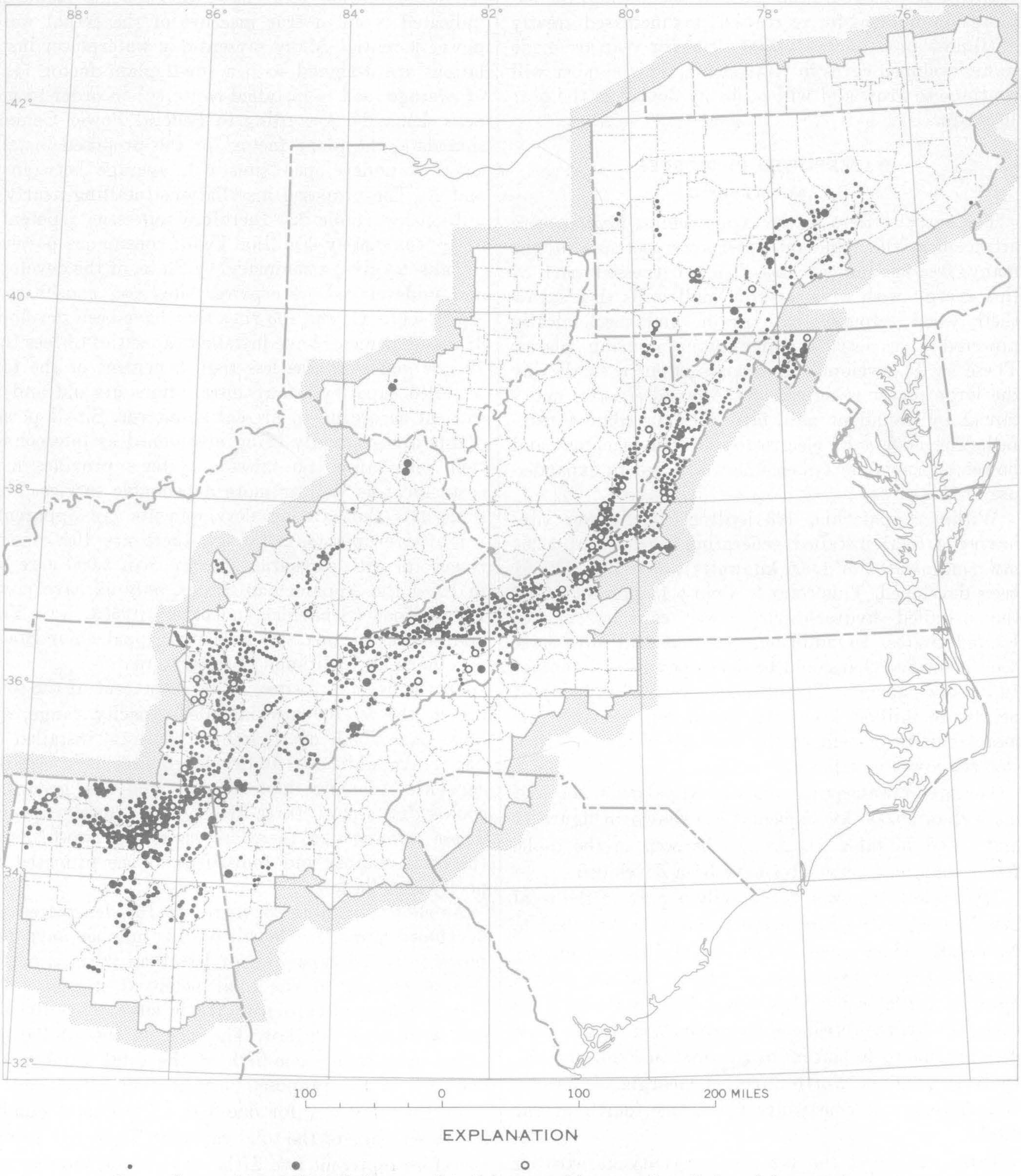
Most large caves of the region are south of central West Virginia and Virginia. Deep pits and caves of great vertical extent are found primarily in southern Appalachia. The deepest is Bull Cave, Blount County, Tenn., that has interconnected opening over a vertical distance of 680 feet.

Most caves in the Valley and Ridge province consist of a few simple, rather straight passages. In a few caves the pattern is similar to city streets, consisting of a grid of numerous intersecting passages. About 20 percent of the caves in the Valley and Ridge province have two or more distinct interconnected levels. In the flat-lying rocks of the Appalachian Plateaus and Interior Low Plateaus, caves are generally on one level and consist of branching passages or a maze of intersecting passages. Passages in most caves are large enough to permit walking but vary in height and width, from low crawlways to galleries 100 feet or more high and wide. Abrupt changes in size of passageways are common.

Most caves are damp and have abundant water seeps and standing pools. About a fifth have streams, many of which fluctuate greatly in amount of flow; flooding of passages occurs frequently.

Within Appalachia, some 33 caves have been developed as tourist attractions, and most of these are now operated as commercial enterprises. Distribution of these caves is shown in figure 10. Between 250,000 and 500,000 visitors are estimated to spend about $1 million annually for admission fees. Successful operation of caves as tourist attractions seems to depend on three principal factors—good location, adequate provisions for safe passage for visitors to the cave, and an attractive cave.

Several additional caves in Appalachia appear to warrant consideration for commercial development (fig. 10). The potential for successful development depends, however, on a great increase in tourist travel throughout the region. Many of the present commercial caves are marginal operations and at least a three-fold increase in tourism is apparently needed if most or all the additional caves are to be developed.



EXPLANATION

• Cave

● Commercial cave, State Park cave, National Park Service cave

○ Potential commercial cave

Note: Each symbol represents a cave or group of closely spaced caves

FIGURE 10.—Caves in the Appalachian Region.

In the last 20 years the sport of spelunking, the exploration of caves for recreation, has increased greatly until now an estimated 10,000 visits per year are made to undeveloped caves in Appalachia. This number will continue to grow and will probably double in the next 10 years.

WATERPOWER RESOURCES

By Arthur Johnson

The early settlers in the Appalachian Region were attracted by the abundant waterpower potential of the many free-flowing streams. They harnessed part of this energy with a variety of small mills that sawed their wood, ground their grain, and mechanically powered a variety of early manufacturing plants. These early developments recognized in a small way the large power resources of the broad streams maintained by abundant and favorably distributed rainfall. The advent of electrically driven machines and power transmission systems naturally led to expanded use of this power.

Within Appalachia, 133 hydroelectric power sites having a total installed generating capacity of 5,265 mw (megawatts, or 1,000 kilowatts), have now (1966) been developed. This total is almost 13 percent of all the installed hydroelectric power capacity in the United States. In addition, 163 potential sites have been identified that could be developed to add another 10,700 mw capacity. The ultimate installed capacity of nearly 16 million kilowatts would represent a little more than 10 percent of the Nation's ultimate hydroelectric power installation.

The major waterpower sites of Appalachia, those of more than 50,000 kw capacity, are shown in figure 11 and listed in table 21. As can be seen in the table, fewer than half these sites have been developed.

Hydroelectric power forms only a part of the total installed capacity of generating plants in Appalachia. Nationally, about one-sixth of the total electric energy is generated at hydroelectric plants, but no overall figure is available for Appalachia. On a State-by-State basis, the hydroelectric-energy production ranges from zero in Ohio to 40 percent of the total in Pennsylvania. In West Virginia, North Carolina, Georgia, Tennessee, and Alabama it constitutes about one-fourth of the total.

Table 22 shows the installed capacity at existing waterpower plants in Appalachia along with the capacities proposed for installation at the undeveloped sites (U.S. Federal Power Comm., 1964). Development of potential waterpower ranges from zero in Ohio to 70 percent in Tennessee.

The 16 million total installed capacity (table 22) indicated is not a true measure of the actual waterpower potential. Many present-day waterpower installations are designed with a small plant factor (ratio of average load to installed capacity) in order to meet peak demands. According to Federal Power Commission data, the plant factor for the proposed installations at undeveloped sites will average between 25 and 30. The proposed installations totalling nearly 11 million kw (table 22) therefore represent a potential of approximately 3 million kw of continuous power.

Table 23 gives a summary, by State, of the developed and undeveloped waterpower sites and capacities of Appalachia. Of the 133 sites that have been developed 68, or 51 percent, have installed capacities of less than 10 mw and comprise less than 3 percent of the total installed capacity. Many installations are old and inefficient according to present standards. Small powerplants are gradually being abandoned as interconnection with large transmission systems provides more economical as well as more dependable service. More than half the existing developments are apparently run-of-river plants. Although there are 102 existing reservoirs with capacities greater than 5,000 acre-feet in 10 of the Appalachian States, only 52 have power installations (Schneider and others, 1965). New York and South Carolina, the other two Appalachian States, may have an additional 12 reservoirs.

Of the developed sites, 16, or 12 percent of the total, are in the 50–100 mw installed-capacity range, and these have about one-fourth of the total installed capacity. An additional 16 developed sites have installed capacities of more than 100 mw, and this group accounts for almost three-fifths of the total capacity. These two groups therefore represent two-fifths of the total number and four-fifths of the proposed capacity installation.

As shown in table 23, there are 163 designated undeveloped sites. One-fourth of this number have proposed installed capacities of less than 20 mw, or less than 6 percent of the total potential capacity. The largest potential capacities are in sites of 50–100 mw and more than 100 mw. The sites in the 50–100 mw range account for one-fifth of the total number and one-fifth of the proposed installed capacity, those of more than 100 mw for one-fifth of the total number but three-fifths of the total capacity. These two groups therefore represent two-fifths of the total number and four-fifths of the proposed capacity.

The trend in waterpower development is away from small projects and toward larger projects. During the 10-year period 1941–50, 36 projects with installed capacities of less than 10,000 hp (7,500 kw) were licensed

FIGURE 11.—Developed and undeveloped waterpower sites in the Appalachian Region of more than 50,000 kw. capacity. Numbers refer to table 21.

TABLE 21.—*List of waterpower sites in the Appalachian Region of 50,000 kw or more capacity*

No. (fig. 11)	Site	Stream	Capacity (kilowatts)
UNDEVELOPED POWER SITES			
Pennsylvania			
1	Mauch Chunk	Lehigh	150,000
2	Flat Brook [1]	Flat Brook	230,000
3	Marysville [1]	Susquehanna	180,000
4	Raystown	Raystown Branch	270,000
5	Half Falls	Susquehanna	160,000
6	Muncy	do	60,000
7	Cammal	Pine Creek	85,000
8	Lock Haven	West Branch Susquehanna	80,000
9	Keating	do	575,000
10	Falls	Susquehanna	250,000
11	Foxburg	Clarion	130,000
12	Mill Creek	do	110,000
West Virginia			
13	Edes Fort	Cacapon	120,000
14	Springfield	South Branch Potomac	60,000
15	Carnifex	Gauley	220,000
16	Meadow River	Meadow	70,000
17	Summersville	Gauley	90,000
18	Thurmond	New	200,000
19	Sandstone	do	240,000
20	Bluestone	do	180,000
21	Beaver Hole	Cheat	450,000
22	Laurel	Tygart	20,000
Kentucky			
23	Celina	Cumberland	227,000
24	Devils Jumps	South Fork	480,000
25	Laurel	Laurel	50,000
26	Cumberland Falls	Cumberland	100,000
Tennessee			
27	Nickajack	Tennessee	97,200
28	Austral	Hiwassee	70,000
29	Nemo	Obed	80,000
30	Melton Hill	Clinch	72,000
31	Tellico	Little Tennessee	135,000
32	Erwin	Nolichucky	65,000
33	Nolichucky	do	40,000
34	Surgoinsville	Holston	72,000
North Carolina			
35	Junction [1]	Yadkin	69,000
36	Styers	do	54,000
37	Upper Donnaha	do	90,000
38	Saluda	Green	50,000
39	Clinchfield	Broad	59,000
40	Horsepasture	Horsepasture	58,000
41	Fines Creek	Pigeon	60,000
South Carolina			
42	Great Gaston Shoal	Broad	128,000
43	Saluda	Saluda	65,000
44	Jocassee	Keowee	150,000
45	Newry-Old Pickins	do	150,000
Georgia-South Carolina			
46	Camp Creek [2]	Chattooga	100,000
47	Rogues Ford [2]	do	120,000
48	Sand Bottom [2]	do	66,000
49	War Woman [2]	do	80,000
Georgia			
50	Franklin	Chattahoochie	50,000
51	Cedar Creek [1]	do	50,000
52	Kingston	Etowah	69,000
53	Gilmer	do	69,000
54	Carters Dam	Coosawattee	250,000
UNDEVELOPED POWER SITES—Continued			
Alabama			
55	Smiths Ford	Locust Fork	115,200
56	Dorsey Creek	Mulberry Fork	63,000
57	Bridgeview	Tallapoosa	105,000
58	Wallahatchee	do	89,000
59	Emuckfaw	do	181,000
60	Crooked Creek	do	139,000
61	Jordan No. 2	Coosa	225,000
62	Logan Martin	do	128,250
63	Lock No. 3	do	72,900
64	Sugar Creek	Elk	100,000
DEVELOPED POWER SITES			
West Virginia			
65	Hawks Nest	New	102,000
66	Lake Lynn	Cheat	51,200
Kentucky			
67	Wolf Creek	Cumberland	270,000
Virginia			
68	Claytor	New	75,000
Tennessee			
69	Hales Bar [3]	Tennessee	99,700
70	Chickamauga	Tennessee	108,000
71	Apalachia	Hiwassee	117,100
72	Watts Bar	Tennessee	150,000
73	Norris	Clinch	100,000
74	Chilhowee	Little Tennessee	50,000
75	Calderwood	do	121,000
76	Fort Loudoun	Tennessee	128,000
77	Douglas	French Broad	112,000
78	Cherokee	Holston	120,000
79	Watauga	Watauga	50,000
80	Boone	S. Fork Holston	75,000
81	Center Hill	Caney Fork	135,000
82	Dale Hollow	Obey	54,000
North Carolina			
83	Hiwassee	Hiwassee	57,600
84	Cheoah	Little Tennessee	110,000
85	Fontana	Little Tennessee	202,500
86	Walters	Pigeon	108,000
South Carolina-Georgia			
87	Hartwell [1]	Savannah	66,000
Georgia			
88	Tallulah Falls	Tallulah	72,000
89	Allatoona	Etowah	74,000
90	Buford	Chattahoochee	86,000
Alabama			
91	Lewis Smith	Sipsey Fork	157,500
92	Thurlow Dam	Tallapoosa	50,000
93	Martin Dam	do	[4] 154,200
94	Jordan No. 1	Coosa	100,000
95	Mitchell	do	[5] 72,500
96	Lay Dam	do	[6] 64,800
97	Weiss	do	87,500
98	Wilson	Tennessee	598,000
99	Wheeler	do	356,400
100	Guntersville	do	97,200

[1] On boundary line of Appalachian Region.
[2] On State boundary within Appalachian Region.
[3] To be replaced by Nickajack Development reducing capacity by 2,500 kw.
[4] Undeveloped potential, 171,000.
[5] Undeveloped potential, 65,000.
[6] Undeveloped potential, 96,000.

by the Federal Power Commission. During the 15-year period 1951–65, only 14 projects in this size range have been licensed. However, prospective sites should not be eliminated solely on basis of size. The merits of the smaller capacity projects are determined by careful economic analysis along with a comparison of alternate sources of power. At some sites the development of a small power project might be coordinated with some other development, such as municipal water supply, to the mutual advantage of both.

Economic development of Appalachia will require additional amounts of electrical energy and the exploitation of practicable sources to provide for the future demands. The technological advances in the production of electrical energy in steampower plants, including those using atomic energy, at times have appeared to reduce the value and significance of waterpower. However, steampower and hydropower are complementary, not competitive. The average power system with the usual changing requirements from hour to hour and from day to night requires generating capacity that can be readily adapted to the changing power load. Large steamplants are not suited to handle fast changes in power demands or to operate economically at low output, whereas hydroplants can readily adapt to changing load demands. The development of additional waterpower can and logically should be a part of the economic development of Appalachia.

GEOLOGY

The following sections on "Economic Geology" and "Regional Geology" summarize information about the mineral deposits of Appalachia and establish the broad geologic setting which determined their distribution and habit. More detailed information about the geology of each type of deposit is given in the individual mineral commodity sections. The "Engineering Geology" section discusses geologic features that affect the works of man.

ECONOMIC GEOLOGY

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"Mineral resources," as used in this report, are the sum total of actual or potential economic mineral deposits, which in turn are accumulations and concentrations of useful minerals and rocks. Those resources usable at any given time depend upon man's needs and the status of his technology. For example, flint was a valuable resource to the Stone Age man, whereas limestone was not; the reverse is true for modern man. Human inquiry literally creates resources by discovery of concealed deposits, by finding new ways to extract and refine raw materials that formerly could not be utilized, and by developing uses for materials formerly considered valueless.

Mineral deposits form through geologic processes, and they are limited in occurrence. They vary with the geologic setting, depending upon the history of the enclosing rocks and their composition, origin, and structure. Some minerals, diamonds for example, are rare and have special properties that make them extremely valuable. Other rare minerals that lack special uses or properties may have little value except to the collector or museum. Minerals and rocks that are commonplace, iron ore and limestone, for example, have relatively low values even though they are essential to civilization. Some mineral raw materials require little processing; others require extensive and expensive treatment before they can be used.

Igneous activity, sedimentation, metamorphism, and weathering are dominant in the formation of mineral deposits. Certain extrusive igneous rocks are of economic value, as for example, pumice, perlite, and lavas used for construction stone. Intrusive igneous rocks also may be of economic value, as are some types of granite that make beautiful decorative and building stones. Many metallic and nonmetallic deposits consist of disseminations or segregations of useful minerals in igneous intrusive rocks. Others occur as veins in the intrusive body or in nearby rocks where they were deposited by hydrothermal solutions released from within the intrusive. Mineral deposits may become exposed through erosion of the covering rocks, or they may remain concealed.

Many mineral deposits are of sedimentary origin, having been deposited along with the enclosing sedimentary rocks. The mineral fuels are excellent examples. Coal represents plant material that accumulated in swamps and marshes and subsequently was transformed during burial and compaction by younger sediments. Oil and gas also are derived from organic materials laid down during the process of sedimentation; however, they may or may not remain in the rocks in which they originally were deposited. Oil and gas can migrate easily in permeable rocks and may move considerable distances and accumulate in geologic traps to make economic deposits.

Other mineral deposits of economic value are produced by metamorphic processes which alter composition and texture of igneous and sedimentary rocks by the increase of temperature and pressure. For example, limestone metamorphoses to marble, bituminous coal to anthracite, and many types of rocks to schist and gneiss.

Weathering processes, either chemical decomposition or mechanical breakdown of minerals and rocks, also form mineral deposits. Certain types of clay form by chemical decay of the feldspars in igneous rocks. The clay may remain in place and form a residual deposit, or it may be transported by water and accumulate as a sedimentary deposit. Sulfide minerals composing most primary metal deposits are weathered and oxidized where exposed at or near the surface. The oxidized material, if it is a relatively insoluble substance such as iron oxide, may be left at the site previously occupied by the unoxidized material to form a residual deposit. Soluble materials may be leached away from the deposit, causing concentration and enrichment of the oxidized material. Solutions of high acidity, formed during weathering, may carry metal ions to a deeper part of the deposit where they are neutralized and the metals redeposited to form secondarily enriched ore. A very soluble material may be carried an appreciable distance from the original source before being redeposited as a secondary deposit. Sand and gravel are products of weathering and abrasion during transport by moving water. Placer deposits of gold and other heavy minerals may form in sand and gravel by differential sorting of mineral particles by the moving water.

TABLE 22.—*Developed and undeveloped waterpower capacity in the Appalachian Region, by State*

[Data from: U.S. Federal Power Comm., 1964]

State	Installed capacity (megawatts)			Percent A/C
	At developed sites A	At undeveloped sites (estimated) B	Ultimate total capacity (estimated) C(A+B)	
New York	8.7	62.4	71.1	12.2
Pennsylvania	73.8	2,756.4	2,829.8	2.6
Maryland	19.2	68.0	87.2	22.0
Virginia	79.7	97.0	176.7	45.2
West Virginia	208.3	2,173.4	2,381.7	8.7
Ohio	0.0	242.0	242.0	0.0
North Carolina	735.0	623.9	1,358.9	54.1
South Carolina	55.2	827.0	882.2	6.3
Georgia	279.1	709.9	989.0	28.2
Kentucky	298.3	546.0	844.3	35.3
Tennessee	1,684.4	716.3	2,400.7	70.3
Alabama	1,823.5	1,876.8	3,700.3	49.3
Total	5,265.2	10,699.1	15,963.9	33.0

The Appalachian Region is geologically complex and contains a great variety of mineral resources, as shown in table 24. Each physiographic province is characterized by certain geologic features, rock types, and types of mineral deposits. The Piedmont and Blue Ridge provinces are underlain principally by

TABLE 23.—*Summary of waterpower sites in the Appalachian Region*

State	Less than 10		10–20		20–50		50–100		More than 100		Total	
	Sites	Mw	Sites	Mw	Sites	Mw	Sites	Mw	Sites	Mw	Sites	Mw
Installed capacity (megawatts), developed sites												
New York	7	8.7	0	0	0	0	0	0	0	0	7	8.7
Pennsylvania	5	5.0	0	0	1	28.8	1	40.0	0	0	7	73.8
Maryland	0	0	1	19.2	0	0	0	0	0	0	1	19.2
Virginia	5	4.7	0	0	0	0	1	75.0	0	0	6	79.7
West Virginia	7	11.5	3	43.6	0	0	1	51.2	1	102.0	12	208.3
Ohio	0	0	0	0	0	0	0	0	0	0	0	0
North Carolina	22	54.8	2	30.8	5	171.3	1	57.6	3	420.5	33	735.0
South Carolina	15	37.2	1	18.0	0	0	0	0	0	0	16	55.2
Georgia	6	14.6	3	51.0	2	67.5	2	146.0	0	0	13	279.1
Kentucky	0	0	0	0	1	28.3	0	0	1	270.0	2	298.3
Tennessee	0	0	3	39.3	8	272.4	5	403.7	7	969.0	23	1,684.4
Alabama	1	8.0	0	0	3	127.1	5	422.3	4	1,266.1	13	1,823.5
Total	68	144.5	13	201.9	20	695.4	16	1,195.8	16	3,027.6	133	5,265.2
Summary:												
Total sites percent	51.1		9.8		15.1		12.0		12.0		100.0	
Total mw do		2.7		3.8		13.2		22.8		57.5		100.0
Proposed installed capacity (megawatts), undeveloped sites												
New York	1	6.1	1	10.3	1	46.0	0	0	0	0	3	62.4
Pennsylvania	2	18.0	7	106.0	9	255.0	4	321.0	9	2,055.0	31	2,755.0
Maryland	0	0	1	20.0	1	48.0	0	0	0	0	2	68.0
Virginia	1	10.0	3	53.0	1	34.0	0	0	0	0	5	97.0
West Virginia	0	0	5	87.0	13	387.1	4	290.0	6	1,409.3	28	2,173.4
Ohio	1	10.0	2	32.0	7	200.0	0	0	0	0	10	242.0
North Carolina	2	20.0	3	49.1	2	76.9	7	477.5	0	0	14	623.5
South Carolina	0	0	1	12.0	1	22.0	1	65.0	6	728.0	9	827.0
Georgia	1	10.0	3	41.9	5	204.0	3	204.0	1	250.0	13	709.9
Kentucky	1	7.3	1	14.4	5	197.3	0	0	2	327.0	9	546.0
Tennessee	1	5.8	1	20.0	3	107.0	7	448.5	1	135.0	13	716.3
Alabama	1	7.3	4	65.5	8	253.7	5	385.9	8	1,164.4	26	1,876.8
Total	11	94.5	32	511.2	56	1,831.0	31	2,191.9	33	6,068.7	163	10,697.3
Summary:												
Total sites percent	6.8		19.6		34.4		19.0		20.2		100	
Total mw do		0.9		4.8		17.1		20.5		56.7		100

TABLE 24.—*Classification of mineral deposits of the Appalachia Region*

[Minerals in roman type were produced in 1964; those in italic not produced in 1964]

Physiographic province(s)	Deposits of igneous origin			Hydrothermal deposits	Metamorphic deposits	Sedimentary deposits	Residual deposits	Placer deposits
	Pegmatite	Granite and alaskite	Dunite and peridotite					
Piedmont, Blue Ridge.	Feldspar, mica, silica, gem stones, *tin, niobium and tantalum, thorium and rare-earth metals, lithium and beryllium minerals, zircon, uranium.*	Feldspar, mica, silica, granite.	Olivine, asbestos [1], vermiculite [1], *corundum, chromium, cobalt and nickel, talc and soapstone* [1], *titanium, gem stones.*	Copper, zinc, pyrite and pyrrhotite, silver, gold, barite, talc, *silica, iron ore, tin, thorium and rare-earth metals, titanium, uranium, vanadium, cobalt, manganese, lead, tungsten, arsenic, molybdenum.*	Marble slate, sericite schist, *thorium and rare-earth metals, titanium, vanadium, emery, garnet, talc and soapstone, kyanite and sillimanite, graphite, mica.*	Sand and gravel, limestone, *phosphate rock, zircon, titanium, coal.*	Kaolin, mica, *gold, cobalt and nickel, titanium, aluminous laterite, iron ore, manganese, phosphate rock.*	Gem stones, *gold and silver, tin, chromium, thorium and rare-earth metals, uranium, titanium, zircon, corundum, niobium and tantalum, tungsten.*
Valley and Ridge.	------------	------------	------------	Zinc lead, cadmium, silver, talc, *barite, fluorspar, copper.*	Anthracite, slate, *pyrophyllite.*	Iron ore, silica, limestone [2], dolomite, rock salt, sandstone, clay and shale, sand and gravel, gypsum and *anhydrite,* bituminous coal, petroleum and natural gas, peat, *asphalt*(?), *oil shale, uranium, phosphate rock, strontium.*	Iron ore, barite, clay, tripoli, rottenstone, bauxite, *manganese, cobalt and nickel, zinc, lead, nitrates* (cave earth).	Coal, *mica.*
Appalachian Plateaus, Interior Low Plateaus, Central Lowland, Coastal Plain.	------------	------------	------------	*Barite, copper, uranium and vanadium* [3], *zinc, lead, strontium, fluorspar, pyrite.*	------------	Bituminous coal, petroleum and natural gas, peat, limestone, sandstone, sand and gravel, silica sand, clay and shale, brines, asphalt, *iron ore, oil shale, strontium, phosphate rock, uranium.*	*Tripoli, barite*----	

[1] Formed by hydrothermal alteration; weathering influenced formation of vermiculite.

[2] Includes "Tennessee marble," a fossiliferous limestone.

[3] Red-bed deposits.

Precambrian and Paleozoic igneous intrusive and metamorphic rocks in which are many types of deposits. The rocks of these provinces and the adjacent Valley and Ridge province have been more deeply weathered than those of other parts of Appalachia, and therefore most of the residual deposits of Appalachia are found here. Because heavy minerals are more abundant in the Blue Ridge and Piedmont than elsewhere in Appalachia, most placer deposits are found in these provinces. The Valley and Ridge province consists of folded and faulted sedimentary rocks of Cambrian to Pennsylvanian age, in which are a wide variety of sedimentary deposits as well as low-temperature hydrothermal metalliferous deposits. The Appalachian Plateaus province is underlain by flat-lying sedimentary rocks ranging from Mississippian to Permian age, characterized by extensive and very large bituminous coal resources. The small parts of western Appalachia lying within the Interior Low Plateaus and Central Lowland provinces are underlain chiefly by flat-lying sedimentary rocks of Ordovician to Mississippian age in which the principal mineral deposits are limestone, petroleum, and natural gas.

The mineral deposits of igneous origin (table 24) are widespread and abundant in the Piedmont and Blue Ridge provinces and some compose large or potentially large resources. Because this region is little known geologically, the distribution and importance of these resources cannot be assessed with accuracy. Nevertheless, the general distribution of the different rock types and related mineral deposits is known, and one can estimate that new deposits will be found in belts or regions where certain types of deposits are already known to exist. Thus, pegmatite and alaskite, containing abundant mica, feldspar, and lesser amounts of other minerals, are found throughout these provinces and are particularly abundant in the western Carolinas and northeastern Georgia (fig. 84, p. 316). Dunite and peridotite, containing large amounts of olivine (a refractory mineral) and lesser amounts of other mineral commodities (fig. 86, p. 326), occur in a belt extending from east-central Alabama to southwestern Virginia, and are particularly abundant in western North Carolina.

Of the metals in the Piedmont and Blue Ridge, copper and gold offer good potential for future large production. Copper deposits of the massive sulfide type (copper-bearing pyrite-pyrrhotite bodies) are mainly in a belt extending from northwestern Georgia to southwestern Virginia (fig. 98, p. 381). The potential for finding hidden ore bodies in this belt is excellent, and their exploitation could result in a manyfold increase in the production of copper and sulfur in Appalachia. Most of the gold in Appalachia is found in veins in granitic intrusive rocks and associated metamorphic rocks of the Piedmont province from Alabama to southwestern Virginia and in alluvial and residual deposits derived by erosion of these rocks. The known highest grade gold deposits of the region were mined long ago, but the prospects are good for discovery of lower grade deposits, exploitable by modern large-scale low-cost methods. The region also has other deposits such as monazite-bearing placers, residual kaolin, aluminous laterite, barite, kyanite, sillimanite, talc, soapstone, and asbestos.

Zinc and lead deposits are found in all the physiographic provinces of Appalachia (fig. 115, p. 463) but are by far the most abundant and economically important in the Valley and Ridge in eastern Tennessee and southwestern Virginia. Zinc production from this region, mainly from ore bodies discovered during the past two decades, is large and constitutes nearly a fourth of the national output. Further exploration should result in discovery of important zinc deposits, and the potential resources are probably many times the sum of known reserves.

In addition to zinc and lead, the Valley and Ridge province has large and extensive sedimentary deposits of limestone, dolomite, silica, and iron ore, as well as of anthracite. The anthracite deposits are the world's largest and have long been mined. These and deposits of other mineral commodities now are being exploited, and production could be greatly expanded. Of particular industrial importance are (1) the extensive deposits of high-calcium limestone used in the manufacture of chemicals and portland cement and as fluxing stone and (2) deposits of high-purity silica used in glass manufacture and for other purposes. The most abundant high-calcium limestone is in formations of Ordovician and Mississippian age found throughout the length of the Valley and Ridge province. High-silica sandstone is in several formations ranging in age from Cambrian to Mississippian. The most important source, however, is sandstone of Silurian and Devonian age which is extensively mined in Pennsylvania. Sedimentary rocks suitable for crushed stone and dimension stone for construction are very abundant. Although sedimentary iron ores of Silurian age are abundant, they are utilized now only in steel plants in the region of Birmingham, Ala. Other types of deposits, of lesser importance, are shown in table 24.

The Appalachian Plateaus province has immense fuel resources. The bituminous coals constitute one of the world's most valuable resources. The exploitable coal beds occur mainly in the Pennsylvanian rocks and generally range from a few feet to 12 feet in thickness. The great Pittsburgh coal bed of western Pennsylvania is as much as 22 feet thick and is perhaps the most valuable mineral deposit in the world. Hundreds of coal beds have been exploited, but nine are among the most extensive and have had the greatest production. Moderately large resources of petroleum also are present, and nearly all oil and gas fields of Appalachia are in this province, in the region extending from northern Tennessee to southern New York (figs. 48, 49, p. 146, 147).

The Pennsylvanian and Permian rocks contain abundant clay and shale that are extensively mined for many purposes; among the most valuable is the underclay of coal beds. Rock salt and brine are found in the northern part of the Appalachian Plateaus and have been exploited at several places (fig. 87, p. 331). Rock salt is found in rocks of Silurian age, brine mainly in rocks of Devonian, Mississippian, and Pennsylvanian age.

Limestone is abundant in the Mississippian rocks along the borders of the Appalachian Plateaus province and in the Interior Low Plateaus province. It is of relatively restricted extent and thickness in the Pennsylvanian and Permian rocks of the Appalachian Plateaus. Several thin limestone layers have been exploited in the Pennsylvanian and Permian rocks of Pennsylvania, West Virginia, and Ohio, but the largest production has been from the Vanport Limestone of western Pennsylvania, which is used as fluxing stone, cement limestone, and general purpose crushed stone. The Mississippian limestone extending from Alabama to Ohio has one or more widespread formations or units of excellent high-calcium limestone. The Appalachian Plateaus province also has abundant sandstone. Sand and gravel deposits are found along major rivers of the province and in the Interior Low Plateaus and Central Lowland provinces; some are exploited as sources of high-grade silica and others for construction material.

In conclusion, it may be stated that Appalachia has a wide variety of mineral resources, each type related to the geology of the area or areas in which it occurs. The search for new deposits or for extensions of known deposits, therefore, must depend on an understanding of the geology of the region. Although the fossil fuels and construction materials far exceed the other mineral commodities as present and potential resources, the many other minerals listed in table 24 are or have been important contributors to the economy of the region and form an important part of its resource base.

GENERAL GEOLOGY

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INTRODUCTION

Appalachia is a classic geologic region, the site of some of the earliest geologic investigations in the New World. William Maclure in 1809 published a "Geologic Map of the United States," and many other pioneers of American geology made field studies of the rocks and landforms of Appalachia and surrounding areas. Maclure's map covered the area east of the Mississippi River and divided the rocks of the Appalachian Region into four large groups according to age. Although this highly simplified map contains many geologic and geographic inaccuracies, it displays striking similarities in its overall appearance to the geologic map that accompanies this report (pl. 2). Some 25 years after publication of Maclure's map, more detailed studies of the geology of the Appalachian region were begun by the newly organized State surveys. Among the great names in these early investigations were the Rogers brothers in Virginia (including West Virginia) and Pennsylvania, James Hall in New York, David Dale Owen and Edward Orton in Ohio, Philip Tyson in Maryland, David Dale Owen in Kentucky, James Safford in Tennessee, Elisha Mitchell and Ebenezer Emmons in North Carolina, Michael Tuomey in South Carolina, John Cotting in Georgia, and Michael Tuomey and Eugene Smith in Alabama.

As the decades have passed, more and more geologists have published significant contributions to the understanding of Appalachian geology, so many in fact that it is impractical to record all of them here. Two men, however, have been key figures in building the framework of geologic knowledge of Appalachia: Arthur Keith working mainly in the predominantly crystalline rocks of the Piedmont and Blue Ridge provinces and Charles Butts working in the Paleozoic sedimentary rocks of the folded Appalachians and Appalachian Plateaus. These men studied large areas and published many reports on the regions of their respective interests. So excellent was their work that few major revisions of their broader concepts have been necessary, though much detail and many refinements have been added in ensuing years.

Recent works in the form of regional syntheses by G. W. Colton, P. B. King, and John Rodgers have been particularly useful in preparation of this section. U.S. Geological Survey geologists whose maps, reports, and, in some cases, personal assistance have been invaluable are H. H. Arndt, Henry Bell, III, H. L. Berryhill, Jr., D. A. Brobst, Bruce Bryant, J. M. Cattermole, L. C. Conant, W. C. Culbertson, L. W. Currier, D. F. Demarest, C. S. Denny, Wallace deWitt, Jr., J. S. Diller, A. A. Drake, Jr., W. H. Emmons, K. J. Englund, J. O. Fuller, J. T. Hack, Warren Hamilton, L. D. Harris, J. W. Huddle, T. L. Kesler, Laurence LaForge, D. M. Larrabee, R. A. Laurence, F. G. Lesure, R. Q. Lewis, M. W. Marcher, W. M. McMaster, C. H. Maxwell, W. H. Monroe, R. H. Morris, R. B. Neuman, W. C. Overstreet, J. F. Pepper, W. C. Phalen, D. W. Rankin, J. B. Roen, J. C. Reed, Jr., J. A. Reinemund, R. E. Thaden, J. S. Watkins, and G. H. Wood, Jr.

In addition, use was made of the following reports and maps of geologists outside the Survey. These reports were published by State geological surveys and in various scientific journals. For New York: Broughton and others (1962); Tesmer (1963); and Rickard and Zenger (1964). For Pennsylvania: I. C. White (1881); Ashley (1928); Sisler (1932); Willard and Cleaves (1938); Willard, Swartz, and Cleaves (1939); Gray and others (1960); Flint (1962); Carswell and Bennett (1963); Hobson (1963); Poth (1963); Shepps (1963); Gwinn (1964); and Kent and others (1965). For Ohio: Stout (1916); Stout and others (1923); J. K. Rogers (1936); Bownocker (1947); Lamborn (1951); Hyde (1953); Brant and DeLong (1960); Hoover (1960); W. L. Calvert (1962, 1963a, b); and Fuller (1965). For Maryland: O'Harra (1900); Cloos (1951a, b); and Amsden (1953). For Virginia: Eby (1923); B. N. Cooper (1936, 1944a, b, 1945); Butts and Edmundson (1943); Edmundson (1945, 1958); B. N. Cooper and G. A. Cooper (1946); Stose and Stose (1957); Bick (1960, 1962); Brent (1960); Calver (1963); and Meyertons (1963). For West Virginia: I. C. White (1903); Hennen (1917); Stose and Ljungstedt (1932); Price, Tucker, and Haught (1938); McCue, Lucke, and Woodward (1939); Headlee and Nolting (1940); Woodward (1941, 1943, 1949, 1951); Martens (1945); Bayles and others (1956); and Woodward and others (1959). For North Carolina: Oriel (1950); and Dietrich (1961). For Kentucky: Jillson (1929); McFarlan (1943); Freeman (1951); Koenig (1956); and G. R. Thomas (1960). For Tennessee: C. H. Gordon (1924); Secrist (1924); John Rodgers and Kent (1948); Wilson (1949); John Rodgers (1953); Stearns (1954); Hershey (1960);

Swingle (1960); and Hershey and Maher (1963). For Georgia: McCallie (1904); W. S. Bayley (1928); Sullivan (1942); Butts and Gildersleeve (1948); Munyan (1951); Crickmay (1952); Herrmann (1954); Hurst (1955); and Salisbury (1961). For Alabama: E. A. Smith and others (1926); Semmes (1929); Gault (1945); Griffin (1951); McMaster and Harris (1963); and Alabama Geol. Soc. (1964, 1965). The reports listed represent either reports of large geographic scope or geologic maps and reports covering smaller areas that have been selected as typical of the geology of larger areas. A statewide geologic map has been published for each State in Appalachia.

Although geologic studies in Appalachia began more than 150 years ago and geologic mapping on scales as large as 1:125,000 (approximately 2 miles to an inch) began about 75 years ago, large parts of Appalachia still are not covered by geologic maps on a scale this large. Geologic mapping at 1:125,000 scale proved to be inadequate for many uses as far back as the turn of the century. At about this time the U.S. Geological Survey began to publish topographic maps at 1:62,500 (about 1 mile to an inch). These maps provided better bases on which to prepare geologic maps, and in the ensuing years geologic maps for about 30 percent of Appalachia were published at this scale. Much of this mapping, however, is now obsolescent and needs revision.

In the 1930's, development of the resources of the Tennessee Valley required maps on a still larger scale, and a 7½-minute topographic map series at 1:24,000 (about 1 mile to 2½ inches) was started. All of Appalachia within the drainage basin of the Tennessee River is now covered by these maps, as is all of Kentucky and parts of the other Appalachian States. In all, about two-thirds of Appalachia is covered by published topographic maps at 1:24,000 scale (fig. 5). These maps have proved most useful for modern detailed geologic map bases and for engineering geology studies in many areas. Geologic maps for less than 10 percent of Appalachia have been published at this scale.

SEDIMENTARY ROCKS

Sedimentary rocks underlie all of Appalachia west of the Blue Ridge province, considerable parts of the Blue Ridge, small parts of the Piedmont, and the Coastal Plain at the southern tip of Appalachia. These rocks range in age from late Precambrian in the Blue Ridge through all the Paleozoic systems in the Valley and Ridge, Appalachian Plateaus, Interior Low Plateaus, and Central Lowland provinces. Part of a small basin of Upper Triassic sedimentary rocks is included in the Piedmont of North Carolina and sedimentary rocks of Late Cretaceous age from the innermost belt of the Coastal Plain in Alabama are also within Appalachia. Glacial deposits of Pleistocene age mantle much of the bedrock in New York State, northern Pennsylvania, and Ohio, and Recent sediments, principally stream deposits, are present on the valley floors in many parts of Appalachia. Pleistocene and younger unconsolidated deposits are not shown on the geologic map (pl. 2), but the southern limit of glacial deposits is shown by lines on the map.

The Precambrian and Paleozoic sedimentary rocks of Appalachia have been deposited in a downwarped segment of the earth's crust commonly called the Appalachian basin. This basin is bounded by the Blue Ridge on the east and a broad arch on the west (the Cinncinnati arch) which trends roughly south-southwest from the western tip of Lake Erie to the northwest corner of Alabama. The basin extends north of the Appalachia boundary into New York State and northeast into eastern Pennsylvania and New Jersey. The character and mode of deposition of sediments in this basin have been well summarized by G. W. Colton (1961). Parts of this summary are quoted below.

> The Appalachian basin * * * outlines an elongate downwarped segment of the earth's crust in which a great thickness of sediment accumulated. Most of the sediment accumulated in shallow seas that occupied the downwarped area for long periods. Diastrophic processes later uplifted and deformed the sedimentary material that had accumulated and in some areas deformed the Precambrian crystalline floor of the basin. Finally erosional processes which are still active modified the surficial form of the mass of uplifted rock material.
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> The processes of subsidence and deposition commenced in late Precambrian time in the eastern part of the basin, and continued throughout most of the basin until late Paleozoic or early Mesozoic time. As the basin subsided, sediments derived largely from highland areas to the east were carried westward to accumulate in the seas that occupied the basin. During the early part of the Paleozoic era, when the eastern highland areas contributed relatively little sediment, some sediment was derived from the west. During the later Paleozoic some sediment entered the basin from the north.
>
> The rates of subsidence and of deposition were greatest along the east edge of the basin close to the main source area of most of the sediments * * *.
>
> Study of stratigraphy and sedimentary structures suggest that most of the sediments were deposited in shallow water and indicate that the rate of deposition closely balanced the rate of subsidence of the sea floor. At times the rate of deposition exceeded the rate of subsidence, and predominantly red, brown, or tan sediments accumulated above sea level. Rocks of these colors are most common near the periphery of the basin, especially in the northeast part. At other times subsidence halted or uplift ensued, resulting in periods of nondeposition or in the erosion of previously deposited sediments. Gaps in the stratigraphic section due to nondeposition or to erosion are most pronounced along the western, northern, and eastern margins of the basin.
>
> Vertical changes in the lithology of the rocks comprising the

> stratigraphic column at any place in the basin indicate that the environment of deposition changed with time. Lateral changes in a stratigraphic unit indicate that the environment of deposition changed geographically. In general most of the sediments in the eastern part of the basin—especially in the northeastern part—accumulated in a deltaic environment; most of the sediments in the central part of the basin accumulated offshore in the trough of the marine basin; and most of the sediments in the western part accumulated on the shallow platform or shelf bordering the west edge of the basin. The areal distribution of the principal rock types in the Appalachian basin * * * reflects the geographic location of the predominant environments of deposition. Siltstone and sandstone comprise a relatively high percentage of the stratigraphic columns in the eastern and northeastern parts of the basin where deltaic environments prevailed throughout much of the history of the basin. Argillaceous rocks comprise a higher percentage of the rock sequence in the central part of the basin or the trough of the basin of accumulation than they do elsewhere. Carbonate rocks predominate in the western part of the basin where shelf or platform environments prevailed.
>
> The sediments that accumulated during late Precambrian and Paleozoic time attained a composite maximum total thickness of approximately 60,000 feet. However, the greatest thickness preserved at any one place in the basin is between 35,000 feet and 40,000 feet. This thick sequence, which occurs in east-central Pennsylvania, is composed of rocks ranging in age from Early Cambrian to Early Pennsylvanian. A large but unknown volume of rock has been removed by erosion, largely since late Paleozoic time. The volume of Paleozoic rocks present in the basin today is approximately 510,000 cubic miles.

The sedimentary rocks of Appalachia are discussed in order of age, starting with the oldest, and each of the following subheadings corresponds to one of the smallest rock units shown in the explanation of the geologic map (pl. 2). Columnar sections from different parts of Appalachia (pl. 3) show rock sequences typical of the pre-Pennsylvanian Paleozoic Systems, which form the bedrock in much of Appalachia west of the Blue Ridge. Wherever possible, mention is made of the formations that have special economic importance, and additional information about these formations can be found in the mineral commodity sections.

UPPER PRECAMBRIAN SEDIMENTARY AND VOLCANIC ROCKS

OCOEE SERIES

Rocks of the Ocoee Series occupy a large area in western North Carolina, eastern Tennessee, and northern Georgia, where they form a complex sequence of clastic sedimentary and metasedimentary rocks which may be as much as 50,000 feet thick (King, 1964). They are more or less metamorphosed throughout their outcrop area, but least so in eastern Tennessee, where a great variety of clastic sedimentary types can be recognized. In recent studies of this area, the Ocoee Series has been divided into 13 formations arranged in 3 major groups. A summary of the lithology and named units of the Ocoee Series in Blount, Sevier, and Cocke Counties, Tenn., and in Swain and Haywood Counties, N.C., is given in table 25.

TABLE 25.—*Ocoee Series of eastern Tennessee and western North Carolina*

Rock unit	*Description*	*Terminology of Keith (1892–1907)*
Walden Creek Group:		
Sandsuck Formation.	Siltstone, fine- to coarse-grained sandstone, and conglomerate.	Hiwassee slate, Citico conglomerate, Sandsuck shale, Pigeon slate, Wilhite slate.
Wilhite Formation	Siltstone with abundant carbonate, limestone, and fine- to medium-grained sandstone.	
Shields Formation	Largely conglomerate and sandstone.	
Licklog Formation	Noncalcareous siltstone and sandstone.	
Sequence broken.		
Cades Sandstone and related rocks.	Coarse-grained conglomeratic sandstone interbedded with dark-gray argillite and siltstone.	Cades conglomerate.
Sequence broken.		
Great Smoky Group	------------------------------	Great Smoky formation.
Anakeesta Formation.	Carbonaceous and sulfidic slate, siltstone and sandstone, arkosic conglomerate, minor carbonate rocks.	Nantahala slate.
Thunderhead Sandstone.	Feldspathic sandstone, arkosic conglomerate, and interbedded slate and siltstone; thick to medium bedded.	Hazel slate, Thunderhead, Clingman, and Cades conglomerates.
Elkmont Sandstone	Coarse- to fine-grained feldspathic sandstone, silty sandstone, and argillite; medium to thin bedded.	
Snowbird Group	------------------------------	Snowbird formation.
Metcalf Phyllite	Greenish phyllite and interbedded feldspathic sandstone.	
Pigeon Siltstone	Laminated feldspathic siltstone with interbedded slate and fine-grained sandstone.	Pigeon slate.
Roaring Fork Sandstone.	Fine-grained feldspathic sandstone and siltstone, minor slate and phyllite; medium to thin bedded.	
Longarm Quartzite	Feldspathic quartzite and arkose.	
Wading Branch Formation.	Feldspathic sandstone and sandy slate or phyllite, locally conglomeratic.	

Rocks of the Great Smoky Group underlie about 80 percent of the Ocoee outcrop area, including all the central and southeastern parts. The Walden Creek Group occupies a belt a few miles wide along the northwestern border of the area. The Snowbird Group is restricted to the northern part of this belt.

Thick-bedded feldspathic metasandstone of the Great Smoky Group interbedded with dark slate, phyllite, or schist is the dominant rock in most of the Ocoee area. Southeastward these rocks grade by increasing metamorphism to interlayered quartz-feldspar gneiss and muscovitic schist resembling the lower Precambrian micaceous gneiss and schist.

Rocks of the Ocoee Series are notable as host rocks for the sulfide deposits of Ducktown, Tenn., and Fontana, N.C. Rocks of the Walden Creek Group have furnished small amounts of slate and limestone, and the Pigeon Siltstone crushed rock for local uses.

GRANDFATHER MOUNTAIN FORMATION AND MOUNT ROGERS VOLCANIC GROUP

Upper Precambrian(?) rocks in Avery and Watauga Counties, N.C., and in western Grayson County, Va., and adjacent areas include volcanic rocks associated with generally coarse clastic sedimentary rocks. The volcanic rocks are most abundant in Grayson County and include flows of rhyolite, quartz latite, and basalt with an aggregate thickness of several thousand feet and a lateral extent of about 30 miles. They rest on a unit of graywacke and conglomerate, which in turn rests locally on lower Precambrian granitic rocks. They are overlain by feldspathic sandstone, red and gray siltstone, and volcanic conglomerate older than the basal Cambrian clastic rocks of the area.

In Avery and Watauga Counties, N.C. the upper Precambrian(?) rocks are known as the Grandfather Mountain Formation and consist largely of arkose, conglomerate, siltstone, and graywacke, with minor volcanic rocks. The volcanic rocks are mostly metamorphosed basalt or andesite, but some quartz latite is present. The total thickness of these rocks is between 10,000 and 20,000 feet. They lie on lower Precambrian granitic rocks and are overlain by thrust sheets of lower Precambrian gneiss and basal Cambrian clastic rocks.

CATOCTIN GREENSTONE

Two small areas in Washington County, Md., are underlain by chlorite schist and greenstone of the Catoctin Greenstone and by associated sericite schist and altered rhyolite. These volcanic rocks are similar in lithology and stratigraphic position to those of the Mount Rogers Volcanic Group and are probably similar in age.

BASAL CAMBRIAN CLASTIC ROCKS

The crystalline rocks of Precambrian age and the upper Precambrian sedimentary rocks of eastern Tennessee and adjacent areas are overlain by a sequence of clastic rocks of Early Cambrian and Early Cambrian(?) age that occur along the west slope of the Blue Ridge, in places lapping to its crest. Isolated blocks of these same rocks are also upfaulted or upfolded west of the Blue Ridge. They are predominantly resistant rocks, forming or capping prominent ridges or mountain ranges. These rocks have been mapped separately on plate 2 because they are lithologically very different from the crystalline rocks that form most of the Blue Ridge and are also different from the younger Cambrian rocks that border or surround their outcrop areas.

The basal Cambrian clastic rocks are predominantly sandstone (or quartzite), conglomerate, siltstone, and shale (or slate). These rocks are about 3,000 feet thick in southeastern Tennessee, where the sequence is named the Chilhowee Group and has been divided into several formations (pl. 3, columns 14, 16). Thinner but similar sequences of clastic sediments of approximately the same age, also called the Chilhowee Group, are present along the west side of the Blue Ridge in Washington County, Md., Jefferson County, W. Va., Botetourt County, Va., and in Georgia and Alabama. Because the succession of mappable lithologic units differs from one area to another, different formation names are used for rocks which may be of equivalent age. Some of the most commonly used formation names are shown, together with the lithology of each formation, on plate 3. The basal Cambrian clastic rocks dip beneath the surface at or a few miles west of the foot of the Blue Ridge and do not reappear westward in Appalachia. A few deep wells in eastern Kentucky have shown that only a few hundred feet of clastic rocks are present above the basement which may be in part equivalent to the thick sequence to the east.

LOWER AND MIDDLE CAMBRIAN ROCKS UNDIVIDED

Above the resistant basal clastic formations of earliest Cambrian age is a thick sequence of rocks, predominantly carbonate but with significant thicknesses of argillaceous to sandy rocks, in Tennessee, Georgia, and Alabama. These rocks are duplicated by thrust faulting in east Tennessee and southwest Virginia and are present at the surface in belt after belt from the Blue Ridge front westward to the front of the Appalachian Plateaus. Folds and major faults cause a similar duplication of Lower and Middle Cambrian rocks in Georgia, Alabama, Botetourt County, Va., Jefferson County, W. Va., and Washington County, Md. Steep dips and numerous folds and faults characterize the rocks in most of these belts. Although correlative rocks of Early and Middle Cambrian age are present in southeastern Pennsylvania, they crop out beyond the limits of Appalachia.

In Washington County, Md., and adjacent West Virginia, Lower and Middle Cambrian rocks crop out in the Shenandoah Valley just west of the Blue Ridge where they are assigned to three formations: the Tomstown Dolomite of Early Cambrian age, the Waynesboro Formation of Early Cambrian age, and the Elbrook Dolomite, mostly of Middle Cambrian age but possibly with some beds of Late Cambrian age at the top. The Tomstown consists of dolomite and limestone. Deposits of limonitic iron ore, either in the bedrock or in residual clay derived by weathering of the dolomite and limestone, are common in the Tomstown, but because of their low iron content they are of historic interest only and are noncompetitive in the modern iron industry. The overlying Waynesboro is composed mainly of shale, including much red shale, but it also includes some sandstone and dolomite. The Elbrook Dolomite is predominantly dolomite and limestone but contains beds of argillaceous limestone. In Maryland, the Tomstown is probably as much as 1,000 feet thick, the Waynesboro 500 feet thick, and the Elbrook 2,000 feet thick.

This sequence continues southwestward in the Shenandoah Valley and reappears within the boundary of Appalachia in Botetourt County, Va. Farther southwest, rocks of Early and Middle Cambrian age reappear in southwest Virginia and are continuously present from there southwestward to central Alabama where they disappear beneath the Coastal Plain. The lithologies are similar, but the formations thicken and the names change from Tomstown Dolomite and Waynesboro Formation to Shady Dolomite and Rome Formation, respectively. Sandstone units in the Rome Formation form characteristic serrate ("comby") ridges of intermediate height in northeastern Tennessee, and become lower southwestward. Limestone may also be present in the Rome but is subordinate to dolomite. Many of the beds of sandstone and carbonate rocks contain abundant glauconite.

Rocks equivalent to the Elbrook Formation also persist southwestward from Virginia to central Alabama, but gradually become more argillaceous and less dolomitic through facies changes and by intertonguing. Thus, in Scott County, Va., and the eastern part of the Valley and Ridge province in Tennessee, the Elbrook equivalents from the base upward are Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. In the western part of the valley in Tennessee, however, all the thick limestone units that are given formation status in eastern Tennessee have disappeared, and the sequence is predominantly shale like the Nolichucky and Rogersville Shales, with only thin beds of limestone and dolomite. To this sequence the overall name Conasauga Formation (or Conasauga Shale) is applied. The Conasauga continues southwestward into southern Tennessee, Georgia, and Alabama. These rather complex relationships between the Elbrook and Conasauga and equivalent named formations are well illustrated by Rodgers in his explanatory text to the geologic map of east Tennessee (1953, fig. 3). Thicknesses of the Shady and the Rome and of the Elbrook, Conasauga, and equivalents in the southern Appalachian States are variable from place to place and from fault belt to fault belt. In fact, complex structure makes it difficult to obtain accurate measurements in most places. Approximately 1,000 feet is perhaps a fair average for each of the three formations, although some published thicknesses indicate that the formations may in places be somewhat thinner or much thicker.

Shady Dolomite and the residual clay derived from it are the host rock for many small manganese and iron deposits in eastern Tennessee and southwestern Virginia. Important zinc deposits are also found in the Shady in the Shenandoah Valley near Austinville, Va. A little zinc has also been found in the Shady in Bumpass Cove, northeastern Tennessee. Limestone units of the Lower and Middle Cambrian sequence are in many places suitable for crushed stone.

KNOX GROUP

The Knox Group is a thick sequence of carbonate rocks spanning the systemic boundary between Cambrian and Ordovician, the lower part of the group being of Late Cambrian age and the upper part of Early Ordovician age. These rocks crop out in the Valley and Ridge province of southwest Virginia, Tennessee, Georgia, and Alabama. In much of the Valley and Ridge province the group consists of a remarkably homogeneous sequence of carbonate rocks, almost entirely thick-bedded dolomite. In the easternmost belts of Tennessee, however, much of the Knox is thick-bedded limestone, and in Georgia and Alabama the upper part is limestone whereas the lower part is dolomite. In most places, the Knox Group is divided into four or five formations; the names Copper Ridge Dolomite and Chepultepec Dolomite for the two lowest formations are in wide usage from southwestern Virginia to Alabama. Although there is no unconformity between the Copper Ridge and Chepultepec, fossil evidence indicates that the Copper Ridge is of Late Cambrian age and the Chepultepec of Ordovician age. In Georgia and Alabama the Longview Limestone and Newala Formation are the two top formations of the Knox Group, whereas in parts of Tennessee and southwest Virginia, Longview Dolomite, Kingsport Formation, and Mascot Dolomite have been used for the uppermost part of the Knox Group.

Recognition of individual formations of the Knox Group is based principally on chert content, presence of oolites and their size, shape, and abundance, purity and type of the carbonate, color, and fossil content. Although these criteria permit geologists familiar with these rocks to recognize and map the individual formations of the Knox Group, the similarities between formations are certainly greater than the differences. In most areas the Knox is 2,000–3,000 feet thick; in the Valley and Ridge province of the southern Appalachians it underlies greater areas than any other mapped unit, and in most of these areas it forms lowlands.

The rich zinc deposits of east Tennessee are in the carbonate formations of the Knox Group. In many places these dolomite or limestone units are quarried for crushed stone. For years petroleum geologists have speculated on the potential for oil and gas of the Knox, and a few deep wells especially in central Tennessee, eastern Kentucky, and eastern Ohio were drilled through rocks apparently equivalent to the Knox, but with limited success. In 1962, however, prolific production was found in the Copper Ridge Dolomite (as identified by W. L. Calvert, 1962) in Morrow County of central Ohio (outside of Appalachia). Since then, many successful wells have been drilled into this unit in central Ohio. Exploratory activity in this unit is being extended southward and eastward into Kentucky and West Virginia.

CAMBRIAN ROCKS UNDIVIDED

In Maryland, Virginia, and West Virginia, the equivalent to the lowest formation of the Knox Group (the Copper Ridge Dolomite), is predominantly limestone, called Conococheague Limestone. In central Pennsylvania, however, the equivalent sequence is divided into Warrior Limestone and Gatesburg Formation. In these States almost all the Cambrian rocks above the basal clastics are carbonates, and the conspicuous lithologic change that marked the base of the Knox Group farther south is not recognized. For this reason the name Knox has not been used in this northern part of the Valley and Ridge province. On the geologic map (pl. 2) the Conococheague, or the Warrior and Gatesburg, which are all of Late Cambrian age have been combined with the Waynesboro Formation and Tomstown Dolomite of Early Cambrian age and the Elbrook Formation of Middle and Late Cambrian age into a unit shown as Cambrian undivided. This unit includes all formations of Cambrian age except the basal Cambrian clastics.

MIDDLE AND UPPER ORDOVICIAN ROCKS

Rocks of Middle and Late Ordovician age form a mapped unit on the geologic map from Pendleton County, W. Va., southward where the underlying rocks of Early Ordovician age have been included in the Knox Group. The Middle and Upper Ordovician rocks form one of the most stratigraphically complex and variable sequences in Appalachia. They change lithology not only from northeast to southwest along the Appalachian structural trend, but also from fault belt to fault belt. Because of this, many difficult identification and correlation problems have arisen, involving particularly the lower Middle Ordovician rocks.

In contrast with the underlying formations of the Knox Group, which in most parts of Appalachia are dolomite, the formations of Middle Ordovician age are predominantly limestone, though some formations are argillaceous limestone or shale interbedded with limestone. Locally, some of this limestone is mined for high-calcium stone; some is quarried for cement. In general, the Middle Ordovician formations are moderately to abundantly fossiliferous, in contrast with the carbonate formations of the Knox Group, which are sparingly fossiliferous.

In easternmost Tennessee and parts of northwest Georgia only the lowest beds of the Middle Ordovician (Lenoir Limestone) are limestone. Above these is a thick sequence of shale (Sevier, Ottosee, and Athens Shales) overlain by another thick sequence, principally sandstone (Bays Formation and Tellico Sandstone).

In the central part of the Great Valley of Tennessee and in Georgia and Alabama the numerous limestone beds of Middle Ordovician age were lumped together by the earliest workers under the name Chickamauga Limestone, a usage that Rodgers (1953) revived for his geologic map of east Tennessee. The name Chickamauga Limestone, as used in Georgia and Alabama, also included beds of Late Ordovician age. In Tennessee the names Lenoir Limestone, Holston Limestone (or Marble), and Ottosee Shale (or Limestone) have been used for equivalents to the lower part of the Chickamauga Limestone. Of these, the most important economically is the Holston, which is abundantly quarried for marble near Knoxville and has also been quarried for cement and high-calcium limestone. In the easternmost part of the Great Valley of Tennessee, most of this limestone sequence is represented by shale and sandstone of the aforementioned Athens, Sevier, and Bays Formations. This complex intertonguing relationship is well illustrated by Rodgers (1953, fig. 4).

Rocks of Late Ordovician age from Tennessee to Pennsylvania along the Valley and Ridge province consist principally of two formations: the Reedsville or Martinsburg Shale which includes beds of Middle Ordovician age in its lower part, and the overlying Juniata Formation, consisting of red and green sandstone and shale. In central Pennsylvania the resistant Oswego Sandstone lies between the Juniata and Reedsville. In southern Pennsylvania and in southwestern Virginia and adjacent Tennessee, rocks equivalent to Martinsburg Shale are divided into a lower (Middle Ordovician) limestone named the Chambersburg or Trenton Limestone and an upper shale called the Reedsville Shale (Upper Ordovician). The Trenton is of special interest because the only oil field of the Valley and Ridge province produces from the Trenton Limestone in Lee County, Va. Beds of Trenton type and age have also yielded oil in the plateau areas of Tennessee and in Monroe County, Ky.

The Juniata Formation is of continental origin and crops out in Pennsylvania, Maryland, Virginia, and

West Virginia, but in southwestern Virginia and across Tennessee into Alabama the unit has changed into fossiliferous calcareous mudstone named the Sequatchie Formation. It is predominantly red and green, but is of marine and not continental origin.

In the Central Lowland of Ohio and the Interior Low Plateaus of Kentucky and Tennessee, the Middle and Upper Ordovician rocks again crop out. The Middle Ordovician rocks are almost entirely limestone, purer and sparingly fossiliferous in the lower part, more argillaceous and very fossiliferous in the upper part. The Upper Ordovician rocks are limestone, argillaceous limestone, and shale, also abundantly fossiliferous.

ORDOVICIAN ROCKS UNDIVIDED

In northern West Virginia, Maryland, and Pennsylvania, as discussed previously, rocks of Late Cambrian age are included with those of Early and Middle Cambrian age in a map unit designated Cambrian rocks undivided. In these same areas, rocks of Early Ordovician age (equivalent to the upper part of the Knox Group farther south) are included with rocks of Middle and Late Ordovician age, described above, in a map unit designated Ordovician rocks undivided. The Lower Ordovician rocks included in this unit belong to the Beekmantown, a group which is divided into several formations in some areas, but which is considered one formation in others. The Beekmantown, whether group or formation, is entirely carbonate, containing more dolomite than limestone in most areas, and including abundant chert in nodules and thin layers. Dolomite and limestone from the Beekmantown were abundantly used for agricultural lime in the days when many farms had their own lime kilns. Where belts of Ordovician rocks are too narrow to show at the scale of the geologic map (pl. 2), they have been combined with rocks of one or more other systems including the underlying Cambrian and the overlying Silurian, Devonian, and Mississippian.

SILURIAN ROCKS

Silurian rocks are very prominent topographically in most of the Valley and Ridge province because of the presence in the lower part of the Silurian of a very resistant conglomerate and sandstone sequence which crops out in southeastern New York east of the Catskill Mountains under the name Shawangunk Conglomerate. This sequence extends southwestward into Pennsylvania and through Maryland, Virginia, and West Virginia and into Tennessee as the units Tuscarora Sandstone and Clinch Sandstone. Because of the duplication of rocks of the Silurian and other mid-Paleozoic Systems by folding in central Pennsylvania and by faulting in southern Virginia and Tennessee, the Shawangunk, Tuscarora, and Clinch form many mountain ridges in the Valley and Ridge province.

Throughout the northern half of the Valley and Ridge province the Clinch, Tuscarora, and Shawangunk are overlain by red hematitic shale and sandstone of Middle Silurian age called the Clinton Formation (Clinton Group in parts of Maryland and Pennsylvania). In Tennessee, the Clinch Sandstone, which is largely, if not entirely, of Early Silurian age, changes to red shale and sandstone indistinguishable lithologically from the overlying Clinton Formation. Where this change occurs, the combined sequence is called Rockwood Formation in Tennessee and Red Mountain Formation in Georgia and Alabama. Near Rockwood, Tenn., beds of hematitic iron ore in the Rockwood Formation were extensively mined until very recent years, and in the Birmingham district of Alabama similar beds in the Red Mountain Formation supply iron ore for the Birmingham steel mills. The Clinton ores were also mined many years ago in southwestern Virginia, eastern Kentucky, Maryland, Pennsylvania, and northwestern Georgia. In Maryland and Pennsylvania rocks equivalent to the Clinton compose the Rose Hill Formation which consists of red shale and yellow sandstone with hematite-rich zones, the Keefer Sandstone, and the Rochester Shale at the top.

Rocks of Late Silurian age are absent in Georgia and Alabama, but in northeast Tennessee and southwest Virginia a Silurian and Devonian formation named the Hancock Limestone (or Dolomite) intervenes between rocks of Clinton age and overlying Devonian rocks. Northeastward in northern Virginia, West Virginia, Maryland, and Pennsylvania, other Upper Silurian formations, predominantly shale, limestone, and sandstone, are present as shown in the graphic sections from Pennsylvania and Maryland (pl. 3, columns 4, 5, 7). In Pennsylvania and West Virginia these Upper Silurian formations intertongue to the northwest of the Valley and Ridge with an extensive dolomite sequence containing anhydrite and salt. This sequence, called the Salina Group, is mined for salt in New York and northern West Virginia (pl. 3, column 6).

DEVONIAN ROCKS

Rocks of Devonian age are several thousand feet thick and cover large areas in the New York and Pennsylvania parts of Appalachia. They become thinner southward and are absent locally in the easternmost belts of the Valley and Ridge province in the Southern States. The first successful well drilled for oil was into rocks of Late Devonian age in Venango County, northwestern Pennsylvania.

New York State is the standard reference area for Devonian rocks in North American (G. A. Cooper and others, 1942, p. 1732). In Otsego County, N.Y., the most complete section of Devonian rocks in Appalachia is present and has been divided into 22 formations by Rickard and Zenger (1964). The thicker and better known of these units are shown in the columnar section (pl. 3, column 1). The formations of Early Devonian and earliest Middle Devonian age are predominantly limestones. Starting in Middle Devonian time, however, clastic sediments appear which become coarser upward. These clastics represent the western edge of the Catskill delta, which by Late Devonian time occupied southeastern New York, all of eastern Pennsylvania, and parts of Virginia, West Virginia, and Maryland.

On the southeast side of the Pocono Plateau along the Delaware Valley in northeastern Pennsylvania and westward, formations of Lower and Middle Devonian age are present, quite similar to those in Otsego County, N.Y. Of these, the Oriskany Sandstone, which is in places both very clean and also very porous, is of great economic importance because of its use as a glass sand and also because it is a prolific gas reservoir in Pennsylvania and West Virginia. Westward in New York and Pennsylvania the overlying thick coarse clastic sediments of the Catskill delta thin and change to finer grained sandstone and shale. These sands, the so-called Bradford sands of western Pennsylvania, have been prolific oil producers for many years.

In western Pennsylvania the Devonian formations pass beneath the Carboniferous formations of the Allegheny Plateau. Where they reappear west of the plateau in central Ohio and eastern Kentucky, beds of Early Devonian age are no longer represented, Middle Devonian rocks are predominantly limestone, and rocks of Late Devonian age are dark gray to black shale. To the south, in West Virginia, Kentucky, and Virginia, an organic-rich black shale sequence is one of the principal gas-producing zones of the Appalachian region. From central Pennsylvania southward along the Valley and Ridge province, in Maryland and West Virginia, the formations of Early and Middle Devonian age are well represented by a series of units of which the Helderberg Group at the base is principally limestone and the Oriskany continues to be a clean calcareous or siliceous sandstone. Above the Oriskany almost all the rocks of Middle and Late Devonian age are shale and siltstone, to various parts of which different formation names have been applied in different States.

In southwestern Virginia Lower and Middle Devonian formations are thin and sporadically distributed, whereas interbedded dark shales and lighter colored silts of Late Devonian and Early Mississippian age, collectively named the Chattanooga Shale, are as much as 1,000 feet thick. Westward and southward the Chattanooga thins to as little as 35 feet, but it is present below Mississippian rocks in almost all belts in east Tennessee, Georgia, and Alabama, and also around the rim of the Nashville Basin in central Tennessee. In most of these belts all other Devonian formations are absent, and the Devonian is represented only by the thin Chattanooga. Locally a few tens of feet of limestone of Early Devonian age and sandstone of early Middle Devonian age are present.

Devonian rocks form such narrow belts of outcrop from Virginia southward that they have everywhere been combined with rocks of subjacent and (or) superjacent systems on the geologic map (pl. 2).

MISSISSIPPIAN ROCKS

Rocks of Mississippian age are present from northeastern Pennsylvania southwestward along the Valley and Ridge province to Alabama, and also on the west side of the Appalachian Plateaus from Ohio to Alabama. Between these two subparallel belts of outcrop, wells drilled for oil and gas have penetrated the Mississippian rocks beneath the cover of overlying Pennsylvanian and Permian rocks in many places.

In the outcrop belts east of the Appalachian Plateaus, the Mississippian rocks are predominantly clastic, principally sandstone and shale, although a thick limestone sequence lies near the middle of the sequence in States south of Pennsylvania. To the west they are dominated by limestone, although thin units of shale and sandstone are present in both lower and upper parts. Because the lithologies of mapped units and also most of the formation names are different in the outcrop belts on opposite sides of the Appalachian plateaus, the Mississippian rocks in the two areas are described separately.

In the easternmost area of outcrop in eastern Pennsylvania, the Mississippian System consists of clastic rocks of continental origin, which are divided into two formations, the Pocono Sandstone below and the Mauch Chunk Shale (or Formation) above. The Pocono is a drab sandstone averaging about 1,300 feet thick, and the Mauch Chunk, which is in places more than 3,000 feet thick, is composed predominantly of red shale but has considerable quantities of red siltstone and sandstone. The Pocono Formation and Mauch Chunk Shale extend westward into central Pennsylvania, where a fossiliferous marine limestone intervenes between the two. This limestone thickens westward and southwestward into West Virginia where it is named the Greenbrier Limestone. South and southwest of Pennsylvania it is almost everywhere at least several hundred feet thick, and it attains a maximum thickness of about 1,800 feet in the subsurface in southern West Virginia. Drillers and geologists commonly refer to it as the "big lime."

Southwestward along the Valley and Ridge province from central Pennsylvania, the Mississippian rocks are quite similar to those in central Pennsylvania. The name Pocono Formation is replaced by the name Price Sandstone in southwestern Virginia, where coal beds are interbedded with the sandstone in Pulaski and Wythe Counties. The coals, which are the oldest commercial coals in the United States, were mined for many years.

In southeastern West Virginia and southwestern Virginia a red shale formation, the Maccrady Shale, lies between the Price Sandstone and the Greenbrier Limestone. The Maccrady is the salt-bearing formation of Smyth and Washington Counties, Va. Above the Greenbrier, beds equivalent to the Mauch Chunk are drab gray and greenish gray and consist of shale, siltstone, and thick resistant sandstone which are referred to collectively as the Pennington Group. Two resistant ridge-making sandstone units in the Pennington Group are the Stony Gap Sandstone Member of the Hinton Formation and the Princeton Sandstone.

In Tennessee, beds of shale and siltstone equivalent to the Price Sandstone and Maccrady Shale of Virginia compose the Grainger Formation, and the limestone formation, approximately equivalent to the Greenbrier Limestone, is named the Newman Limestone. Between the areas of outcrop of the Grainger and the Newman, however, another formation, the Fort Payne Chert, appears in northernmost Tennessee and becomes thicker southward and westward. The Fort Payne is very prominent topographically because of its extreme resistance to erosion. It forms ridges in the Valley and Ridge province from Tennessee southward into Georgia and Alabama.

In northwestern Georgia and northeastern Alabama a thick sequence of clastic rocks of Mississippian age is divided into Floyd Shale below and Parkwood Formation (which includes some Pennsylvania beds) above. Still farther northwest in both of these States, carbonate rocks predominate, but the sequence of lithologies and formation names are more closely allied to those recognized in Kentucky and central Tennessee. Hence, they will be described along with that sequence of Mississippian rocks.

In central Pennsylvania the Mississippian rocks dip beneath the Appalachian Plateaus, but in northwestern Pennsylvania the belt of Mississippian crosses the northern part of the plateaus and passes into Ohio. In this region the Mississippian is represented only by the Pocono Formation.

Where the rocks of Mississippian age come to the surface in Ohio on the west side of the Appalachian Plateaus and within Appalachia, they are less than 1,000 feet thick. The Pocono interval is occupied by a sequence of sandstones and shales named in order upward Bedford Shale, Berea Sandstone (these two formations may actually be Devonian), Sunbury Shale, Cuyahoga Formation, and Logan Formation. The Berea is particularly noteworthy because it is quarried extensively as a construction stone, and it is also an important gas-bearing sand in the subsurface beneath the Appalachian Plateaus. Overlying this sequence of clastic rocks is a limestone formation, the Maxville Limestone, of spotty distribution, which is approximately equivalent to the Loyalhanna Limestone of Pennsylvania and the Greenbrier Limestone of West Virginia. The upper part of the Maxville Limestone is eroded away in most places, and the entire formation is eroded in some places. There are no Mississippian rocks younger than the Maxville, and hence equivalent to the Mauch Chunk, in Ohio. If any were ever deposited during this time interval, they were eroded before the first sediments of Pennsylvanian age were laid down.

In northern Kentucky the lowermost part of the Mississippian section is very similar to the section in Ohio, but the name Borden Formation is applied to a thick shale-silt sequence overlying the Sunbury Shale and underlying a thin limestone that is only locally present. This limestone may be the same as the Maxville Limestone of Ohio. Southwestward in Kentucky the lower part of the Mississippian changes to a cherty limestone and shale as much as 35 feet thick named the Fort Payne Formation. This formation, the same one that forms narrow ridges where the beds are inclined in the Valley and Ridge province, caps extensive low plateaus in the region of flat-lying rocks in southern Kentucky and also in central Tennessee and northern Alabama. The middle part of the Mississippian section in southern Kentucky is predominantly limestone, roughly equivalent to the Greenbrier of West Virginia and the Newman of east Tennessee. The limestone has been subdivided in many areas, however, and sandstone tongues are interlayered with the limestone. As a result, as many as six formations are recognized in southern Kentucky and a still larger number in Tennessee and Alabama, which are together approximately equivalent to the Greenbrier and Newman Limestones of the Valley and Ridge province. In

Kentucky these formations in order upward are the Salem and Warsaw Formations, St. Louis Limestone, Monteagle Limestone including the Ste. Genevieve Limestone Member, Hartselle Sandstone, and Bangor Limestone. This sequence is everywhere overlain by the Pennington Shale, or Pennington Formation, which is composed of interbedded shale, calcareous shale, and limestone ranging from 50 to 200 feet thick. In Kentucky and Tennessee the Pennington is the youngest Mississippian formation but in parts of Alabama the Parkwood Formation, which is composed of sandstone and shale and in places is as much as 2,000 feet thick, lies between the Pennington Formation or the Bangor Limestone and the Pottsville. The upper part of the Parkwood Formation may be of Pennsylvanian age although the bulk of the formation is believed to be Mississippian. In Alabama, two additional sandstone units besides the Hartselle are included within the carbonate sequence of the middle part of the Mississippian. These are the Cypress Sandstone, which lies 25–60 feet below the Hartselle Sandstone and is as much as 40 feet thick, and the Bethel Sandstone, which is about 100 feet lower but is nowhere more than 20 feet thick. This sequence of interbedded limestone and sandstone units which ranges from 125 to 350 feet thick and lies below the Hartselle has been named the Pride Mountain Formation by Welch (1958). The Mississippian section in northern Alabama in places also includes another formation, the Tuscumbia Limestone, lying between the Fort Payne Chert and Pride Mountain Formation. The complete Mississippian section in northern Alabama from the base upward thus becomes Fort Payne Chert, Tuscumbia Limestone, Pride Mountain Formation, Hartselle Sandstone, Bangor Limestone, and Pennington Formation.

In parts of Appalachia both the lower and upper boundaries of the Mississippian rocks are somewhat obscure. The Chattanooga Shale in some places, as in central Tennessee, seems to be entirely Devonian, but elsewhere, as in southwest Virginia, the uppermost part of the Chattanooga carries Mississippian fossils (conodonts). At the top, the contact of Mississippian and Pennsylvanian rocks appears to be marked by an unconformity in the northern part of Appalachia, but in southwestern Virginia and adjacent Kentucky and Tennessee, rocks of the Pennington Group (or Formation), which has been called Mississippian, intertongue with rocks of the Lee Formation which has been called Pennsylvanian (Englund, 1964). Farther south this boundary may lie within the Parkwood Formation as previously indicated.

PENNSYLVANIAN ROCKS

The Pennsylvanian System is approximately coextensive with the physiographic province known as the Appalachian Plateaus. In Georgia, Alabama, and northeastern Pennsylvania, however, Pennsylvanian rocks are also present in structural troughs, or synclines in the Valley and Ridge province. In southwestern Pennsylvania and adjacent West Virginia and Ohio, the Pennsylvanian rocks are covered by rocks of the Permian System.

Most rocks of the Pennsylvanian System are of continental origin. Sediments were spread out over the land by streams or deposited in bodies of fresh or brackish water. The interior of the continent was, however, occupied by a vast inland sea which from time to time spread eastward into what is now the central part of Appalachia. During these periods of marine invasion from the west, lime mud containing shells of marine animals was deposited and thus became interlayered with gravel, sand, silt, and mud derived from highlands to the east. The coarser grained rocks of Pennsylvanian age without interbedded limestone are most abundant in the eastern part of Appalachia, and the finer clastic sediments with interbedded limestone predominate in the western part.

Between periods of deposition of clastic sediments from the east or invasions of the sea from the west, vast areas of Appalachia from Pennsylvania southward were broad swamps, some covering thousands of square miles. Here accumulated the remains of a lush vegetation which was preserved and later transformed into the extensive coal beds of the Pennsylvanian System. Several hundred different coal beds in the region are thick enough to have been mined, and most have been named by geologists or miners.

The problems of correctly correlating Pennsylvanian coal beds from region to region are among the most difficult in all stratigraphy, and as modern detailed mapping is done in the coal-bearing regions, many of the earlier identifications or correlations of named coals have had to be revised. The stratigraphy of Pennsylvanian rocks is shown graphically in figures 35–40 and tables 33–35 of the section on "Coal" (p. 102).

Throughout Appalachia, fine-grained clastic rocks, siltstone and shale, are the most abundant rock types of Pennsylvanian age, but because they are easily eroded, they are relatively inconspicuous. Ironstone bands and nodules are abundant in many of the shale units but have no economic potential. Sandstone and conglomerate are somewhat less abundant, but sandstone beds or thick sandstone units are present and crop out widely in all parts of Appalachia where Pennsylvanian rocks are present. Much of the sandstone is conspicuously crossbedded. Conglomerate is particularly abundant in the lower part of the Pennsylvania sequence and in easternmost belts of outcrop. Limestone is prominent in western Pennsylvania and Ohio. In other parts of Appalachia almost no limestone is present, although shale beds are calcareous. Coal beds are distributed through the Pennsylvanian System from base to top. Locations and names of the important coals geographically and stratigraphically are given in the section on "Coal" (p. 111 to 119) and will not be treated here. There is a tendency for these various rock types to be repeated in a regular sequence called a cyclothem; this phenomenon is also described in the section on "Coal" (p. 102).

Economically, the Pennsylvanian System is the most important one in Appalachia. It contains almost all the mined coals, and has yielded a substantial part of the oil and gas production. In addition, thick beds of underclay associated with some of the coals are mined extensively in some areas, particularly in Ohio. Both sandstone and limestone units of Pennsylvanian age are exploited for building stone as well as for crushed stone. Porous Pennsylvanian sandstone units are an important source of commercial brine.

The lowest part of the Pennsylvanian System typically contains thick units of resistant conglomerate and sandstone; these rocks commonly make mountains where the beds are steeply inclined or cap high plateaus where the beds are nearly flat. North of Tennessee these basal beds of the Pennsylvanian are rivaled as ridge makers only by the Shawangunk, Tuscarora and Clinch Formations of the Silurian. From Tennessee on south the Lower Silurian rocks change to weak shale, and the basal Pennsylvanian rocks forming the rim of the Cumberland Plateau and other plateaulike ridges in southern Tennessee, Georgia, and Alabama are the most resistant rocks of the sedimentary section.

The Pennsylvanian System has been divided into four sequences in the eastern coal regions. These are, in ascending order, the Pottsville Group (or Formation), Allegheny Group (or Formation), Conemaugh Formation, and Monongahela Group (or Formation). The name Pottsville comes from the anthracite coal region in eastern Pennsylvania, the other three names from western Pennsylvania. All four sequences are represented in Pennsylvania, eastern Ohio, and northern West Virginia, but only the Pottsville is present in southern West Virginia. In southeastern Kentucky and southwestern Virginia the youngest sedimentary rocks in the coal basin may be of Allegheny age, but all the underlying Pennsylvanian beds are of Pottsville age. All coal-bearing strata of Tennessee, Georgia, and Alabama are believed to be of Pottsville age.

It has been customary to think of the Mississippian and Pennsylvanian Systems as separated by an unconformity. Indeed, the basal unit of the Pennsylvanian rocks is, in many places, a coarse conglomerate beneath which is an erosional unconformity. Recent detailed mapping and subsurface work is showing, however, that the so-called Pennsylvanian coarse clastic sediments intertongue with the less resistant fine sandstone and siltstone of the underlying so-called Mississippian. The first appearance of "Pottsville-type" conglomerate and sandstone is thus not necessarily at the same stratigraphic position, even in localities only a few miles apart (Englund, 1964).

The Pennsylvanian rocks, like rocks of the older systems, thin from east to west. In the Southern Anthracite Field of central Pennsylvania, 5,100 feet of Pennsylvanian rocks is exposed. In Washington County, southwestern Pennsylvania, where deep drilling transects all of the Pennslvanian System, 1,300 feet of rocks of Pennsylvanian age is present, and in eastern Ohio only 1,100 feet is present. At the southern end of the Appalachian Region in Alabama, Pennsylvanian rocks, all Pottsville in age, are 7,400 feet thick in the Coosa coal field, the easternmost of the four Alabama coal fields, 4,500 feet thick in the Black Warrior field, the westernmost, and 10,000 feet thick in the southeastern part of the Cahaba coal field.

Rocks of the Pottsville Group are present in the isolated structural basins of the anthracite region of northeastern Pennsylvania. They are also almost continuously present at the surface from northwestern Pennsylvania to central Alabama where they disappear beneath the Coastal Plain rocks of Cretaceous age. Conglomerate and sandstone make up a greater proportion of the Pottsville than of the younger groups of Pennsylvanian age. In many parts of Appalachia these resistant rocks form prominent ridges or escarpments. In the anthracite region, conglomerate is the dominant lithology, but sandstone, siltstone, and shale are present, and coals which are collectively named the Lykens Valley coals are also included. In western Pennsylvania, northern West Virginia, and Ohio, conglomerate, though present, is subordinate in amount to sandstone, and siltstone and shale compose most of the remainder. A few thin coals are included in the Pottsville in this region. The group as a whole thins from about 1,100 feet in the anthracite region to 250 feet in Ohio. In western Pennsylvania the Homewood Sandstone Member at the top of the Pottsville Formation is a popular building stone. Several thin iron ore beds below the Homewood were mined years ago but are no longer economically important.

In McDowell, Mercer, and Summers Counties of southern West Virginia, the Pottsville Group thickens to nearly 4,000 feet and is divided into three formations, in ascending order the Pocahontas, New River, and Kanawha. Sandstone is the most abundant rock type in this region; shale and siltstone are common; conglomerate is sparingly present, but limestone is absent. Coals occur throughout the sequence, the most important of which are the Pocahontas coals in the formation of the same name. A little farther to the southwest in the coal fields of southwestern Virginia and adjacent Kentucky, the basal unit of the Pennsylvanian is the resistant Lee Formation which consists dominantly of conglomerate and quartzose sandstone. The Lee forms heights such as Cumberland and Pine Mountains. The important mined coals are in the overlying formations called the Norton Formation, Gladeville Sandstone, Wise and Harlan Formations in Virginia and the Breathitt Formation or Group in Kentucky. These are composed predominantly of impure sandstone and siltstone. In southwestern Virginia this sequence averages about 5,400 feet in thickness but thins to less than 2,000 feet in southeastern Kentucky and to less than 1,000 feet in northeastern Kentucky.

In the Cumberland Plateau of Tennessee the rocks of Pottsville age have been separated into the groups (Wilson, Jewell, and Luther, 1956) shown in the columnar section of Pennsylvanian rocks (fig. 12). Lithologically, the sequence is similar to that in southern Virginia and Kentucky. According to Wilson, the lowest three groups, totaling about 1,300 feet of beds and containing many thick sandstone units, are equivalent to the Lee Group of earlier workers (Lee Formation in Kentucky). The upper six groups, about 2,500 feet thick, consist largely of siltstone and shale but contain thin sandstone units. These rocks are equivalent to the Briceville, Jellico, Scott, and Anderson Formations of earlier workers in Tennessee and to the Breathitt Formation of Kentucky. Coal beds are present throughout the sequence, but of the 10 thick and important mined coals, 9 lie in the middle part. One, the Sewanee coal, is near the base.

In Georgia and Alabama the several areas of Pennsylvanian rocks are isolated from each other by structural uplifts along which pre-Pennsylvanian rocks are

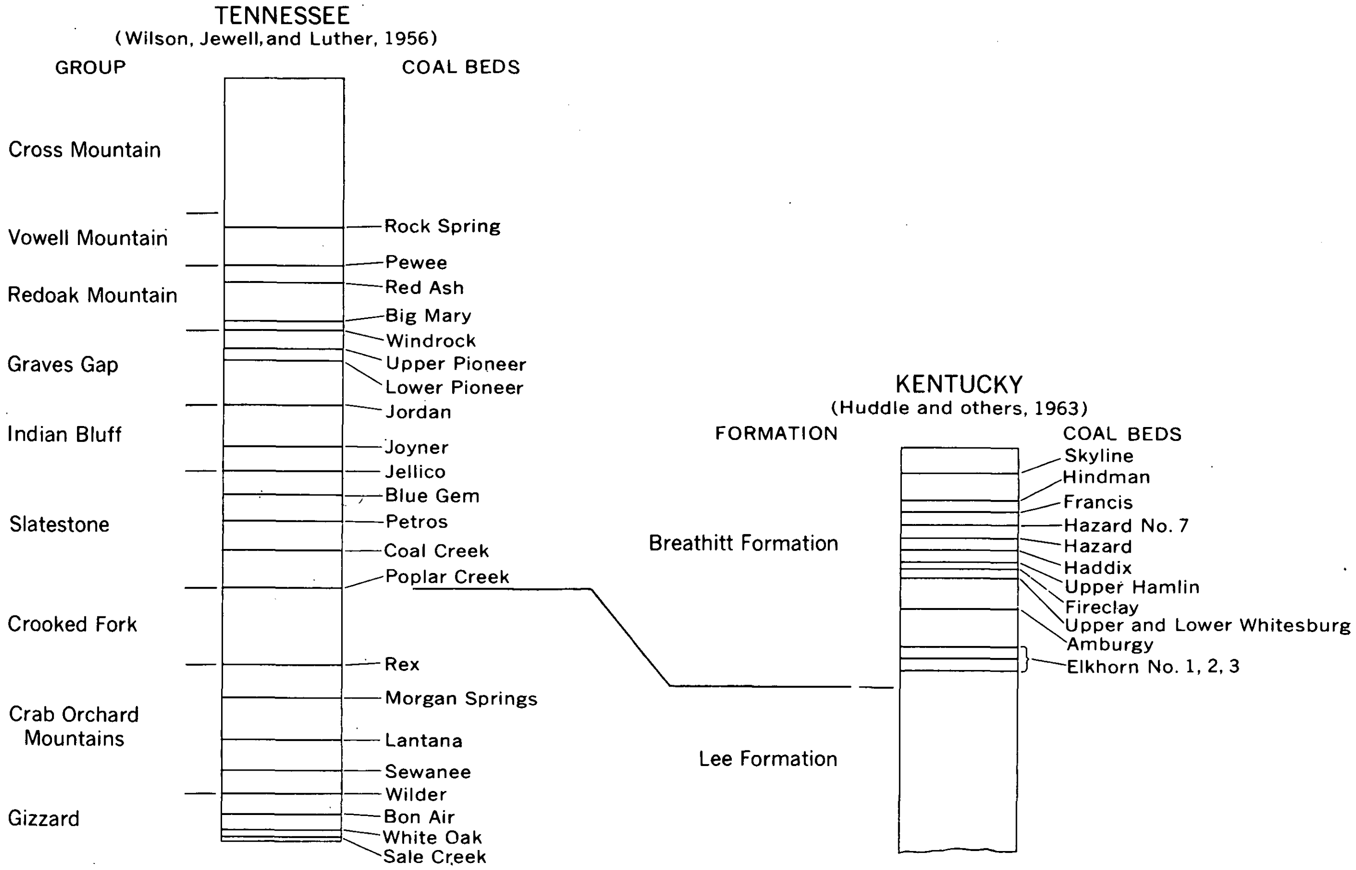


FIGURE 12.—Columnar sections of Pennsylvanian rocks in Tennessee and Kentucky.

exposed. In the northwest corner of Georgia, Pennsylvanian rocks are present in two areas, the Sand Mountain coal field on the east and the Lookout Mountain coal field on the west. Only two formations are recognized, the Lookout Sandstone composed of 300–400 feet of sandstone, conglomerate, shale, coal, and a little limestone, and the Walden Sandstone composed of about 900 feet of similar rocks. There are as many as five coal seams in the Lookout Sandstone and seven in the Walden Sandstone.

Pennsylvanian rocks cover extensive areas in the northern part of Alabama, where they are divided into two formations, the Parkwood Formation and the Pottsville Formation. Only the upper part of the Parkwood is of Pennsylvanian age. It consists of about 450 feet of shale, siltstone, sandstone, and one important coal bed which lies at the top of the formation. The overlying Pottsville Formation attains thicknesses as great as 9,000 feet in the southeastern part of its area of outcrop. It is composed of shale, thin-bedded sandstone, thick-bedded sandstone, very massive conglomerate, and coal. Conglomerate is conspicuous at the base of the formation, and the lower part, which is as much as 1,500 feet thick, is predominantly sandstone and conglomerate. This sequence contains few and thin coals and has been informally called "the lower unproductive beds" (Culbertson, 1964). The overlying beds are predominantly shale and siltstone but contain numerous coals. Areas of these so-called "upper productive beds" are separated from each other by areas of the "lower unproductive beds" and in places also by beds of older rocks and thus divided into four separately named coal fields. These are the Plateau coal fields in the northern part of the State, and in order east to west, the Coosa, Cahaba, and Warrior coal fields in the central part of the State. Preserved thicknesses of the Pennsylvanian rocks are greatest in the Cahaba and Coosa fields. The section diminishes westward and northward both by actual thinning of equivalent units and also by erosion of beds at the top; it is less than 2,000 feet thick in the Plateau coal fields and in the northern part of the Warrior coal field.

The Allegheny Group (or Formation) overlying the Pottsville, is named from the valley of the Allegheny River in western Pennsylvania where the Allegheny Formation, as it is known there, includes all beds from the top of the Homewood Sandstone Member to the Upper Freeport coal. The Allegheny Group was originally called the Lower Productive Coal Measures because of its important coals. It is present in continuous belts from Pennsylvania and Ohio as far south as southern West Virginia and northeastern Kentucky. A few hundred feet of beds capping several of the highest mountains in southeastern Kentucky may also belong in the Allegheny. Farther south whatever beds of Allegheny age that may have been deposited have been eroded. In western Pennsylvania the Allegheny is about 300 feet thick. It consists predominantly of shale, sandstone, and coal, but also has units of both marine and fresh-water limestone. The best limestone unit is the Vanport Limestone. Some of the coal beds have thick underclays which have been mined. Of these the Clarion and Lower Kittanning underclays are the most important commercially. The Lower Freeport coal and associated beds also contain small amounts of uranium in parts of western Pennsylvania. The most important coals of the group are the Freeport and Kittanning coals. The sequence in West Virginia is about the same thickness as in Pennsylvania but it thins westward into Ohio. In West Virginia, fewer and thinner limestone units are included than in Pennsylvania, but in Ohio, limestone is more abundant. In Kentucky, beds equivalent to the Allegheny Group form the upper part of the Breathitt Formation.

In the anthracite region of eastern Pennsylvania the rocks overlying the Pottsville Group are of continental origin, and almost all except the coals are clastic rocks, that is, conglomerate, sandstone, siltstone, and shale. Correlation of these post-Pottsville rocks and their contained coals with those of western Pennsylvania has proved exceedingly difficult. As a result, Wood and others (1962) did not use the Allegheny and Conemaugh as rock units in the anthracite region, but they named the sequence that contains most of the important seams of anthracite coal the Llewellyn Formation. The Llewellyn is, however, probably of Allegheny and Conemaugh age, and beds of Monongahela age are absent.

Rocks of the Conemaugh Formation are also restricted to the northern part of the Appalachian coal basin. They are present at the surface in western Pennsylvania, western Maryland, eastern Ohio, northern West Virginia, and northeastern Kentucky. All beds between the base of the Upper Freeport coal and the bottom of the Pittsburgh coal are included in the Conemaugh Formation. This sequence was originally called the Lower Barren Measures in Pennsylvania, where the type area of the Conemaugh is located and where the beds attain a thickness of 950 feet. This sequence thins westward into Ohio where only 400 feet of beds lie between the aforementioned coals at base and top of the formation. In both West Virginia and Ohio only about 3 percent of the original coal is estimated to have been in coals of the

Conemaugh Formation. The Conemaugh Formation is predominantly sandstone and gray and red shale, but contains many tongues of limestone as much as 20 feet thick.

The Monongahela Group (or Formation) has the Pittsburgh coal at its base and the Waynesburg coal at its top. In western Pennsylvania some 400 feet of beds lie between the two coals in the type area along the Monongahela River. Included are three other coals of minable thickness in Pennsylvania and West Virginia, of which the Sewickley is most important, and four others in Ohio, of which the Meigs Creek bed is most important.

In Pennsylvania the Monongahela contains much more limestone than the underlying Conemaugh Formation, probably as much as 50 percent of the total in places. The remainder is made up principally of shale, siltstone, and sandstone. Limestone is also abundant in the Monongahela of Ohio where the group totals 250 feet in thickness. Southward into West Virginia the limestone becomes less abundant. Red shale becomes conspicuous and sandstone beds are thicker and more resistant, hence more prominent.

PERMIAN ROCKS

Rocks of Permian age in Appalachia and indeed in all of eastern United States are confined to an elliptical area in Pennsylvania, Ohio, West Virginia, and Maryland. This elliptical area lies in the center of the region of Pennsylvanian rocks and on the geologic map has the appearance of an "eye of Appalachia." These rocks were called the Upper Barren Group by Rogers (1858) in his description of the geology of Pennsylvania, but were later named the Dunkard Creek Series by I. C. White (1891), a name that was subsequently changed to Dunkard Group. The group consists of the Washington Formation below and the Greene Formation above. Recent work has shown that the lower part of the Washington Formation is Pennsylvanian in age.

The Dunkard Group is 1,100–1,200 feet thick in western Pennsylvania and northern West Virginia, but thins to about 600 feet in eastern Ohio. The rocks that make up most of the Dunkard are predominantly shale, shaly sandstone, and limestone. The Waynesburg Sandstone Member near the base is extensive and topographically prominent. The Washington Formation contains several coals, of which the most important economically is the Washington coal. Several other coals in the Washington Formation and still others in the overlying Greene Formation are too thin or too shaly to be mined economically. The limestone units and coals thin or disappear southwestward, and in most of West Virginia the Dunkard is predominantly red shale and sandstone. Underclays of the coals in the Dunkard are thin.

TRIASSIC ROCKS

Rocks of Late Triassic age in eastern United States fill a series of downfaulted basins within older crystalline rocks of the Piedmont province. Of these only the southern tip of one of the smaller basins, the Dan River basin in Stokes and Forsyth Counties, N.C., and a tiny outlier to the southwest are within Appalachia. The Dan River basin is downfaulted on the northwest side, and the rocks dip to the west at angles averaging a little more than 20°. The smaller patch of Triassic is also downfaulted on the northwest by two echelon faults (pl. 2).

The first coals mined in the United States were in one of the Triassic coal basins near Richmond, Va.; coal has also been mined in the Deep River Triassic basin of North Carolina. Both are outside the limits of Appalachia. There has never been any coal mining in the Dan River basin, and Triassic rocks in it seem to contain no economic coals, though coal beds a few inches thick are known. There may be as much as 8,000 feet of sedimentary rock filling the Dan River basin. Shale and sandstone make up most of this sequence but zones of pebble conglomerate are included. The shale is black, yellow, and red, and the sandstone gray, yellow, and green.

The Triassic sedimentary rocks are intruded by diabase dikes that cut across the beds and diabase sills that lie parallel to the beds. The thickest dike recorded is 130 feet thick.

CRETACEOUS ROCKS

From the Precambrian through the Triassic, all systems of rocks are represented within the borders of Appalachia. The Jurassic System, which succeeds the Triassic, is not present, however. In Cretaceous time clastic sediments were deposited in the seas that lapped over and invaded the margins of a continent quite similar in its major outlines to the eastern North America we know today. Sedimentation at this time is in marked contrast to that of the Triassic in downfaulted and downwarped basins and that of the Paleozoic Era in interior seaways separated from the ocean to the east by highland areas.

Although Cretaceous strata were deposited over the present eastern and southern margins of the United States from New York to Mexico, they are included within the borders of Appalachia only in northwestern and central Alabama (pl. 2). These strata are of Late Cretaceous age and comprise the Tuscaloosa Group below and the Eutaw Formation above.

The Tuscaloosa Group consists of about 1,000 feet of gravel, sand, and clay predominantly continental in origin. Locally, the beds are carbonaceous, and seams of lignite are present near the base and in the middle. Marine sand and clay layers intertongue with the continental beds in the lower and upper parts of the group. Sands at the top of the Tuscaloosa contain glauconite.

The overlying Eutaw Formation, 150–300 feet thick, consists of glauconitic sand, gray shale, and clay. The rocks are of marine origin and, in contrast with the underlying formations, are abundantly fossiliferous in places.

Although Cretaceous beds yield oil in parts of the Gulf Coast area, the Upper Cretaceous wedge included within the borders of Appalachia holds little prospect for oil and gas because of its thinness.

QUATERNARY ROCKS

Rocks of Tertiary age cover much of the Atlantic and Gulf Coastal Plains to the east and south of Appalachia but these rocks are not represented in Appalachia. Quaternary deposits are present, however; they comprise glacial deposits of the Pleistocene, which cover the northern part of Appalachia, and various Recent alluvial deposits, principally along major river valleys.

The northern part of Appalachia was covered by at least two major advances of continental glaciers in Pleistocene time. Ice advances which scoured away preexisting soils and some of the underlying bedrock, piled up terminal moraines at the ice margin and outwash alluvial deposits in front of the ice. As the ice front receded, recessional moraines were formed in many places, representing stillstands of the ice front of considerable duration. Ground moraine, that is widespread debris left on the bedrock surface as the ice melted away, covers most of the rest of the glaciated areas.

The geologic map (pl. 2) shows the limit of advance of glaciers of the two periods but does not show the deposits left by the glaciers. The earlier ice advance, labeled pre-Wisconsin on the geologic map, extended farther south than the later or Wisconsin Glaciation in much of Ohio and northwestern and eastern Pennsylvania. Morainal deposits formed by the older glaciation are deeply weathered, and many have been eroded away in the intervening time or covered by alluvium washed out from the later ice front of Wisconsin time. They are in most places less than 20 feet thick and consist of sand, gravel, and clayey till without prominent terminal or recessional moraines.

The later or Wisconsin Glaciation extended farther south than the pre-Wisconsin ice advance in north-central Pennsylvania and in parts of Ohio. Thus, it obliterated traces of the earlier moraines in those areas. The terminal moraine left by the glaciers of Wisconsin time is in many places a conspicuous ridge or a belt of hummocky hills that may rise several hundred feet above the surrounding terrane. The moraine, composed of boulders, gravel, sand, and clay, may be followed from northern New Jersey northwestward across the ridges and valleys of Pennsylvania into southwestern New York around a nonglaciated embayment known as the Olean reentrant, thence southwestward into Ohio where it lies partly within and partly outside the boundary of Appalachia. Recessional moraines, similar in appearance to the terminal moraine, but lying farther north, are present in northwestern Pennsylvania and southern New York. Ground moraine cover is found nearly everywhere north of the terminal moraine. Fluvial and lacustrine deposits both in front of and behind the terminal moraine were formed by melt water flowing out in front of the ice sheet or ponded by it.

In general, deposits of the Wisconsin Glaciation consist mainly of unsorted gravel and sand, but well-sorted sand, silt, and clay are also present, particularly in the water-laid sediments. The rock types in the glacial deposits consist of the more resistant of the rocks overriden by the glacier, normally with those closer at hand to the north present in greater abundance than those farther away. Thus, the character of the rock debris changes from place to place.

Glacial deposits are an abundant source of sand and gravel in the northern part of Appalachia. Stony soils of the glaciated regions are less favorable for most types of agriculture than the residual soils derived from weathering of bedrock. On the other hand, dairying and fruitgrowing flourish in the glaciated areas.

Deposits of Recent age are present in all parts of Appalachia. They consist principally of unsorted debris on slopes in the mountainous regions and gravel, sand, and clay deposited by rivers and streams and in lakes. Deposits on mountain slopes are of three closely related types: colluvium, alluvial cones, alluvial fans. Colluvium is debris which has been derived from cliffs or steep slopes and has fallen, rolled, or crept downhill, mantling the bedrock on the slopes below the source. Colluvial deposits may be thin veneers or may be scores of feet thick. The debris is poorly sorted and not uncommonly includes blocks as big as small houses. In many places, debris derived from cliffs or steep slopes is channeled down ravines or steep valleys and accumulates where the gradient becomes more gentle. The deposits are commonly more or less cone shaped, and are called alluvial cones.

Similar stream deposits which cover much larger areas at the mouths of steep valleys, are called alluvial fans. Along some ridges in Appalachia, fans flaring out from closely spaced subparallel ravines merge on the lower slopes to form a mantle that may be continuous for thousands of feet or even miles.

Many rivers of Appalachia have formed extensive terraces and flood plains along their courses. Gravel, sand, and silt have been deposited on these surfaces when the rivers overflowed their channels at flood stage. Sand and gravel also accumulate in the riverbeds. These deposits may be a thin veneer or may be scores of feet thick. They are much better sorted than the colluvial deposits and in some places contain quartz sand of excellent quality. Terrace and floodplain deposits are extensively used as sources of sand and gravel in many parts of Appalachia.

IGNEOUS AND METAMORPHIC ROCKS

Igneous and metamorphic rocks of a wide variety of types and ages underlie the southeastern part of Appalachia. They are the characteristic rocks of the Blue Ridge and Piedmont province of Virginia, the Carolinas, Georgia, and Alabama. Their ages and structural relations in most places are not well known; they do, however, include rocks as old as Precambrian in most of the Blue Ridge and as young as Triassic in the Piedmont. Although geologic information about them is less complete than for the sedimentary rocks previously described, the igneous and metamorphic rocks are highly diverse in mineral content and have been the source of a large variety of metallic and nonmetallic mineral products.

LOWER PRECAMBRIAN METAMORPHIC ROCKS

Much of the Blue Ridge belt from northern Georgia to southern Virginia consists of metasedimentary and metaigneous rocks older than the Ocoee Series and of other upper Precambrian rocks. These rocks are largely micaceous and hornblendic schists and paragneisses to which Keith (1903) applied the terms Carolina Gneiss and Roan Gneiss. In most places they are distinctly layered and apparently represent much altered clastic sedimentary and volcanic rocks. Commonly, however, they are granitic or migmatitic as a result of long burial in the deeper and hotter parts of the earth's crust. Biotite- and muscovite-quartz-feldspar gneisses and schists predominate in most of the belt. Hornblende gneisses, including both layered and massive types, are commonly associated with the micaceous gneisses. Hornblendic rocks are particularly abundant in Jackson, Macon, Yancey, and Mitchell Counties, N.C., where they amount to as much as 40 percent of the rocks present.

Distinction between the more metamorphosed parts of the upper Precambrian rocks and the lower Precambrian paragneisses is difficult at many places in the Blue Ridge; therefore areas of upper Precambrian rocks may be included with the older rocks, especially in Floyd and Carroll Counties, Va.

Although the older rocks probably originated in earlier Precambrian time, much of their metamorphism took place after deposition of the upper Precambrian rocks and was probably associated with emplacement of alaskite and pegmatite bodies in many areas, notably Yancey and Mitchell Counties, N.C., and, to a lesser extent, in Avery, Jackson, and Macon Counties. Isotopic ages of minerals in the pegmatites and the metamorphic rocks indicate that the pegmatite bodies were emplaced and the metamorphic rocks were last recrystallized in middle or late Paleozoic time.

PRECAMBRIAN GRANITIC ROCKS

Rocks along the northwestern border of the Blue Ridge belt northeast of Haywood County, N.C., and Cocke County, Tenn., are commonly nonlayered and granitic in composition in contrast with the layered gneisses and schists farther south and southwest. They are commonly associated with migmatite and other mixed rocks derived from micaceous and amphibolitic gneisses like those elsewhere in the Blue Ridge. The granitic rocks are varied in composition and texture and include quartz monzonite, granodiorite, quartz diorite, and granite. Biotite, epidote, and magnetite are the chief mafic constituents, but hornblende is present in some rocks and most contain minor quantities of muscovite. Some granitic rocks, featured by conspicuous megacrysts of potassium feldspar were referred to by Keith as Max Patch Granite. Similar rocks in the Grandfather Mountain area of Caldwell County, N.C., are referred to as Blowing Rock Gneiss.

Most of the Precambrian granitic rocks are foliated and have crudely concordant though gradational contacts with the enclosing rocks. Some bodies have dimensions measured in thousands of feet, but most are smaller and intimately mingled with layered gneisses and schists. In many places the granitic rocks are strongly sheared and converted to mylonite gneisses resembling foliated metasedimentary rocks.

PALEOZOIC(?) METAMORPHIC ROCKS

Most of the Piedmont counties of Appalachia are underlain by layered gneisses, schists, and other metasedimentary rocks of uncertain age but currently believed to be younger than the metamorphic rocks of the Blue Ridge Belt. They range in metamorphic grade from slate and phyllite to sillimanite gneiss. The intensity of metamorphism increases generally across the regional trend from northwest to southeast, where mixed gneisses of metamorphic and migmatitic origin are abundant and resemble parts of the older Precambrian metamorphic complex.

Diversified metamorphic rocks make up the Talladega belt (fig. 13, p. 74) extending through parts of Chilton, Shelby, Talladega, Clay, and Cleburne Counties, Ala., into Haralson County, Ga. The principal rocks are slate, phyllite, and metasandstone, accompanied locally by prominent units of limestone, marble, quartzite, conglomerate, and cherty sandstone. The aggregate thickness of these rocks is estimated to be as much as 25,000 feet. Poorly preserved fossils in parts of the series show that middle and upper Paleozoic rocks are present. Other parts of the series are probably older Paleozoic, and some may be late Precambrian in age. Their structure and stratigraphy are complex, however, and not well known.

Somewhat similar though more intensely metamorphosed rocks extend from the Talladega belt in Haralson County northeastward through northern Georgia into southwestern North Carolina. They are known as the rocks of the Murphy belt (fig. 13). They consist of dark carbonaceous and pyritic slate and interbedded quartzite, associated with various quartz-feldspar-mica schists, generally fine grained and thin bedded. The schists are commonly distinguished by conspicuous biotite, garnet, chloritoid, and staurolite crystals. The Murphy Marble, a carbonate unit 150–500 feet thick, extending throughout the length of the belt, is exploited for crushed stone, dimension stone, and talc. The rocks of the Murphy belt are apparently younger than the adjacent Ocoee Series and are presumably Lower Cambrian in age.

A third belt of metamorphic rocks, extending from Coosa and Elmore Counties, Ala., across Georgia to Oconee County, S.C., is known as the Ashland-Wedowee belt (fig. 13). The rocks in this belt differ from those farther northwest by their greater metamorphism and by the presence of granitic intrusive rocks. They consist largely of muscovitic, hornblendic, chloritic, and graphitic schists, phyllite, micaceous quartzite, and layered biotite gneiss locally containing conglomeratic layers. Biotite and garnet are conspicuous metamorphic minerals, and kyanite is abundant in several parts of the belt. These rocks appear to overlie the older gneisses of the Blue Ridge belt in northeastern Georgia, and their lithology suggests that they may be equivalent in part at least to the rocks of the Ocoee Series and Murphy belt to the northwest. The Ashland-Wedowee belt is separated from the Talladega belt in Alabama by a narrow but remarkably persistent belt of chlorite-plagioclase-hornblende schist and related rocks, the Hillabee Chlorite Schist, which may represent gabbroic intrusives along a major fault zone.

The Dadeville-Inner Piedmont belt (fig. 13), the southeasternmost belt of Paleozoic metamorphic rocks within Appalachia, extends from Tallapoosa and Chambers Counties, Ala., northeastward across Georgia and the Carolinas. The rocks in this belt are dominantly muscovite-, biotite-, and biotite-sillimanite schists and gneisses accompanied locally by hornblende gneiss and schist, and more rarely by thin units of lime-silicate rocks, marble, and quartzite. Muscovite-poor biotite-sillimanite gneiss, migmatite, and pegmatites are abundant in the central part of the belt. Many irregularly concordant bodies of foliated granitic rocks are also present throughout the belt. Much of the gneiss is compositionally layered and presumably of sedimentary or volcanic origin. Some hornblende gneiss is, however, of plutonic origin and grades into massive gabbro or diorite. Gradations are common also between hornblende gneiss and biotite gneiss. Carbonate rocks are found mainly in association with hornblende gneiss northwest of Walhalla in Oconee County, S.C., but also in small exposures at other places throughout the belt.

The Dadeville-Inner Piedmont belt is separated from belts to the northwest by a narrow belt of rocks a mile to a few miles wide, known as the Brevard belt from exposures near the town of Brevard, Transylvania County, N.C. This belt is characterized by strong topographic lineaments of remarkable continuity and by various types of schist, phyllonite, mylonitic gneiss, and other rocks, including marble, many of which show evidence of strong shearing and retrogressive metamorphism. It has been recently interpreted as a major zone of strike-slip faulting and is so shown on the accompanying geologic map (pl. 2).

PALEOZOIC(?) GRANITIC ROCKS

Intrusive granitic rocks are widespread throughout the southeastern belts of Paleozoic(?) metamorphic rocks and in parts of the older Precambrian metamorphic complex. They are regarded as being Paleozoic rather than Precambrian in age because of their association with belts of more intense regional metamorphism of Paleozoic age, and because some of them appear to have been emplaced relatively late in the deformational history of the region. Isotopic ages of minerals in these granitic rocks are generally between 250 and 370 million years, or Middle Devonian to Permian time. The bodies vary greatly in size, shape, and distribution; therefore areas shown as granitic rocks on the available geologic maps are much generalized and include considerable amounts of gneiss and schist. Conversely, many smaller granitic bodies are not shown. The rocks range from granite to quartz-diorite, and nearly all are characterized by both biotite and muscovite. Most are gneissic and at least crudely concordant with structures in the surrounding rocks. Many have gneissic and gradational borders.

Fine- to medium-grained, variably porphyritic rocks form large and small bodies just southeast of the Brevard zone in North Carolina. These are locally referred to as Henderson Gneiss, characterized by conspicuous crystals of white feldspar in a micaceous granitic matrix. The rock is generally strongly foliated, and augen gneiss is a common type. Finer grained, equigranular variants occur, especially in Oconee County, S.C.

Other granitic bodies in the Dadeville-Inner Piedmont belt are fine- to coarse-grained biotite granite gneiss. Such rock occupies areas equal to the Henderson Gneiss in South Carolina and is more abundant in Georgia where it was referred to as the Lithonia Gneiss by Watson (1902). Most of the granitic rocks in Wilkes, Burke, and Rutherford Counties, N.C., are of this type. They are characteristically lenticular or sheetlike and concordant with broadly folded foliation in the enclosing rocks. Similar granite bodies in Macon, Jackson, and Transylvania Counties, N.C., were referred to by Keith (1907b, p. 4–5) as the Whiteside Granite and were interpreted by him as being much younger than the enclosing Precambrian gneisses.

Most of the granitic bodies in the Ashland-Wedowee belt are of the Lithonia type, consisting of gneissic biotite granite, granodiorite, and quartz diorite with gradational and migmatitic borders. The Pinckneyville Granite in Coosa County, Ala., is one of the largest of these bodies.

A few smaller granite bodies in the region are more uniform in composition and texture and are mostly nonfoliated. They are generally lenticular or elliptical in plan and have sharp boundaries commonly discordant with the structure of the surrounding rocks. Such bodies are the ones most used commercially, and include the Mt. Airy granite of Stuckey and Conrad (1958) of Surrey County, N.C., and, in Georgia the Stone Mountain Granite of Watson (1902) and Elberton granite of Chayes (1952).

PALEOZOIC DIORITE AND GABBRO

Much of Davie County and adjacent parts of Yadkin and Forsyth Counties, N.C., consist of metamorphosed diorite and gabbro of intrusive origin, together with intervening areas of mixed mafic and granitic rocks. The mafic rocks are composed largely of plagioclase, hornblende, and pyroxene and include massive to foliated and schistose types. They represent mafic intrusive bodies of poorly known size and shape but are generally older than the associated granitic rocks. Both types of rock finger out into gneissic and metavolcanic rocks belonging to the Paleozoic(?) metamorphic complex of the Carolina Piedmont.

ULTRAMAFIC ROCKS

Several hundred bodies of ultramafic or magnesia-rich silicate rocks occur in the Blue Ridge and Piedmont provinces where they have been found in crude "belts" within an elliptical area extending southwestward from Floyd County, Va., to Tallapoosa County, Ala., and from Madison County, N.C., eastward across Spartanburg County, S.C. Varieties of peridotite, pyroxenite, serpentinite, soapstone, and talc schist are present. Although small in total volume, these rocks are important for the deposits of olivine, soapstone, talc, corundum, asbestos, and vermiculite associated with them.

The ultramafic rocks in southern Virginia are mainly discontinuous soapstone bodies in long narrow belts, those in northwestern North Carolina are harzburgite and dunite lenses and irregular bodies, those farther southwest in western North Carolina and northern Georgia are chiefly dunite lenses, and to the southwest beyond these soapstone is again prevalent.

The intrusives range in size from soapstone or serpentinite bodies as much as 100 feet wide and 8 miles long to dunite lenses only 4 feet by 20 feet. They are generally more or less concordant with foliation and layering in the enclosing rocks. The large ringlike dunite body in Jackson County and the Buck Creek peridotite in the Buck Creek area, Clay County, N.C., are notable exceptions both in size and shape.

The age of the ultramafic rocks is uncertain, but most are probably of early Paleozoic age. They were intruded into metamorphic rocks of Precambrian and possibly Early Cambrian age and some are cut by pegmatites that have been dated as later Paleozoic in age.

TRIASSIC DIKES

Northwest-trending diabase dikes prominent throughout the Dadeville-Inner Piedmont belt are correlated with the intrusive and volcanic rocks of similar composition in the Triassic basins of the Piedmont. These dikes, some of which can be traced for many miles, trend consistently northwest across the structural trends of the belts. A few extend across the Brevard zone into the adjoining Blue Ridge and Ashland-Wedowee belts. Dikes more than 200 feet wide are rare, but many smaller ones are known. The rocks are largely normal diabase, not regionally metamorphosed, and are clearly younger than the hornblende gneiss and other metamorphic rocks of these belts. They are very conspicuous on aeromagnetic maps of the region.

INTRUSIVE ROCKS OF UNCERTAIN AGE

Small bodies of ultramafic igneous rocks occur in several localities in the Appalachian Plateaus and Valley and Ridge provinces of the Appalachian Region. These bodies are too small to be shown individually on the geologic map, so their approximate locations are indicated. One is in Union County, Tenn., another in Elliott County, Ky. There are many occurrences in Highland County, Va., and adjacent Pendleton County, W. Va., and also in Tompkins County, N.Y. Some of the bodies are dikes; others are pipe- or stock-like bodies called diatremes. Many include abundant fragments or breccias of various sedimentary rocks. Most bodies consist of olivine-rich mafic rocks with little or no feldspar, and have unusual calcium, magnesium, iron, and titanium minerals. Most rock contains phlogopite mica and is therefore termed mica peridotite. In the Appalachian Region the bodies intrude rocks ranging from Ordovician to Pennsylvanian age; similar intrusive rocks in Arkansas are Cretaceous in age.

STRUCTURE

An understanding of the structure of Appalachia is essential in the systematic search for mineral deposits. Many metallic mineral deposits are formed by circulation of liquids along structurally controlled channels such as faults and shear zones. Oil migrates along structurally controlled paths and may accumulate in structural traps such as anticlines or faulted permeable beds. Other mineral deposits such as coal, limestone, and salt, though not controlled in their formation by structure, owe their outcrop pattern or their position in the subsurface to the local structural conditions.

The physiographic provinces serve as a framework for discussing the geologic structure of Appalachia. The differences in structural style and in history of structural development between the physiographic provinces are summarized in table 26, and the major structural features of each province are discussed in the pages that follow. Reference to the tectonic map of Appalachia (fig. 13) will be helpful in locating the structural features discussed. Four cross sections (figs. 14, 15) illustrate the major structures of the sedimentary rocks in Appalachia.

TABLE 26.—*Structures of the physiographic provinces of the Appalachian Region*

Province	*Representative structure and features*	*Age*
Piedmont	Isoclinal folding and pervasive shearing of Paleozoic rocks. High-angle reverse faults and a strike-slip fault of large displacement. No conclusive evidence of a Precambrian basement.	Not well known. Ordovician and Carboniferous to Permian orogenies are probably represented.
	Normal faults and tilted beds.	Late Triassic.
Blue Ridge	Isoclinal folding and pervasive shearing; large low-angle thrust faults; rocks typical of Valley and Ridge province exposed in windows. Precambrian basement exposed.	Not well known. Precambrian and Paleozoic orogenies are represented
Valley and Ridge	Overturned and asymmetric folds, local shearing and large low-angle thrust faults. Folding more prominent in northern part of province, faulting in southern part. Depth to Precambrian basement uncertain. Probably 25,000—35,000 feet in places.	Late Pennsylvanian to Early Triassic.
Appalachian Plateaus.	Beds in most places nearly horizontal with local open folds and arches. Low-angle thrusts are exposed in Cumberland Mountain and Cumberland Plateau sections and probably are present in subsurface in Allegheny Mountain section and northern Kanawha section.	Late Pennsylvanian to Early Triassic.
	Normal faults in east-striking zone in Kentucky.	Various periods of faulting throughout Paleozoic.
	Depth to Precambrian basement 5,000 feet in west, increasing eastward to as much as 20,000 feet.	
Interior Low Plateaus and Central Lowland.	Beds nearly horizontal with broad arches and basins. Normal faults in east-striking zone in Kentucky. Depth to Precambrian basement 3,000—5,000 feet.	Occasional faulting in Paleozoic.
Coastal Plain	Very gentle southerly dip of beds. Cretaceous rocks, generally less than 500 feet thick, overlie flat-lying rocks of the Appalachian Plateaus, folded rocks of the Valley and Ridge, and crystalline rocks of the Piedmont.	Cretaceous.

VALLEY AND RIDGE PROVINCE

The Valley and Ridge province is a classic area for students of structural geology because of the abundance of anticlines, synclines, and large overthrust faults. The rocks of the Valley and Ridge province are almost everywhere tilted at moderate to steep angles, and in places the beds are overturned. The dominant structural features of the Valley and Ridge province northeast of central Virginia are large anticlines and synclines. Southwest of central Virginia the dominant large features are overthrust faults with which are associated high-angle faults in many places. The tectonic map (fig. 13) illustrates this difference in structural pattern. In the northern part of Appalachia erosion of the weaker rock units in the folded sequence has proceeded at a faster rate than that of the resistant units, and tilted resistant rock units have been left standing as mountain ridges. When one of these resistant units comes to the nose of a plunging fold, it doubles back on itself and thus produces the zigzag pattern of mountain ridges so prominent in central Pennsylvania where the fold belt is widest.

In northeastern Pennsylvania, four conspicuous synclines have been formed along the margins of the Appalachian Plateaus, within which coal-bearing rocks of Pennsylvanian age have been preserved from erosion. These four synclines or basins are the anthracite coal fields of Pennsylvania. Here, because of

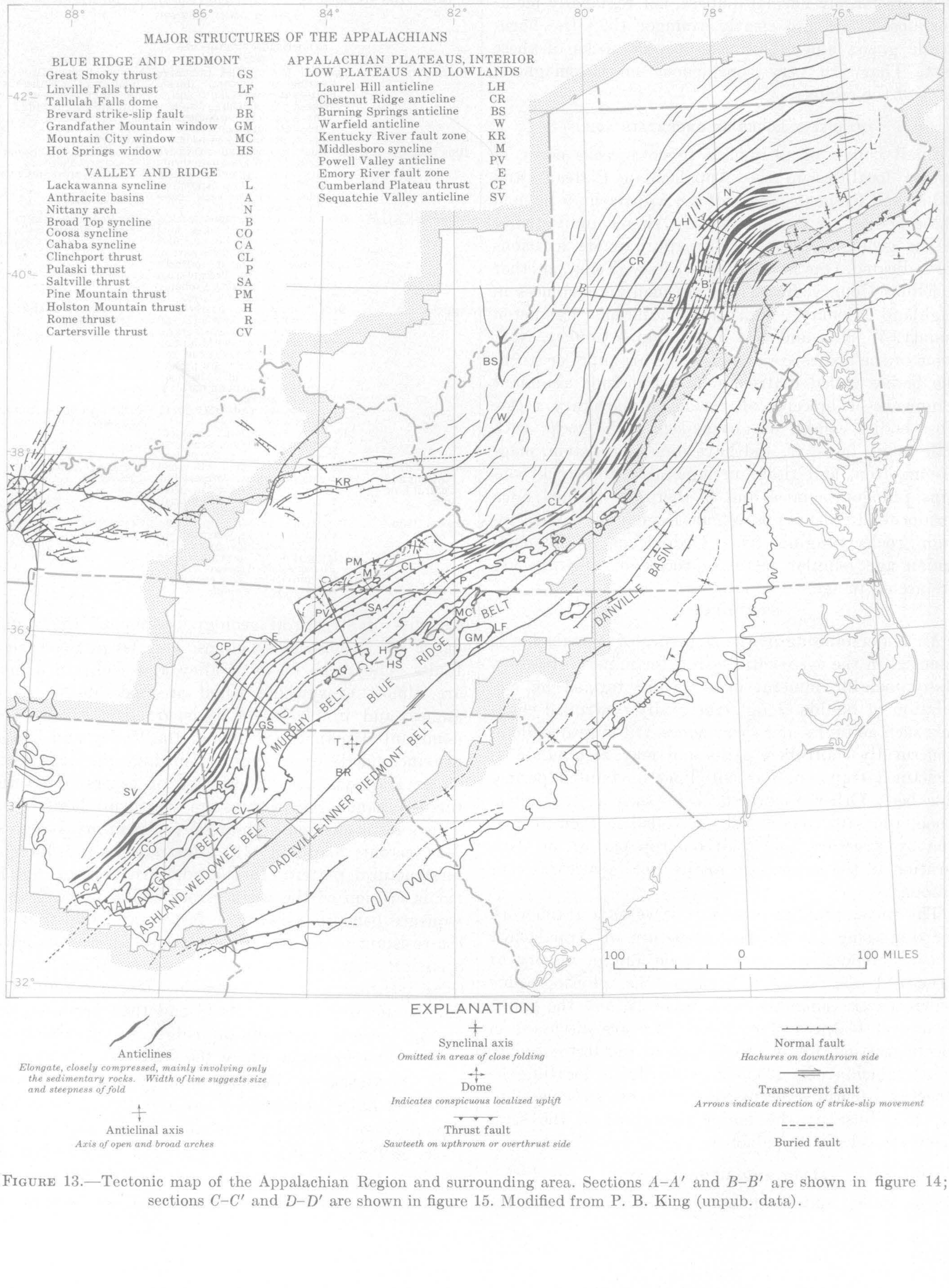


FIGURE 13.—Tectonic map of the Appalachian Region and surrounding area. Sections *A–A′* and *B–B′* are shown in figure 14; sections *C–C′* and *D–D′* are shown in figure 15. Modified from P. B. King (unpub. data).

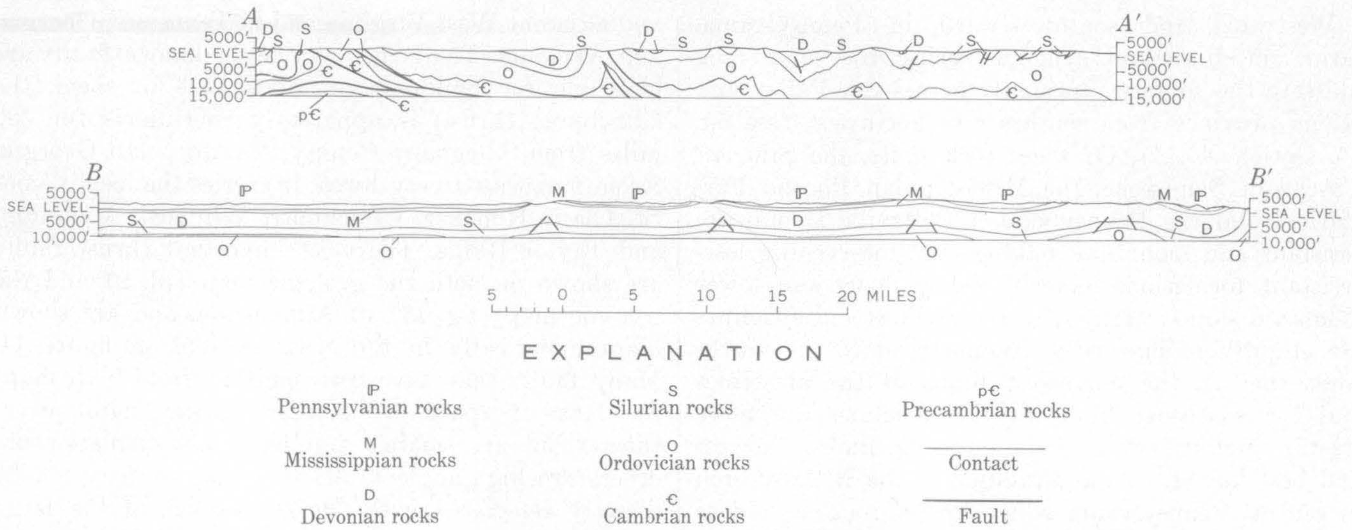


FIGURE 14.—Schematic cross sections across southern Pennsylvania; location of sections shown in figure 13. From Gray and others (1960).

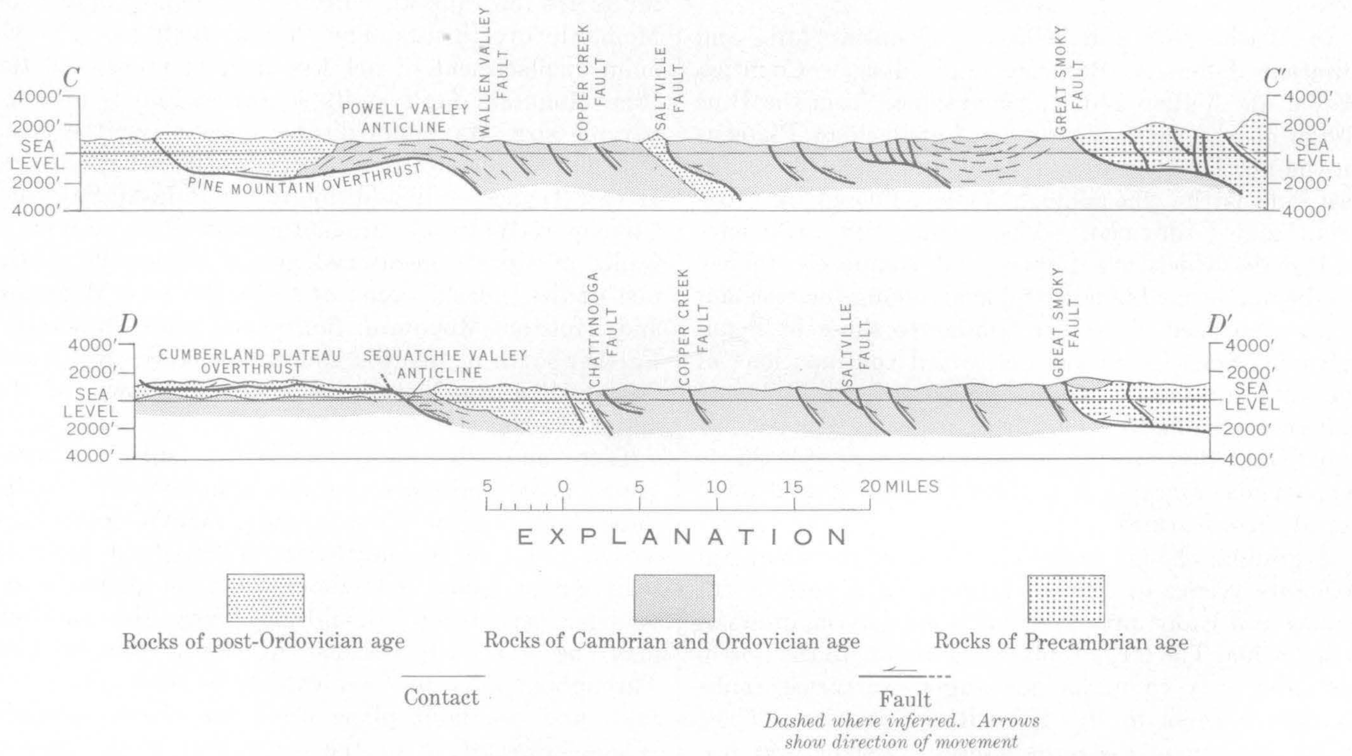


FIGURE 15.—Schematic cross sections across eastern Tennessee; location of sections shown in figure 13. Modified from Watkins (1964).

the depth of burial and the heat and pressures attendant on the downfolding, a large part of the volatile constituents of the coal have been driven off, and the coal has thus been raised to higher rank than that in the other coal fields of Appalachia. The northernmost basin is a simple syncline named the Lackawanna syncline; the three southern basins are more complexly folded. Recent work has shown the presence of low-angle thrust faults in the anthracite region in addition to the major folds. These were formed early in the deformation of the region and have been subsequently folded with the enclosing rocks. One of these, the Pottchunk fault, is large enough to show at the scale of the geologic map (pl. 2).

Westward and southwestward in Pennsylvania, large anticlines and synclines bring the same rock units to the surface repeatedly across the Valley and Ridge province from southeast to northwest (see fig. 14, section *A–A′*). Of these rock units, the Silurian Tuscarora Sandstone, the Mississippian Pocono Formation, and the Pennsylvanian Pottsville Group are resistant and mountain making; the intervening less-resistant formations underlie valley floors and lower mountain slopes. Many of the anticlines and synclines are slightly to markedly asymmetrical to the northwest, that is, the northwest limbs of the anticlines and the southeast limbs of the synclines are more steeply inclined than their opposite limbs. Largest and best known of the anticlines is the Nittany arch in central Pennsylvania which brings rocks as old as Late Cambrian to the surface. The best known of the synclines is the Broad Top syncline in the core of which the coal-bearing Pennsylvanian rocks are preserved.

In Washington and Allegany Counties, Md., and adjacent Jefferson, Berkeley, and Morgan Counties, W.Va., the Valley and Ridge province from the Blue Ridge on the southeast to the Appalachian Plateaus on the northwest is within Appalachia. On the southeast side is the Shenandoah Valley, floored by Cambrian and Ordovician rocks, principally carbonates and shale which are tightly and complexly folded. To the northwest the large folds involving the resistant units mentioned above are similar to those in Pennsylvania. Some folds are southward continuations of the anticlines and synclines of central Pennsylvania and are traceable for as much as 100 miles. The tectonic map (fig. 13), which includes areas peripheral to Appalachia, gives an indication of the size and number of these features.

A gradual change in the character of the dominant structure occurs in central Virginia in a part of the Valley and Ridge province that is outside the limits of Appalachia. The large folds of the region to the northeast give way to major low-angle overthrust faults similar to those in the Blue Ridge province. These faults are among the most interesting structural features of North America. Most are low-angle overthrusts inclined to the southeast, but some of those nearer the Blue Ridge front have been folded subsequent to their formation and may in places dip northwestward. Displacement on most of these faults is difficult to determine accurately but is commonly in terms of miles, the overriding blocks being consistently displaced northwestward. Overthrust faults of this type, parallel or subparallel to each other, predominate in the Valley and Ridge province in southern Virginia and adjacent West Virginia and in Tennessee, Georgia, and Alabama. The larger and better known faults are traceable for hundreds of miles. One of them, the Clinchport thrust, is apparently continuous for 380 miles from Alleghany County, Va., to north Georgia. From northeast to southwest it carries the local names St. Clair, Honaker, Clinchport, Whiteoak Mountain, and Taylor Ridge. The most important thrust faults are shown on both the geologic map (pl. 2) and the tectonic map (fig. 13) of Appalachia, and are shown diagrammatically in the cross sections in figure 14. Many faults that have been omitted from both maps for lack of space are similar to the major overthrusts but are smaller and have less displacement; others are high-angle faults that may or may not be directly associated with one or another of the large overthrusts.

In southwestern Virginia and adjacent parts of West Virginia, Kentucky, and Tennessee the largest faults are the Pulaski, Saltville, Clinchport, and Pine Mountain overthrusts. The Pulaski fault has a maximum displacement of not less than 11 miles, and the Pine Mountain fault at its southwest end is of comparable size. Maximum displacement along the Saltville and Clinchport overthrusts may be somewhat less. In east Tennessee, in addition to the Pulaski, Saltville, Clinchport-Whiteoak Mountain, and Pine Mountain faults previously mentioned, major thrusts lie southeast of the Pulaski fault; of these, the Iron Mountain and Holston Mountain faults are most important. Farther south in Georgia and Alabama, the Rome and Cartersville overthrusts are the best known of the major overthrusts.

These and other large overthrust faults not mentioned above have many features in common. Along these faults, great slices of the earth's crust have moved miles to the northwest. Throughout most of their extent, older beds above the fault plane lie on younger beds below, though in places this position may be reversed because of local complexities. Throughout most of their extent, the beds above the fault and the fault plane itself are almost parallel. Where crosscutting of the overriding blocks occurs, the fault plane transgresses from older beds to the southeast up into younger beds to the northwest, generally quite abruptly.

Fault zones in the Valley and Ridge most commonly occupy one of three zones of weak strata. The oldest zone is the relatively weak shale beds near the base of the Lower Cambrian Rome Formation where these beds overlie the thick, more competent Shady Dolomite. The next youngest zone lies at the base of the Upper Cambrian Maynardville Limestone where the carbonate rocks of the Maynardville and the overlying formations of the Knox Group form a thick competent sequence lying on weak shale of the Conasauga. The third and uppermost zone is within the weak black shale near the base of the Devonian Chattanooga Shale. Thus, faults involving the rocks exposed near the Blue Ridge-Smoky Mountain Front and in the central part of the Valley and Ridge province commonly show the Rome Formation overthrust onto younger Cambrian to Mississippian rocks. The Shady Dolomite and older formations lying below the Rome do not occur in the fault blocks in the central part of the Valley and Ridge province but are restricted to a narrow belt near the Blue Ridge where thrust faults cut Precambrian and Cambrian strata. To the northwest the carbonates of the Maynardville Limestone or the overlying Copper Ridge Dolomite are commonly the rocks directly above the fault plane. The Pine Mountain fault in Kentucky, Tennessee, and Virginia developed successively in each of the three zones of weak rocks in different parts of its extent.

The Pine Mountain fault (see figs. 13 and 15, section *C–C′*) which crops out in southeastern Kentucky and adjacent Tennessee some 15 miles west of the plateau front is cut off on both northeast and southwest by large tear faults almost at right angles to the regional trend of all other large structural features. Thus, a rectangular block known as the Pine Mountain (or Cumberland) overthrust block is outlined (pl. 2). This block is believed to have moved westward 2–11 miles, displacement being greatest in the southwest part of the block. The Pine Mountain fault clearly illustrates aspects of thrust faults formed elsewhere in Appalachia. In places, the fault plane may be warped or folded upward and erosion may have cut entirely through the overriding fault slice. Through the holes or windows thus formed, the overridden rocks may be seen. Windows of this sort are found in the Blue Ridge-Piedmont area. Windows may be simple, involving only one fault, or compound, involving more than one—and they may be only a few hundreds of feet in longest diameter, as are many small windows in the Pine Mountain Block in Lee County, Va., or 60 miles long, as is the Mountain City window in northeast Tennessee.

In early studies and mapping of the faulted rocks of the Valley and Ridge province it was presumed that the major overthrust faults continued downward into the underlying basement (Precambrian) rocks not far southeast of where they were seen at the surface. However, recent mapping and surface geological studies, coupled with geophysical studies (Watkins, 1964), are providing increasing evidence that the basement rocks are not involved in the overthrust faulting beneath most, if not all, of the Valley and Ridge province.

Although overthrust faults dominate the structure of the central and southern parts of the Valley and Ridge province, large folds are present in places. Mention should be made of the Greendale syncline in southwest Virginia and east Tennessee, and such important coal-bearing basins as the Lookout Mountain and Sand Mountain synclines of Tennessee-Georgia, and the Coosa and Cahaba synclines of Alabama.

APPALACHIAN PLATEAUS PROVINCE

The major structural features of the Appalachian Plateaus province include many broad anticlines and synclines in Pennsylvania and West Virginia, the Pine Mountain and Cumberland Plateau overthrusts in Kentucky and Tennessee, and the Sequatchie Valley anticline and Coalburg-Walden Ridge syncline in Tennessee and Alabama.

Early concepts of the structure of the Appalachian Plateaus as compared with that of the Valley and Ridge, were of an abrupt, almost complete fading out of strong deformation at the plateau front. Nearly flat-lying beds from surface to crystalline basement were believed present almost everywhere west of this front, deformed only at a few places by broad anticlines such as the Laurel Hill anticline in Pennsylvania or Sequatchie Valley anticline in Tennessee and Alabama. Surface and subsurface studies in many parts of the plateau in recent years have caused modification of this simple picture. True, the folding and faulting is in general less pervasive west of the front, but the front itself is a prominent boundary principally because of the resistant conglomerate and sandstone of the Pottsville that makes a high precipitous plateau margin, not because of an abrupt or complete change of structural pattern.

In West Virginia, many, somewhat smaller anticlines and synclines cause the surface rocks to dip moderately to steeply. Most of the folds in the northern part of the Appalachian Plateaus trend parallel or subparallel to the Plateau front and to the folds and faults of the Valley and Ridge province to the east. The Burning Springs anticline in west-central West Virginia, however, trends almost north-south, and other folds in southwestern West Virginia swing around more to the west as though to merge with the nearly due east trend of the Kentucky River fault zone (fig. 13).

Farther south, the Middlesboro syncline within the Cumberland overthrust block is a major coal basin in the tristate region of Virginia, Kentucky, and

Tennessee. In southern Tennessee and Alabama the Sequatchie Valley anticline upwarp brings rocks as old as Early Ordovician to the surface in the plateau area (fig. 15, section *D–D′*).

As the knowledge of the plateau has improved because of more detailed surface studies and more deep drilling for oil and gas, additional faults have been found. In Tennessee a zone of tear faults, known as the Emory River fault zone, merges with the Cumberland Plateau overthrust, forming a fault system approximately 10 miles long (fig. 15, section *D–D′*). In recent years, deep drilling for oil and gas within the plateau has demonstrated that one or more major faults duplicate and, in some instances, even overturn many hundreds of feet of beds. These major overthrusts have no surface expression and were previously unsuspected. Among the deep wells that have penetrated major concealed overthrust faults are those on the Powell Valley anticline in Lee County, Va., just east of the plateau front, on the Wills Creek anticline in Pendleton County, W.Va., and on the Burning Springs anticline in Wood County, W.Va. Gwinn (1964) has presented evidence that other prominent anticlines in the central part of the Appalachian Plateaus, which seem unfaulted at the surface, are faulted at depth (fig. 14, section *B–B′*) in the lower part of the Paleozoic sequence. Gwinn suggests the plateau rocks have been thrust several miles northwestward along fault planes within the Rome and Waynesboro Formations and the Salina Group. The basement rocks do not seem to be involved in this faulting.

High-angle faults of predominantly vertical displacement are present in parts of the Appalachian Plateaus. A swarm of faults with displacements as much as 200 feet is present in the Warrior coal field of Alabama. Farther north in eastern Kentucky, a group of normal faults called the Kentucky River fault zone lies mostly west of Appalachia, but extends into Appalachia almost to the West Virginia border. Displacement is as much as 600 feet, but in most places is considerably less. Within Appalachia this fault zone is partly in the plateau and partly in the Central Lowland that borders the plateau on the west.

INTERIOR LOW PLATEAUS AND CENTRAL LOWLAND PROVINCES

West of the Appalachian Plateaus, rocks of pre-Pennsylvanian age are at the surface and are almost everywhere undeformed and unfaulted except for the previously mentioned Kentucky River fault zone. Depths to Precambrian basement range from 3,000 to 5,000 feet in the Appalachia part of the Interior Plains. This depth is due in part to the thinning of parts of the stratigraphic sequence westward away from the source areas for most of the sediments, but also to the effect of the Cincinnati arch, a broad, elongate uplifted area west of Appalachia. The axis of the Cincinnati arch passes from north-central Ohio through the Cincinnati area and the Blue Grass Basin of Kentucky to the Nashville Basin of Tennessee. The latter two features are topographic basins produced by erosion on the Cincinnati arch. Eastward from the axis of the arch, the beds dip gently eastward to southeastward. This eastward inclination is manifest in the pre-Pennsylvanian sediments along the irregular western border of Appalachia and causes progressively older rock layers to be exposed at the surface westward from the west rim of the plateau.

INTENSELY DISTURBED LOCAL AREAS

In three places in Appalachia the layered rocks in small nearly circular areas have been intensely deformed. These are the Serpent Mound disturbed area in Adams County, Ohio, the Middlesboro Basin distured area in Bell County, Ky., and the Flynn Creek disturbed area in Jackson County, Tenn. The structural features of all three include (1) a nearly circular outline; (2) an outer uplifted rim marked by a series of faults that enclose the shattered area; (3) intense shattering, brecciation, and faulting inside the rim, with faulted blocks tilted in all directions; and (4) a core of rock at the center that is older than the exposed rocks in the rest of the disturbed area or in the surrounding undisturbed area. At Serpent Mound the disturbed area is 4 miles in diameter and the rocks involved are Upper Ordovician to Lower Mississippian. At Middlesboro the strongly disturbed area is 3½ miles in diameter and the rocks are of Early Pennsylvanian age (Breathitt and Lee Formations). At Flynn Creek the rocks involved range from Ordovician to Mississippian, and the disturbed area is about 2 miles in diameter. The Serpent Mound disturbed area was attributed by Bucher (1936) to subterranean explosions of volcanic gases. The Middlesboro Basin disturbed area has been attributed by Englund and Roen (1962) to impact of large meteorites. Both interpretations have been advanced for the Flynn Creek area. Because the three areas have so many structural characteristics in common, it seems likely that all three were formed in the same manner, and the meteorite-impact theory is favored. Locations are shown on the geologic map (pl. 2). Features of this type have been called "cryptovolcanic [hidden or covered + explosive] structures" by Bucher and "astroblemes" (star + wounds) by Dietz (1959, 1961).

BLUE RIDGE AND PIEDMONT PROVINCES

The structure of the Blue Ridge and Piedmont parts of Appalachia is exceedingly complex. Major folds and low-angle faults are prominent along the northwestern border of the Blue Ridge province, and smaller faults and folds in the sedimentary and metamorphic rocks are abundant everywhere in both the Blue Ridge and Piedmont. Little is known, however, of most of the large structural features. The information available decreases southeastward across the Blue Ridge and Piedmont from the belts of less metamorphosed rocks to those in which deformation, metamorphism, and plutonic activity have been most intense and have been repeated in several periods of earth history. In general, more is known about the Blue Ridge than the Piedmont, mainly because of the higher relief and better exposures in the Blue Ridge.

The northwestern border of the Blue Ridge throughout the Appalachian Region is marked by large folds and low-angle thrust faults along which Precambrian and Lower Cambrian rocks have been thrust northwestward over Paleozoic rocks of the Valley and Ridge province. The principal faults are the Great Smoky fault extending from Cocke County to Polk County, Tenn., and the Cartersville fault in northern Georgia. In part these faults cut the larger folds, but in many places the faults have been folded along with the displaced rocks, and erosion of the resulting anticlinal or domical uplifts has exposed the underlying rocks in windows such as those in Sevier and Blount Counties, Tenn. Movement along the Great Smoky fault is at least 10 miles and rocks of late Precambrian age are thrust over rocks as young as Middle Ordovician. The fault is younger than the regional metamorphism of the transported rocks.

Major overthrusts along the northwest border of the Blue Ridge in northern Georgia extend into Alabama where metamorphic rocks of the Talladega belt are commonly represented as thrust over the relatively unmetamorphosed rocks of the Valley and Ridge province. Maps of this area indicate extensive and folded low-angle faults and even recumbent folding, but the metamorphic and structural relations are little known because of poor exposures and lack of detailed study.

Low-angle faults of great displacement reach far back into the older granitic and metamorphic rocks of the Blue Ridge. These include the Greenbrier fault in Sevier County, Tenn., and Haywood County, N. C., which has an estimated displacement of 15 miles, and the Linville Falls fault around the Grandfather Mountain window in Avery, Watauga, and Caldwell Counties, N.C., which has at least 35 miles displacement. Similar faults involving lower Precambrian rocks are associated with the Hot Springs window in Madison County, N.C., and with the Mount Rogers Volcanic Group in Grayson County, Va. The ages of these basement faults are less well known. Many are younger than the Paleozoic metamorphism of the Precambrian rocks and probably are late Paleozoic in age. Some, like the Greenbrier fault, antedate the period of most intense Paleozoic metamorphism of the Upper Precambrian rocks and may be as old as middle Paleozoic.

A major shear zone or fault may be associated with the mafic Hillabee Chlorite Schist of Alabama, but the stratigraphic relations of the rocks on either side of the Hillabee belt are insufficiently known to indicate the significance of this fault.

Large anticlines, synclines, and domes are found throughout the Blue Ridge province and in parts of the Piedmont. One of the largest of these structural features exposes Precambrian and Lower Cambrian rocks beneath the Linville Falls fault in the Grandfather Mountain window (fig. 13). Smaller windows in others expose rocks beneath the Greenbrier fault in Swain County, N.C., and beneath other low-angle faults in Madison County and possibly Stokes County, N.C. Others are the Tallulah Falls dome in Rabun County, Ga., and a steep-sided dome in lower Precambrian paragneisses that is responsible for the ringlike shape of the ultramafic intrusives near Addie and Webster, Jackson County, N.C. Major synclines have preserved the rocks that contain the alaskite and pegmatite bodies in the vicinity of Spruce Pine, N.C., and also the rocks of the Murphy belt.

As mentioned previously, major structural features in the metamorphic rocks of the Piedmont are not well known, and information about them is generally limited to trends of foliation and minor folds. In the belts northwest of and adjacent to the Brevard fault zone, foliation and fold axes commonly trend northeast parallel to the regional structural trend, and steep to moderate southeasterly dips are dominant. Farther southeast, especially in the Dadeville-Inner Piedmont belt, low-dipping foliation and layering in the gneiss of many areas reveal domes and structural basins separated by zones of more sharply folded rocks with steeper dips and variable trends.

The Brevard fault zone was once thought to be a narrow syncline containing rocks younger than those on either side, but more recent interpretations have suggested that it represents a major strike-slip fault of continental proportions, analogous to the San Andreas fault of California, but much older. Distinctive, strongly sheared metamorphic rocks appear at various places along the zone in Georgia and North Carolina, but it seems most improbable that these rocks belong to a single synclinal belt with anything like the extent of the Brevard zone or that they can be correlated stratigraphically for long distances along it. The total movement along the Brevard zone may have been large, but the age and structure of the rocks on either side, especially in the Piedmont, are too little known to permit a definitive estimate of the amount of movement or its direction. The rocks of the Brevard zone are cut by undeformed diabase dikes, presumably of Triassic age; this relation indicates that no important movement has occured since this time, that is during the past 200 million years.

The development of fault blocks and basins along the eastern continental margin in Triassic time extended at least into the eastern part of Appalachia in Stokes and Yadkin Counties, N.C. These sedimentary basins have been partly produced by high-angle faulting. Presumably the faults extend into the crystalline rocks beyond the limits of the basins, and zones of sheared and silicified rocks found in this region may mark such faults.

ENGINEERING GEOLOGY

By William E. Davies, U.S. Geological Survey

INTRODUCTION

Engineering geology studies, which combine geological principles and engineering fundamentals, provide information and guidelines for planning and construction. They provide guidance in three principal areas of engineering concern: on the kinds of rocks and soils and general range of conditions in an area, for selecting the sites of structures and construction, and on specific construction problems and natural hazards. Subsurface data obtained from borings and geophysical methods have very important roles in these types of studies, although direct observation of surface features and outcrops are useful in many places. Quantitative data for natural material obtained through laboratory and field tests are also an important adjunct to other observations.

Engineering geology was first applied in Appalachia about a century and a half ago when American engineering was in its youth and when canal and railroad building were just beginning. Probably the first use was in the tunnel of the Schuylkill Canal Co. in 1820.

Prior to 1900, engineering geology was an integral part of civil and mining engineering. There were pioneering efforts at the beginning of the 20th century in the application of geology to large-scale engineering projects of the city of New York, and to problems of dam foundations and slides in the Panama Canal. With the advent of large Federal construction programs in the late 1920's and early 1930's, engineering geology developed an identity. In Appalachia, the Tennessee Valley Authority and the U.S. Army Corps of Engineers assembled staffs of geologists to cooperate with engineers in selecting damsites, investigating subsurface conditions, advising on foundation design, evaluating construction materials, and in solving geologic problems that arose during construction. Engineering geologists worked on the Pennsylvania Turnpike and aided in achieving record construction time. Since the early 1930's, they have played a more and more important role in highway construction, and most State highway departments in Appalachia now maintain staffs of engineering geologists.

Information about engineering geology in Appalachia is to be found in only a few publications. Most of the large amount of data resulting from site selection and route work remains in the minds of those who have worked in the field and in the files of construction companies and State and Federal agencies. TVA work has been summarized (Tennessee Valley Authority, 1949), and technical papers have been published on some aspects of other projects, but no comprehensive and systematic publications are available for general use.

ENGINEERING ASPECTS OF APPALACHIAN ROCKS AND SOILS

The seven major physiographic provinces of Appalachia reflect differences in rock types and topography (table 20; fig. 6). Because of these differences, each province has distinctive engineering problems (table 27). The rocks vary greatly from region to region and include practically all major types. Igneous and metamorphic rocks prevalent in the Piedmont and the Blue Ridge provinces contrast sharply in engineering aspects with the sedimentary rocks in the mountains and plateaus to the west. In turn, there are marked differences between the folded sedimentary rocks of the Valley and Ridge province and the flat-lying sedimentary rocks of the Appalachian Plateaus province.

PIEDMONT AND BLUE RIDGE PROVINCES

The Piedmont province is underlain by crystalline rocks, principally granitic intrusions and metamorphic rocks such as schist, gneiss, and slate. Chemical weathering is extensive, and decayed minerals and weathered rock occurs at depths of as much as 120 feet (fig. 16). True soils, lacking residual rock structures, are generally 2–6 feet thick; below this is saprolite, a loose rotten rock commonly 50 feet or

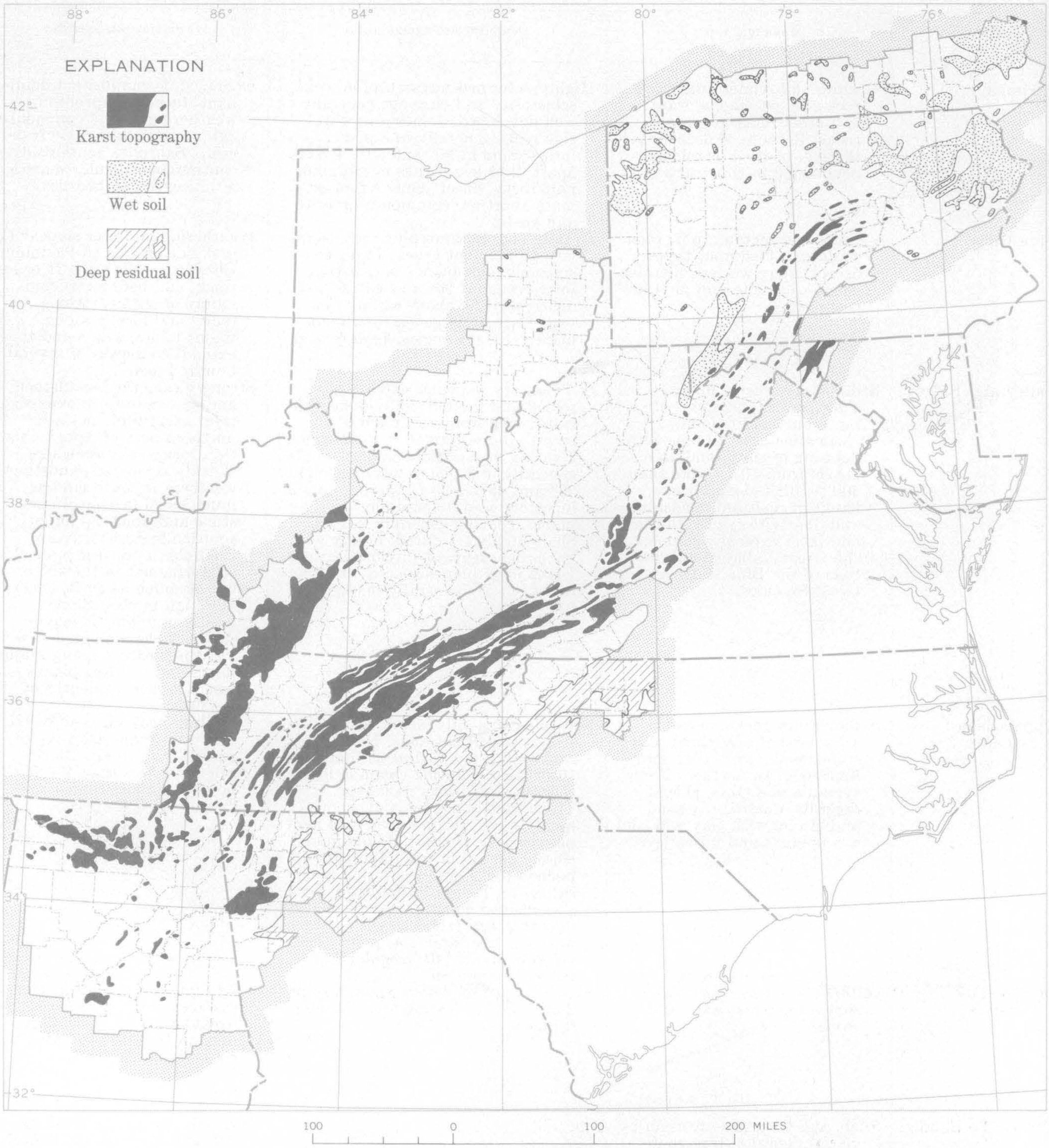


FIGURE 16.—Areas of karst topography, wet soils, and cover by deep soil in the Appalachian Region.

TABLE 27.—*Engineering geology of the physiographic*

[Data shown are the normal range characteristic of dominant rock types, but because of the great extent of Appalachia, variations in excess of the ranges shown

Province	Major rock types	Dominant structural features	Weathering characteristics
Piedmont	Granite and related intrusive rocks; schist, gneiss, slate, and other metamorphic rocks. Because of deep weathering, bedrock is seldom penetrated in construction.	Highly deformed metamorphic rocks; schistosity and cleavage generally well developed. Jointing in intrusive rocks generally in 3 planes intersecting at 90° and 45°, 4–8 ft apart; 2 or less planes in metamorphic rocks. Sheet joints a foot or more apart are common in granite and gneiss.	Chemical decomposition dominant, forming saprolite; weathering effects commonly extend to depths of 50 ft or more. Saprolite contains discontinuous irregular masses of unweathered bedrock.
Blue Ridge	Granite and metamorphic rock similar to Piedmont types, except along western margins where quartzite and phyllite occur.	Granite and metamorphic rocks similar to Piedmont types. Three conspicuous joint planes in quartzite intersecting at 90° and 45°, 6–20 ft apart; phyllite shows strong cleavage fracturing, generally 2 joint planes at right angles, 4–10 ft apart.	Weathering on lower slopes of east side similar to Piedmont. Elsewhere soils are 4 ft or less thick, and bedrock is commonly at surface. Along faults and locally along major joints, weathered zone extends to depths of several hundred feet.
Valley and Ridge	Sedimentary rocks, mainly shale, sandstone, quartzite, limestone, and dolomite. Coalescing alluvial fans with deposits of clay, sand and gravel from 10 to more than 300 ft thick along lower flanks of resistant sandstone and quartzite ridges; thickest and most extensive fans in the Great Valley along the base of the Blue Ridge and Great Smokies.	Sedimentary sequence extensively folded and faulted; individual rock beds range from a fraction of an inch to more than 10 ft in thickness. Jointing in sandstone and quartzite generally in 3 planes intersecting at 90° and 45°, 2–20 ft apart; joints in limestone and dolomite in 3–5 planes, spacing generally 2–10 ft. Shale highly fractured, locally with low-order cleavage (mylonitization), 1 or 2 joint planes spaced 10–30 ft occur but are generally masked by fractures.	Strongly cemented sandstone and quartzite form extensive talus and rubble fields in northern part of Appalachia, thin rocky soils elsewhere. Weakly cemented sandstone weathers to loose sand as much as 40 ft deep. Limestone and dolomite have solution features, caverns, sinkholes, and rock pinnacles; soils irregular in thickness, but as much as 30 ft, generally high in clay. Shale weathers to plastic clayey soil with shale chips, less than 2 ft thick except along major joints and bedding planes where it reaches depths of 10–30 ft.
Appalachian Plateaus.	Sedimentary rocks, repeated sequences of sandstone, siltstone, shale, clay, coal, and limestone. In northern Pennsylvania and Ohio, glacial deposits, dominantly sand and gravel with clay and silt, cap uplands and fill valleys.	Flat-lying to gently west dipping strata; few broad folds. Individual rock beds a few inches to more than 10 ft thick. Jointing common but spacing varies with rock type. Thick sandstone and shale commonly have 2 or more vertical joint planes, 5–10 ft apart. Joints more closely spaced in weak and thin-bedded rocks, and fracturing is extensive. Indurated clay beds have slickensided curved shear planes and flow structures; sheeting is common in shale. Limestone has poorly developed joints, but irregular fractures are common.	Soils thin, bedrock near surface. Clay and shale slake rapidly on exposure to air. Glacial soils from less than 100 ft on upland to more than 100 ft in valleys.
Interior Low Plateaus.	Sedimentary rocks, primarily shale, limestone, and sandstone.	Flat-lying strata; joints commonly in 2 or more vertical planes, 5 or more ft apart.	Soils thin, bedrock at or near surface; soils over limestone irregular, as much as 30 ft deep in troughs separated by rock pinnacles.
Central Lowland	Shale and limestone overlain by glacial deposits; terrace deposits along major streams.	do	Bedrock covered by sand, gravel, and other glacial deposits as much as 100 ft thick.
Coastal Plain	Thin unconsolidated deposits of silt, sand, and gravel capping rocks similar to those in adjacent parts of the Piedmont, Valley and Ridge, and Plateaus provinces.	Flat-lying unconsolidated strata unerlain by rocks similar to those in adjacent provinces.	Soils thin; overlie unconsolidated sediments.

provinces of the Appalachian Region

may occur at any specific point. Data are shown as a guide and should not be accepted as applicable to specific engineering geology problems nor as design criteria]

Slope stability (vertical on horizontal)	Bearing strength (tons per square foot)	Drilling rate (feet per hour air-hammer, 6-in. bit)	Blasting yield (pounds 40 percent dynamite per cubic yard)	Drainage
Cut faces stand 1 on 1 but require protection against deep rilling and gullying; 1 on 2 or less where mica is abundant in saprolite.	Saprolite 2–8	Saprolite is excavated without drilling; bedrock like that in Blue Ridge.	Blasting not needed in saprolite; bedrock like that in Blue Ridge.	High water table commonly causes problems in shallow excavations and reduces slope stability.
Areas of deep soils similar to Piedmont. In bedrock cuts, faces stand at 2 on 1 to vertical.	25 or more except on fractured rock on steep slopes; saprolite on lower east flank 2–8.	25–63 in granite and metamorphic rock except greenstone with high epidote content where rate is 25–30; ¼–4 in quartzite.	1.5–2.5 pounds in open face; 4.5–5.5 in tunnels in granite and metamorphic rocks; 1.6–5.5 pounds in open face and 1.6–5.5 pounds in tunnels in quartzite.	Rocks generally tight and dry below weathered zone.
Unweathered sandstone, quartzite, limestone, and dolomite stand in deep cut faces 3 on 1 to vertical. Some interbedded shale reduces stability to 1 on 1 and lower. Clay-silt seams in limestone stand at 1 on 1 or less. Cut faces in fresh shale stable at 2 on 1 to vertical. In cuts less than 30 ft deep, 1 on 1 in deeper cuts. Cuts in alluvial fans stable at 1 on 3 to 1 on 1, depending on water content.	Sandstone and quartzite as much as 50 tons; limestone and dolomite 25–40, greatly reduced in cavernous areas; shale 8–25, greatly reduced on steep slopes where shale is not confined; alluvial fans 4–8, except in water-saturated zones.	Quartzite, ¼–4; sandstone, limestone, and dolomite 30–60; shale, 80–100.	1.6–5.5 pounds in open face and in tunnels in quartzite and strongly cemented sandstone; 0.8–1.1 pounds on open face and 2.3–2.6 pounds in tunnels in sandstone, limestone, and dolomite; 0.3–0.4 pound in open face and 2.0–2.5 pounds in tunnels.	Quartzite dry at shallow depths, except in fault zones where saturation may extend to more than 1,000 ft; shale generally dry 20 ft below surface; limestone and dolomite contain subterranean streams and lakes to depths of several hundred feet below surface; high water table in alluvial fans.
Varies with rock type from vertical in sandstone to 1 on 5 or less in clay. Overall slope stability involving full sequence 1 on 1 to 4 on 1. Slumps and slides common. Cut faces stable at 1 on 1 or less in glacial deposits, slumping common.	Massive sandstone 25 or more, shale 8, other rock units 4 or less. Well-drained glacial deposits 4–8, poorly drained deposits less than 4.	60–100, depending on amount of sandstone.	0.3–0.4 pound in open face, 2–2.5 pounds in tunnels.	Locally saturated where subsurface drainage impeded by clay seams. Water table high in glacial deposits; bogs extensive.
Sandstone and limestone cuts stable at 3 on 1 to vertical; clay seams in limestone stable at 1 on 1 or less. Shale stable at 1 on 1 or less.	Sandstone and limestone 25–40, greatly reduced in cavernous areas; shale 8–25.	Sandstone and limestone 30–60; shale 80–100.	Sandstone and limestone 0.3–0.4 pound in open faces, 2.0–2.5 pounds in tunnels.	Rocks generally dry and tight below weathered zone except in limestone where subterranean streams and lakes occur to depths of more than 100 ft.
Bedrock similar to that in Interior Low Plateaus. Glacial and terrace deposits stable at 1 on 2 or less.	Similar to that in Interior Low Plateaus. Glacial and terrace deposits 4–8 where well drained.	do	do	High water table in glacial deposits and underlying bedrock.
------	------	------	------	High water table in unconsolidated sediments and underlying bedrock.

more thick that retains vestiges of the original rock structure. Narrow zones and bands of more durable rocks form intricate patterns of unweathered bedrock within the deeply weathered rocks. Most of the residual material is sandy and micaceous.

Excavation and grading in saprolite are easy with machinery, and only isolated residual rock masses require blasting. Slopes are stable only at low angles, and deep rilling and gullying occur where the surface is not protected by vegetation. The bearing strength of saprolite is low, and the abundant mica in the soils makes mechanical compaction of fills and subgrade difficult.

The Blue Ridge province contains some rocks that have engineering characteristics similar to those in the Piedmont as well as some that are similar to those in the Valley and Ridge province. Along the lower flanks on the east side of the Blue Ridge, deep saprolitic soils are similar to those in the Piedmont. On the higher parts of the Blue Ridge, bedrock is at or near the surface, and all construction involves blasting and difficult excavation. The rocks throughout most of the Blue Ridge are granite, gneiss, greenstone, and related metamorphic rocks which form high, stable cut slopes and strong foundations. Weak rocks, primarily phyllite, are interbedded with the competent rocks and stable only on low-cut faces. Where confined, they have high bearing strength.

On the western flank of the Blue Ridge, quartzite and siliceous phyllite are extensive. These rocks are difficult to excavate and require extensive blasting, but they are stable in steep cut faces and have high bearing strength.

VALLEY AND RIDGE PROVINCE

The Valley and Ridge province is underlain by folded and faulted sedimentary rocks, mainly sandstone and quartzite, limestone and dolomite, and shale. These various rock types have distinctly different engineering properties, and where they occur together in steeply dipping sequences, they give rise to complex engineering problems.

Strongly cemented sandstone and quartzite are widespread in the Valley and Ridge province; because of their strength, hardness, and durability, they are important to engineering. They occur in the lower parts of the Cambrian, Silurian, Mississippian, and Pennsylvanian systems. They are difficult to excavate, but steep cut slopes are stable and foundations are strong. Soil cover is generally only a few feet thick, and most of the mountain ridges formed by these rocks have extensive talus and rubble fields. The talus is unstable, especially where it is underlain by deeply weathered shale and limestone and may slide when cut into by excavations (Cleaves, 1961, p. 36–54). Such a slide recently occurred on Interstate Highway 81 along Tinker Mountain near Roanoke, Va. Rubble fields are most extensive in central and eastern Pennsylvania (fig. 17) and are common as far south as Clifton Forge, Va. Only a few small areas occur still farther south.

FIGURE 17.—Rubble field, Doubling Gap, Perry County, Pa.

The weakly cemented sandstone common in many formations but most prevalent in the lower parts of the Cambrian and Silurian and in the Upper Devonian and Mississippian is similar in many respects to the quartzite and hard sandstone. However, it is more deeply weathered and, in the weathered zone, the bearing strength is low.

The Valley and Ridge province includes extensive areas of limestone and dolomite. Where solution weathering is slight, these rocks have high bearing strength, are stable on steep cut slopes (fig. 18), and can be excavated with moderate difficulty. However, much of the limestone has been affected by extensive solution activity, and caverns (fig. 19), open fissures,

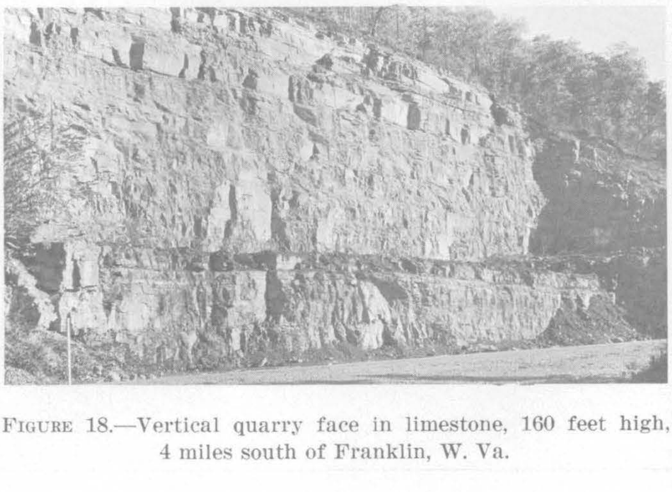


FIGURE 18.—Vertical quarry face in limestone, 160 feet high, 4 miles south of Franklin, W. Va.

and earth-filled sinkholes greatly weaken bearing strength and slope stability. The irregular bedrock-soil interface in the form of pinnacles and ridges (fig. 20) separated by deep narrow troughs gives rise to difficulties in design and in excavation and grading. Slaking of thin-bedded limestone and limy shale is commonly rapid, surface effects appearing within a few hours to several days after excavation. The slaking gives rise to problems in obtaining good bonds between the bedrock and manmade structures and often results in slippage and other foundation failures.

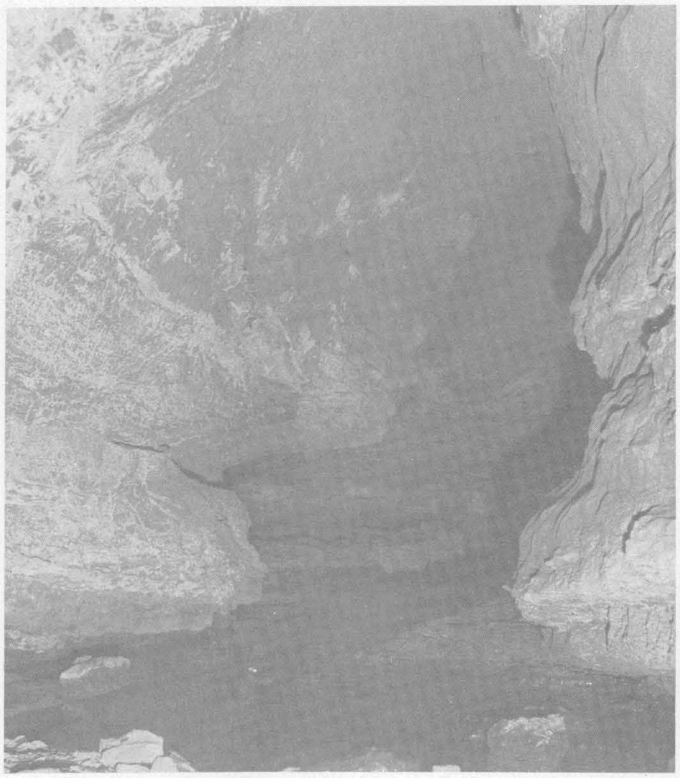


FIGURE 19.—Solution opening, 4–5 feet wide and 10 feet high, in Martens Cave, Lobelia, W. Va.

FIGURE 20.—Limestone pinnacles beneath soil cover, Bluegrass, Highland County, Va.

Ground water in limestone gives rise to engineering problems. Excavations often intercept underground streams and lakes with large quantities of water, and occasionally rapid flooding results. Most of the intersected subterranean drainageways require special engineering effort to prevent postconstruction flooding, slumping of cuts, and collapse of foundations.

Shale and shaly sandstone are widely distributed throughout most of the Valley and Ridge province. In general, shale underlies the valleys or is on rounded spurs and subordinate ridges flanking higher mountains. The soil and weathered rock over the shale are generally thin, a few feet at most, and most excavations are in bedrock. Although the shale is generally considered as weak rock from an engineering viewpoint, it shows a great range in strength and stability.

Cuts are generally stable only at low angles, but in most cuts less than 30 feet deep the shale stands in very steep faces. Bearing strength is lower than most other rocks, and where not confined, shale is subject to surface creep.

Much of the shale in the Valley and Ridge province is highly fractured and can be easily excavated (fig. 21). Spalling and slaking are generally rapid, and give rise to instability in foundations and cut faces. Weathered shale and soil derived from shale are plastic, and in valleys where the water table is high, road pavement pumping is a problem.

FIGURE 21.—Vertical transverse joints cutting shale at Poverty, Highland County, Va.

APPALACHIAN PLATEAUS PROVINCE

From the standpoint of engineering geology, the sedimentary rocks throughout the Appalachian Plateaus province can be considered as a unit with the exception of a narrow belt of thick karst limestone along the western border and limestone and hard sandstone along the eastern border. The rocks forming this unit comprise repetitious sequences of nearly flatlying siltstone, sandstone, shale, clay, coal, and limestone, each sequence 60–100 feet thick (fig. 22). Because of the great variation in physical and chemical properties of these rocks and their cyclical repetition, they form a separate entity in engineering geology (Philbrick, 1960, p. 49). Their engineering behavior reflects not so much that of an individual member of a sequence, but the integrated behavior of all members.

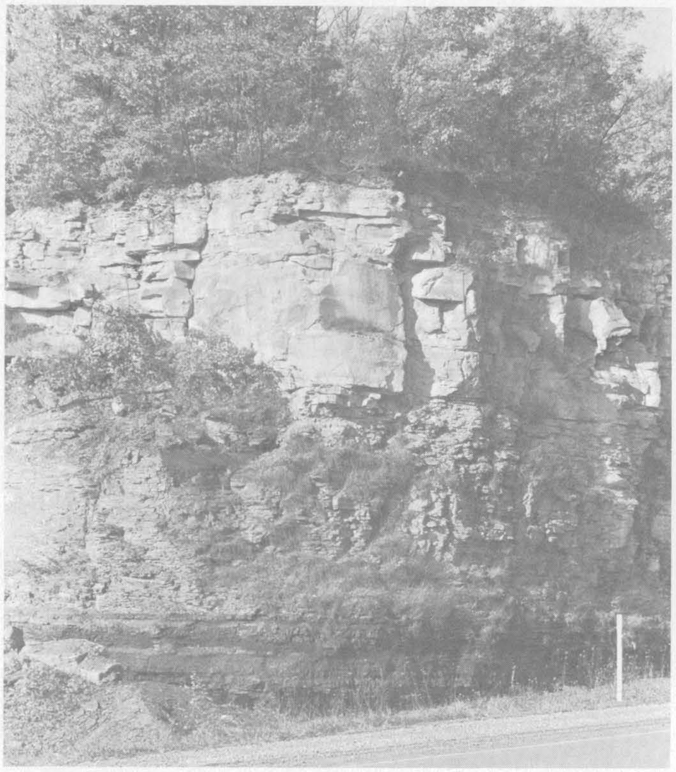


FIGURE 22.—Sequence of coal (at base), clay, shale, limestone and massive sandstone (at top), Harding W. Va.

Most grading, excavation, and other engineering work are in bedrock because soil in the plateau area is thin. Cuts in the rock sequences penetrate successive beds with great differences in slope stability and weathering characteristics, and the overall stability is a balance between weak and competent beds. In addition, open joints, permeability of rock units, and clay seams that act as barriers to movement of water greatly reduce the stability of the rocks and cause landslides and rockfalls.

Typical of rockfalls and landslides are those in the Pittsburgh, Pa., area, which have been costly in lives and money. A short distance northwest of that city, on State Route 93, is a deep cut through sandstone and shale. Formerly the cut was contained between a railroad and a high tree-covered hill and had very steep slopes, steeper than were safe for such rocks. On December 22, 1942, about 150 cubic yards of rocks plunged into the cut and killed 21 persons in a bus. In the previous year, failure of a rock slope moved 100,000 cubic yards into a railroad cut at nearby Brilliant, Pa.; remedial excavation costing $100,000 was required. Inasmuch as 97 such slides occurred in the Pittsburgh area from 1920 to 1954 (Ackenheil, 1954) and 542 occurred in recent years along West Virginia highways (Cavendish, 1953), safe excavations in Appalachia obviously require more than a rule-of-thumb approach. Even in western Pennsylvania, West Virginia, and eastern Ohio, where the plateau is low and rolling, slumps are common where clay and shale beds are abundant.

Bearing strength in the rock sequence varies greatly, being low in coal, clay, and shale, and high in sandstone. Because of the interbedding of weak rocks, footings for foundations often require special design to carry the weight of structures on competent rock. The fact that the clay and shale also slake rapidly gives rise to additional foundation problems (Philbrick, 1960, p. 51).

Glacial deposits are a significant factor in engineering geology in the Appalachian Plateaus of northern Pennsylvania and adjacent parts of New York and Ohio (see glacial boundaries on pl. 2). The material varies in composition from clay through coarse gravel. Most of the deposits on uplands are less than 100 feet thick, but deposits in valleys may be 100 feet thick or more. The glacial material has a shallow water table and much of it is saturated. Impervious clay impedes drainage both vertically and laterally and causes cut faces to be unstable and foundations weak.

In Ohio, many large tributary valleys south of the glaciated area contain extensive thick deposits of clay, sand, and gravel washed from the former glaciers. These deposits, which lie on irregular bedrock surfaces, contain large quantities of water and are very unstable. Even shallow cuts with low slopes on their faces slump, and steeper cuts, natural or manmade, commonly result in landslides (Marshall, 1953).

The Interior Low Plateaus province in Appalachia contains flat-lying shale, limestone, and sandstone forming low plateau uplands and isolated knobs and hills. Cherty limestone caps the hills and upland in Tennessee and southern Kentucky. Slumping and sliding are not common except along the eastern edge where relief is higher and interbedded thin shale, limestone, and sandstone are present. Most construction involves bedrock, and excavation requires blasting and heavy machinery.

Caverns and subterranean drainage are problems along much of the eastern part of the Interior Low Plateaus where thick limestone underlies the upland (fig. 16).

The Central Lowland consists mainly of flat-lying shale and limestone covered by extensive areas of wet glacial soils. Cuts in the glacial soils are generally stable only on low slopes, and slumps and slides are common. Terrace deposits along major tributaries of the Ohio River contain thick but unstable gravel deposits that commonly slide or slump when disturbed by construction. Bearing strength of glacial soil is low. Although relief in the Central Lowland is generally less than 150 feet, talus slopes, primarily in limestone areas, are steep and unstable. In the vicinity of Cincinnati, Ohio, several slides caused by construction in talus have resulted in considerable damage to roads and railways. Caves and subterranean drainage, with accompanying engineering problems, are present in the Central Lowland in Kentucky. Most construction is in deep soil, and excavation is easy with machinery. Only in the limestone area is extensive blasting required to remove pinnacles of bedrock.

SPECIAL FEATURES INFLUENCING ENGINEERING GEOLOGY

To a great extent the abnormal rather than normal conditions play a dominant role in engineering geology. Weak soils, landslides, caverns and other unique features, even though of limited extent, generally exert a controlling influence in selecting sites and in construction of various structures. The geologic features involving abnormal conditions fall into two groups, those that are natural and those that are manmade.

NATURAL FEATURES

In the large area of Appalachia, landscape features in combination with various rock conditions give rise to many features that are of importance in engineering geology. Such features as caves and karst topography in limestone are confined to one type of rock. Others, such as faults and landslides, involve many different types of rocks.

FAULTS

In the eastern part of Appalachia, especially in the Blue Ridge and southern part of the Valley and Ridge province, the rocks are cut by many faults (pl. 2). Most of the faults are small, but many prominent large low-angle thrust faults persist for great distances, some being more than 100 miles long. The fault planes range from nearly horizontal to nearly vertical; angles 60°–80° with the horizontal are common. In the Appalachian Plateaus most faults are vertical. These faults are inactive at present, but fracture and gouge zones along them, which contain weak and deeply weathered rock, cause many problems in foundations and tunnels.

Quartzite and hard sandstone that have been involved in faulting are closely fractured and in some places pulverized to loose sand. Shale is highly fractured and sheared into small plates. Extreme shearing, causing zones of highly altered and pulverized rock material, occurs along large faults in shale. These zones, as much as 10 feet thick, generally are weak and cause failures in cut slopes and tunnel excavations. In some limestone and dolomite the shattered rock adjacent to faults has been recemented to form a rock equal in strength to solid limestone.

Weathering along faults, in all types of rocks, generally extends to 300 feet, and to as much as 1,000 feet in some places.

Local obscure faults cause more engineering problems in Appalachia than the large obvious ones because their existence becomes known only when construction works find them, too late for adequate advance planning to counter their effects.

KARST

About 10,400 square miles of limestone and dolomite terrain within Appalachia has solution features developed to a degree that they seriously affect engineering. The landscape, known as karst (fig. 16), consists of sinkholes, open shafts, and blind valleys terminating abruptly at swallow points of streams, and is commonly underlain by caves (fig. 10). Karst features are not developed to the same degree on all limestone and dolomite. Most areas show little or no large-scale surface features associated with solution; other areas are dominated by solution features.

Caverns extend mainly from a few feet to about 400 feet below the surface and are a fraction of a foot to as much as 300 feet wide and high. Distinct cavern passages may be less than 100 feet long, yet many caves are formed of interconnected passages measured in miles, and some have passages at several distinct levels. Throughout a cave system, and extending great distances beyond, are small solution cavities and channelways. Foundations over large cavern openings are subject to settling and possible collapse, and under particular conditions, where large heavy structures are to be placed over caverns, foundation treatment is necessary. The location and delineation of the caverns may require extensive drilling, tunneling, and soil stripping. To prevent leakage, solution openings in foundations and abutments of dams in limestone and dolomite areas generally require grouting or other cement filling.

Natural earth fillings, ranging from clay through gravel, partly block or completely fill many solution openings. Where the fill is well packed and tight, the loss in strength in foundation is greatly reduced. However, if much cavern fill can be flushed out under moderate to high heads of water, replacement by concrete may be necessary to prevent leakage after reservoirs are filled.

Some dams in Appalachia built before those of the Tennessee Valley Authority had serious leakage through foundations constructed on limestone and dolomite. Hales Bar Dam near Chattanooga, Tenn., built 1905–13 and later acquired by TVA, was so seriously affected by leakage through solution channels beneath the dam that its use in power production was restricted. Several attempts to reduce the leakage by blocking the solution channels were only partly successful.

Until the 1930's, defects in foundations of dams in limestone and dolomite resulted from a lack of knowledge of solution features more than from poor engineering. Since then, data based on practical experience and observation concerning the nature, origin, and extent of solution in limestone and other soluble rocks have become available and, with proper geological investigations, costly engineering failures can now be avoided.

Most drainage in karst areas is by underground streams (fig. 19). The subterranean drainage ranges from seeps along cracks to large rivers in cavern passages. Lakes containing as much as several hundred million gallons of water also occur in caverns. Tapping underground lakes and rivers in excavations and tunnels can be disastrous unless steps are taken to shield or drain off the water in advance. At many places, the flow of water from these lakes and rivers is so great that it cannot be controlled economically, and open excavations are permanently flooded. Subterranean streams, like surface streams, vary greatly in discharge, reflecting the quantity of surface drainage diverted to them; shields, dams, and other engineering works used to block the subterranean streams must cope with such fluctuations. Where road and railroad cuts penetrate caves with streams, special drainage structures are generally required to prevent subterranean impoundment and subsequent flooding. Water-saturated faults and joints in limestone and dolomite give rise to problems similar to those of caves.

Nonhazardous but economically important effects often occur when engineering operations alter subterranean streams that furnish water to municipalities and farms. Underground streams commonly ignore normal surface drainage divides and follow complicated courses many miles in length, controlled by gravity and hydraulic head (Zotter, 1963–65); an apparent minor local diversion or siltation may ultimately affect areas quite remote from the diversion or siltation.

Karst terrain may have only a few scattered sinkholes or may be areas such as in Greenbrier County, W. Va., where the surface is a mass of coalescing depressions. Most sinkholes contain thick soils that have been washed into them. Water percolates through this soil to enter underground channels, and under natural conditions a balance is maintained between soil carried to subterranean streams and that brought into the sinkhole. Naturally, or when disturbed during construction, the soil may subside into a cavern lying below the sinkhole. Sinkholes may become plugged and filled with ponds. Subsidence can be disastrous as it was at Staunton, Va., in 1910, when six houses were damaged or swallowed by caving of deep soil in a karst area (Kindle, 1911). A similar collapse occurred in Birmingham, Ala., in 1964 (Robert Laurence, written commun., 1965).

Acquisition of property for engineering purposes in karst areas often involves unanticipated costs. Landowners value caves as potential tourist attractions or as habitats of unique animal life. Others consider karst springs as highly valuable sources of water. To arrive at equitable purchase prices, extensive subterranean exploration must be anticipated, and extensive measurements made of water wells and seasonal flows of springs prior to purchase of properties.

BOGS AND WET SOILS

Bogs, some with deep standing water, are common in the area of former glaciation in northern Pennsylvania and southern New York, and are especially numerous in the Poconos of eastern Pennsylvania. The bogs cover a few acres to more than 20 square miles and contain peat, clay, glacial rock flour, and marl deposits as much as 60 feet deep. Most of the bog deposits are saturated a few feet below the surface and are incapable of supporting any loads placed upon them. Bogs without standing water will support low cut-and-fill slopes if thoroughly drained and aerated. Slump, however, is common after rainfall, as are seepage and high-volume changes. Construction across most bogs requires excavation of saturated organic material and clay and backfilling to obtain suitable foundations. Piling driven to rock or firm soils also is used to provide foundations.

A dozen or so bogs occur along the eastern part of the plateau area south of the glaciated area (Rigg and Strausbaugh, 1949, p. 129–137). In West Virginia and Maryland these bogs occupy depressions in the bedrock and consist of clay at the base overlain by marl and peat 11 feet or more thick. The surface is wet, generally flat, and covered with sphagnum, lichens, and sedges. In some of the bogs, trees cover part or all of the area. Because of their small size, the bogs can be easily avoided in construction.

Along the eastern part of the plateau area from central Pennsylvania to central West Virginia, some of the upland and valley soils are poorly drained; they form extensive areas of wet soils or glades (fig. 16). Many of the wet areas cover several thousand acres and consist of meadow and open forest. The soil is plastic silty clay with beds of fine sand and is 6 feet to more than 20 feet deep. Below a depth of 30 inches the soil is saturated. Except for swales on the upland which occasionally contain ponds, the glades are free of standing water. The wet soil is unstable on gentle slopes and slumps readily in shallow cuts.

GULLY EROSION

Gully erosion is a severe problem in the saprolites of the Piedmont and in parts of the Appalachian Plateaus. Dripping or seeping water from buildings lacking rain gutters, road and railway cuts, and ditches commonly start gully erosion (Ireland, Sharpe, and Eargle, 1939, p. 37–79). In the early stages, erosion is by downward scour followed by headward cutting and enlargement. Where downward scour dominates, shallow channels and rills develop in the resistant clay in the upper 2–6 feet of soil and decayed rock. When gullies have cut to the base of the clay, potholes form by cutting into the weaker decayed rock below, and narrow deep gullies may form in the underlying saprolite. Waterfalls and seep caves form at gully heads, and downstream undercutting and deep trenching cause spalling, flowing, slumping, and caving. Some of the slump and cave blocks contain as much as 2,000 cubic yards of material. The debris from such mass movement clogs the gullies for much of the year, but it is removed during seasons of heavy rainfall. Sand may accumulate in the lower reaches of gullies and form large fans at their mouths.

Most gullies reach a point where plant growth, first on side slopes within the gully and then on the bottom, retards erosion. If the healing process is not interrupted by drought, excessive rainfall, or human interference, stabilization is reestablished and gullying is arrested.

Rate of gully development varies greatly depending on land use, rainfall, and topography. During periods of heavy rainfall, gullies have been extended headward as much as 15 feet in 2 days and increased in width as much as 12 feet. However, such erosion rates are exceptional, and headward cutting is generally not more than 25 feet per year. In a century some gullies have eroded areas as much as 750 feet long, 500 feet wide, and 45 feet deep.

Soils subject to severe gully erosion require special drainage provisions and stabilization of cut slopes to preserve the vegetation and the upper clay soil. Where gullying occurs, roadbeds and structures are subject to slump and caving, and culverts, bridges, and grades have to be designed to cope with larger quantities of sand fill deposited along drainageways leading from gullies.

In east-central and southeastern Ohio and adjacent parts of Pennsylvania, West Virginia, and Kentucky, residual soils on shale, limestone, and sandstone are subject to severe gullying (Borst, McCall, and Bell, 1945, p. 8–11). Gullies are shallower and shorter than in the Piedmont, reaching a maximum of 500 feet in length and 30 feet in depth. They tend to be closely spaced and extend down to bedrock.

DEBRIS SLIDES

Debris slides have caused recurring disasters in many parts of Appalachia, and recognition of potential slide areas is important if loss of life and damage to engineering works is to be kept at a minimum. A typical debris slide occurred in east-central West Virginia in 1949 after 16 inches of rain in a 24-hour period caused many "gully washers" along hundreds of mountain streams. At the height of the storm, masses of saturated soil and vegetation slid rapidly down the steep mountainsides, scarring them from summit to base. The slides spread in the valleys and filled secondary streams; they forced changes in the stream courses and dammed the North Fork of the South Branch Potomac River (fig. 23). Damage from floods and slides was more than $7 million, and 2,400 persons were driven from their homes; at least 8 persons were killed (Stringfield and Smith, 1956). Adjacent parts of Virginia had damage in excess of $2 million and had three deaths. The Blue Ridge in North Carolina was the site of debris slides in 1892 and 1916. In 1924 and 1938, several areas in eastern Tennessee were scarred by debris slides during periods of heavy rainfall (Moneymaker, 1939).

The combined factors of slope, nature of soil cover, attitude of stratified bedrock, and rainfall influence debris slides. Surface slopes of 20° or more on the flanks of ridges, particularly those with more than 1,000 feet of relief, contribute to slides. Large slides commonly occur where slopes are more than 40° on drainageways near ridge summits. Soils in slide areas are generally less than 6–10 feet thick and are composed of coarse residual material containing large

FIGURE 23.—Debris slide, Royal Glen, Petersburg, W. Va., June 18, 1949.

quantities of rock fragments. The soils generally are on hard sandstone and metamorphic rocks, but in a few places they overlie limestone and shale. Slides tend to occur where the dip of the rock beneath thin soil is equal to or slightly less than the surface slope. Abnormally high rainfalls that saturate the soil in a short period of time trigger slides. Debris slides extend to, and at places include, a part of bedrock, the loosened material moving off along bedding or cleavage planes. Where the dip of the rock strata is steeper than surface slopes, debris slides are lacking or are small. The resistance rock layers intersect the surface slope and apparently stabilize the soil.

Debris slides range from those a few feet wide and deep and less than 100 feet long to those, as much as 1½ miles long and 200 feet wide, which may involve movement of 175,000 cubic yards of soil. At their toes, the slides form distinctly terraced fans as much as 60 feet high and several hundred feet wide. The material in such fans is quickly reworked by streams in the valleys into which they debouch (fig. 23).

EARTHQUAKE EFFECTS

Appalachia, like other areas in eastern United States, has little earthquake activity. Only five earthquakes of moderate intensity (strong enough to damage ordinary substantial buildings) have been centered in the area in the last 200 years (Heck and Eppley, 1958). However, the epicenters of the strongest earthquakes that have occurred in the United States (New Madrid, Mo., 1811 and 1812, and Charleston, S.C., 1886) were within 200 miles of the southern part of Appalachia. Destruction in Tennessee, the Carolinas, Georgia, and Alabama would probably be severe if similar earthquakes occurred now because of denser population and larger structures. Most earth tremors in Appalachia apparently are deep seated and active faults are scarce. Recent displacement of surface formations has been reported only along faults in southwestern North Carolina (Conley and Drummond, 1965).

The Great Valley in southern Virginia and eastern Tennessee has been shaken by 15 earthquakes since 1877. All of these were strong enough to be noticeable to people, some were strong enough to cause people to flee from buildings, and four were strong enough to shake down chimneys and crack walls. The western part of North Carolina has been the center of nine noticeable tremors since 1890, but none caused significant damage. Many of the shocks during the last 50 years have been in a zone extending from south of Asheville, N.C., northeast to Pulaski, Va. (MacCarthy, 1956). Five tremors, two of which shook down chimneys and cracked walls, have occurred in northeastern Alabama since 1860. The Appalachian part of Pennsylvania has been the center of three earthquakes, of which only the Wilkes-Barre earthquake of 1954 caused any damage.

Inasmuch as the damage from earthquakes in Appalachia has been negligible, special protective construction has not been economically justifiable, except for dams and powerplant chimneys.

CLIMATIC EFFECTS

Because of the great north-south extent of Appalachia, climatic effects on construction vary considerably. In Pennsylvania and New York, construction is curtailed by cold weather from early December to late March. This period of curtailment is greatly reduced southward; south of central Virginia, short periods of wet weather, rather than cold, interrupt construction in winter. In the Great Smokies and adjacent parts of the Blue Ridge, however, winter conditions curtail or stop construction from late November to mid-March.

Frost penetration in northern Pennsylvania and New York is 30–36 inches; in southern Pennsylvania and south to Tennessee along the higher mountains in eastern Appalachia it is about 15 inches; elsewhere it is 6–10 inches, except in Georgia and Alabama where it is 3–6 inches.

MANMADE FEATURES

As a result of more than a century of intense coal mining, the hazards of waste-pile slides, coal-bed fires, and mine subsidence are found throughout most of the Appalachian Plateaus, and the problems involved are probably as great as any presented by natural hazards.

STRIP MINING

In the early 1820's, the mountainsides at Summit Hill, Schuylkill County, Pa., and at Beaver Meadow in adjacent Carbon County showed the first scars of strip mining, scars that eventually marked much of Appalachia (Cash and von Bernewitz, 1929, p. 46–47).

Strip-mining operations in the bituminous coal fields of Appalachia were small until 1914, at which time there were only 11 operations in southeastern Ohio, southwestern Pennsylvania, and Alabama. In the early 1920's, strip mining extended to eastern Kentucky, Tennessee, West Virginia, and Maryland, and the number of operations greatly increased in the 1930's. Stripping operations, during and after World War II had phenomenal growth, and they were extended to most of the Appalachian coal fields except those in Tennessee and Alabama where such operations continued to be few and scattered (fig. 24). At present, an estimated 12,000 active and inactive strip mines affect about 576,000 acres in Appalachia.

The effects of past strip mining may be a nuisance or a serious problem, depending upon the surrounding terrain and the age of the operation. Stripping done more than 45 years ago in the anthracite fields resembled other coal mining in that the overburden was transported to small dumps. These dumps or spoil piles, are generally stable for with the lapse of time, adequate drainage is established. After the introduction and extensive use of large shovels and draglines in the 1930's, overburden was dumped immediately adjacent to the operation. Almost always the dump was downslope from the mine, and the bedrock lip along the outer edge of the cut and the adjacent dump intercept both surface and subsurface drainage (fig. 25); where the operation is in an area with relief of 100 feet or more and the natural slope 30° or more, large-scale mass wasting occurs (Savage, 1950). Slow, intermittently moving earthflows and mudflows in the waste and soil mantle are common, and it is estimated that 12 percent of the spoil piles are now sliding (Weigle, 1966). The slowly moving material is saturated, and silt and clay muck commonly flows out from the toe of the slide. The earthflows and mudflows disrupt foundations, dislodge small structures, and override highways and agricultural lands. Sporadic falls of rock from the high walls along the stripping face is common long after mining has ceased.

On the upper part of the spoil pile, movement initially is by downslope tumbling of coarse material, until the angle of repose is attained. Earthflow on the lower slope, however, may reactivate the tumbling by oversteepening of the bank.

Backfilling and grading aid in restoring stability to strip mine areas (Bergoffen and Schessler, 1964, p. 14–21); drainage of the regraded deposits greatly reduces the potential hazard of earthflow and mudflow. Time alone is not sufficient to remove the hazard, as illustrated by failure of waste piles almost a century old in Sweden. Any disturbance of the old and apparently stable spoil piles, including areas of regrading and backfilling, commonly reactivates earthflows and mudflows unless provisions for proper drainage are made.

Strip mining for residual iron and manganese ores is similar to that of coal, and the spoil piles create similar earthflow hazards. However, such stripping operations are relatively few and generally small. Only in Franklin and Colbert Counties, northwestern Alabama, and near Cartersville, Ga., are individual iron ore strip mines large enough to create serious engineering problems. Clay strip mines, similar to the coal mines, are extensive in southern Ohio and northeastern Kentucky. Strip mining also has been done for barite in Virginia, Tennessee, Georgia, and Alabama, and for bauxite in the last two States.

SUBSIDENCE

Subsidence over coal mines is a common phenomenon in Appalachia, such subsidence taking place where insufficient support is left in the mine. The degree of surface subsidence is affected by the depth to failure and the total thickness of the openings at and above the point of failure. In general practice,

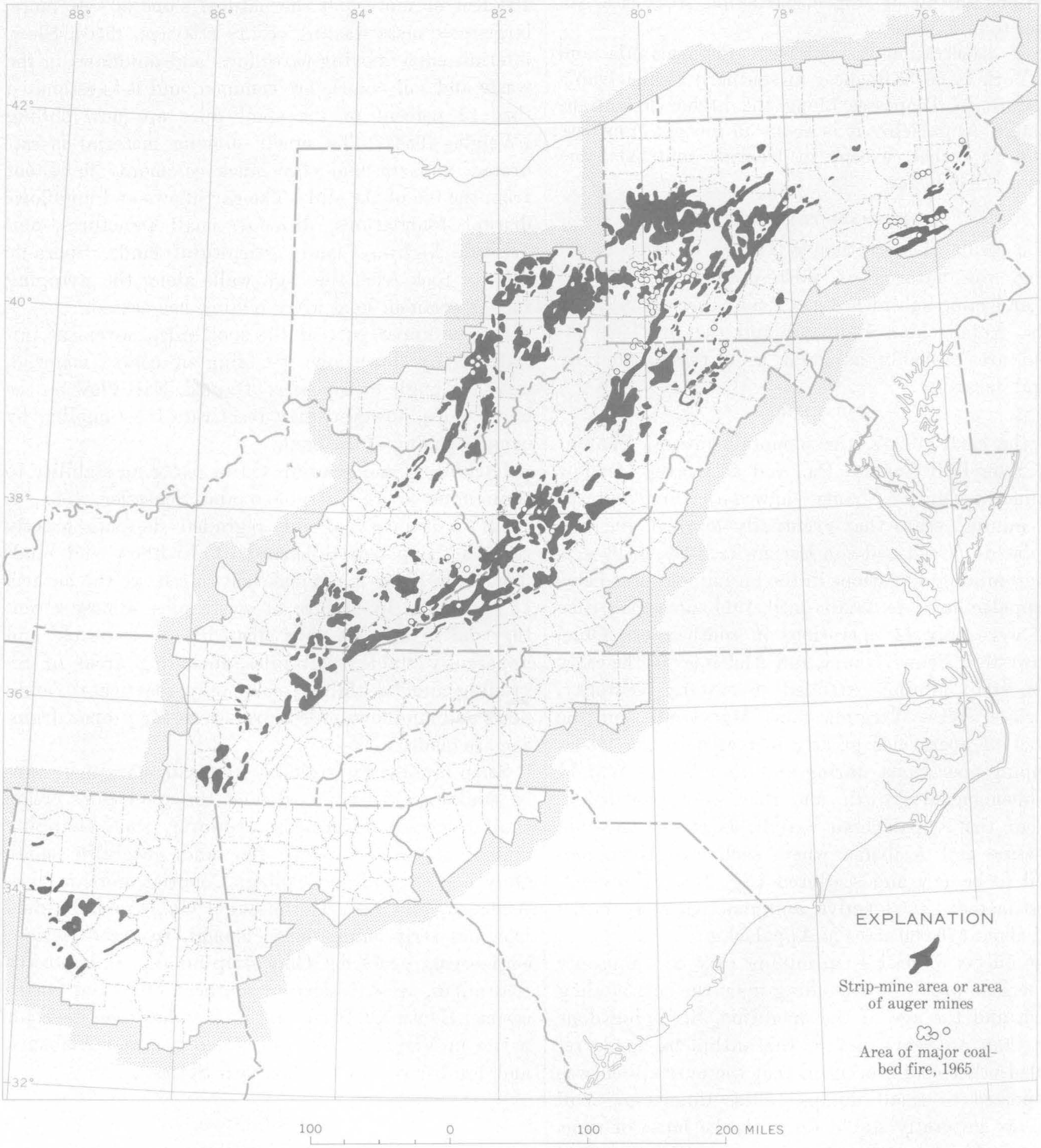


FIGURE 24.—Strip-mine areas and coal-bed fires in the Appalachian Region.

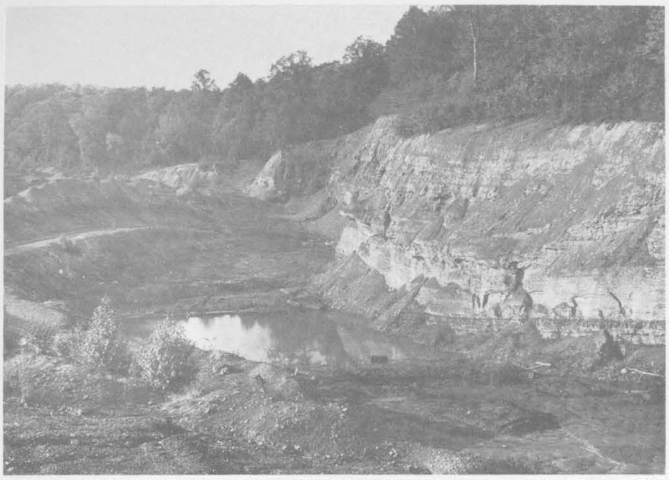


FIGURE 25.—Strip coal mine, Coalton, W. Va.

84–90 percent of the coal is removed, except in areas beneath buildings and railroads where 25–50 percent is taken out. Under such conditions, surface subsidence is 50 percent of the thickness of the coal removed when failure is 150 feet or less in depth, and 25–30 percent where depth of failure is 300 feet. Observations indicate that subsidence is greater when sandstone overlies mined-out coal and least where shale is the overlying rock. Subsidence generally occurs slowly but persistently. When all pillars are removed in a mined-out area 300–400 feet deep, subsidence shows at the surface in 12 months (Young and Stoek, 1916, p. 23–24, 28–50). In shallower mining, rock failure may move upward at a rate of several inches per hour.

Subsidence causes surface cracks as much as 4 feet wide and vertical displacement of a few inches to 20 feet over areas of several thousand square feet (fig. 26). Railroad and highway grades are involved in subsidence, but the vertical movement is slow enough to permit adjustments (Montz, 1930, p. 104–111). Until the advent of the superhighway, rebuilding of highways damaged by subsidence involved expenditures far less than the value of coal extracted from pillars, the cause of the subsidence. In city areas, subsidence results in damage to buildings and rupture of water and sewer lines, especially in zones of fracture along the boundary of the slump. In farm areas, ponds and wet soils form in depressions resulting from subsidence. In common practice the hazard of mine subsidence is dealt with by excavation and refilling to grade if the mine is within 35 feet of the grade line of a road under construction. For mines no more than 75 feet beneath grade line, tight backfilling is satisfactory. Below 75 feet, no corrective measures are taken in most road construction. Special footings are used to avoid damage from subsidence in the construction of buildings, whereas dams and similar massive structures are placed so as to avoid foundations involving mines.

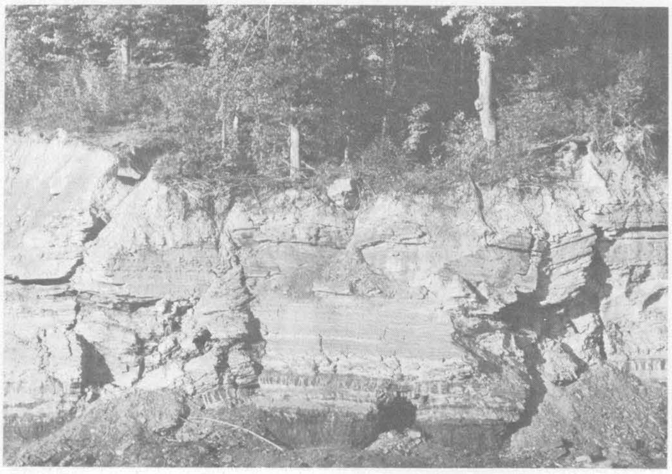


FIGURE 26.—Subsidence over a coal mine, Coalton, W. Va.

Scranton, Pa., has probably had more problems with coal mine subsidence than any other city in the United States. By 1911, 198 million cubic yards of rock had been removed from 11 anthracite coal seams beneath the city, 3 million cubic yards more than were excavated in the whole Panama Canal. It is little wonder that 15 percent of the city has been subject to subsidence with resulting serious engineering problems. Until 1909, most abandoned mines were left open, but rapid subsidence affecting a school brought legislation requiring backfilling of mines in Pennsylvania.

Where coal is mined in areas covered by glacial deposits, as in part of the anthracite field in eastern Pennsylvania, a special type of subsidence may occur. In these areas, large natural depressions as deep as 200 feet and old valleys filled with loose glacial deposits are common. Such depressions and valleys have been intercepted by shallow mines with disastrous results. In the Prospect Colliery, Lehigh Valley Coal Co., thin bedrock beneath a kettlehole broke in 1915, and allowed 140,000 cubic yards of earth and 350 million gallons of water to enter the mine. A similar collapse, when a mine pierced a kettlehole at Nanticoke, Pa., caused the death of 26 miners.

Most mines in Appalachia, other than coal mines, consist of small openings that cause little trouble from subsidence. Exceptions are limestone mines where collapse is rare but can be catastrophic. In 1961, an area of 250,000 square feet of the Lowmoor mine near Clifton Forge, Va., subsided 30–80 feet because of pillar failure in the mine. The failure occurred without warning and was instantaneous.

OTHER HAZARDS

Large spoil banks were formerly left adjacent to coal breaking and washing plants. These were of two types, one formed of waste rock—shale, sandstone, slate, and low-grade coal—and the other composed largely of small-size waste coal. Most of the latter type, called culm banks, have been reworked in recent times to salvage the coal. The waste banks are generally unstable and water saturated; debris slides and serious slumps may occur when the banks are cut by excavations. Many catch fire and burn slowly for years. Grading of unburned waste banks gives rise to hazardous foundation conditions because of the danger of spontaneous or manmade fires.

Debris washed from spoil banks may cause severe silting of nearby streams. The quantities of silt and rock debris may be so great that standard culverts and bridges are clogged within a year of their construction. To combat the clogging, settling ponds and greatly increased culvert and bridge openings are necessary. Drainage of acid waters from strip and other types of coal mines cause extensive stream pollution (Biesecker and George, 1966), and the acid waters corrode metal and attack concrete, greatly reducing the life of bridges, dam gates, pipes, and other structures.

In several areas, primarily in Ohio and Pennsylvania, coal beds have burned for long periods of time, and the fires have consumed the coal from under thousands of acres of land (fig. 24). Several deaths from asphyxiation and from falling into smoke-filled fissures have occurred, and damage to urban areas has been extensive in Pennsylvania (Mann, 1960; Business Week, 1963). At present, there are 103 active and controlled fires in Appalachia—3 in Kentucky, 2 in Maryland, 6 in Ohio, 76 in Pennsylvania, 1 in Virginia, and 15 in West Virginia (U.S. Bur. Mines, unpub. data, 1965). The fires, which commonly reach the surface, cause great loss in strength of rocks and soils; even when they are 100 feet or more underground they greatly weaken the rocks above. Burned-out areas should be avoided in most construction but, if heavy structures must be placed over such areas, the rock should be totally excavated to the fire level, or foundation wells and special footings are needed.

SPECIAL CONSTRUCTION ASPECTS

DAMS

Most of the unweathered rocks in Appalachia provide foundations that will support large dams. The problems arising in construction of dams are due to joints, faults, thin seams of clay in otherwise competent beds, solution cavities, deep weathering, and the problems inherent in the repetitive sequences of relatively weak rocks in the Appalachian Plateaus.

In the Blue Ridge of eastern Appalachia, foundations are affected by deep weathering along joint planes and faults, at places extending to depths of as much as 50 feet beneath riverbeds and 150 feet on adjacent hills. In such areas, excavation or grouting commonly is necessary to secure firm watertight foundations and abutments.

In the Valley and Ridge province north of central Virginia, many sites for large water impoundments are practically free of serious problems. The narrow steep valley walls offer sites for dams less than 1,000 feet long, and foundations and abutments at most sites would be on strong sandstone with impoundments backed into areas of shale and sandstone. Weathering is generally to a depth of less than 30 feet. Joints, generally well developed and closely spaced, would permit minor leakage in a zone 10–50 feet below the surface. Some reservoir sites abut high mountain slopes that approximate the dip of rocks forming them, and slides, common on such slopes, might reduce the capacity of the reservoir and possibly produce large destructive waves in the reservoir.

South of central Virginia most sites for large impoundments involve dams with foundations on cavernous limestone; large solution tubes and cavities (fig. 19) may be present in valley walls and beneath rivers to a depth of 200 feet or more (Tennessee Valley Authority, 1949, p. 256). Grouting or filling of the openings is necessary to prevent subfoundation and abutment leakage. Clay seams, resulting from weathering along joints, faults, and bedding planes in the limestone, commonly extend to depths of 50–100 feet and weaken foundations and abutments. The clay is often flushed out by impounded waters, and openings for seepage and leakage are left.

In the Appalachian Plateaus province, the sequence of alternating strong and weak rocks causes problems in dam construction. In general, only those members such as sandstone and sandy shale, that bind well with concrete, are satisfactory in foundations (Philbrock, 1960, p. 54–58). The foundation rock influences the type of dam best suited to a given site. Thick sandstone is generally adequate for a straight gravity dam as much as 150 feet high. Weak shale and coal in the foundation often require construction of earth-fill or buttress dams to lighten loads on the foundation. Because abutments at most damsites generally intersect weak members of the sequence regardless of the member utilized for foundation, true arch dams are not practicable inasmuch as the stability is dependent upon forces transmitted to the abutment.

Throughout Appalachia where weak soft rocks or clay seams are present in the foundation, the width of the base of gravity dams and spillways must be broadened to distribute the foundation load. Shear walls and similar structures have also been necessary in the heel of some dams to avoid weak rocks in the foundation.

Most rocks of Appalachia form reservoir banks that are stable under raised water-table conditions caused by impoundments.

TUNNELS AND OTHER UNDERGROUND OPENINGS

The great variety of rocks and rock structures in Appalachia result in many engineering problems in tunneling. Rocks that are inherently weak or greatly reduced in strength from weathering and fracturing require extensive support; hard sandstone commonly underlies most ridges in which tunnels are constructed and advances of headings are slow; copious quantities of water at great depth beneath ridges produce drainage problems requiring special engineering works during and after construction.

Tunnels are seldom constructed in the Piedmont because of the low relief and deep soil. Tunneling in this area would require extensive support to maintain openings, and subterranean structures would be best constructed by cut and cover methods.

In the Blue Ridge and Valley and Ridge provinces, tunnel excavation is generally in hard competent rocks, primarily granite, greenstone, quartzite, limestone, sandstone, and some interbedded weaker shale. The bedded rocks dip steeply in most areas where tunneling is necessary, and tunnels commonly pass through successive zones of different rock types. Where the rocks are unweathered, they stand with little support, but weathering along fault zones may extend many hundreds of feet below a mountaintop and create extremely weak water-saturated zones, from a few feet to more than 200 feet wide at the tunnel level. Zones of weakness along joints, fractures, and faults commonly extend downward for a hundred feet or more and are saturated with water, some of it under high pressure. Away from these zones, most rocks are dry below 300 feet, except for limestone which may have solution channels with streams or ponds to depths of 700 feet or more. Except in weathered zones, most quartzite, sandstone, limestone, greenstone, and granite will stand without support in openings as wide as 50 feet. Shale, slate, and interbedded shale and sandstone generally require support as excavation progresses. Upon completion, however, most tunnels are now lined with concrete.

Where shale is penetrated in portal areas adjacent to hard sandstone or other strong rock, the shale may be deeply weathered and contain large quantities of water which acts as a lubricant along joints, fractures, and bedding planes. It is difficult to support such shale, and generally it is excavated in an opencut that may be as much as 100 feet deep and the tunnel is opened in the stronger rock.

Rocks in the Appalachian Plateaus are relatively weak, and most tunnels require support and lining during and after construction.

The rate of advance of tunnel headings depends on several factors, including rock type and structure, size of heading, length of working day, and proportion of full face excavated. The average rate of advance ranges from 19 to 78 feet per day (table 28).

Excavations for underground structures for defense and storage purposes and for powerplants have been made at several places in Appalachia. Many excellent

TABLE 28.—*Advance of headings, Appalachian tunnels*

[Based on full 24-hour daily operation]

Tunnel	Rock and structure	Size of face and excavation (feet)		Rate of advance (ft per day, each face)
		Width	Height	
Chesapeake & Ohio RR., Blue Ridge, Waynesboro, Va.	Granite, quartzite, and mica schist.	20	26	13.
TVA., Appalachia, Polk County, Tenn.	Quartzite and slate, folded rock.	20 (diameter)	------	30; 53 ft maximum.
Power, northwestern New York state.	Dolomite and limestone, horizontal beds.	51	29	78 (one face).
Norfolk & Western RR., Elkhorn, Bluefield, W. Va.	Sandstone and shale, horizontal beds.	36	35	34 (two 10-hour shifts).
Norfolk & Western RR., Sandy Ridge, Russell County, Va.	-----do-------------------	20	27	36.
Cabin-Paint Creek, W. Va. Turnpike.	-----do-------------------	33	30	19.
Fort Pitt, Pittsburgh, Pa-------	-----do-------------------	35	30	32.

sites for large underground openings occur. Among the best sites are those in the eastern part of Appalachia, in the granite and greenstone of the Blue Ridge and the anticlinal mountains of the Valley and Ridge formed by thick arches or quartzite. The rocks are dry below 300 feet, and openings more than 100 feet wide may stand with little support. Excavating the hard, tough granite and greenstone is generally slow, but because of their dry, tight conditions excavations in these rocks are well suited for storing natural gas.

Caves and mines have been used for storage and underground construction in Appalachia. However, most caves are generally impractical for such purposes because of difficult access, irregular passages, high humidity, and danger of flooding. Of the many thousands of mines in Appalachia, only limestone, salt, and pyrite mines are suitable for use as storage or underground construction (U.S. Army Corps of Engineers, 1956). Most of these mines, of which there are 65 (fig. 27), are of room and pillar type and range from small single openings a few hundred feet long to vast excavations a mile or more on a side. The mines generally need some artificial support structures to keep them open indefinitely.

CONCLUSIONS

Either under present or accelerated rates of development, substantial amounts of earth and rock will be moved in a wide variety of engineering and construction projects in Appalachia. The decisions needed in site selection, the actual methods employed in excavation and construction, and the avoidance of unanticipated movements of rocks and soil during and after construction, can all gain in efficiency and in reduced costs by application of engineering geological studies before such projects begin. Although some types of heavy construction, including highways and dams, are preceded by engineering geological studies in most Appalachian States, the foregoing pages indicate that broader application is possible and is needed.

In addition to specific studies for given engineering projects, it is necessary to expand basic geologic mapping at medium and large scales in the Appalachian Region, with particular emphasis on providing the quantitative lithologic and structural data needed by engineers. Emphasis should also be placed on subsurface investigations by borings and geophysical methods. Future geologic mapping in Appalachia should include more detail on distribution, thickness, and nature of soils and weathered rock; such information is of paramount interest to all involved in construction. Geologic studies also should be expanded to cover field observations on slope stability, subsidence, drilling rates, and other specific data applicable to engineering and to cover laboratory investigations of specific physical characteristics of rocks.

Urban areas, particularly the larger and more actively expanding cities, and rural areas where special or large-scale construction is planned both merit large-scale engineering geology mapping. The resulting maps and reports will serve for long-range planning and in early economies in all types of construction.

Most mapping should be done by conventional methods by geologists and specialists in the engineering applications of geology. However, new instruments that can be used to delineate subsurface contacts between rock and soil have been developed for use in airborne surveying. Included are the microwave radiometer, induced pulse transient systems, and the Ryan scattometeter. These instruments may find wide use in one of the most costly and difficult engineering problems in Appalachia, the determination of the subsoil profile of limestone which is so important in foundation work and highway construction.

MINERAL COMMODITIES

For convenience of discussion, the mineral commodities are separated into four groups: fuels, construction materials, nonmetals, and metals. The principal or only use of most commodities is indicated by the group name; a few, however, are more widely used in Appalachia for other purposes than indicated by the conventional grouping. For example, peat is used as a packing material and soil conditioner rather than as a fuel; asphalt is a construction material. Most lime is used for chemical, metallurgical, and agricultural purposes; comparatively little is used in construction. Bauxite mined in Appalachia is for use as a chemical or refractory material rather than a source of aluminum.

FUELS

ASPHALT, HEAVY CRUDE OIL, AND SHALLOW OIL RESERVOIRS

By RICHARD F. MEYER, U.S. Geological Survey, and JOHN W. SWEENEY, U.S. Bureau of Mines

Various deposits of naturally occurring bitumens and certain crude oils that might be of commercial value by other than normal oil-field methods are considered here. A summary of such deposits in Appalachia is given in table 29, and locations of deposits are shown on figure 28.

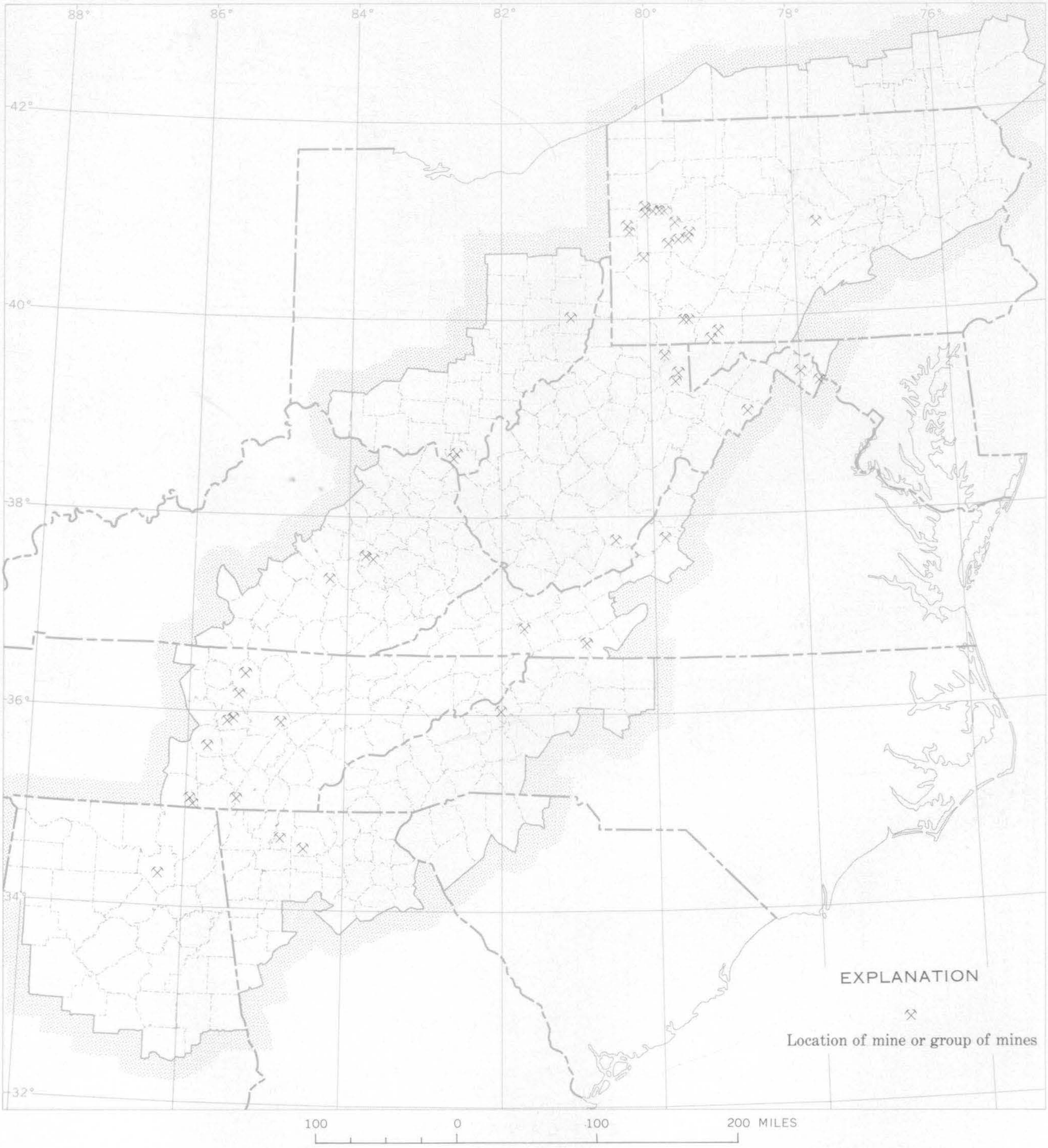


FIGURE 27.—Mines in the Appalachian Region suitable for use as underground installations.

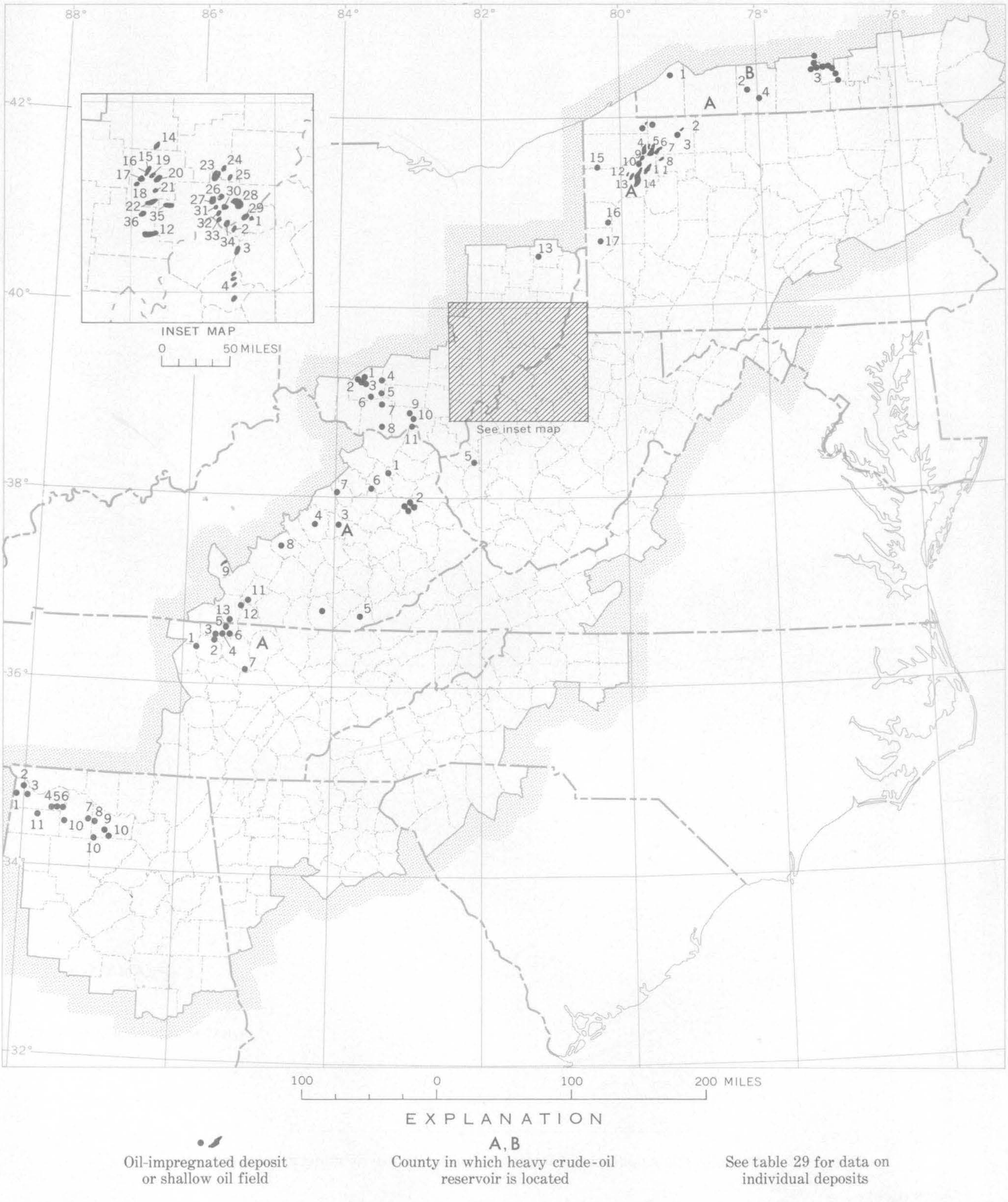


FIGURE 28.—Location of surface and near-surface oil-impregnated rocks, shallow oil fields, and heavy crude oil reservoirs in the Appalachian Region.

TABLE 29.—*Surface and shallow oil-impregnated rocks, shallow oil fields, and heavy crude oil reservoirs in the Appalachian Region*

[Sources of data: Ball Associates, Ltd. (1965); Dietzman and others (1965); Ford, Bacon & Davis, Inc., 1951–52, Alabama, Kentucky, Ohio, and Pennsylvania volumes]

No. (fig. 28)	Name of field or deposit	Geologic age of reservoir	County	Type of deposit	Average depth (feet)	Average thickness (feet)	Type of operation	Impregnated deposits		Remarks
								Yield (gallons per ton)	Asphalt (percent)	
				Alabama						
1	Margerum	Mississippian	Colbert	Impregnated	Surface	12	Quarry	7–12	3.0–5.0	Outcrop 25–30 miles long; reserves 710 million tons.
2	Colbert Creek	do	do	do	do		None			290 acres.
3	Cherokee	do	do	do	do	5–8	Quarry	9	3.0–8.5	Outcrop 25 miles long; reserves included with no. 1.
4	Littleville	do	do	do	do	8–16	Prospect			3,840 acres.
5	Shine Springs	do	do	do	do	12	do	9		
6	Town Creek	do	Lawrence	do	do	7–8	do	18–21	7.7–9.4	Several miles long.
7	Caddo	do	do	do	do	16–18	None	9	4.0	
8	Flint	do	Morgan	do	do	6	Quarry	10	4.0–7.0	
9	Hartselle	do	do	do	do	4–6	do	13–16		Several miles long.
10	Bangor Limestone outcrop.	do	Lawrence-Morgan.	do	do		do			
11	Frankfort	do	Franklin	do	do	12				1 mile long.
				Kentucky						
1	Soldier	Pennsylvanian	Carter-Rowan	Impregnated	15–20	5–10	Quarry			Less than 3 miles diameter.
2	Paint Creek	do	Morgan-Johnson	do	Surface	4–12	None			Outcrops.
3	Ravenna	Devonian	Estill	do			Mine			2–3 bbls/day oil to 1921.
4	Madison County		Madison	do	Surface					Small outcrop(s).
5	Bell County		Bell	do	do					Do.
6	Ragland	Silurian	Bath-Rowan	Shallow oil	381	14				
7	Mt. Sterling	Ordovician	Montgomery	do						
8	Jumbo	Devonian	Lincoln	do	250	7				
9	Greensburg	Silurian	Green-Taylor	do	450	11				
10	Williamsburg	Pennsylvanian	Whitley	do	300	10				
11	Rock House Bottom.	Ordovician	Russell	do	450					
12	Bush Creek	do	Cumberland	do	400					
13	Kelly Creek	do	do	do	400					
A	Irvine Furnace	Devonian	Estill	Heavy crude	70–1,200	30	Thermal combustion.			
				New York						
1	Laona	Devonian	Chautauqua	Impregnated		5	Quarry			Exposures in sandstone quarries.
2	Rockville	do	Allegany	do	Surface		do			Outcrop, very bituminous.
3	Part of Western New York.	do	Steuben-Schuyler	do	do	0.4–0.8				Noncontinuous outcrop.
4	Browning	do	Allegany	Shallow oil	400	50				
A	Fancy Tract		Cattaraugus	Heavy crude						
	Farmersville		do	do						
B	Bolivar (Richburg)		Allegany	do			Thermal combustion.			
	Grove		do	do						
	Rawson		do	do						
	Short Tract		do	do						
				Ohio						
1	Fallsville	Silurian	Highland	Impregnated	Surface	10	Quarry			Exposed in quarry, in rock cavities.
2	Brick School	do	do	do	do	20	do	6		Exposed in quarry; reserves 4 million tons.
3	Hillsboro	do	do	do		20	do			
4	Plum Run	do	do	do	Surface	32	None			Outcrops along road.
5	Sinking Spring	do	do	do	do	3	Quarry			Exposed in quarry, pockets of asphalt.
6	Fairfax	do	do	do	do	20	None			Exposed in quarry.
7	Locust Grove	do	Adams	do	do	22	Quarry			Do.
8	Lynx	do	do	do	do	34	do			Do.
9	Lucasville	Mississippian	Scioto	Shallow oil	150	7				
10	Schisler Hollow	do	do	do	350	8				
11	New Boston	do	do	do	400	8				
12	Stewart	Pennsylvanian	Athens	do	400	15				
13	Tabor	do	Carroll	do	150					
14	Ruraldale	do	Muskingum	do	100					
15	Joetown	do	Morgan	do	300	15				
16	Chaneyville	do	do	do	475	17				
17	Buck Run	do	do	Shallow oil and impregnated.	150, 200	20, 17				Impregnated depth 37–200 ft., thickness 10 ft.

TABLE 29.—*Surface and shallow oil-impregnated rocks, shallow oil fields, and heavy crude oil reservoirs in the Appalachian Region*—Continued

No. (fig: 28)	Name of field or deposit	Geologic age of reservoir	County	Type of deposit	Average depth (feet)	Average thickness (feet)	Type of operation	Impregnated deposits		Remarks
								Yield (gallons per ton)	Asphalt (percent)	
				Ohio—Continued						
18	Ringgold	Pennsylvanian	Morgan	Shallow oil	300, 350					
19	Hapdale	do	do	do	300	15				
20	McConnelsville	do	do	do	240, 275	25, 20				
21	Pennsville	do	do	do	375, 425					
22	Chesterhill	do	do	Shallow and impregnated.	475	10-50				Impregnated depth 65-80 ft, thickness 2-30 ft.
23	Macksburg	do	Noble-Washington.	do	160	25				Impregnated depth 80-140 ft, thickness 5 ft.
24	Middle Creek	do	Noble	Shallow oil	200	20				
25	Harrietsville	do	do	do	500	20				
26	Bonn	do	Washington	do	200	28				
27	Whipple, South	do	do	do	200	15				
28	Cow Run	do	do	Shallow and impregnated.	350	40				Impregnated depth 80-140 ft, thickness 5 ft.
29	Newport	do	do	Shallow oil	450	25				
30	Caywood	do	do	do	300					
31	Duck Creek	do	do	do	270					
32	Goose Run	do	do	do	150					
33	Mitchell	do	do	do	400					
34	Lower Newport	do	do	do	250, 400	27, —				
35	Wolf Creek	do	do	do	450					
36	Amesville	do	Athens	do	200					
				Pennsylvania						
1	Corry	Devonian	Erie	Impregnated	Surface		None			Thin outcrop, associated oil seeps.
2	Warren, North	do	Warren	Shallow oil	495	20				
3	Glade	do	do	do	490	30				
4	Church Run	do	Crawford	Shallow and impregnated.	400, 450	12, 30				
5	Selkirk	do	Warren	Shallow oil	400	40				
6	Colorado-Goodwill Hill-Grand Valley.	do	do	Shallow and heavy crude.	300	30	Thermal combustion.			Heavy crude average depth 400 ft.
7	Tidioute	do	do	Shallow oil	300, 400, 430, 475.	25, 35, 35, 15.				
8	Hickory, West	do	Forest	do	490, 475	25, 20				
9	Octave	do	Venango	do	450	30				
10	Petroleum Center	do	do	do	420	50				
11	Walnut Bend	do	do	do	300	16				
12	Sugar Creek-Niles	do	do	do	250, 350	50, 35				
13	Franklin-Oak Forest.	do	do	Shallow and impregnated.	270, 450	50, 55				
14	Foster-Reno	do	do	Shallow and heavy crude.	400	24	Thermal combustion.			
15	Atlantic	Mississippian	Crawford	Shallow and impregnated.	400	10				
16	Slippery Rock	do	Lawrence	Shallow oil	200	30				
17	Purdy	Pennsylvanian	Beaver	do	450	40				
A	Venango?		Venango	Heavy crude			SI			
				Tennessee						
1	Unnamed	Ordovician	Smith	Shallow oil	214					
2	Tinsleys Bottom	do	Clay	do	429, 484					
3	Arcott School	do	do	do	452					
4	Peterman Bend	do	do	do	295, 380					
5	Good Pasture Bend	do	do	do	465					
6	Fox Springs	do	do	do	161, 242					
7	Spring Creek	Mississippian	Overton	do	52					
A	Unnamed	Ordovician	Fentress	Heavy crude	1, 006					
				West Virginia						
1	St. Marys [1]	Pennsylvanian	Pleasarts	Shallow and heavy crude.	400	16-22	Thermal combustion.			
2	Horseneck	do	do	Shallow oil	185-330					
3	Volcano	do	Wood-Ritchie	do	360	10-50				
4	Burning Springs	do	Ritchie-Wirt	do	200, 350, 356, 390.	20-100, 40-60, 15-55, 17-25.				
5	Milton	do	Cabell	do	400					

[1] Name of heavy crude field given as Columbia Southern (Cow Run).

Asphalt is a brown or black tarlike substance, a variety of bitumen, found in a natural state or obtained as a residue by distilling petroleum. The most important use has been as road paving, although native or rock asphalts are considered to be possible sources of crude oil (Stern, 1960). Native asphalt is associated with rock, such as sand, sandstone, limestone, clay, and shale, as impregnations or cavity fillings. It also occurs in surface pools resulting from seepage from oil-impregnated rocks.

Surface and shallow oil-impregnated rocks are those whose void spaces are more or less completely filled with bituminous material; such deposits are commonly termed natural asphalts or tar sands. Shallow oil fields are considered to be those which lie within 500 feet of the earth's surface. Heavy crude oil is one of 25° or less gravity API. Heavy crude oil reservoirs may be susceptible to thermal recovery methods, particularly steam injection and in-place combustion. The desirable parameters and their generally accepted limitations in choosing a prospect for thermal recovery are:

Parameter	*Steam Injection*	*In-place combustion*
Lithology	Preferably limited to sandstone.	
Reservoir depth feet	<3, 000	300–3, 000
Minimum viscosity centipoise	50	100
Reservoir thickness net feet	>50	10–50
Gravity of oil	5°–25° API	5°–35°API
Oil in place bbls per acre ft	750	750
Porosity minimum percent	20	20
Permeability minimum millidarcys	1, 000	100

Although there are successful thermal recovery projects in which all these limitations are not met, these requirements are, nevertheless, generally accepted by industry to represent the minimum for thermal recovery.

In 1963, total national production of asphalt and road oil from crude oil was 118.7 million barrels. For the past 10 years, asphalt and road oil have maintained an almost constant yield position of about 3.5 percent of crude oil processed. Both asphalt and road oil play an important role in the road-building and construction industries.

According to Foley (in U.S. Bur. Mines, 1965c), shipments of native asphalt (bituminous limestone and sandstone) in the United States in 1964 totaled 1.4 million short tons, valued at $3.5 million (1958 constant dollars), exclusive of production and value of gilsonite, an asphaltite. In 1964, native asphalt was produced in Alabama, Missouri, and Texas, and gilsonite in Utah. Other States with commercial deposits of asphalt not presently being exploited include Arkansas, California, Kentucky, Louisiana, Oklahoma, and Oregon.

Native asphalt was discovered in 1840 in Lawrence County, Ala., and between 1840 and 1923 several "carloads" were mined for experimental extraction of mineral tar. About 1920, prospecting was carried out and large "ore" bodies outlined (Jones, 1928). Asphalt production began in 1923 in Colbert County, Ala., and has continued to the present. Production from 1923 through 1927 was 88,000 short tons valued at $340,000; data on production since 1927 are withheld to avoid disclosing individual company data. However, production in Alabama represents only a small percentage of the national production.

Surficial asphaltic deposits are found at scattered localities throughout Appalachia (fig. 28), but only those of Alabama are of large areal extent. The Alabama deposits, as well as those at other places, are thin (table 29), but reserves may be large. In the Margerum-Cherokee area there were reserves of 710 million tons of asphaltic rock in 1928, having a calculated yield of at least 100 million tons of liquid hydrocarbons. Only the richest material, a small fraction of the total reserve, has been exploited.

Shallow oil fields are more numerous and widespread in Appalachia than are native asphalt deposits. They generally occur at depths of 200–500 feet, and the reservoir rocks are generally less than 20 feet in average thickness (table 29). Under these conditions, certain of the pools may be amenable to exploitation by thermal recovery. This operation has been attempted at a few places, but success was limited by the highly paraffinic nature of the crude oil.

Present and potential future production of hydrocarbons derived from asphalt deposits and near-surface and heavy crude oil fields in Appalachia is small. However, the resources of asphalt-bearing rocks in Alabama are large and may be exploited in the future. Kentucky contains reserves estimated at more than 500 million tons of oil-impregnated material, but nearly all this lies outside Appalachia. Kentucky also has the largest number (76) of shallow oil fields in the United States, but only a few of these are in Appalachia. Most of the numerous shallow fields of Ohio and Tennessee are outside Appalachia. Only a few of the 2,000 heavy crude oil reservoirs of the United States occur within Appalachian States.

COAL

By Harold H. Arndt and Paul Averitt, U.S. Geological Survey, and James Dowd, Donald J. Frendzel, and Phillip A. Gallo, U.S. Bureau of Mines

Coal is Appalachia's most abundant and valuable mineral resource. The vast Appalachian bituminous coal basin covers an area of 72,000 square miles in parts of nine States, and the well-known Pennsylvania anthracite fields cover 484 square miles in 10 counties in northeastern Pennsylvania (fig. 29). These coal-bearing areas represent 39 percent of the total area of Appalachia.

Since the days of earliest settlement and the beginning of mining, bituminous coal and anthracite have supplied the prodigious quantities of energy that, in conjunction with petroleum and natural gas, fueled the industrial growth of the eastern seaboard States and contributed to the westward expansion of the Nation. The estimated cumulative production of anthracite and bituminous coal in Appalachia from the beginning of mining to January 1, 1965, is about 28 billion tons, which is 75 percent of the total cumulative production of the United States.

ORIGIN OF COAL

Coal is a sedimentary rock formed by the accumulation, alteration, and compaction of plant remains in a reducing environment like that found in swamps. The thick sequence of coal-bearing rocks in the Appalachian bituminous coal basin and in the Pennsylvania anthracite fields represents a slow accumulation of silt, sand, and plant material throughout most of Pennsylvanian time. The area of deposition was near sea level on the western flank of an ancient landmass lying east of all present outcrops of Pennsylvanian rocks. The area of deposition extended at least as far east as the Pennsylvania anthracite fields, as far north as central Michigan, and as far west as the Interior coal basins of the Mississippi valley. The present Appalachian bituminous coal basin and the Pennsylvania anthracite fields are remnants of the former more extensive area of coal-bearing rocks, preserved in structural basins.

The broad area of Pennsylvanian deposition subsided slowly as sediments were washed in from the eroding landmass, but for many long intervals the area of deposition was a broad swampland on which ancient vegetation flourished. Each coal bed represents a place of plant accumulation during such an interval. It has been estimated that a foot of bituminous coal contains plant material accumulated over centuries. As subsidence continued and as more and more sand and silt were washed in, many layers of plant material were formed in an irregular sequence, one above the other. As material continued to be added, the plant material was altered and compacted to coal, the silt to shale, and the sand to sandstone.

Sometime after the period of deposition and consolidation the coal-bearing rocks were uplifted and folded by large-scale movements of continental scope. These movements created the present structural basins in which the coal-bearing rocks are preserved. The processes of erosion set in motion by this uplift have dissected the ancient coal-bearing rocks to form the present valleys, ridges, and plateaus. The outcrops of rocks and coal exposed in this dissected landscape exhibit many differences in thickness and composition both laterally and vertically because of vagaries in the sources of material, rates of deposition and subsidence, irregularities on the floors of the intermittent swamps, and local erosion contemporaneous with deposition. A coal bed is typically an irregular lens-shaped body that may terminate locally where a stream cut across the former coal swamp, or that may thin against an area of high ground in the former swamp. Many coal beds in the Appalachian Region are continuous over large areas, but others thin to extinction a few miles or tens of miles from the points of maximum thickness. Most coal beds contain partings of impure coal or clay representing an influx of silt into the coal-forming swamp. Virtually all coal beds are underlain by a layer of clay that typically exhibits rootlet impressions and channels and that represents a soil in which the coal-forming plants were rooted. Such underclay layers may have properties that make them desirable for the manufacture of fire brick and other refractory products. All coal beds exhibit differences in composition and purity representing variations in the plant ingredients and variations in the amounts of silt washed into the swamp.

Study of many coal beds and associated rocks reveals a tendency toward a rhythmic repetition in the sequence of deposition. This rhythmic deposition was first described in Illinois where the term "cyclothem" was coined by Weller (1931) as a name for the rocks in a single complete unit in the rhythmic sequence. An idealized cyclothem, as that term is used in Ohio, is shown in figure 30. Cyclothems are best developed in the Pennsylvanian strata of Illinois and Indiana and on the western side of the Appalachian bituminous coal basin because these areas were more distant from the ancient landmass that contributed the sedimentary materials and sedimentation was correspondingly slower and more uniform. A single, complete cyclothem cannot be recognized in areas closer to the ancient landmass, such as the anthracite fields of eastern

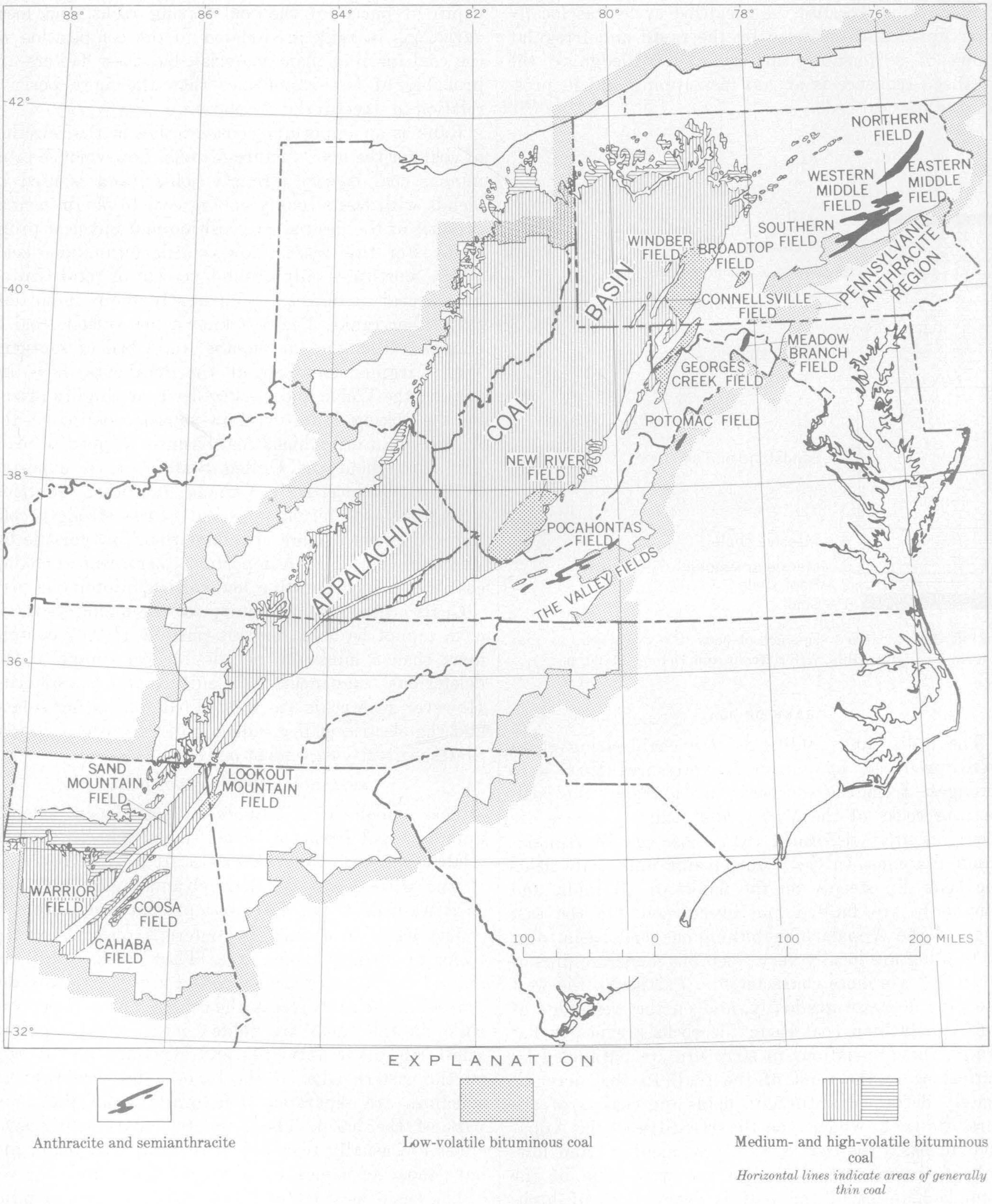


FIGURE 29.—Coal fields of the Appalachian Region.

Pennsylvania, because the idealized cycle was locally interrupted and distorted by the rapid and irregular influx of sedimentary materials. Knowledge of the idealized sequence is an aid in mapping and in prospecting for coal beds.

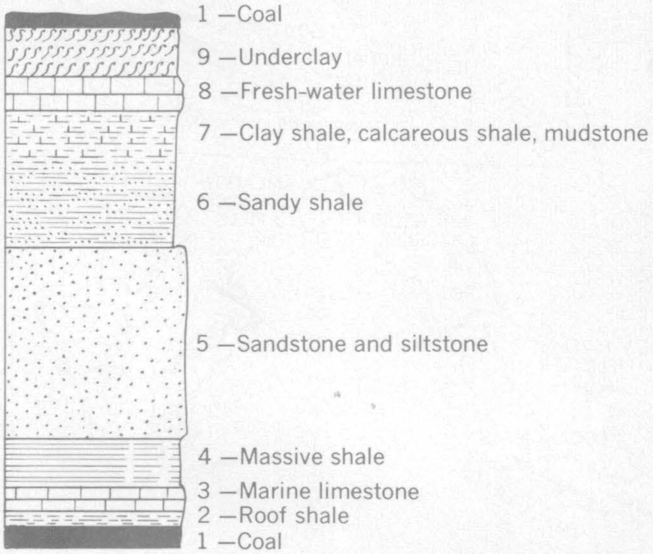


FIGURE 30.—Idealized sequence of beds in a cyclothem, as that term is used in Ohio. After Brant and Delong (1960, p. 23).

RANK OF COAL

The uplift and folding of the coal-bearing rocks were produced by tangential pressures that were strongest from the southeast. As a result, the coal-bearing rocks of the Valley and Ridge province are more intensely deformed than those of the Appalachian Plateaus. In the Pennsylvania anthracite fields the beds dip steeply on the flanks of all folds, and commonly are faulted and overturned. On the east edge of the Appalachian bituminous coal basin, dips of bedding are locally very steep but moderate dips of about 20° are more characteristic. Farther to the west the dips decrease gradually, and on the west edge of the Appalachian coal basin the rocks are nearly flat lying. These variations in structure are paralleled by variations in the rank of the coal. In the more intensely deformed anthracite fields the coal is of anthracitic rank, whereas on the east edge of the Appalachian basin the coal is locally of medium- and low-volatile bituminous rank; on the west edge of the Appalachian basin the coal is everywhere of high-volatile bituminous rank. Some of the observed difference in rank of the bituminous coal across the Appalachian structural basin may be due to initial depth of burial of the coal-bearing rocks, and local variations in rank are related to the composition of the coal-forming plant material, but these factors are probably of less importance than the more positive relation to structural deformation.

Rank is an important consideration in the selection of coal for the manufacture of coke. Low-volatile bituminous coal is very strongly coking and is used in blends with less strongly coking coal to obtain a final product of the desired composition and physical properties. For this reason, low-volatile bituminous coal, which constitutes only about 1 percent of total United States coal resources, is inherently more important than other ranks. The best known low-volatile coal is obtained from the Pocahontas No. 3 bed of southern West Virginia. However, all the Pocahontas beds, including the Welch and Beckley beds, are highly prized by the coking industry. Low-volatile coal from the Appalachian bituminous coal basin is shipped to markets throughout the United States, and is exported to Japan, France, Italy, Canada, and other countries.

High-volatile bituminous coal is less strongly coking and is much more abundant than low-volatile bituminous coal. It is an important constituent in coking coal blends incorporating low-volatile bituminous coal.

Coals otherwise satisfactory for the manufacture of coke cannot be used for this purpose if they contain more than a minimum permissible percentage of the deleterious components ash, sulfur, and phosphorus. However such coals are well suited for raising steam, and the electric utility industry in the eastern United States is greatly dependent on them.

APPALACHIAN BITUMINOUS COAL

The Appalachian bituminous coal basin extends uninterrupted from northern Pennsylvania to western Alabama, a distance of 800 miles. It is 175 miles wide at the widest part in Pennsylvania and Ohio, and 35 miles wide at the narrowest part in Tennessee.

The basin is defined by outcrops of coal-bearing rocks of Pennsylvanian age. These rocks crop out around the edges of the basin and are structurally depressed about 2,000 feet in the center. The coal-bearing rocks in the basin are folded into several hundred small subsidiary anticlines and synclines, and locally on the eastern edge of the basin a few coal-bearing synclines are separated structurally from the main part of the basin. These isolated coal-bearing synclines are usually regarded as separate coal fields and have separate names as shown on figure 29.

The basin has yielded about 23 billion tons of bituminous coal from the beginning of mining to January 1, 1965. This huge total is 62 percent of the total cumulative coal production of the United States.

THE INDUSTRY

History

Information on the dates of actual discovery of bituminous coal on initial production in Appalachia is obscure. Most of the early explorers, who traveled by waterway, no doubt saw deposits exposed along the streams and rivers. During this early period, the presence of coal probably received little attention because there were no steam plants and charcoal was used in iron-making.

Before hostilities between the Colonies and Great Britain began in 1775, most of the coal used in the northern Colonies came from England and Nova Scotia and a small amount came from Virginia. Although originally imported for heating, coal became necessary for the manufacture of munitions.

As settlements pushed westward, deposits of coal along the streams and rivers were opened. Thus the coal along the James, Susquehanna, Monongahela, Allegheny, Ohio, Kentucky, Cumberland and the Big Muddy Rivers (and their tributaries) was exploited early. Where streams were not available for transportation, production was limited to that for local use. Small mines were started by local people but as markets expanded, larger companies moved in and consolidated many mines. The early coal industry was so far-flung that its growth attracted little attention.

In the era of canal construction, which began about 1820, little thought was given to coal as an energy source. However, when railroads were built parallel to waterways, coal became a major commodity in overland freight traffic. After the Civil War some railroads were built solely for coal traffic and movements by canal rapidly diminished.

Annual production in Appalachia totaled 139,359,000 tons in 1900, soared to 374,117,000 tons in 1918 during World War I, and fell to 220,187,000 tons in 1932 during the Great Depression.

Trends in production since World War II are shown in figure 31. In 1947, bituminous coal production in the Appalachian coal basin reached an all-time maximum of 468 million tons. Such output was brought about because considerable coal was shipped to Europe during the postwar recovery period. Production then declined to a postwar low of 316 million tons during 1949. Once again, a maximum was reached in 1951 when 399 million tons of coal was produced. The heavy demand was brought about by the Korean con-

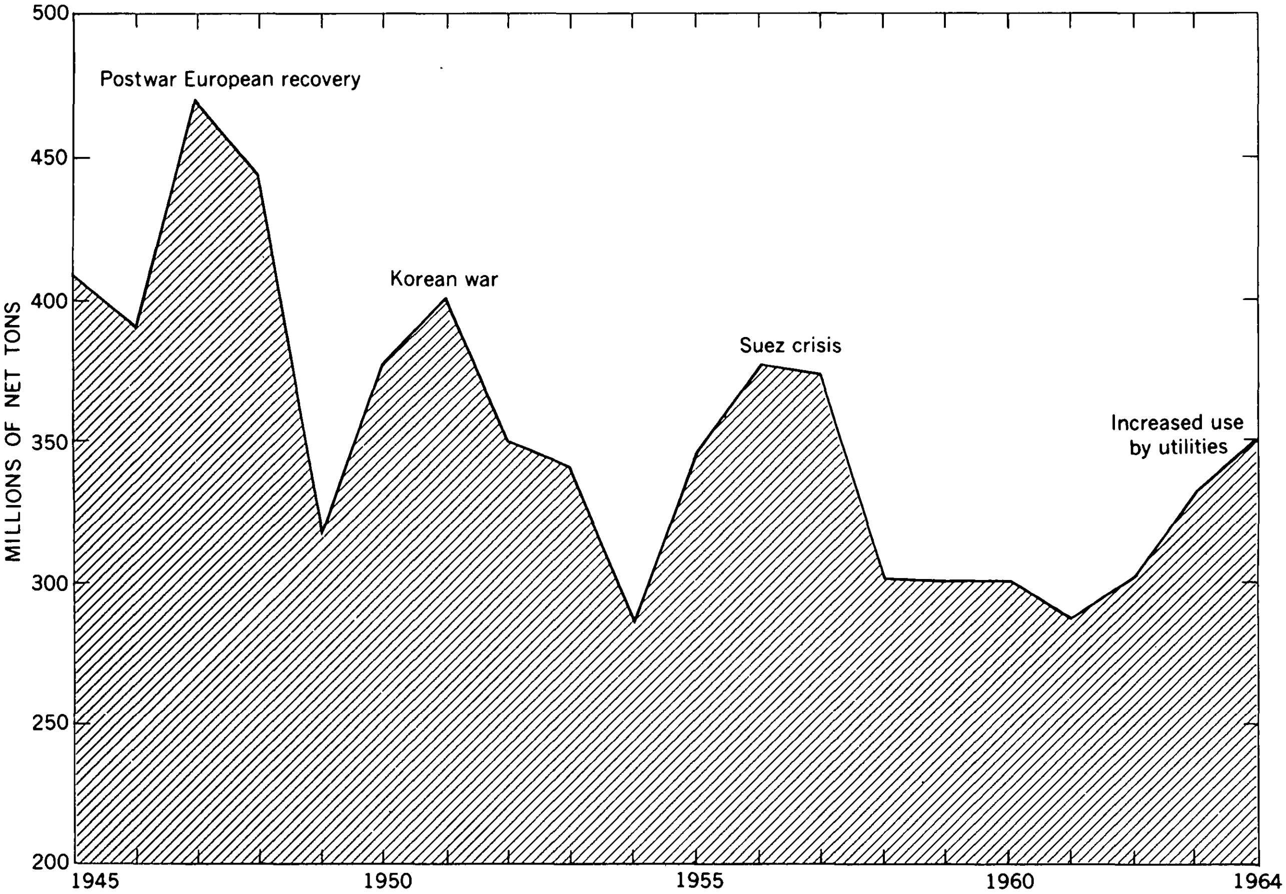


FIGURE 31.—Coal production in the Appalachian bituminous coal basin, 1945–64.

flict. Production then declined to a low of 285 million tons during 1954. Finally, another production peak was attained in 1957 when 372 million tons of coal was produced. The increased production was brought about by the Suez crisis when Europe again required increased imports of coal from the United States. At present (1966), coal production in Appalachia is again increasing. This increase in production is not the result of emergency situations, but is based on sound gains in dependable markets and therefore may be a trend that will continue for some time.

During the 1945–64 period, the national coal industry lost, almost in its entirety, 125 million tons of annual coal production that formerly was consumed by the railroads. Another 100 million tons of coal production was lost primarily in the heating market. Most of this output loss has been in Appalachia.

During this same period, however, the coal industry gained a large share of the increase in energy requirements of the electric utility industry. Since 1945, the national coal industry has increased its annual sales to electric utilities by more than 150 million tons. There is good reason to believe that the annual demand for coal by the electric utility industry will continue to grow and that by 1980, this demand will reach about 550 million tons. Appalachian coal should supply a significant part of this market.

Research into new industrial processes using coal suggest some very promising new developments, such as the conversion of coal into liquid hydrocarbons, char, and electrical energy. The Office of Coal Research in the Department of Interior estimates that by 1980 it is quite possible that as much as 10 percent of the petroleum requirements of the country may be obtained from about 50 million tons of coal. A comparable amount of coal may also be used to manufacture pipeline gas. Additional broad new applications undoubtedly will be developed to extract other materials and to utilize the energy content of coal in other ways.

Production and organization of the industry

During 1964, more than 350 million tons of bituminous coal was produced in the Appalachian coal basin. Every State but New York, North Carolina, and South Carolina reported coal production (fig. 32). Of the 373 counties that make up Appalachia, 151 produced bituminous coal in 1964, and 20 additional counties have produced coal during 1954–64. West Virginia led in production in 1964 with an output of more than 141 million tons from 36 counties. The next highest production was reported for Pennsylvania at more than 76 million tons. Kentucky, Ohio, and Virginia, in that order, produced 44.9, 34.5, and 31.6 million tons. Together these five States produced 329 million tons of bituminous coal in 1964 or more than two-thirds of the total for the United States.

During 1964 there were about 7,000 coal mines operating in the Appalachian coal basin (table 30). Average daily employment was nearly 107,000. These men worked more than 23.8 million man-days and were paid an estimated $619 million in wages. The average annual gross salary from coal mining was $5,800 for men who worked full time (223 days per year), but it must be kept in mind that many workers did not work full time.

The organization of the industry follows the familiar lines of private enterprise. The industry is highly competitive, the largest single producer accounting for less than 9 percent of total production. In number, the industry consists principally of single-mine companies. Larger companies, however, operate several mines, and there is a growing trend toward consolidation in order to effect greater economics of operation and administration. These larger companies produce the major part of the national total; in 1963, only 9 percent of the mines produced 78 percent of the coal.

TABLE 30.—*Coal production and related statistics for the Appalachian bituminous coal basin, 1964*

[Individual State totals include only those counties located in Appalachia. Salary computed on the basis of $26.00 per day as the average wage. Source: U.S. Bur. Mines]

State	Production (tons)	Mines	Men working daily (average)	Man-days worked	Value of coal produced (current dollars)	Salary of men working (current dollars)
Alabama	14, 435, 454	175	5, 421	1, 187, 345	102, 267, 000	30, 870, 970
Georgia	3, 900	1	13	1, 444	15, 000	37, 544
Kentucky	44, 891, 352	1, 903	18, 039	3, 397, 366	185, 575, 000	88, 331, 516
Maryland	1, 135, 836	67	316	74, 503	4, 511, 000	1, 937, 078
Ohio	34, 471, 125	342	7, 858	1, 847, 170	128, 519, 000	48, 026, 420
Pennsylvania	76, 530, 758	1, 123	23, 349	5, 304, 866	388, 218, 000	137, 926, 516
Tennessee	5, 990, 405	253	3, 032	590, 120	22, 674, 000	15, 343, 120
Virginia	31, 645, 538	1, 397	9, 338	2, 175, 154	123, 094, 000	56, 554, 004
West Virginia	141, 408, 498	1, 743	39, 308	9, 234, 723	693, 572, 000	240, 102, 798
Total	350, 512, 866	7, 004	106, 674	23, 812, 691	1, 648, 445, 000	619, 129, 966

FIGURE 32.—Area of 1964 coal production (shaded) in the Appalachian bituminous coal basin.

A sizable part of total production, 14 percent in 1963, is by "captive" mines. Most of these mines are affiliated with the steel industry, a much smaller number with the electric utility industry (U.S. Bur. Mines, 1965a, p. 120–121).

Present and future trends

The last few years have been rewarding for the bituminous coal industry in that coal production has increased from a low of 287 million tons in 1961 to a high of 350 million tons in 1964 (table 31). This overall increase of 63 million tons is an average increase of 21 million tons annually for 3 years. Production of bituminous coal in the Appalachian coal basin has increased at a slightly faster rate during the last 3 years than in the Nation as a whole. The annual rate of growth for the Appalachian segment of the industry has been about 6.8 percent, whereas national annual bituminous coal production has increased by only 6.5 percent.

TABLE 31.—*Production and value of coal from the Appalachian bituminous coal basin compared with total United States production, 1945–64*

[Source: U.S. Bur. Mines]

Year	United States bituminous coal and lignite production (thousands of tons)	Appalachian bituminous coal basin			
		Production (thousands of tons)	Percent of United States production	Value (thousands of dollars)	
				Current dollars	1958 constant dollars
1945	577, 617	408, 896	70.8	1, 341, 440	1, 767, 347
1946	533, 922	389, 189	72.9	1, 432, 294	1, 864, 990
1947	630, 624	468, 609	74.3	2, 080, 259	2, 515, 449
1948	599, 518	444, 002	74.1	2, 369, 867	2, 745, 965
1949	437, 868	316, 789	72.3	1, 649, 807	1, 900, 743
1950	516, 311	376, 568	72.9	1, 936, 941	2, 206, 176
1951	533, 665	399, 948	74.9	2, 075, 197	2, 203, 029
1952	466, 841	347, 532	74.4	1, 795, 281	1, 881, 813
1953	457, 290	340, 524	74.5	1, 768, 813	1, 875, 649
1054	391, 706	285, 716	72.8	1, 358, 431	1, 462, 215
1955	464, 633	346, 240	74.5	1, 644, 598	1, 789, 488
1956	500, 874	377, 013	75.2	1, 927, 660	2, 031, 176
1957	492, 704	372, 885	75.7	2, 011, 866	2, 044, 659
1958	410, 445	300, 113	73.1	1, 546, 392	1, 546, 392
1959	412, 027	298, 541	72.4	1, 500, 144	1, 479, 442
1960	415, 512	289, 934	71.9	1, 376, 937	1, 463, 792
1961	402, 977	287, 021	71.2	1, 382. 254	1, 373, 961
1962	422, 149	301, 498	71.4	1, 427, 285	1, 417, 294
1963	458, 928	329, 696	71.8	1, 526, 790	1, 520, 684
1964	486, 998	350, 513	72.0	1, 648, 446	1, 640, 204

Recent production gains have been based on sound economic factors. The overall confidence of the industry is reflected in the fact that during 1964 approximately $800 million was spent by the coal industry for improving and building new mining facilities and equipment and for operation and maintenance. This high investment rate has generated many technical improvements. In underground mining, for example, two new types of continuous machine miners were introduced, and several improvements were made in existing types of miners. New face haulage equipment was introduced which, when used with modern mining machines, holds promise of increasing productivity even further. In surface mining, the last few years have brought about improvements in auger drilling (figs. 33, 34) and spectacular gains in larger and more efficient earth-moving equipment. During 1964, a 140-cubic yard shovel went into operation. This shovel set a record for its size. In 1965, the record was again broken when a 180-cubic yard shovel went into operation.

A revolution in coal transportation is well underway. In overland transportation there has been significant use of the unit-train concept and in ocean transportation the use of supercolliers is increasing. The net result of the improvements in both overland and ocean transportation is that haulage rates are being substantially reduced. The use of unit trains has lowered rates by as much as $1.50 per ton. Large supercolliers have caused ocean freight rates to be lowered by as much as $1 a ton on coal going to Europe and $2 a ton on coal going to Japan.

The economic and technical improvements in mining and transporting coal have in turn improved considerably the competitive status of coal as an energy source. Three of the largest electric utilities in Florida are now consuming coal; this State was once the exclusive domain of other fuels. It was recently announced that a coal-burning, electric generating unit will be built in Mississippi, the first to be constructed in that State. Three new long-term contracts were recently signed to supply Appalachian coal to New England electric powerplants. Several electric utilities have built or plan to build mine-mouth generating plants in the Appalachian area. These plants will consume great quantities of coal at or near the mine site and supply electricity to markets inside and outside Appalachia.

Other changes in the Appalachian bituminous coal industry are taking place in employment, productivity, and value of production. In the absence of readily available information of this type for Appalachia, national trends may be applied to the industry in Appalachia because the bulk of the Nation's coal-mining activity is in this region. Young and Anderson (1965) presented a summary of national historical trends for the 1890–1964 period. Trends in production by mining method, however, have been tabulated from the actual Appalachian output for the 1955–1964 period.

In 1890, the number of employees in the industry was 192,204; this number reached a maximum of 704,793 in 1923, then in 1964 fell to 106,674 (table 30) the lowest since 1890. The drastic decrease in employment continues to be a serious problem to the coal-producing counties in the region because the Appalachian economy has long been structured around the bituminous coal industry.

Productivity in terms of average tons produced per man-day was 2.56 tons in 1890; in 1964 productivity reached an all time high of 16.84 tons. The tremendous increase in productivity resulted primarily from opening of more strip mines and from increased mechanization of underground mines. In 1917 only 1 percent of total United States production was mined by stripping; by 1964, nearly one-third of the total came from strip mines. The introduction of the continuous mining machine in 1948 was an important development in raising productivity in underground mining.

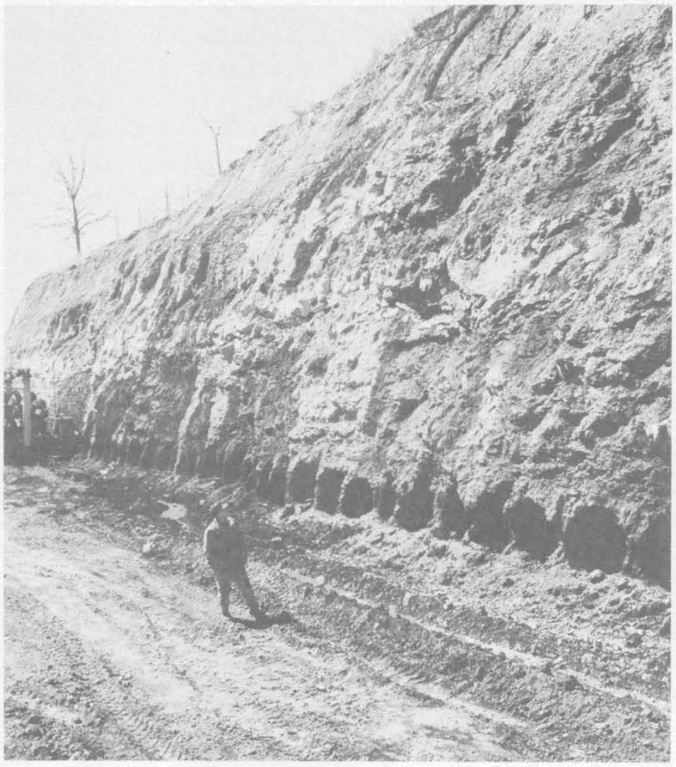


FIGURE 33.—Contour stripping and series of 48-inch auger holes drilled on 54-inch centers in 54-inch coal beds.

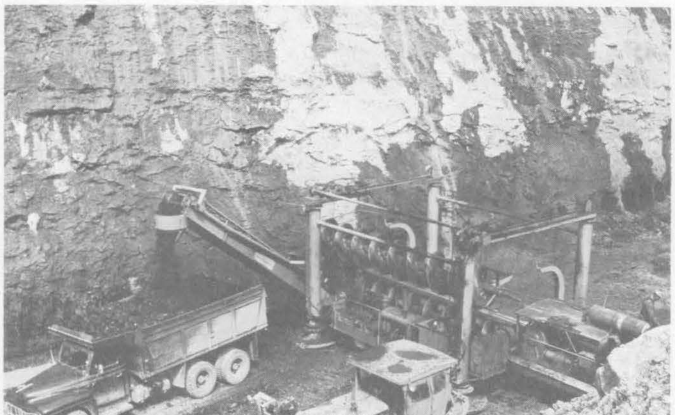


FIGURE 34.—Coal auger drilling 48-inch hole and loading coal into truck with integrated elevating conveyor.

In current dollars the average value per ton of bituminous coal produced at the mine in 1890 was \$0.99; the record per ton was \$5.08 in 1957. Recent values have been \$4.39 in 1963 and \$4.45 in 1964. The record year for total value of production was 1948—nearly \$3 billion.

Recent trends in Appalachia production by mining method are presented in table 32. In 1955, 82 percent of total production came from underground mines, 16 percent from strip pits, and 2 percent from auger mines. In 1964, 77 percent of total output originated in underground mines, 19 percent in strip pits and 4 percent in auger mines.

TABLE 32.—*Production (in thousand short tons) of Appalachian bituminous coal by mining method, 1955–64.*

[Source: US. Bur. Mines]

Year	Underground mines	Strip pits	Auger mines	Total
1955	282,679	57,552	6,009	346,240
1956	303,683	65,364	7,966	377,013
1957	301,955	63,084	7,846	372,885
1958	237,044	55,929	7,140	300,113
1959	233,853	57,194	7,504	298,551
1960	234,371	56,643	7,900	298,914
1961	224,193	54,828	8,000	287,021
1962	232,765	58,366	10,367	301,498
1963	252,758	64,639	12,299	329,696
1964	271,613	65,825	13,075	350,513

The future demand for bituminous coal will be keyed to the demand of the following four markets: industrial, coking, export, and electric utility. Analysis of historical trends in these markets and recent technological improvement, indicate that by 1980 production from the Appalachian bituminous coal basin will be about 550 million tons of coal annually.

The national coking industry requires nearly 100 million tons of bituminous coal and other industries an additional 100 million tons. These markets are expected to remain relatively stable over the next 15 years. In 1964, Appalachia supplied 160 million tons of bituminous coal to these industries. This supply is also expected to remain at the same level for the next 15 years.

The Appalachian bituminous coal basin is the source of virtually all the coal exported from the United States, and during the next 15 years this market is expected to grow at a rate slightly in excess of a million tons annually. Therefore, in 1980 Appalachia is expected to produce nearly 70 million tons of bituminous coal for the export market.

During 1964, the electric utilities consumed nearly 225 million tons of coal. Appalachia produced about 60 percent, or nearly 135 million tons of bituminous coal for this market. By 1980, the electric utilities are expected to use about 550 million tons of bituminous coal. Of this amount, Appalachia is expected to supply nearly 55 percent or 300 million tons.

GEOLOGIC AND TECHNOLOGIC INFORMATION

Because of the importance of fuel in the early phases of the industrial growth of the United States, the bituminous coal of the Appalachian basin was the subject of very early geologic and technologic investigations. One of the earliest reports on the occurrence of coal was that of H. D. Rogers (1838) who recorded data on the occurrence and distribution of coal in Pennsylvania. Since that date, coal investigations and the resulting reports have increased in number and in detail through the years. Many reports were published between 1880 and 1930 when use of coal was in the ascendancy. Between 1930 and 1950 the number of published coal reports declined significantly in part because of the prolonged depression of the 1930's and in part because of the increased attention devoted to the search for oil and natural gas. Beginning about 1950 and continuing to the present time, the number of published coal reports again has increased in response to the need for up-to-date information to stimulate greater production and utilization of Appalachian coal.

The bibliography of geologic reports pertaining to bituminous coal in the Appalachian basin now contains about 600 titles. To this figure must be added a comparable number of reports on coal production, use, composition, mining engineering, and technology and also more than 1,000 detailed topographic maps. Most of these reports pertain to specific areas or problems. A few, however, provide comprehensive summaries of the geology and occurrence of coal in individual States and include selected bibliographies. Among these are reports on Alabama (Culbertson, 1964), Georgia (V. H. Johnson, 1946), eastern Kentucky (Huddle and others, 1963), Maryland (Toenges and others, 1949, 1952), Ohio (Brant and DeLong, 1960), Pennsylvania (Reese and Sisler, 1928), Tennessee (Luther, 1959), Virginia (Audrew Brown and others, 1952), and West Virginia (Price and others, 1938; Headlee and Nolting, 1940). Special bibliographies on coal have also been prepared by the U.S. Bureau of Mines (1962), the U.S. Geological Survey (Berryhill, 1951), and by State agencies.

THICKNESS AND DISTRIBUTION OF COAL-BEARING ROCKS

The coal-bearing rocks in the Appalachian coal basin in general are thickest on the eastern edge of the basin, and they thin to the west, though there are many local variations to this trend. At Big Stone Gap, Va., rocks of Pennsylvanian age are 6,000 feet thick. In the Cahaba coal field of Alabama, the Pottsville Formation and the Pennsylvanian part of the underlying Parkwood Formation, which is the basal unit of the Pennsylvanian, are nearly 10,000 feet thick (Culberton, 1964). In marked contrast, rocks of the same age are 500 feet thick or less almost everywhere on the western edge of the basin.

To facilitate study and description, the Pennsylvanian rocks are divided into four major units (terms according to the usage in most areas):

Monongahela Group (locally Formation) (youngest)
Conemaugh Formation
Allegheny Group (locally Formation)
Pottsville Group (locally Formation) (oldest)

These units are subdivided into thinner units. The stratigraphic nomenclature used in coal reports in various parts of Appalachia is summarized in the section on "General Geology" (p. 55). Rocks representative of all Pennsylvanian time occur only in the northern part of the Appalachian bituminous coal basin. The sequence in this area therefore establishes the standard to which rocks elsewhere may be related.

The northern part of the Appalachian bituminous coal basin also contains in the structurally depressed center a thin sequence of beds of Permain age, which overlies the Pennsylvanian (pl. 2). These Permian beds are also coal bearing, but only one or two beds are of minable thickness.

In the southern part of the Appalachian bituminous coal basin the sequence of Pennsylvanian rocks, although locally very thick, represents only Pottsville time, and in places much of the upper part of this sequence has been removed by erosion.

Summaries of Pennsylvanian stratigraphy, as it relates to the occurrence and distribution of coal in individual States, are contained in previously cited reports.

Several beds of semianthracite in the Price Formation of Early Mississippian age have been mined in Pulaski and Wythe Counties, Va. This area, in the Valley and Ridge province, is part of the "Valley Coal Fields" of Virginia and lies outside the main Appalachian bituminous coal basin. Reserves in these two counties are estimated at 223 million tons (Andrew Brown and others, 1952, p. 36).

NUMBER AND DISTRIBUTION OF COAL BEDS

Coal beds of varied thickness and extent are at irregular stratigraphic intervals throughout the sequence of Pennsylvanian rocks. In Alabama, 43 coal beds have been named and described, of which 38 are thick enough locally to be mined. In Kentucky, 190 coal bed names have been used, but because different names have been applied locally to the same bed or beds, the actual number of beds is much smaller. About 33 beds are believed to be thick and continuous over considerable areas. In Ohio, 67 coal beds have been named and described, and 24 of these have been used in the preparation of resource estimates. In Pennsylvania, 36 beds have been named and described, of which 19 have been used in the preparation of resource estimates. In Tennessee, 45 beds have been named and described, and 27 have been used in the preparation of resource estimates. In Virginia, 60 named beds have been used in the preparation of resource estimates. In West Virginia, 117 beds have been named and described, of which 62 are thick enough locally to be mined.

Figures 35–40, respectively, show the names and sequence of coal beds in Alabama, Georgia, eastern Kentucky, Maryland, Ohio, and Virginia; tables 33–35, respectively, show the names and sequence in Pennsylvania, Tennessee, and West Virginia.

Important coal beds

Of the many coal beds listed on figures 35–40 and tables 33–35, a few are thick and continuous over large areas or possess special qualities that render them commercially desirable. As a consequence, a small group of beds has yielded the bulk of past production. In the northern part of Appalachia where a complete sequence of Pennsylvanian rocks is present, the coals are more numerous and are better developed in the upper part of the sequence. In this area the important beds are the Pittsburgh bed at the base of the Monongahela Group, the Upper Freeport bed at the top of the Allegheny Group, and the Lower Kittanning bed in the lower part of the Allegheny Group.

In the southern part of Appalachia, the coal beds are all in the Pottsville Formation and are the lowest in the sequence of Pennsylvanian rocks, with the exception of the thin Brock coal, which is in the underlying Parkwood Formation of Late Mississippian and Early Pennsylvanian age (Culbertson, 1963, fig. 193.1). In this area the extensively mined beds are the Fire Clay and the Upper Elkhorn No. 3 beds in Kentucky, the Pocahontas beds in Virginia and adjacent parts of West Virginia, the Sewanee bed in Tennessee, and the Pratt bed and beds in the Mary Lee coal zone in Alabama.

Production figures are not routinely collected for individual beds and no precise figures can be given for these nine most important coal beds, or zones, but they obviously have yielded the great bulk of past production in the Appalachian bituminous coal basin and in the Nation. It is estimated that the nine beds collectively have yielded about 75 percent of the cumulative past production of the basin and about 50 percent of the cumulative past production of the United States.

Pittsburgh bed

The Pittsburgh bed has been described by Ashley (1938, p. 56) as the most valuable individual mineral deposit in the United States and perhaps in the world. It is of minable thickness and is remarkably uniform in character over an area of about 6,000 square miles in Pennsylvania, West Virginia, Maryland, and Ohio. It is recognizable as a stratigraphic unit over a much larger area. According to Cross (1954, p. 34) and Wanless (1956, p. 122), it attains maximum thickness in western Maryland and northeastern West Virginia, and thins in all directions from this area. It is 22 feet thick at places in Mineral County, W.Va., and almost 20 feet thick in small areas in Preston County, W.Va. Farther to the west in southwestern Pennsylvania and northern West Virginia it is 8–14 feet thick. In easternmost Ohio and southern West Virginia it is 4–6 feet thick. It thins to generally less than 3 feet in northwestern Pennsylvania, eastern Ohio, and northern Kentucky. Much of the thicker and more accessible coal has, of course, been mined out, but large resources of coal of minable thickness remain in the ground.

An extrapolation of data assembled by Ashley (1938) and by Latimer (1962) indicates that the Pittsburgh bed has yielded about 8 billion tons of coal from the beginning of mining to January 1, 1965. This total is about 35 percent of the cumulative production of the Appalachian bituminous coal basin and 21 percent of the cumulative production of the United States over the same period.

Coal from the Pittsburgh bed has a high heat content and excellent coking properties. It was a major factor in the establishment of the iron and steel complex at Pittsburgh, Pa.

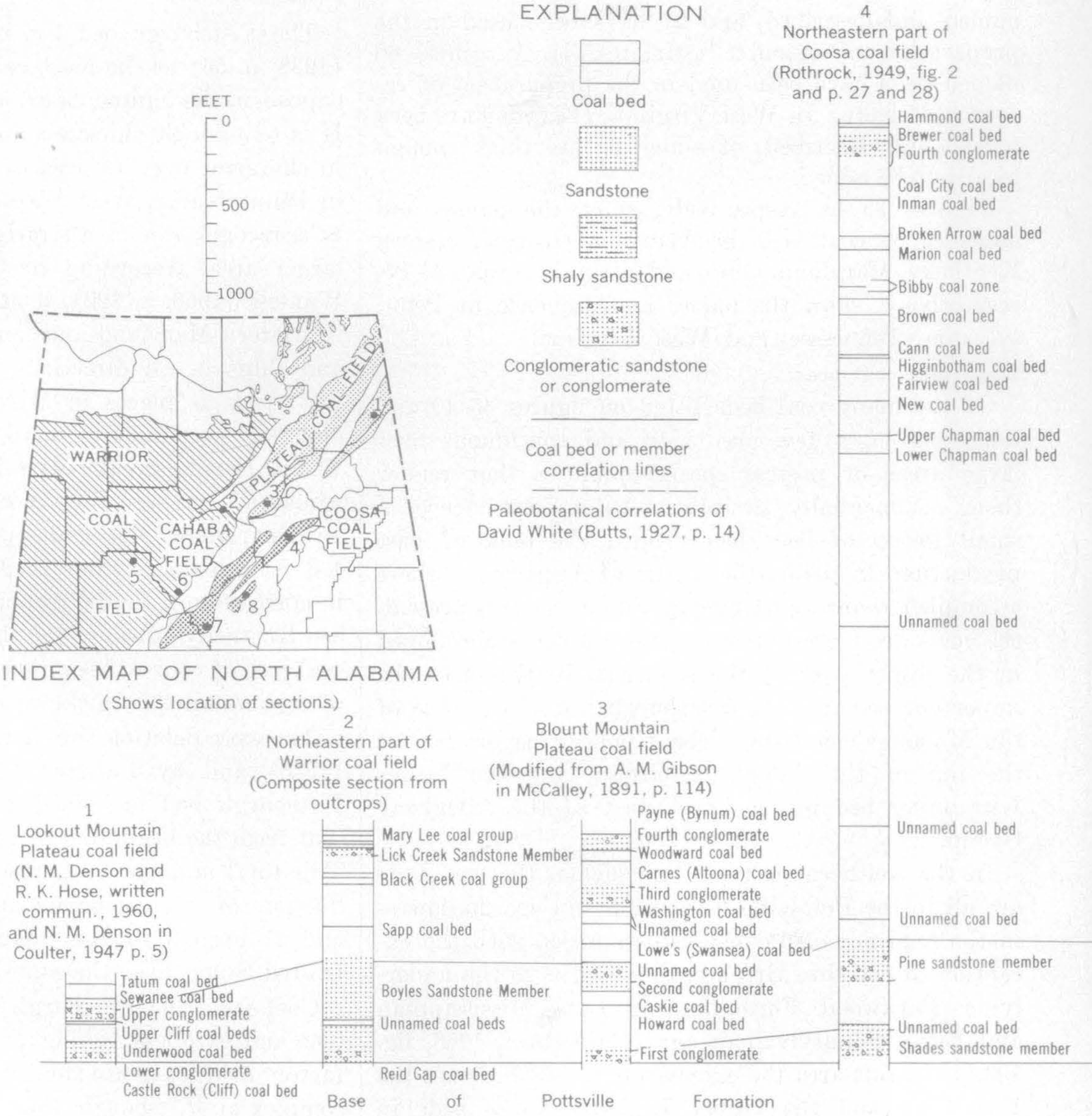
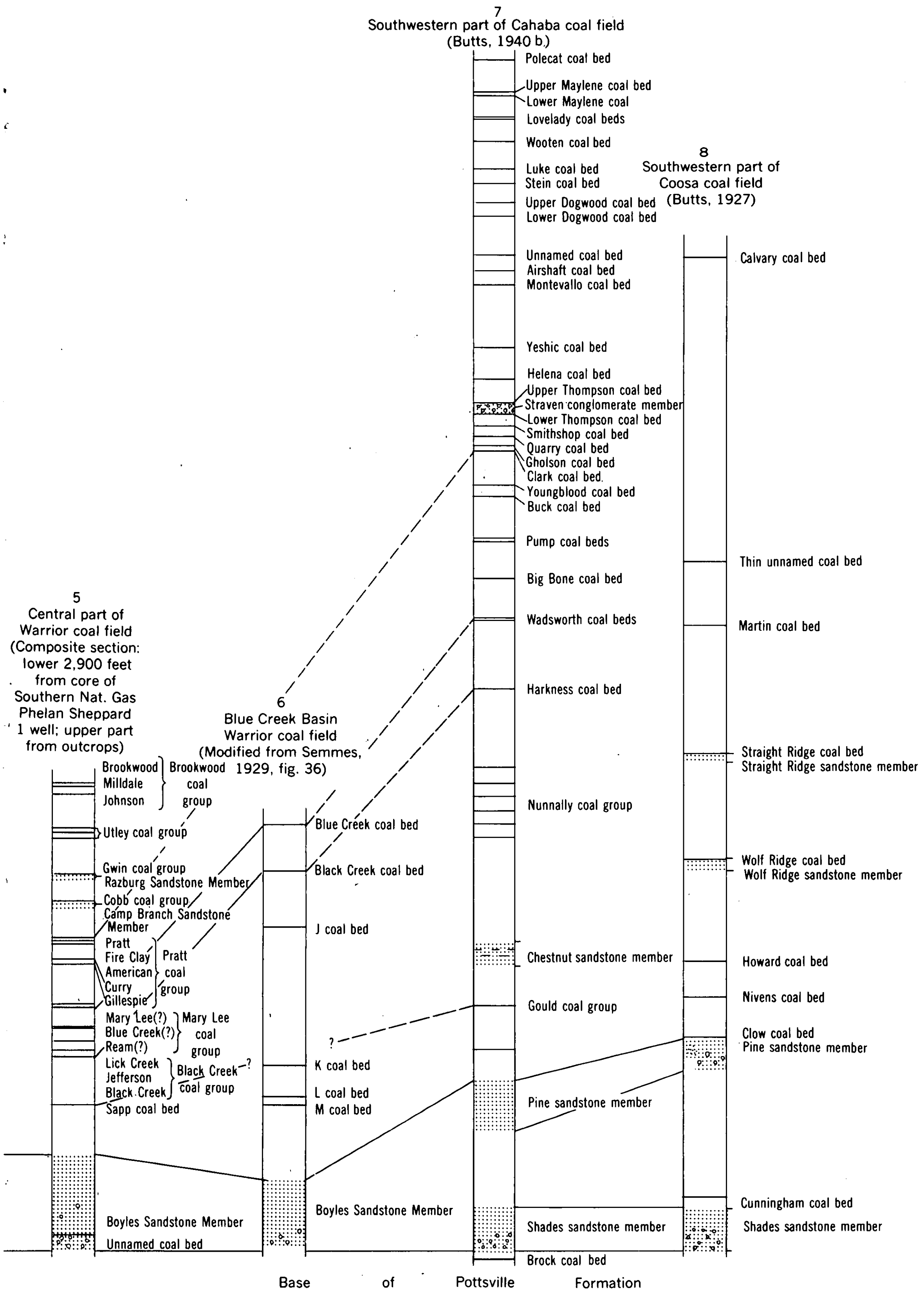


FIGURE 35.—Generalized sections of Pennsylvanian rocks in Alabama, showing sequence of



and approximate intervals between coal beds. Modified from Culbertson (1964, pl. 3).

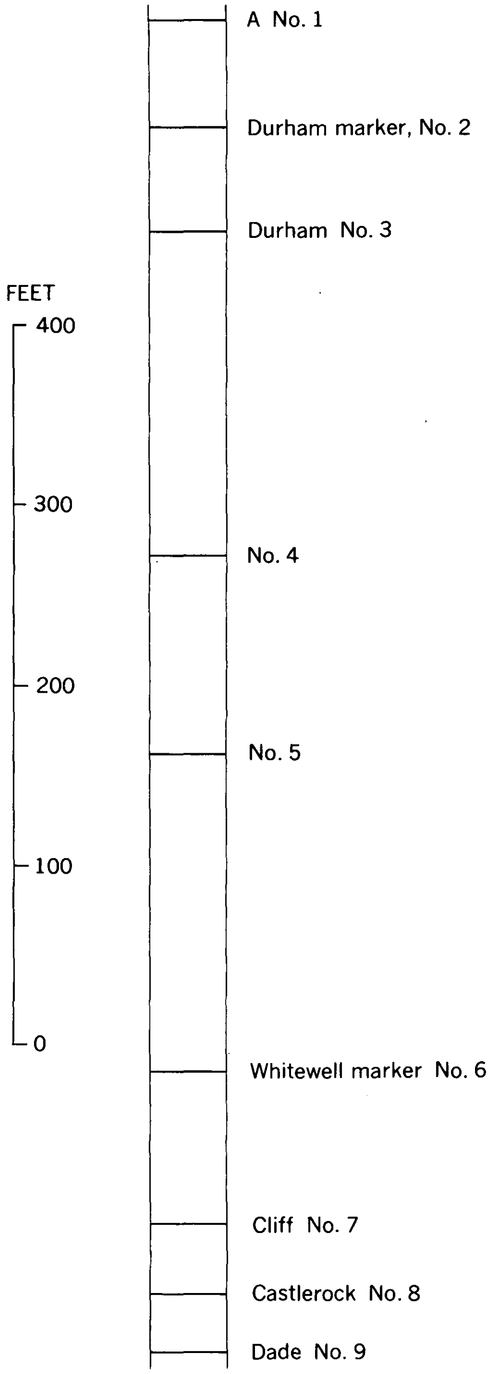


FIGURE 36.—Generalized section of Pennsylvanian rocks in Georgia, showing sequence of and approximate intervals between coal beds. After V. H. Johnson (1946).

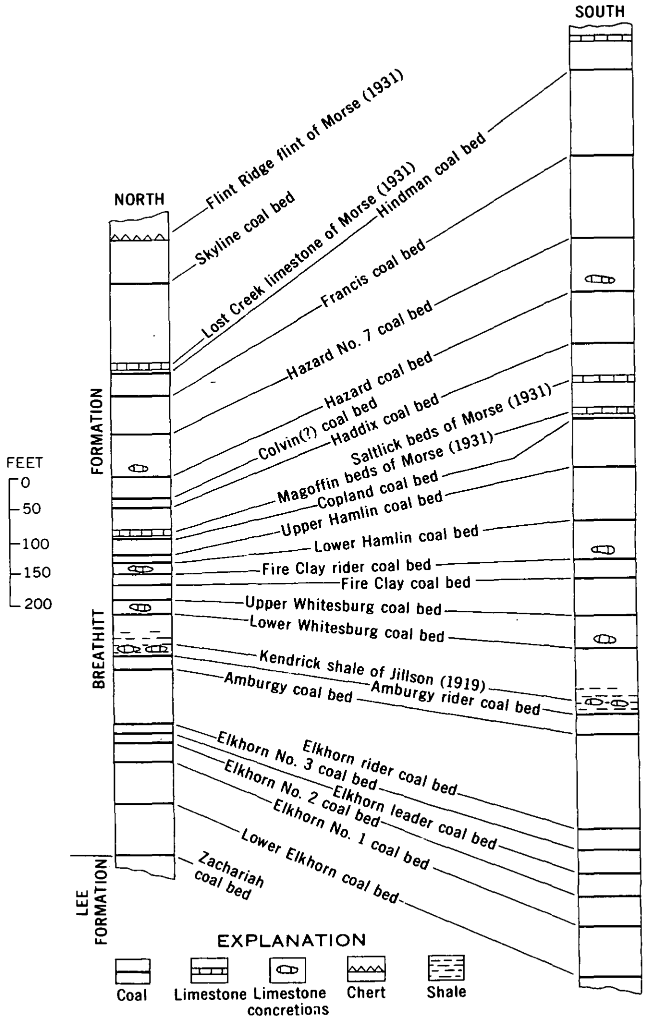


FIGURE 37.—Generalized sections of Pennsylvanian rocks in Breathitt, Knott, Leslie, and Perry Counties, and parts of Letcher and Harlan Counties, eastern Kentucky, showing sequence of and approximate intervals between coal beds. After Huddle and others (1963, p. 103).

Lower Kittanning (No. 5 Block) bed

The Lower Kittanning bed is thinner than the Pittsburgh bed, but it covers a larger area and contains larger resources. The Lower Kittanning bed, including other beds that are possibly stratigraphic equivalents, extends almost continuously throughout the northern part of the Appalachian coal basin in Pennsylvania, West Virginia, Ohio, and Maryland. It also extends into northern Kentucky where it is known as the Princess (No. 6) bed, and it may have a stratigraphic equivalent in the High Splint bed of Virginia, which crops out in southwestern Virginia.

According to Headlee and Nolting (1940, p. 44–49) and Wanless (1965, p. 112), the Lower Kittanning is thickest in central West Virginia and thins very gradually in all directions. With minor local variations, thicknesses are commonly as follows: central West Virginia, maximum of 12 feet; northern West Virginia, 4 feet; western Pennsylvania, 2½–4 feet; Ohio, 2–4 feet; Maryland, generally less than 3 feet; and southern West Virginia, 3–7 feet.

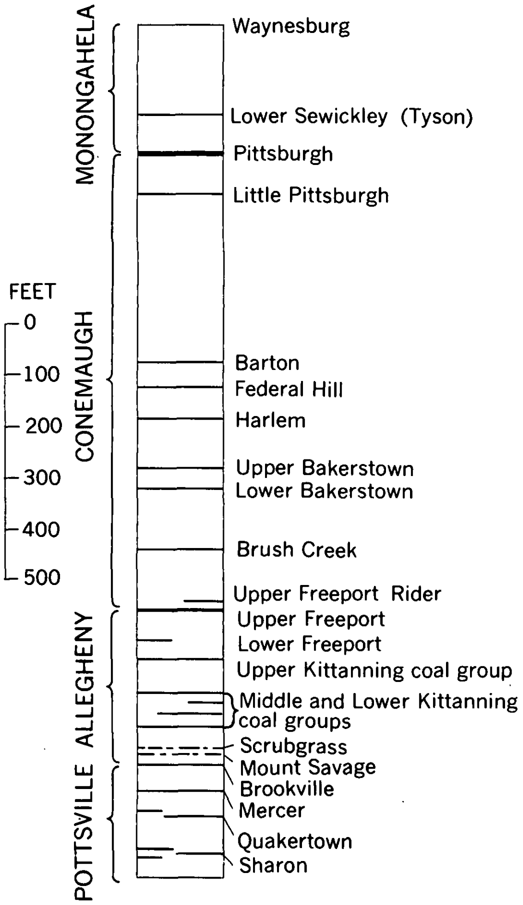


FIGURE 38.—Generalized section of Pennsylvanian rocks in Maryland, showing sequence of and approximate intervals between coal beds. After Toenges and others (1952, p. 21) and Vokes (1957, p. 110).

The Lower Kittanning bed has been mined in most areas where it is more than 4 feet thick, and it is second only to the Pittsburgh bed as a major source of bituminous coal in Appalachia.

Upper Freeport bed

The Upper Freeport bed is less uniform in thickness than the overlying Pittsburgh bed, or the underlying Lower Kittanning bed because it was subjected to local uplift and erosion before deposition of the overlying rocks. Nevertheless, it is a persistent bed throughout large areas in Pennsylvania, West Virginia, and Ohio, and is the third most important bituminous coal bed in the northern part of Appalachia, both in production and in contained resources.

Data assembled by Ashley (1928, p. 112), and Headlee and Nolting (1940, p. 33–37), and Wanless (1956, p. 120), show that the bed is thickest on the eastern edge of the Appalachian coal basin in southwestern Pennsylvania and central West Virginia.

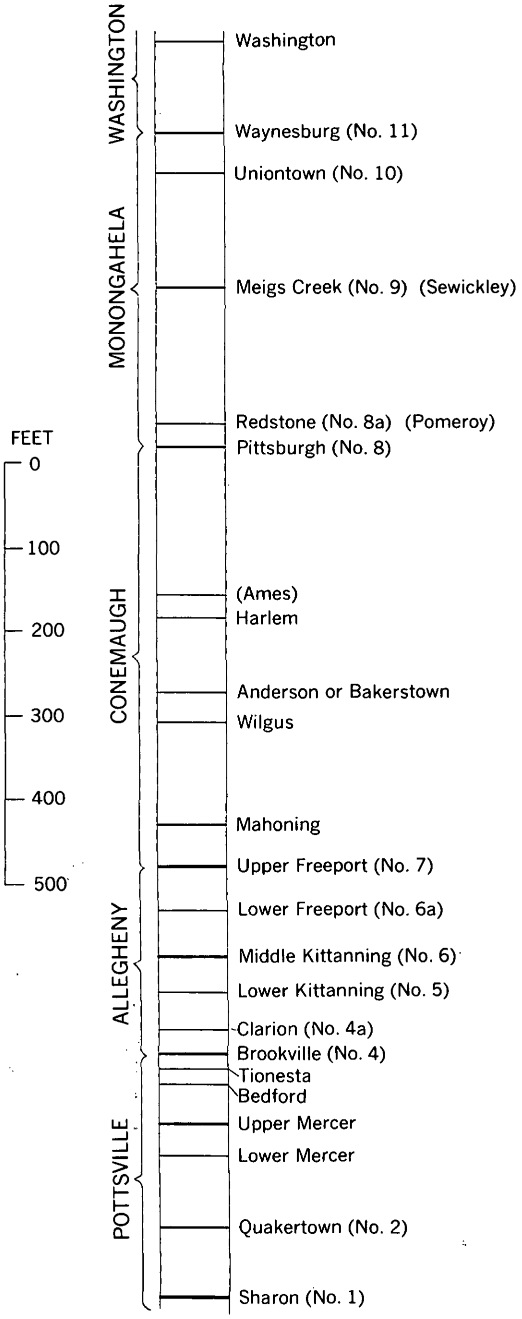


FIGURE 39.—Generalized section of Pennsylvanian and Lower Permian rocks in Ohio, showing sequence of and approximate intervals between coal beds. Modified from Brant and Delong (1960, p. 24).

In Pennsylvania, the Upper Freeport bed is thick and continuous in the counties around Pittsburgh and in the southwestern part of the State, where it ranges in thickness from 2 to 10 feet, and is 4–6 feet thick over considerable areas.

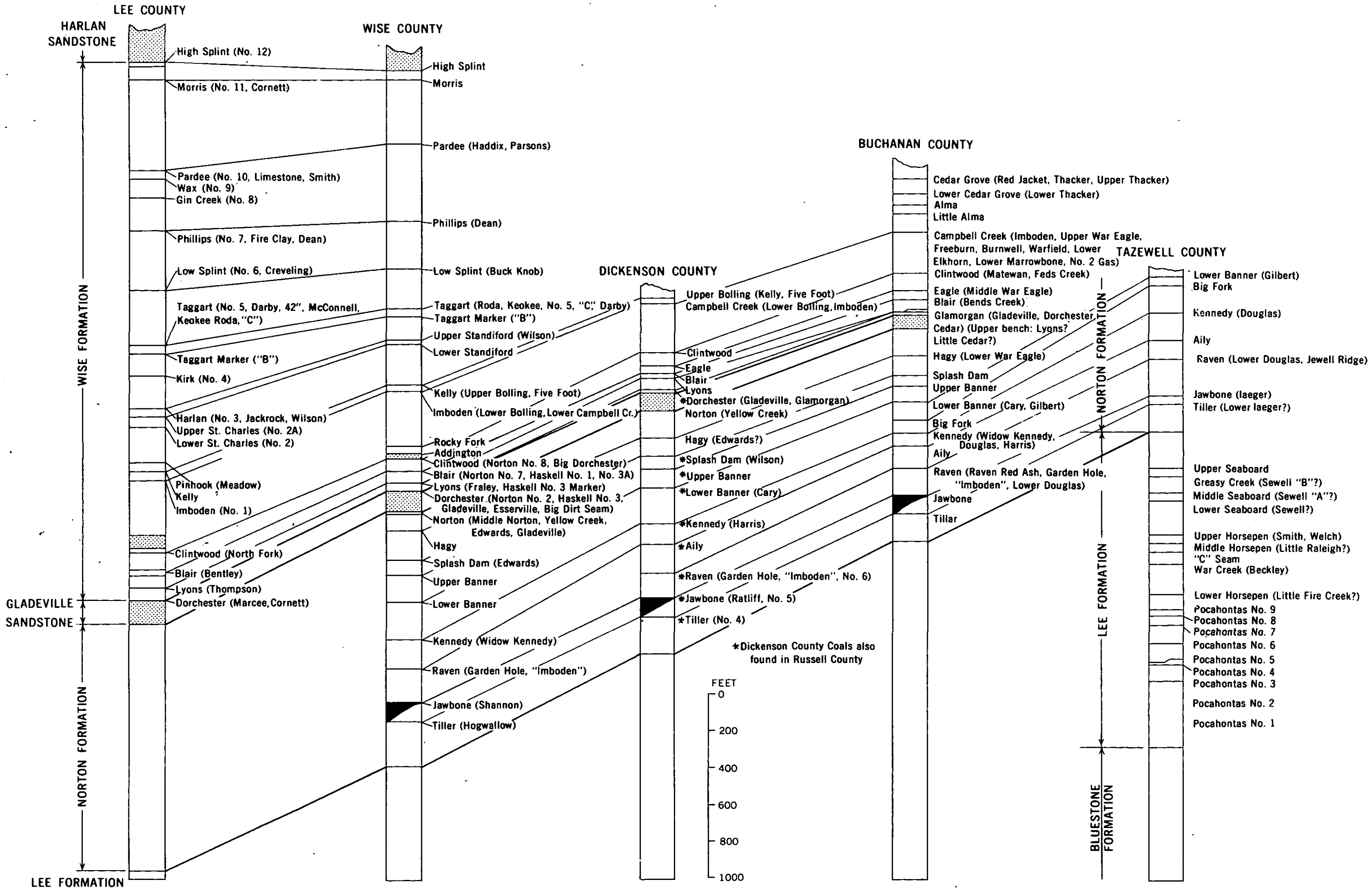


FIGURE 40.—Generalized sections of Pennsylvanian rocks in southwestern Virginia, showing sequence of and approximate intervals between coal beds. Modified from Andrew Brown and others (1952, pl. 3).

TABLE 33.—*Sequence and correlation of coal beds in Pennsylvania*

[After Reese and Sisler (1928, p. 6).*, bed used in coal-resource calculations]

Group or formation	*Coal bed and correlatives*
Washington	Washington*.
	Waynesburg A.
Monongahela	Waynesburg*.
	Uniontown*.
	Sewickley, Mapleton, Tyson, Berlin*.
	Redstone*.
	Pittsburgh, Rider*.
	Pittsburgh, Price* (mined very extensively).
Conemaugh	Morgantown.
	Little Pittsburgh.
	Franklin.
	Lonaconing.
	Hoffman.
	Clarksville.
	Wellersburg.
	Barton.
	Dequesne.
	Harlem.
	Upper Bakerstown*.
	Lower Bakerstown*.
	Brush Creek.
	Gallitzin.
	Mahoning.
Allegheny	Upper Freeport, E, Kelly* (mined very extensively).
	Lower Freeport, D, Moshannon, Dudley*.
	Upper Kittanning, C, Barnettstown, Seymour*.
	Middle Kittanning, C, Twin Bed, Morgan, Darlington*.
	Lower Kittanning, B, Barnett, Bloss, Miller* (mined very extensively).
	Scrubgrass.
	Clarion, A^1, Fulton, Clermont (in McKean County)*.
	Brookville, A, Gordon, Bear Creek, Clermont, Pardoe*.
Pottsville	Homewood, Tionesta(?).
	Upper Mercer, Upper Alton*.
	Lower Mercer, Lower Alton*.
	Quakertown.
	Sharon*

TABLE 34.—*Sequence of coal beds in Tennessee*

[After Luther (1959, p. 11); *, bed used in coal-resource calculations]

Group or formation	*Coal bed*
Cross Mountain	Bald Knob.
	Wild Cat.
	Cold Gap*.
	Grassy Spring*.
Vowell Mountain	Rock Spring*.
	Pine Bald*.
	Petree.
	Split.
Redoak Mountain	Pewee* (mined extensively).
	Walnut Mountain*.
	Red Ash*.
	Sharp.
	Beech Grove.
	Big Mary* (mined extensively).
Graves Gap	Windrock*.
	Craig.
	Pioneer*.
	Norman Pond.
	Jordan*.
Indian Bluff	Indian Fork.
	Stockstill.
	Joyner*.
Slatestone	Jellico* (mined very extensively).
	Terry Creek.
	Blue Gem*.
	Petros.
	Coal Creek*.
	Ant.
Crooked Fork	Poplar Creek* (mined extensively).
	Unnamed coal.
	Hooper*.
	Potters Falls.
	Rex*.
Crab Orchard Mountains.	Nemo*.
	Morgan Springs*.
	Oakdale.
	Lantana*.
	Unnamed coal.
	Sewanee* (mined extensively).
	Richland*.
Gizzard	Wilder* (mined extensively).
	Lower Wilder*.
	Bon Air*.
	White Oak*.
	Sale Creek.

TABLE 35.—*Sequence and correlation of coal beds used in preparation of resource estimates in West Virginia*

[Modified from Headlee and Nolting (1940, p. 236)]

Group or formation	*Coal bed and correlatives*
Washington	Washington.
Monongahela	Waynesburg.
	Uniontown.
	Sewickley.
	Redstone.
	Pittsburgh (mined very extensively).
Conemaugh	Little Pittsburgh.
	Little Clarksburg.
	Elk Lick.
	Harlem.
	Upper Bakerstown.
	Bakerstown, Thomas (mined extensively).
	Brush Creek.
	Mahoning:

TABLE 35.—*Sequence and correlation of coal beds used in preparation of resource estimates in West Virginia*—Continued

Group or Formation	*Coal bed and correlatives*
Allegheny	Upper Freeport (mined extensively).
	Lower Freeport.
	Upper Kittanning (mined extensively).
	Middle Kittanning.
	Lower Kittanning, No. 5 Block (mined very extensively).
	Clarion.
Kanawha	Upper Mercer, Stockton "A" (mined extensively).
	Stockton, Lower Mercer (mined extensively).
	Coalburg.
	Buffalo Creek.
	Winifrede, Quakertown(?).
	Chilton "A".
	Chilton.
	Hernshaw.
	Dingess, Williamson(?).
	Williamson.
	Cedar Grove, Thacker (mined extensively).
	Lower Cedar Grove.
	Alma (mined extensively).
	Campbell Creek, Peerless.
	Campbell Creek, No. 2 Gas (mined very extensively).
	Powellton, Brownstown.
	Matewan.
	Eagle (mined extensively).
	Bens Creek.
	Little Eagle.
	Cedar.
	Lower War Eagle.
	Glenalum Tunnel.
	Gilbert.
	Douglas.
	Lower Douglas.
New River	Iager, Hughes Ferry.
	Castle.
	Sewell "B".
	Sewell (mined extensively).
	Welch.
	Little Raleigh.
	Beckley.
	Fire Creek (mined extensively).
	Pocahontas No. 9.
	Pocahontas No. 8.
Pocahontas	Pocahontas No. 7.
	Pocahontas No. 6.
	Pocahontas No. 5.
	Pocahontas No. 4.
	Pocahontas No. 3 (mined extensively).
	Pocahontas No. 2.

In West Virginia, the Upper Freeport bed is considered to be of minable thickness and purity over an area of 1,165 square miles in a belt running north-south through the central part of the State. In the northern part of the belt the bed ranges in thickness from 3 to 12 feet and is 4–5 feet thick over large areas. It thins to the south and is generally less than 2 feet thick in Clay and Braxton Counties.

In Ohio, the Upper Freeport bed is very irregular in thickness. It is locally as much as 8 feet thick, but typically thins within a few miles, or tens of miles, to less than 14 inches. However, because of its wide distribution, it is the fourth most important bed in Ohio in known resources.

Elkhorn No. 3 bed

Of the many coal beds in eastern Kentucky described by Huddle and others (1963), the Elkhorn No. 3 bed and the Fire Clay bed are the most important in terms of production and contained resources. Both beds are recognizable as stratigraphic horizons over most of eastern Kentucky and parts of adjoining States. The Elkhorn No. 3 bed is of minable thickness over an area of 2,000 square miles in eastern Kentucky and 1,470 square miles in West Virginia, where it is known as the Cedar Grove bed. It has been mined extensively in southeastern Kentucky and in Logan, Mingo, Boone, and Kanawha Counties, W. Va. In areas where it is mined it is typically 3–4 feet thick, but locally it is as much as 8 feet thick. It has yielded more coal than any other bed in eastern Kentucky and it contains the largest remaining resources.

Fire Clay bed

At most exposures the Fire Clay coal bed contains in its lower part an easily recognizable parting of hard medium-brown flint clay, typically 4–6 inches thick. Because of this distinctive parting, the Fire Clay bed is an important horizon in stratigraphic correlations and structural interpretations throughout eastern Kentucky, southern West Virginia, Virginia, and Tennessee. The bed is of minable thickness over an area of 1,800 square miles in eastern Kentucky and 1,170 square miles in West Virginia, where it is known as the Chilton bed. It has been mined extensively in southeastern Kentucky and in Logan and Mingo Counties, W. Va. In areas where it is actively mined it is typically 3–4 feet thick, but local maximum thickness of as much as 8 feet have been observed. In eastern Kentucky, the Fire Clay bed is second only to the Elkhorn No. 3 bed in past production and in remaining resources.

Pocahontas beds

The name "Pocahontas" has been assigned to nine coal beds that crop out in the basal part of the Pennsylvanian sequence on the eastern edge of the Appalachian bituminous coal basin near the town of

Pocahontas, Va. (fig. 40). These beds extend over a rather small area in Tazewell and Buchanan Counties, Va., and adjoining counties in West Virginia. The Pocahontas beds have been mined very intensively because of their low ash, high heat content, and special coking properties, and consequently they have relatively small remaining resources. The Pocahontas coal is of medium- to low-volatile bituminous rank and is very strongly coking. For this reason it can be used to upgrade blends incorporating large amounts of high-volatile bituminous coal, which is less strongly coking. It is shipped to major steel manufacturing centers throughout the eastern United States.

The Pocahontas beds are numbered from 1 to 9 beginning at the bottom of the sequence. The Pocahontas No. 3 bed is the most important of the group. As described by Headlee and Nolting (1940, p. 143–145) and by Andrew Brown and others (1952, p. 11), it extends as a minable bed over 650 square miles in West Virginia, and a somewhat smaller area in Tazewell and Buchanan Counties, Va. Within this area the coal is 2–11 feet thick and is about 8 feet thick in most operating mines. The coal thins to the southwest and to the northeast. The Pocahontas No. 3 bed has been mined intensively since 1883, and most of the thicker and more accessible coal has been mined out. Most of present mining in the area is in other beds of the Pocahontas sequence, which are of similar quality but of smaller areal extent.

Sewanee bed

Most of Tennessee coal production is obtained from six coal beds (see table 34); the Sewanee bed is one of the best of these. The Sewanee bed crops out throughout the central and southern part of the Tennessee coal field and extends into nearby parts of Georgia and Alabama. It is mined extensively in the southernmost counties of Tennessee (Luther, 1959, p. 183–184, 189–190, 197–199, 260–262), where it is typically 2½–3½ feet thick but locally is 4 feet thick.

Pratt bed

The Pratt bed was an important factor in the establishment of the iron and steel industry at Birmingham, Ala. Through the years it has yielded large amounts of excellent coking coal to support this industry, and it still contains large resources. The bed is of minable thickness over an area of 775 square miles in the Warrior coal basin. In Jefferson County, Ala., near Birmingham, it ranges in thickness from 2½ to 6 feet, and averages about 4 feet. Farther to the west in Walker County it thins to less than 3 feet and is lower in rank and somewhat higher in ash and sulfur (Culbertson, 1964, p. 32).

Mary Lee coal zone

The Mary Lee coal zone, about 400 feet below the Pratt bed, covers a larger area and contains more coal than any other bed in Alabama. Culbertson (1964, p. 29–31), described the zone as consisting of five closely spaced beds that vary considerably in thickness and spacing. At places an individual bed is thick enough to be mined separately. At other places two or more beds coalesce and present the appearance of a multiple bed containing one or more thick partings. The Mary Lee zone contains at least one bed or multiple bed over an area of 1,500 square miles. Mines generally recover 4–6 feet of coal from the zone and locally may recover as much as 9–10 feet. The Mary Lee coal is relatively high in ash and low in sulfur. It has been mined extensively in the eastern part of the Warrior basin for the manufacure of coke.

Other coal beds

The nine coal beds described above are of such widespread regional importance that they overshadow many other thick beds of great local importance. Still other beds of less areal extent, or accessibility, or thickness, or of slightly higher ash and sulfur contents, are present in all parts of the Appalachian coal basin. These beds cannot be discussed separately, but they are shown in figures 35–40 and tables 33–35 and are discussed in the summary reports cited on page 110.

The large potential resources in these economically less competitive beds cannot be mined on a large commercial scale at present because of the lower cost coal obtainable from the thicker and more extensive beds. Nevertheless, these coals supply low-cost fuel for local use and provide a firm bulwark against future energy needs.

MINOR ELEMENTS IN BITUMINOUS COAL

Coal contains small quantities of nearly all elements, which were introduced in one or more of the following ways:

1. As inert material washed into the coal-forming swamp at the time of plant accumulation.
2. As a chemical precipitate from the swamp water.
3. As a minor constituent of the original plant cells.
4. As material, introduced after coal formation, primarily by downward- and lateral-moving ground water.

When coal is burned, most of these elements are concentrated in the coal ash; the compounds of silicon, aluminum, iron, calcium, magnesium, potassium, sodium, sulfur, and oxygen typically make up 93–98 percent of the total weight of the ash (Selvig and Gibson, 1956). The remaining few percent of coal ash contains about 25 different minor elements, the concentration of which differs greatly in different areas and beds.

Most of the minor elements occur in coal in about the same concentration as in the earth's crust, but a few, notably uranium, molybdenum, arsenic, boron, and germanium, occur in vastly greater concentrations and a few others, including barium, strontium, and lead, occur in significantly greater concentrations (Francis, 1954, p. 98; Krauskopf, 1955, p. 418; Mason, 1958, p. 44).

In Appalachia, most occurrences of minor elements in coal are of scientific rather than of economic interest, but occurrences of germanium are fairly common and deserve separate mention.

Germanium

In the United States, germanium is produced primarily as a byproduct of zinc smelting. The expanded use of germanium as a semiconductor in crystal diodes, transistors, and rectifiers in the period following World War II greatly stimulated interest in coal as a secondary source of this element, and, as a result, much new information was obtained (Headlee and Hunter, 1951, Stadnichenko and others, 1953). According to these investigators, germanium is concentrated locally in the top and bottom layers or just above a thick parting in a coal bed, and is much more abundant in the bright bands (vitrain) than in the dull bands.

The commercial coal richest in germanium thus far discovered is the Lower Kittanning bed in eastern Ohio. In this bed, the germanium is concentrated in the lower layer. Samples of this layer contain 0.2 percent germanium in the ash, and the ash ranges from 3.54 to 6.86 percent of the coal (Stadnichenko and others, 1953, p. 1, 9).

Since this period of intensive study, interest in germanium in coal has slackened because of the increasing competition of silicon as a semiconductor and because of increased efficiency in the use of germanium; byproduct and imported germanium therefore continue to supply the commercial demand.

BITUMINOUS COAL RESOURCES

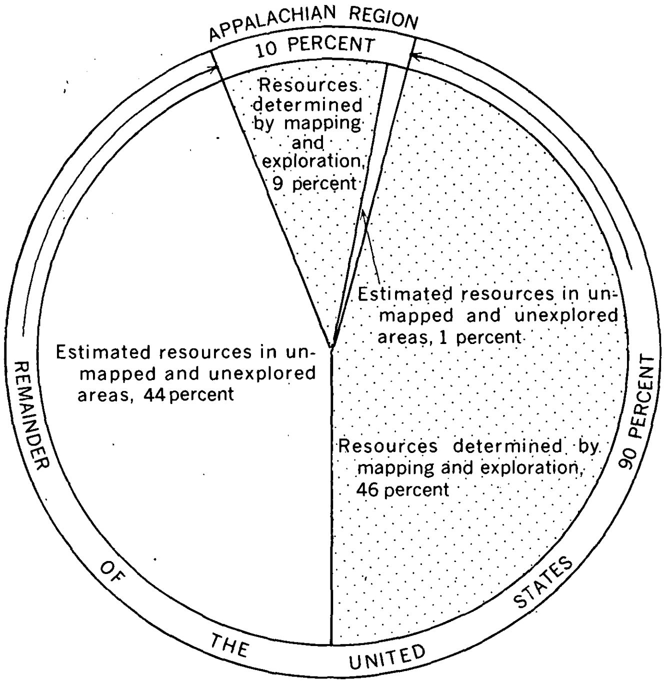


FIGURE 41.—Bituminous coal resources in the Appalachian Region compared with coal resources in the remainder of the United States. Percentages on a tonnage basis include beds of bituminous coal and anthracite 14 inches or more thick and beds of subbituminous coal and lignite 2½ feet or more thick, to a maximum depth of 3,000 feet below the surface.

The bituminous coal resources of the Appalachian bituminous coal basin represent about 10 percent of the total coal resources of the United States expressed on a simple tonnage basis (fig. 41). On a Btu (British thermal unit) basis the percentage is larger because the large tonnage of lower rank coal in the Rocky Mountain and northern Great Plains regions has a lower heat content than the bituminous coal in Appalachia. The bituminous coal in Appalachia remaining in the ground on January 1, 1965, is estimated to be 313,217 million tons, of which roughly half is deemed recoverable. This recoverable tonnage can best be understood by comparison with past production. It is, for example, 440 times the 1964 production of bituminous coal in Appalachia, and 7 times the total cumulative production of bituminous coal in Appalachia from the beginning of mining to January 1, 1965.

The distribution of this tonnage by State is given in table 36. As noted in column 7 of table 36, West Virginia has the largest estimated total, followed in order by Pennsylvania, eastern Kentucky, and Ohio.

A large part of the estimated coal resources of Alabama, eastern Kentucky, Ohio, Tennessee, and Virginia has been classified in considerable detail according to thickness of beds, thickness of overburden, and other features. The total thus classified in the five States is nearly 100 billion tons, or about one-third of the total estimated to be present in Appalachia. The percentage distribution of this tonnage by thickness of beds is shown on figure 42. This illustration clearly shows the substantial percentage concentrated in beds in the intermediate thickness category of 28–42 inches, and in the thick category of more than 42 inches.

TABLE 36.—*Bituminous coal resources of the Appalachian Region, Jan. 1, 1965, by State*

[In millions of short tons. Includes beds 14 inches or more thick to a maximum depth of 3,000 feet below the surface]

State	Resources determined by mapping and exploration					Estimated additional resources in unmapped and unexplored areas[4]	Estimated total remaining resources in the ground	Estimated recoverable resources, assuming 50 percent recoverability in mining
	Original or remaining resources in the ground[1]		Resources depleted to Jan. 1, 1965		Remaining resources Jan. 1, 1965			
	Date of publication of estimate	Tons	Production[2]	Production plus loss in mining[3]				
	1	2	3	4	5(2−4)	6	7(5+6)	8(7×½)
Alabama	1964	[5] 13, 774	[6] 89	178	13, 596	[7] 20, 000	33, 596	16, 798
Georgia	1953	100	12	24	76	30	106	54
Eastern Kentucky	1963	[8] 32, 271	[9] 355	710	31, 561	24, 000	55, 561	27, 780
Maryland	1953	[10] 1, 200	[11] 11	22	1, 178	400	1, 578	789
Ohio	1960	46, 488	2, 230	4, 460	42, 028	2, 000	44, 028	22, 014
Pennsylvania	1928	75, 093	8, 619	17, 238	57, 855	0	57, 855	28, 927
Tennessee	1965	[12] 2, 748	[13] 36	72	2, 676	2, 000	4, 676	2, 338
Virginia	1952	12, 051	933	1, 866	10, 185	3, 000	13, 185	6, 592
West Virginia	1940	116, 618	6, 993	13, 986	102, 632	0	102, 632	51, 316
Total	----------	300, 343	[14] 19, 278	38, 556	261, 787	51, 430	313, 217	156, 608

[1] From Averitt, Paul (1961), p. 10–11, supplemented by new data for Tennessee supplied by E. T. Luther (written commun. April 13, 1965).

[2] Production, 1800–1885, from Eavenson (1942); production, 1886-1923, from U.S. Geol. Survey (1883-1927); production 1924–31, from U.S. Bur. Mines (1928–32); production 1932 through 1964 from U.S. Bur. Mines (1933–65).

[3] Assuming past losses equal past production.

[4] Estimate by H. L. Berryhill, Jr. (Virginia), R. A. Brant (Ohio), W. C. Culbertson (Alabama), K. J. Englund (Kentucky), E. T. Luther (Tennessee), and Paul Averitt (remaining States).

[5] Remaining resources, January 1, 1958.

[6] Production 1958-64.

[7] An additional 6,000 million tons is estimated to be present in the Warrior Basin at depths of 3,000–6,000 feet.

[8] Remaining resources, January 1, 1956.

[9] Production 1956–64.

[10] Remaining resources, January 1, 1950.

[11] Production 1950–64.

[12] Remaining resources, January 1, 1959.

[13] Production 1959–64.

[14] Less than total recorded production of about 23 billion tons. See footnotes, 5, 6, 8, 9–13.

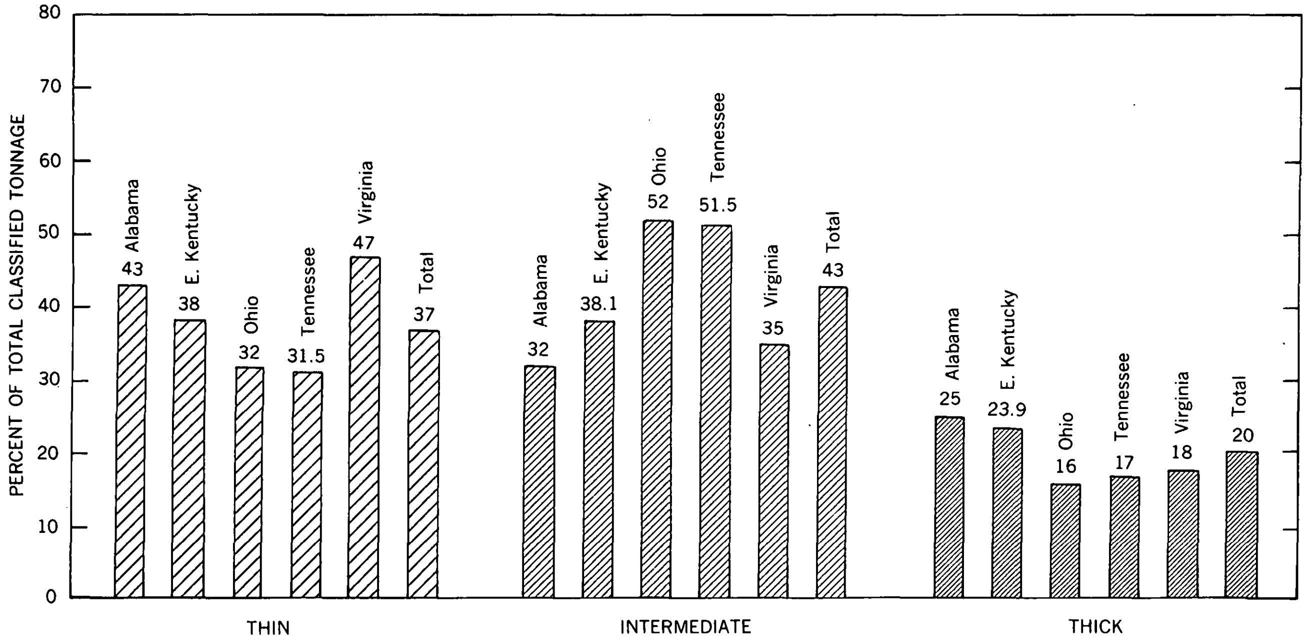


FIGURE 42.—Percentage distribution of classified coal resources in Alabama, eastern Kentucky, Ohio, Tennessee, and Virginia, according to thickness of beds. In Ohio beds classed as intermediate are 28–54 inches, and as thick are more than 54 inches; elsewhere beds classed as thin are 14–28 inches thick, as intermediate are 28–42 inches thick, and as thick are more than 42 inches.

PENNSYLVANIA ANTHRACITE

The Pennsylvania anthracite fields are northeast of and completely separate from the Appalachian bituminous coal basin (fig. 29). The anthracite from these fields has contributed greatly to the industrial growth of Pennsylvania and has had a far-reaching influence upon the early industrial development of the United States.

It is estimated that 5.3 billion tons of coal, valued at $18.65 billion, has been produced in the Pennsylvania anthracite fields since the first regular shipments began in 1820. This substantial output is about 15 percent of the total coal and lignite production in the United States to date, and more than 20 percent of the total production of coal from Appalachia.

In recent years the Pennsylvania anthracite industry has contributed annually only about 1 percent of the Nation's energy supply, largely because of the decline in use of anthracite for household heating. However, anthracite is still an important fuel resource because of the large remaining resources and the proximity and accessibility of the anthracite fields to major points of consumption.

The anthracite occurs in rocks of Pennsylvanian age that underlie four separate but contiguous coal fields named according to their relative geographic locations as the Northern, Eastern Middle, Western Middle, and Southern anthracite fields (fig. 43). The coal-bearing rocks of the anthracite fields cover 484 square miles but, because the coal fields are separated by noncoal-bearing rocks, they are spread over an area of about 3,300 square miles in 10 counties: Carbon, Columbia, Dauphin, Lackawanna, Lebanon, Luzerne, Northumberland, Schuylkill, Susquehanna, and Wayne.

The anthracite fields trend northeast in an echelon arrangement. They range from 24 to 70 miles in length and from a fraction of a mile to 8 miles in width. The coal-bearing rocks are as much as 4,900 feet thick in the deeper parts of the fields, the thickest part of the sequence containing 50 or more coal beds.

The anthracite-producing area is separated by coal-trade usage into three regions: the Wyoming, synonymous with the Northern field; the Lehigh, composed of all the Eastern Middle field and that part of the Southern field lying east of Tamaqua; and the Schuylkill, which includes all the Western Middle field and that part of the Southern field lying west of Tamaqua (fig. 43). Anthracite is also recovered in Berks, Lancaster, and Snyder Counties by dredging the streams and rivers traversing the coal fields, and a small amount of semianthracite produced in Sullivan County is included in annual production statistics. However, the Nation's anthracite production comes almost entirely from the Appalachian Region; only Berks, Dauphin, Lancaster, and Lebanon Counties lie just outside the eastern boundary of the area. In 1964, the latter counties represented only about 5 percent of the total output and about 2 percent of the value of production.

THE INDUSTRY

The anthracite industry is highly complex, ranging from small two-man independent operations to large integrated companies which operate many mines, pits, preparation plants, and other facilities employing several hundred people. Many of the small operations are individual underground mines or strip pits which primarily produce run-of-mine coal for sale to preparation plants. Several preparation plants have no mining facilities but purchase their entire input from independent producers of run-of-mine coal (J. A. Vaughan, in U.S. Bur. Mines, 1965a, p. 45). In 1964, 25 companies produced about 77 percent of the total output.

In the past, the domestic space-heating market has been the largest outlet for anthracite; it consumed more than 3 million tons in 1964 (table 37). Of total shipments to points in the United States, about 50 percent terminated within Pennsylvania. The export market absorbed about 2,700,000 tons, including shipments to U.S. Armed Forces overseas (Vaughan and Cooke, 1965). The exports were chiefly of the space-heating sizes. Public utilities burned

TABLE 37.—*Retail dealer deliveries and consumption of Pennsylvania anthracite in the United States, 1955–64, by selected consumer categories*

[In thousands of short tons. NA, not available. Source: Vaughan and Cooke (1965)]

Year	Retail dealer deliveries [1]	Colliery fuel	Railroads	Electric utilities	Briquet plants	Cement plants	Iron and steel industry		
							Coke making	Sintering and pelletizing	Other
1955	13,019	419	457	3,209	264	199	366	385	443
1956	13,018	342	409	3,296	228	244	377	564	625
1957	10,670	279	361	3,363	156	221	389	868	698
1958	9,386	195	335	2,786	120	183	255	685	686
1959	7,562	129	292	2,629	43	159	369	780	683
1960	6,775	102	248	2,751	31	152	370	754	720
1961	5,070	45	NA	2,509	28	153	320	588	685
1962	4,767	152	NA	2,297	(2)	188	420	560	609
1963	4,055	161	NA	2,155	(2)	184	451	766	670
1964	3,334	144	NA	2,239	(2)	153	492	1,014	NA

[1] Estimated from reports submitted by a selected list of retail dealers. The data do not include deliveries in the local sales area (the production area). Local sales exceeded 3 million tons in both 1963 and 1964, according to data of the Pennsylvania Department of Mines and Mineral Industries.

[2] Concealed to avoid disclosure of individual company data.

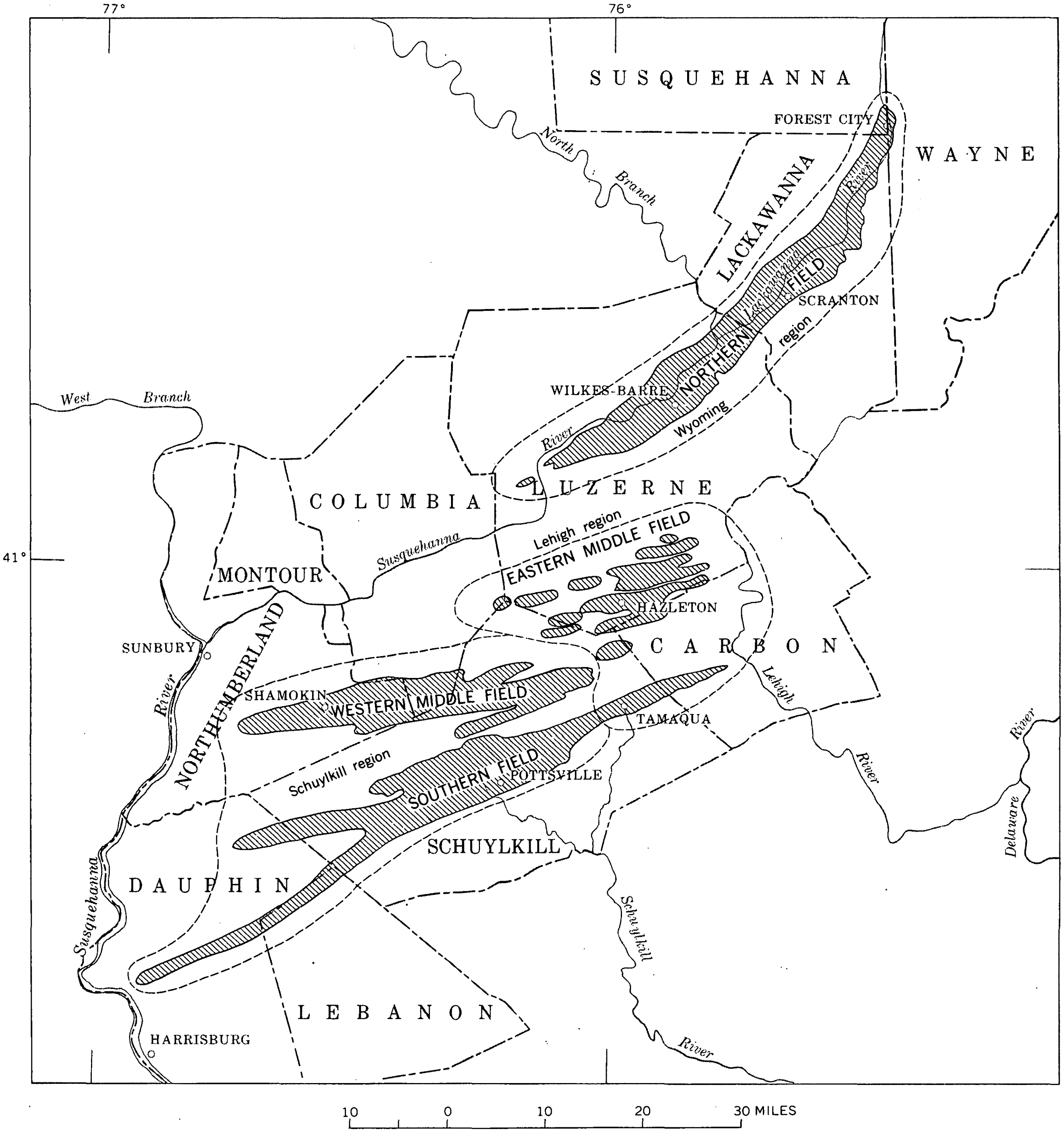


FIGURE 43.—Anthracite-producing regions of Pennsylvania. Modified from Vaughan and Cooke (1965, p. 44).

2,239,000 tons and the iron and steel industry consumed an estimated 2 million tons. The remainder of production went into stocks, colliery fuel, use at cement and briquet plants, and a variety of other purposes such as water and chemical filters and purifiers, electrodes and sundry electronic equipment, telephone components, and carbureted water gas for which definitive data are not available.

History and production

The anthracite industry is generally considered to have commenced in Pennsylvania in 1820, for in that year reasonably complete records of waterborne shipments were initiated. However, the first reference to anthracite in Pennsylvania was made by Gabriel Thomas in 1698 (Eavenson, 1942, p. 138) and many reports are known of its use before 1820. Between 1750 and 1755, Indians traded anthracite to a smith in Nazareth, Pa., in return for repairing their guns. In 1769, the Gore brothers, blacksmiths, used anthracite in a forge at Wilkes-Barre.

The arsenal at Carlisle, Pa., received some anthracite during the Revolutionary War. In 1788, Judge Jesse Fell used anthracite in his nailery at Wilkes-Barre, but it was not then regarded as a suitable domestic fuel. Judge Fell persisted and, in 1808, successfully burned anthracite in an open grate in his fireplace without forced draft. This event marked the inception of the use of anthracite as a domestic fuel. Anthracite production did not flourish, however, at this time because firewood was both plentiful and inexpensive and because the country was nonindustrialized and transportation systems were poorly developed. It is estimated that 20 tons were produced in 1769 and 950 tons in 1808; the first significant surge in output to 43,000 tons occurred in 1825 when the Schuylkill Canal opened (table 38). As other canals and the railroads were constructed to bring coal to rapidly expanding consumption centers, production increased steadily and reached a record output of 99.6 million tons in 1917. Thereafter, anthracite production declined to a low point, in the 20th century, of 16.9 million tons in 1962. Output in 1963 and 1964 increased slightly above the 1962 level. During World War II there was an upswing in production, but fuel oil and natural gas began to make major inroads into fuel markets in the 1920's and 1930's, and today predominate in anthracite's principal markets.

The first anthracite produced came from the Wyoming region, or Northern field, and represented the only output for many years. The lead in production among the regions fluctuated throughout the early history of the industry. Of the 1964 total production, 8,792,000 tons came from the Schuylkill region, 5,206,000 tons from the Wyoming region, and 3,187,000 tons from the Lehigh region.

TABLE 38.—*Production and value of Pennsylvania anthracite for selected years*

[NA, not available. Data in this table are for selected years of production only; from 1769 through 1964, cumulative production exceeds 5 billion tons. Source: 1769–1859, Eavenson (1942, p. 498); 1891–1964, Vaughan (1964); Vaughan and Cooke (1965)]

Year	Production (short tons)	Value	
		Current dollars	1958 constant dollars
1769	20	NA	NA
1788	200	NA	NA
1808	950	NA	NA
1825	43, 119	NA	NA
1828	102, 944	NA	NA
1837	1, 163, 950	NA	NA
1859	10, 092, 013	NA	NA
1891	50, 665, 431	73, 944, 735	321, 496, 919
1917	99, 611, 811	283, 650, 723	595, 893, 439
1923	93, 339, 009	506, 786, 768	841, 823, 500
1933	49, 541, 344	206, 718, 405	493, 354, 145
1944	63, 701, 363	354, 582, 884	495, 919, 622
1960	18, 817, 441	147, 116, 250	145, 806, 915
1961	17, 446, 439	140, 337, 541	139, 495, 516
1962	16, 893, 646	134, 093, 874	133, 155, 217
1963	18, 267, 384	153, 503, 442	152, 889, 428
1964	17, 184, 251	148, 647, 575	147, 904, 337

In 1890, the average number of employees working daily in the industry was 126,000; this number reached a peak of 179,679 in 1914, then decreased to 13,144 in 1964, its lowest point since 1890. The decrease in employment has caused serious social and economic problems in the anthracite producing counties where the industry has provided the base of the regional economy.

Productivity in terms of average tons produced per man-day was only 1.85 tons in 1890; it rose to a high in 1963 of 6.27 tons and declined slightly to 6.11 tons in 1964. The increase in productivity was primarily the result of mechanization coupled with an increase in production from strip pits and culm banks where greater output per man-day is possible than in underground mines.

Trends in production by mining method are presented in table 39. The table does not include 1917, the year of peak underground production, but it does show the record years for strip pits (1948), culm banks (1944), and river dredging (1941).

The average value per ton of anthracite produced in 1890 was $1.43; the record value per ton was $9.67 in 1953, and current values have been $8.40 in 1963 and $8.65 in 1964. The record year for total value of production was 1923—a half billion dollars. Increased labor costs have been the chief contributor to rises in the average value per ton at the mine.

In 1964, production of anthracite was 17,200,000 short tons valued at $148,648,000 (current dollars). Of the total output, 7,177,000 tons came from strip pits, 5,889,000 tons from underground mines, 3,413,000 tons from culm banks, and 705,000 tons from river

TABLE 39.—*Production of Pennsylvania anthracite by mining method, 1941–64*

[In short tons. Source: U.S. Bur. Mines]

Year	Underground mines	Strip pits	Culm banks	River dredging	Total
1941	43,877,264	7,316,574	3,656,866	1,517,563	56,368,267
1942	45,236,699	9,070,933	4,735,064	1,285,033	60,327,729
1943	42,735,798	8,989,387	7,583,698	1,334,737	60,643,620
1944	41,775,416	10,953,030	9,600,180	1,372,737	63,701,363
1945	34,885,699	10,056,325	8,786,659	1,205,226	54,933,909
1946	38,084,457	12,858,930	8,431,092	1,132,394	60,506,873
1947	36,963,112	12,603,545	6,403,646	1,219,706	57,190,009
1948	37,175,291	13,352,874	5,623,779	988,004	57,139,948
1949	27,030,650	10,376,808	4,429,144	865,122	42,701,724
1950	28,155,895	11,833,934	3,467,310	619,564	44,076,703
1951	26,342,239	11,135,990	4,630,200	561,568	42,669,997
1952	24,748,283	10,696,705	4,765,516	372,054	40,582,558
1953	17,893,489	8,606,482	4,011,000	438,181	30,949,152
1954	16,852,408	7,939,680	3,565,482	725,907	29,083,477
1955	14,498,758	7,703,907	3,213,046	788,843	26,204,554
1956	15,054,904	8,354,230	4,774,799	716,287	28,900,220
1957	12,616,053	7,543,157	4,521,410	657,701	25,338,321
1958	10,698,835	6,877,761	2,902,753	691,793	21,171,142
1959	9,415,470	7,096,343	3,420,854	716,619	20,649,286
1960	7,695,978	7,112,288	3,297,012	712,163	18,817,441
1961	6,784,586	7,246,646	2,669,359	745,848	17,446,439
1962	6,672,922	6,822,207	2,671,466	727,051	16,893,646
1963	6,714,746	7,467,842	3,393,066	691,730	18,267,384
1964	5,888,826	7,177,188	3,412,989	705,248	17,184,251

dredging. This production originated in more than a thousand individual operations. The number of operations by type probably did not change substantially from 1963, when there were 834 underground mines, 200 strip mines, 112 culm banks, and 15 dredges. Luzerne, Schuylkill, and Northumberland Counties, the three largest producers in that order, accounted for 81 percent of the year's production, 83 percent of the value, and 84 percent of the employment.

Economics

The high cost of deep mining and the continuing incursion of competitive fuels into traditional anthracite space-heating markets are perhaps the two major factors affecting the output of anthracite. The difficulties of working steeply pitching beds which prohibit extensive use of mechanized extraction methods and the expense of mine-water control are responsible for the high cost of underground mining. Because underground output per man-day is low, labor costs are also a significant part of total mining costs. To combat increasing costs, more strip pits were opened and techniques were developed to adapt modified longwall underground mining methods to steeply pitching beds. In 1941, 78 percent of total production came from underground mines, while only 13 percent originated in strip pits; in 1964, production from the two types of mines was 34 percent and 42 percent respectively (table 39). However, stripping sites with shallow overburden are virtually exhausted and operations have now been directed to deeper pits where mining costs are higher. With the ultimate depletion of strip pit, culm bank, and river coal reserves, the life of the industry depends on the lowering of the high cost of underground mining.

Equal in importance to maintaining mining costs at a minimum is the preservation of old and the creation of new markets for anthracite. But even as a competitively priced fuel, particularly in the space-heating market, anthracite faces the problem of consumer preference and the fact that most new homes have fuel oil, natural gas, or electric heating systems. Heating oils and natural gas have cut drastically into the principal anthracite markets. In 1950, the total fuels consumed (based on Btu content) in the major anthracite sales areas were: anthracite, 34 percent; fuel oil, 55 percent; and natural gas, 9 percent. Comparative data for 1964 indicate that anthracite has declined to 8 percent and that fuel oil and natural gas have risen to 64 and 28 percent, respectively. The tonnage of anthracite consumed in these markets decreased from 33,212,000 tons in 1950 to 12,636,000 tons in 1964.

A slow decline in the public-utility market for anthracite is also evident (table 37). This market is supplied primarily with river and culm bank coal and may cease to exist in the not too distant future as these fuel sources become exhausted.

Relatively stable markets have been the steel and cement industries (table 37). A modest, though increasing, demand is anticipated for sintering and pelletizing iron ore, for industrial carbon, and for various other metallurgical uses.

Overseas exports to Europe which fluctuate from year to year contingent upon a variety of factors will probably remain about 1–2 million tons for the next several years. In addition, the U.S. Armed Forces in Europe will probably require about a million tons annually for some time.

No new large-volume anthracite markets have been developed by research in recent years and principal markets for anthracite can be expected to decline further in the future. Research has been done or is in progress on the use of anthracite for manufacture of high-Btu gas, for making briquets to substitute for metallurgical coke in blast furnaces and foundry cupolas, for low-ash coal for nonfuel purposes, and for production of chemicals.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF ANTHRACITE

Owing to its high percentage of fixed carbon (92–98 percent on a dry mineral-matter-free basis), anthracite represents one of nature's purest forms of carbon. Because of its low-volatile content (2–8 percent on a dry mineral-matter-free basis) it does not develop a high temperature as rapidly as bituminous coal. Nor is the calorific value of anthracite (14,000–15,000 Btu on a moisture- and ash-free basis) quite as high as that of high-rank bituminous coal, but it burns longer than other ranks of coal, giving off a short, steady blue flame, and under proper burning conditions emits little or no soot or smoke. Because it will not slack or weather, anthracite can be stored outdoors for many years. Its hardness (2.75–3 in Mohs' scale), dark-gray to jet-black color, moderately bright to brilliant and even submetallic luster, and conchoidal fracture distinguish it from other forms of coal.

GEOLOGIC AND TECHNOLOGIC INFORMATION

Most of the several hundred publications on Pennsylvania anthracite deal mainly with the history and economics and with mining technology and utilization of anthracite. Many of these publications are listed in a bibliography compiled by the U.S. Bureau of Mines (1962). Several publications relating to geologic investigations of the anthracite fields are listed in a bibliography prepared by L. R. Berryhill (1951).

Geologic investigations of the anthracite fields date back to the first Geological Survey of Pennsylvania in the 1830's. The geology of the coal fields is discussed in annual reports published for the years 1836–42. The summary report of these early investigations (Rogers, 1858) includes the first comprehensive geologic discussion and the first geologic and topographic map of the Anthracite region.

The most complete set of maps and illustrations on the anthracite fields was prepared by the Second Geological Survey of Pennsylvania between 1880 and 1889. These reports were published in 19 atlases and 28 miscellaneous reports, a complete list of the publications appearing in the summary final report (Lesley, 1892–95).

The first careful estimate of anthracite resources was prepared by A. D. W. Smith (1893). Subsequently, this estimate was refined and updated by Ashmead (1926) and by Ashley (1945). Production statistics on Pennsylvania anthracite are tablulated in the annual Minerals Yearbooks prepared by the U.S. Bureau of Mines.

Other notable investigations include those pertaining to the origin and occurrence of anthracite (C. D. White, 1915, 1925), the petrographic and chemical analysis of Pennsylvania anthracite (Turner, 1925, 1930, 1934), and the structural features of the Northern field (Darton, 1940).

Results of recent geologic investigations have been published in 13 coal maps (Rothrock, 1951, 1953; Rothrock, Wagner, and Haley, 1951; Rothrock, Wagner, Haley, and Arndt, 1951; Haley and others, 1953; Haley, 1954; Danilchek, Rothrock, and Wagner, 1955; Kehn and Wagner, 1955; Maxwell and Rothrock, 1955; Wood, Trexler, Yelenosky, and Soren, 1958, 1962; Danilchek, Arndt, and Wood, 1962; Arndt, Danilchek, and Wood, 1963; and Arndt, Wood, and Danilchek, 1963) and in several short papers previously referred to in this text.

CHARACTERISTICS AND DISTRIBUTION OF THE ANTHRACITE-BEARING ROCKS

The anthracite-bearing rocks of eastern Pennsylvania, like most of the coal-bearing sequence in the Appalachian bituminous coal fields, are of Pennsylvanian age. Being of continental origin, they consist of lenticular deposits of conglomerate, sandstone, siltstone, claystone, shale, and coal. The lower part of the sequence is predominantly conglomerate and the upper part is chiefly sandstone and shale. The coal beds are the most persistent lithologic units; the strata between the coal beds commonly exhibit abrupt lateral changes in thickness and lithology.

The original thickness of the Pennsylvanian rocks in the Anthracite region is unknown because the upper part of the sequence has been eroded. The maximum thickness of about 4,900 feet is preserved in the synclines of the Southern field near Pottsville. The sequence, particularly the lower part, thins northwest from Pottsville. The sequence is as much as 2,600 feet thick in the Western Middle field south of Shamokin, as much as 2,200 feet thick in the Northern field near Wilkes-Barre, and less than 2,000 feet thick in the deepest part of the Eastern Middle field in the vicinity of Hazelton.

The sequence of Pennsylvanian rocks in the anthracite fields is subdivided into the Pottsville Formation, of Early and Middle Pennsylvanian age, and the Llewellyn Formation (Wood, Trexler, and Arndt, 1962, p. C41), of Middle and Late Pennsylvanian age.

Pottsville Formation

The Pottsville Formation of Early and Middle Pennsylvanian age (elsewhere in Appalachia these rocks generally are referred to as the Pottsville Group) overlies the noncoal-bearing Mauch Chunk Formation of Late Mississippian and Early Pennsylvanian age and underlies the Llewellyn Formation. The formation ranges in thickness from less than 100 feet in the Northern field to more than 1,400 feet in the Southern field. It generally forms a steep escarpment or ridge around the anthracite fields.

The Pottsville is composed of light- to dark-gray quartz pebble and cobble conglomerate and quartzose sandstone interbedded with lesser amounts of siltstone, shale, anthracite, and semianthracite. It has been subdivided into three members in the southwestern part of the Anthracite region (Wood and others, 1956). The upper and lower members are coarsely conglomeratic. Only the upper member is present in the Northern field according to M. J. Bergin and J. F. Robertson (unpub. data, 1963).

The formation contains as many as 11 coal beds in the western part of the Southern field, five coal beds in the western part of the Western Middle field, and one coal bed in parts of the Eastern Middle field and the Northern field. The coal beds are thickest in the western parts of the Southern and the Western Middle fields where a considerable tonnage of coal has been mined from several of the Lykens Valley coal beds in the middle and lower parts of the formation.

Llewellyn Formation

The Llewellyn Formation of Middle and Late Pennsylvanian age includes all sedimentary rocks above the Pottsville Formation to the erosion surface at the top of the coal measures and contains most of the anthracite mined in eastern Pennsylvania. It is composed chiefly of gray- and brown-hued conglomeratic sandstone, quartzose sandstone and siltstone with lesser amounts of conglomerate, carbonaceous shale, anthracite, and seminanthracite. As much as 3,500 feet of the formation is preserved in the deepest parts of the Southern field, 2,200 feet in the Northern field, 1,900 feet in the Western Middle field, and less than 1,500 feet in the Eastern Middle field.

The lower 400–500 feet and the uppermost several hundred feet of the Llewellyn Formation commonly are coarser grained and darker hued than the rest of the formation, consisting mainly of medium-gray to dark-gray coarse-grained sandstone and conglomeratic sandstone. Interbedded are dark-gray to grayish-black sandstone, siltstone, and shale. The lower coarse-grained sequence also generally includes as many as eight persistent coal beds, two of which, the Buck Mountain and the Mammoth coals of the Southern and both Middle fields, and their possible correlatives, the Red Ash and Baltimore coals in the Northern field, are the most extensively mined coal beds in the Anthracite region. The rocks in the middle part of the formation consist of light-gray to light-olive-gray and moderately yellowish-brown fine- to medium-grained sandstone, siltstone, and shale, and include as many as 15 persistent beds of coal, many of which are also mined extensively. The upper several hundred feet of the formation includes five or more persistent coal beds in the south-central part of the Southern field. Elsewhere, the upper coarse-grained sequence has been removed by erosion.

STRUCTURAL CONFIGURATION OF THE ANTHRACITE FIELDS

In contrast to the gently folded to flat-lying strata that characterize the Appalachian bituminous coal field, the strata in much of the Anthracite region are tightly folded and faulted. The Northern, Western Middle, and Southern anthracite fields occupy the central areas of synclinoria or composite fold systems and the Eastern Middle anthracite field is on the crestal area of an anticlinorium. The anticlinorium and the synclinoria are composed of many linear and commonly sinuous subsidiary folds that range from a few feet to many thousands of feet in amplitude and are as much as 35 miles long. These subsidiary folds tend to be tightly folded and asymmetrically shaped in the western and southern parts of the Anthracite region. They are more open and symmetrical in the eastern part, particularly in the northeastern part of the Northern field.

Many low- to high-angle thrust faults, bedding plane faults, and tear faults further complicate the structure of the coal fields. The thrust faults trend subparallel to the folds; some of the fault planes are warped or folded, so their present attitudes do not necessarily reflect the original inclinations. The apparent dislocation of the strata along the low-angle thrust faults ranges from a few feet to as much as a mile; the greater dislocations are in the Southern field. The dislocation of the strata along the high-angle faults ranges from a few feet to 500 feet, except in the Southern field where displacements of as much as 3,000 feet are not uncommon.

The structural configuration of the Anthracite region becomes increasingly complex from north to south. The variations in features have been described by Arndt and Wood (1960) and classified as different stages of structural development on the basis of increasing complexity. The cross sections on figure 44 illustrate to some degree the structural complexities in each of the anthracite fields. However, no one section can be considered as typical of the structural configuration of a coal field because the complexity of the structures varies from one part of a field to another.

DISTRIBUTION AND CHARACTER OF COAL BEDS

More than 50 coal beds occur in the southern part of the Anthracite region, and 30 or more occur in the northern part. The principal coal beds in each of the anthracite fields are shown on figure 45; many of the coal beds in the upper parts of these sections are of local occurrence and are therefore only of local economical importance. The names and numbers assigned to the coal beds have been partly standardized in the Eastern Middle, Western Middle, and Southern fields. For the most part, these same coal beds occur in the Northern field; however, the correlation of coal beds between the Northern field and the other fields is uncertain and the coal beds in the Northern field are known by different names and numbers. Generally accepted coal-bed correlations are used in this report for purposes of discussion.

Commonly, two or more coal beds merge to form one thick bed. The most notable example of this is the Mammoth coal zone which in some areas is 30–50 feet thick and is devoid of any appreciably thick or persistent partings, but in other areas is divided into three separate beds or "splits" of coal, each averaging 8–10 feet in thickness (note splitting of Mammoth coal in cross section of the Western Middle field, fig. 44). Only the splits of the Mammoth coal are shown in the columnar sections on figure 45 although at least six other persistent coal beds are known to split into two or more beds.

The Lykens Valley, Buck Mountain, Seven-foot, Skidmore, Mammoth, Holmes, Primrose, and Orchard coal zones of the Southern and Middle fields, and the Red Ash (or Dunmore), Ross, Skidmore (or Marcy), Pittston (or Baltimore), Lance (or Checker), and Diamond coal zones, and the Hillman coal bed of the Northern field have been the source of more than 90 percent of the coal mined in the Pennsylvania Anthracite region. Of these principal producing zones, the Mammoth coal zone and its probable Northern field equivalent, the Pittston (or equivalent locally named zones, p. 131) zone, is the most extensively mined; it has contributed more than 30 percent of the total anthracite production. The Buck Mountain coal zone, and its possible Northern field equivalent, the Red Ash (or Dunmore) zone, ranks second; it has contributed about 25 percent of the total anthracite production.

Lykens Valley coal zone

The Lykens Valley coal zone in the Southern field contains 11 separate coals in the middle to lower 900 feet of the Pottsville Formation. The interval between coal beds ranges from 50 to 100 feet and, in general, the coal beds are so discontinuous that rarely are there more than two or three of the Lykens coals of minable thickness at the same locality. The coals commonly contain a high percentage of ash. The Lykens Valley No. 2 – No. 7 coal beds average 4–9 feet in thickness where they have been mined. The No. 2 and No. 5 coal beds are generally the thickest and the No. 2, No. 4, and No. 6 coal beds contain the least ash. Much of the coal is semianthracite in rank.

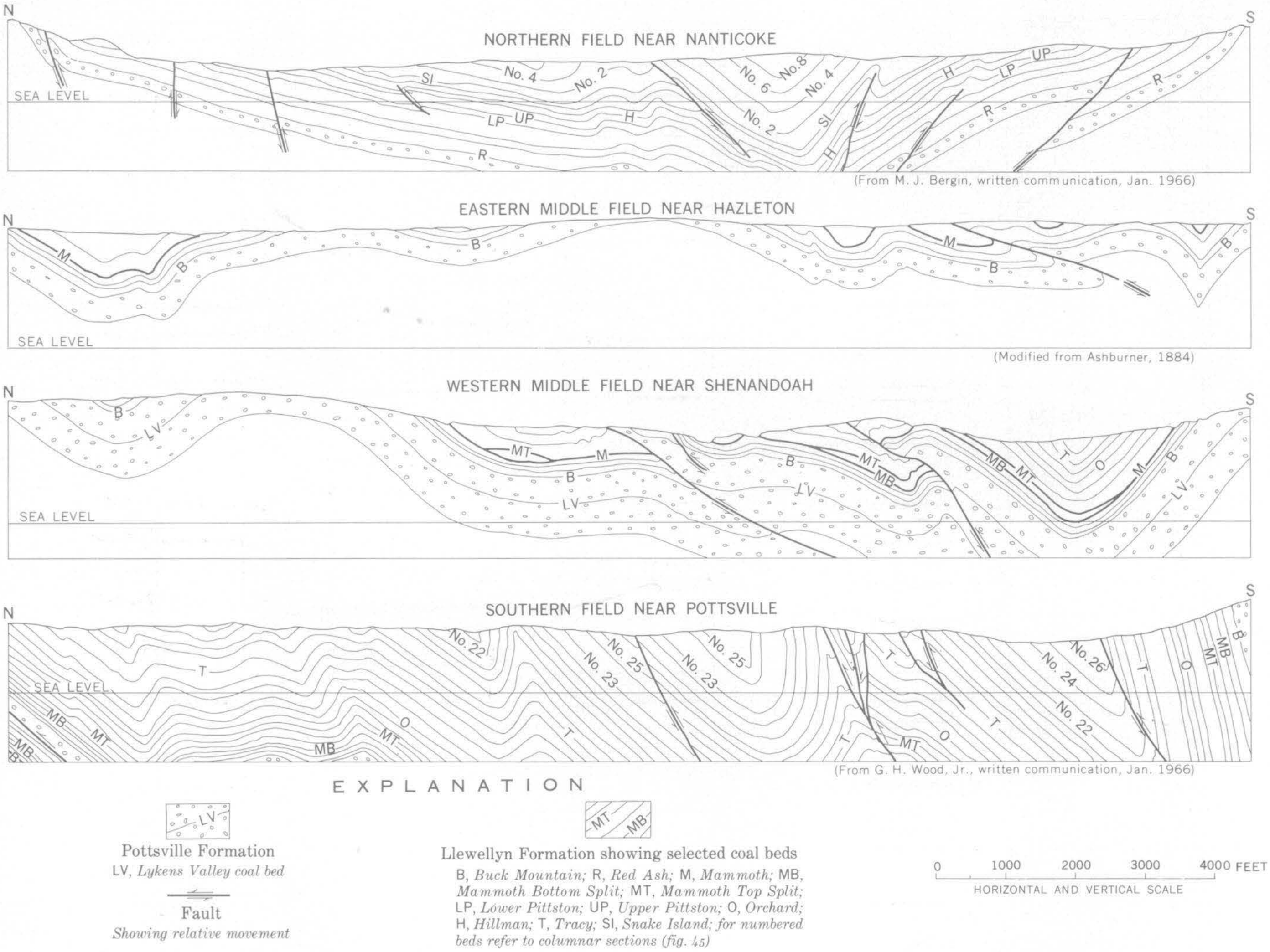
The Lykens Valley coal zone thins northwestward and contains five coal beds in the Western Middle field. Only the Lykens Valley No. 4 coal bed, the lowermost coal in the Western Middle field, appears to be persistent throughout the field. It has been mined most extensively in the western part of the field where it contains an average of 4 feet 10 inches of coal. Coal A, probably the equivalent of either the Lykens Valley No. 2 or No. 3 coal of the Southern field, is about 120 feet above the Lykens Valley No. 4. It has been mined in the western part of the field; it contains an average of 3 feet 10 inches of coal.

The Lykens Valley coals are either absent or are too thin to be of economic importance in the Eastern Middle and Northern fields.

Buck Mountain coal zone

The Buck Mountain coal zone, second only to the Mammoth coal zone in economic importance, is at the base of the Llewellyn Formation. It commonly contains two splits, known in the Southern and both Middle fields as the Buck Mountain Bottom and Top Splits. Inasmuch as the interval between splits may be as great as 80 feet, in most places the splits are mined as separate coal beds. In the Northern field the probable equivalent coal zone contains three coals known as the Lower, Middle, and Upper Red Ash (or Dunmore) coals.

The Buck Mountain zone contains an average 4 feet 9 inches of coal in the Southern field, 6 feet 5 inches of coal in the Western Middle field, and 5 feet 4 inches of coal in the Eastern Middle field. The Lower Red Ash, the probable Buck Mountain equivalent in the Northern field, on the average contains more than 9 feet of coal. The production from the Red Ash coal beds probably exceeds that from the Pittston coal beds, the Mammoth zone equivalent of the Northern field.



(From M. J. Bergin, written communication, Jan. 1966)

(Modified from Ashburner, 1884)

(From G. H. Wood, Jr., written communication, Jan. 1966)

Pottsville Formation
LV, *Lykens Valley coal bed*

Fault
Showing relative movement

Llewellyn Formation showing selected coal beds
B, *Buck Mountain;* R, *Red Ash;* M, *Mammoth;* MB, *Mammoth Bottom Split;* MT, *Mammoth Top Split;* LP, *Lower Pittston;* UP, *Upper Pittston;* O, *Orchard;* H, *Hillman;* T, *Tracy;* SI, *Snake Island; for numbered beds refer to columnar sections (fig. 45)*

FIGURE 44.—Generalized cross sections of the Pennsylvania anthracite fields.

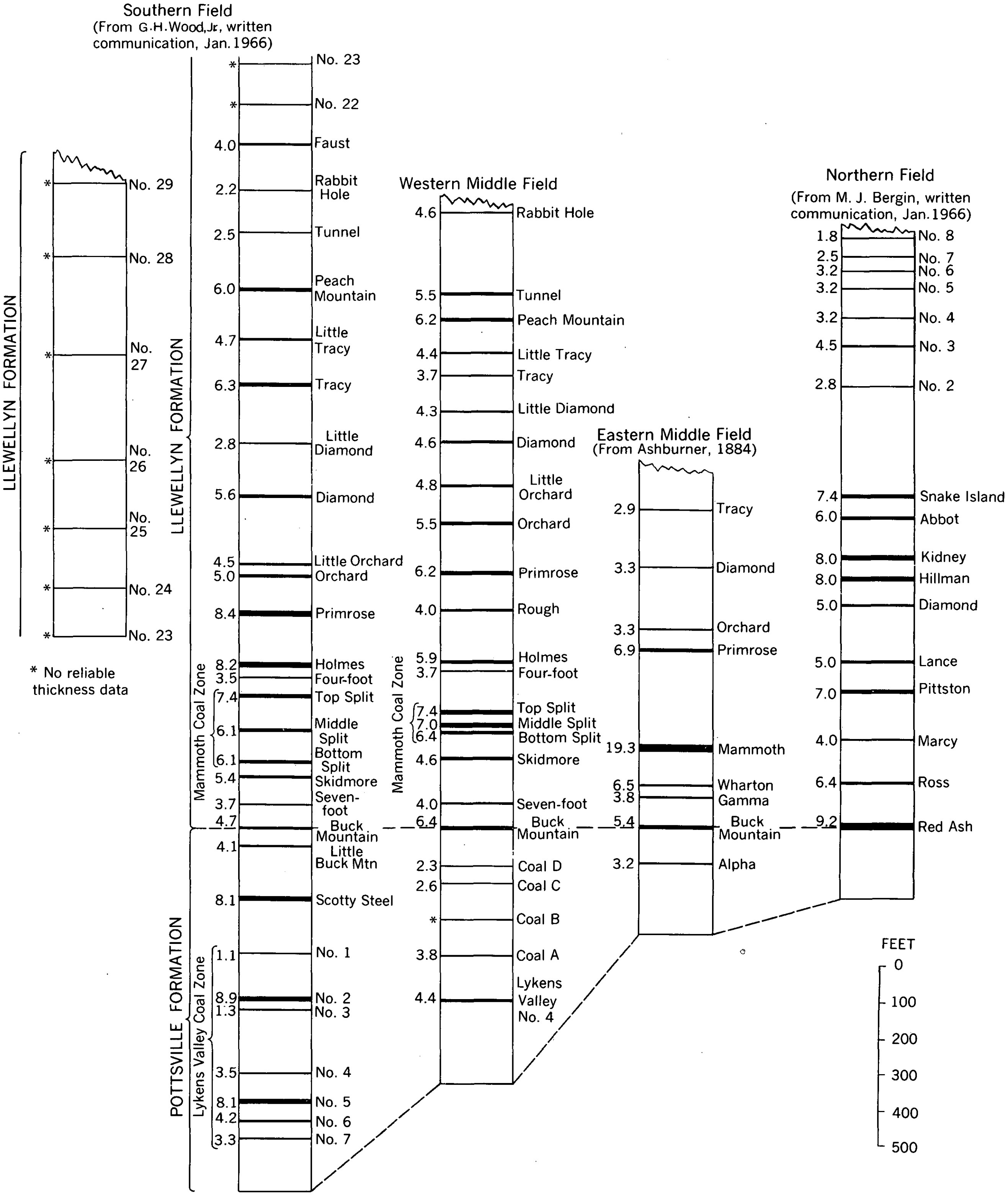


FIGURE 45.—Generalized columnar sections showing names, average thickness of coal, and intervals between coal beds in the Pennsylvania anthracite fields.

Seven-foot coal zone

The Seven-foot coal zone of the Western Middle and Southern fields and its probable equivalents, the Gamma bed of the Eastern Middle field and the Ross beds of the Northern field, are 30–100 feet above the Buck Mountain (Red Ash) coal zone. The Seven-foot coal zone persists throughout the anthracite fields but is not everywhere of minable thickness. It generally consists of one bed containing about 4 feet of coal in the Southern and Middle fields, and is mined more extensively in the Middle fields than in the Southern field. It is mined most extensively, however, in the Northern field where the coal averages 6 feet in thickness in each of the supposedly equivalent Upper and Lower Ross coal beds. Owing to the extensive workings in this zone in the Northern field, it ranks next to the Red Ash (Buck Mountain) coal zone in total production.

Skidmore coal zone

The Skidmore coal zone of the Western Middle and Southern fields is known as the Wharton bed in the Eastern Middle field and as either the Marcy, New County, or Skidmore bed in the Northern field. It is 50–150 feet above the Seven-foot coal zone and in some areas is composed of two or three splits, the bottom split generally containing the greater amount of coal. The zone is most extensively mined in the Northern field where the Lower Marcy bed is 2–7 feet thick and the Upper Marcy bed is 2–4 feet thick. The Wharton bed, which is mined in the Eastern Middle field, locally contains as much as 6 feet of coal. Where the Skidmore coal bed is mined in the Western Middle and Southern fields, it contains 4–6 feet of coal.

Mammoth coal zone

The Mammoth coal zone is economically the most important group of coal beds in the anthracite fields. The bottom of the zone is 200–300 feet above the Buck Mountain coal bed. The zone is persistent and easily identified. It generally consists of the Bottom and Top Splits, and at many places includes a Middle Split. In some places the splits merge to form a single bed whereas at others the Middle Split merges with either the Top or Bottom Splits. Regionally, the zone varies from a single thick coal bed to a 150-foot-thick sequence containing as many as four splits and bottom and top leader coals. It is known as the Mammoth coal zone in all the fields execept the Northern where the names Pittston, Twin, Baltimore, Bennett, and Cooper have been applied.

Where the splits are mined separately, the average thickness of the coal in each split, exclusive of partings, ranges from 4 to 14 feet. The aggregate thickness of coal in the three splits commonly exceeds the total coal thickness where the three principal splits have merged to form one bed. Where the zone is composed of a single bed it locally attains a maximum thickness of 65 feet! The average thickness of the coal where the zone contains only one bed ranges from 10 feet in the Northern field to 29 feet in the Southern field.

The Mammoth coal zone is of greatest economic importance in the Southern field and in both Middle fields where the coal beds have been mined extensively both underground and at the surface. Strip mining is favored because of the thickness of the separate beds and because at many places the entire zone can be mined as a unit.

Holmes coal zone

The Holmes coal zone is 50–200 feet above the Mammoth coal zone. Known for its persistence in the Western Middle and Southern fields, it is not definitely a correlative of any of the coals in the Eastern Middle and Northern fields. The Holmes coal bed contains about 6 feet of coal throughout much of the Western Middle and Southern fields. In the western part of the Southern field the bed tends to be thicker, averaging about 8 feet, but it also contains more partings and impure coal. In the central and eastern parts of the Western Middle field, the Holmes consists of two splits, each of which averages about 4 feet in thickness.

The Lance (or Checker) coal beds of the Northern field may be correlatives of the Holmes coal zone. The Lower Lance (or Lower Checker) coal ranges in thickness from 1½ to 10½ feet and the Upper Lance (or Upper Checker) coal from 1½ to 6 feet. These coals are the fourth or fifth most extensively mined beds in the Northern field. The Holmes coal zone is the third most extensively mined zone in the Western Middle field, and probably the fourth most extensively mined zone in the Southern field.

Primrose coal zone

The Primrose coal zone is 100–250 feet above the Holmes coal zone. Owing to its higher stratigraphic position in the coal-bearing sequence, the Primrose is of more limited occurrence than the Holmes though in parts of the region it is of greater economic importance, particularly in the western part of the Southern field where the Primrose coal zone consists of one coal bed which contains as much as 21 feet of coal. The average thickness in that field is 10 feet, of which about 8 feet is coal. Primrose Bottom and Top Split coal beds occur in the central part of the Western Middle field. The Top Split generally contains about 6 feet of coal and the Bottom Split almost 8 feet of coal. Elsewhere in the Western Middle field, the Primrose coal zone is thinner, on the average containing from 4–8 feet of coal. In the Western Middle field the Primrose coal zone ranks next to the Holmes coal zone in economic importance.

The Primrose coal zone may be represented by two coals in the Northern field which are worked in some mines as the Upper and Lower Stanton beds and in others as the Upper and Lower Diamond, Orchard or Five Foot coals. The lower coal in this zone ranges from 1 to 9 feet in thickness, the upper coal from less than a foot to 7 feet. This supposed Primrose coal zone in the Northern field ranks next to the Lance or Checker (Holmes) coal zone in economic importance. The Primrose zone is present at only a few localities in the Eastern Middle field.

Orchard coal zone

The Orchard coal zone, 30–180 feet above the Primrose coal zone, underlies less area of the anthracite fields than any of the previously described coal beds. In the Southern and Western Middle fields the zone comprises the Orchard and Little Orchard coal beds. The Orchard coal bed is as much as 16 feet thick and contains an average of 5 feet of coal exclusive of partings. The Little Orchard coal bed, which is of somewhat less economic importance, commonly lies 30–100 feet above the Orchard coal in these fields. The Little Orchard contains 4–5 feet of coal and locally it is mined more extensively than the Orchard coal. It merges with the generally thicker and more persistent Orchard coal bed at many places in the Southern field. The Hillman coal bed in the Northern field is the probable correlative of the Orchard coal. It ranges from 4 to 19 feet in thickness. The Orchard coal bed is too limited in occurrence to be of economic importance in the Eastern Middle field. Total production from the Orchard and Hillman coals probably exceeds the total production from the more extensive Lykens Valley zone of the western part of the region.

Other coal beds

The Orchard coal bed occupies a stratigraphic position near the middle of the thickest known sequence of anthracite-bearing rocks and therefore other coal beds are found above it. Over comparatively small areas in the deepest parts of the Western Middle and Northern fields the Orchard coal is overlain by another 1,000 feet of anthracite-bearing rocks. In the south-central part of the Southern field it is overlain by a sequence as much as 2,500 feet thick that may contain as many as 20 coal beds but, because of their limited occurrence, most of these coal beds have little economic importance. However, several of the coal beds in the upper part of the anthracite sequence, notably the Diamond, Tracy, and Peach Mountain coals of the Southern and Western Middle fields and the Kidney, Abbot, and Snake Island coals of the Northern field, have been mined extensively.

ANTHRACITE RESOURCES

In 1945 Ashley reported that about 15.8 billion tons of an original resource of 22.8 billion tons of anthracite still remained for future mining. Ashley's estimate is shown in table 40. In 1947 the U.S. Geological Survey, with the cooperation of the Pennsylvania Topographic and Geologic Survey, began a detailed mapping program in the Pennsylvania Anthracite region, the first such mapping to be initiated in more than 50 years. This work led to a reappraisal of the coal resources in the Western Middle and Southern fields; it showed 30 and 40 percent, respectively, larger resources in those fields than estimated by Ashley (1945). This larger estimate is due partly to the inclusion of coal beds containing 14 or more inches of coal, whereas Ashley excluded coal beds with less than 2 feet of coal, and partly to an increase in knowledge of the distribution and character of the coal beds. Although a reappraisal has not yet been made of the Eastern Middle and Northern fields, it is probable that the estimated original resources in those fields would also be increased by at least 30 percent. Such an increase would give estimated resources, as of January 1, 1965, in the Pennsylvania Anthracite region of 22.6 billion tons (table 41).

About 14.2 billion tons, the bulk of the remaining anthracite resources, is in the Southern field, about 4.9 billion tons is in the Western Middle field, and about 3.5 billion tons is in the Eastern Middle and Northern fields.

TABLE 40.—*Pennsylvania anthracite resources, January 1, 1945*

[From Ashley (1945, p. 8)]

	Billions of short tons
Estimated original resources (includes coal 2 ft or more thick)	22.8
Total production to 1945	4.6
Estimated losses incurred in underground mining (estimated at 61 percent rate of recovery)	2.4
Remaining resources	15.8

TABLE 41.—*Pennsylvania anthracite resources, January 1, 1965*

	Billions of short tons
Estimated original resources (includes coal 14 in. or more thick)	31.3
Total production to 1965	5.3
Estimated losses incurred in underground mining (estimated at 61 percent rate of recovery)	3.4
Remaining resources	22.6
Remaining resources less than 3,000 ft below surface	19.0
Probable recoverable resources (61 percent recovery of coal less than 3,000 ft below surface)	11.6

Nearly all the remaining anthracite in the Eastern Middle, Western Middle, and Northern fields (8.4 billion tons) lies less than 3,000 feet below the surface. About 75 percent, or 10.6 billion tons of that remaining in the Southern field, also lies less than 3,000 feet below the surface. Assuming an average recovery of 61 percent by existing mining methods, it would be possible to recover about 11.6 billion tons of the estimated 19.0 billion tons that lies less than 3,000 feet below the surface. This tonnage of recoverable coal would be valued at about $101.2 billion at the average 1964 value of $8.65 per ton.

Present mining trends are to produce large tonnages of anthracite from strip-mine operations and to replace large-scale underground mining by more economically worked small-scale shallow mining. More than 40 percent of the total annual anthracite production now comes from strip pits, in which recovery commonly approaches 90 percent. Strip pits are now operating at depths exceeding 400 feet and it seems likely that within the next 10–20 years some large-scale stripping operations may reach depths of 1,000 feet. If such great depths are reached, the amount of recoverable anthracite will be greatly increased above the estimated 11.6 billion tons.

OIL SHALE

By Louis C. Conant, U.S. Geological Survey, and Robert G. Stansfield, U.S. Bureau of Mines

INTRODUCTION

Large bodies of black shale, including some impure coal, in about half of Appalachia may well become important sources of energy sometime in the future. This black shale contains appreciable amounts of finely divided organic matter, commonly at least 10 percent, and locally is so rich as to grade into impure coal. Depending on the amount and kind of organic remains that are present, the shale will yield oil in amounts ranging from a few to 100 or more gallons per ton. Where the yield is 10 gallons or more by the process usually used, the material is commonly termed "oil shale."

Before 1860 and the birth of the petroleum industry, shale and coal were used in the United States and other countries to supply crude oil, "coal oil" or kerosene, lubricating oils, and waxes (Baskerville, 1909). After 1860, petroleum afforded a much cheaper source of these materials, and in this country the shale-oil industries quickly died. In some petroleum-poor countries, oil has long been produced from shale or coal, and in a few countries is still being produced (L. W. Schramm and J. B. Lankford, in U.S. Bur. Mines, 1965a, p. 631).

The conventional process of obtaining oil from shale or coal has long been pyrolysis, or destructive distillation, and the standard test for oil yield has been the Fischer assay, which indicates the amount of oil that may be obtained by distillation. The distillation process, however, fails to utilize much of the organic matter that is in the shale, and the Fischer assay does not indicate the full potential of the shale. Experiments have shown that the addition of hydrogen to the shale at high temperatures and pressures will convert most of the hydrocarbons of the complex heavy organic molecules either to light oils or to such gases as methane, ethane, and propane, the final product depending largely on the temperature (Hubbard and Fester, 1959; Shultz, 1965). The process of adding hydrogen is referred to as hydrogenation, or as hydrogasification when the end product is gas. Although much of the potential energy of the shale is consumed in the hydrogenation process, the oil or gas yields are still considerably greater than in the conventional distillation process. Information on the oil shale resources of the world is given by Duncan and Swanson (1965) and by L. W. Schramm and J. B. Lankford (in U.S. Bur. Mines, 1965a).

Modern highly mechanized methods have greatly reduced the cost of mining coal, and experiments by the U.S. Bureau of Mines (East and Gardner, 1964, p. 145) have shown that massive beds of shale in Colorado can be mined even more cheaply. The recent developments in processing and mining techniques are arousing new interest in the oil and gas potential of black shale, with which Appalachia is richly endowed.

Much experimental work has been done for many years, notably by the U.S. Bureau of Mines and by some industrial groups, on the western oil shales because of their high yield and vast quantity (L. W. Schramm and J. B. Lankford, in U.S. Bur. Mines, 1965a). Whether or not the lower grade eastern shales, some of which are more amenable to hydrogenation, will be exploited on a commercial scale remains to be learned (Benson and Tsaros, 1965). In any case, a great deal of research and testing will be necessary before the shale deposits in Appalachia can be exploited.

As supplies of crude oil and natural gas eventually become incapable of supplying the needs of a growing population and economy and as the economic incentive becomes more favorable, oil shales probably will become an important source of energy.

DEPOSITS IN APPALACHIA

Two groups of eastern black shale deposits are of special interest because of their oil and gas potential.

One group is a sequence of Devonian and Mississippian shale extending from Alabama to New York State and known by various names, but chiefly as the Chattanooga, New Albany, Ohio, Marcellus and Sunbury Shales. The other group comprises the widespread shale units in coal-bearing beds of Pennsylvanian age and some of the immediately underlying and overlying beds, and it includes some of the impure coals. The approximate distribution of both types of shale is shown in figure 46.

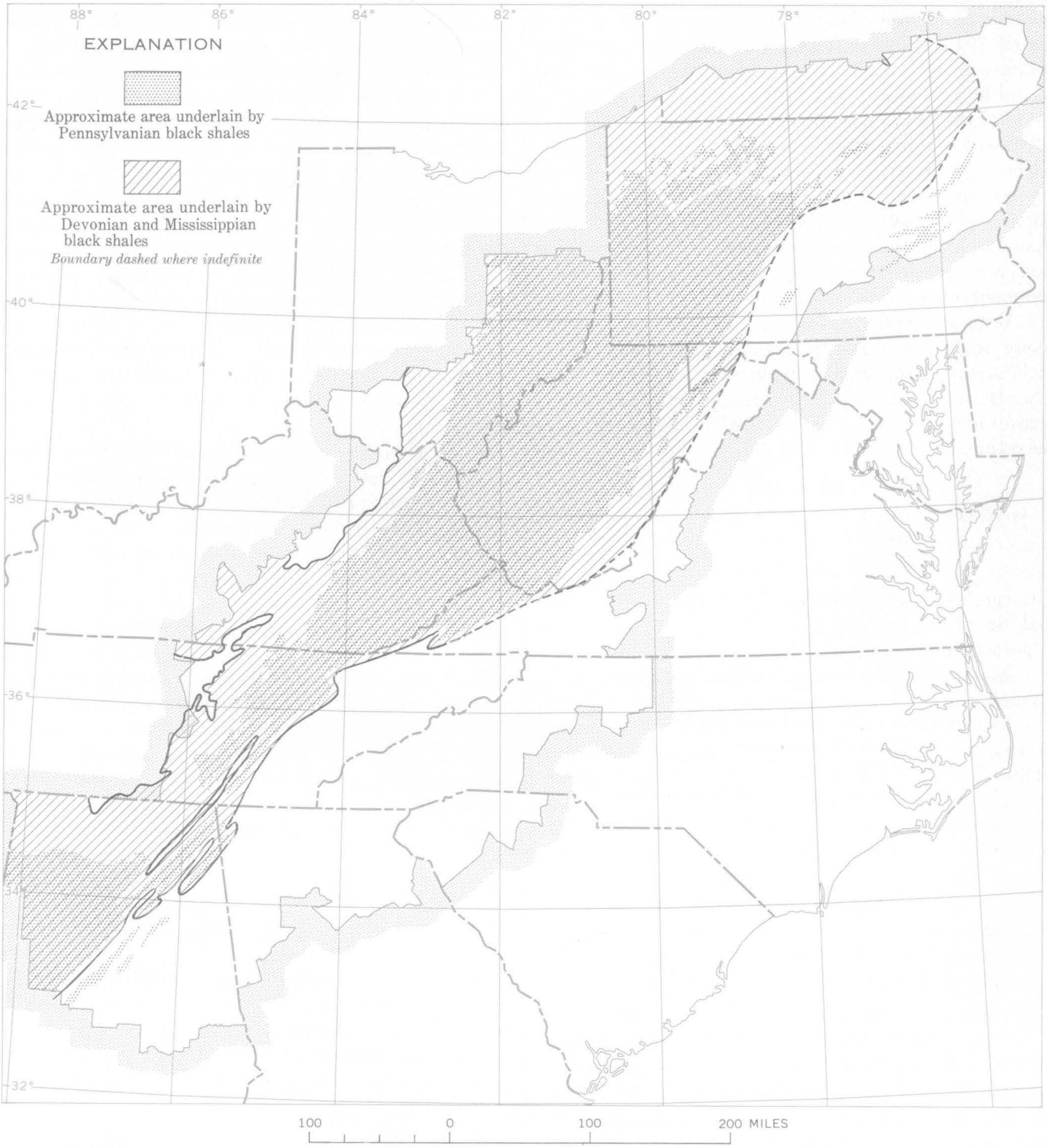


FIGURE 46.—Principal areas of black shale in the Appalachian Region.

The Devonian and Mississippian shale formed in a sea that spread over a large inland area and was connected with the ocean. Although removed from many places by later erosion, the shale is still present in large areas either at the surface or beneath younger rocks. Many analyses have been made of samples from outcrops or shallow drill holes, but most of the area is still inadequately sampled. Enough is known about the shale, however, to warrant the belief that it is continuous and reasonably uniform over large areas. Available Fischer assays show that much of the shale will yield 10 or more gallons of oil per ton by destructive distillation, and that large additional amounts will yield 5–10 gallons. By hydrogenation, however, it is probable that the shale can be made to yield appreciably larger amounts of oil or equivalent quantities of combustible gases. (For more information on the oil yield of the Chattanooga Shale, see Swanson, 1960; J. W. Smith and Stanfield, 1964; Duncan and Swanson, 1965).

No adequate regional study has been made of the oil and gas resources of the eastern shale deposits to permit reliable estimates of the amount of any specified grade that is present, but two examples will illustrate their potential.

In a recent study of the uranium content of the Devonian and Mississippian black shale, some 3,000 samples were taken from outcrops and drill holes, chiefly along the Eastern Highland Rim of central Tennessee, where the uranium content was highest, and about 325 of the samples were analyzed to determine their oil yield. The results of these and many other oil analyses have been summarized by various writers (U.S. Bur. Mines, 1955, p. 70, 72–73; Swanson, 1960, p. 8–14; J. W. Smith and Stanfield, 1964). Swanson pointed out (1960, p. 3) that in the area of intensive sampling a 15-foot bed of shale gives an average yield of about 10 gallons of oil per ton. The shale also contains about 0.006 percent uranium. This shale could, therefore, produce more than 7 million barrels of oil per square mile by the conventional distillation process and would contain about 1,800 tons of metallic uranium as a potential byproduct.

Hydrogenation of such a shale, which contains 15–20 percent organic matter, might produce as much as 15–20 gallons of light oil or 2,000–2,600 cubic feet of gas per ton (Duncan and Swanson, 1965, p. 4). Each square mile would have a potential yield of 10–15 million barrels of oil or some 60–80 billion cubic feet of gas, amounts equal to the production of many oil and gas fields. Shultz (1965, p. 55) stated that the shale deposits in Tennessee have the disadvantage of yielding an undesirably large amount of hydrogen sulfide compared to some others. If, however, means could be found to extract the sulfur as an economical byproduct, the process conceivably could further enhance the value of these deposits. The shale is reasonably uniform in thickness and quality throughout an area of hundreds of square miles (Conant and Swanson, 1961, p. 76), so this potential energy source in any given county is enormous.

If an efficient in-place process can be devised that will permit extracting the oil or gas underground without the necessity of mining and disposing of waste, vast areas of black shale would be available for exploitation with little or no damage to the land surface. If such a process can be developed, it might well permit the exploitation of the shale in Tennessee over an area of at least 2,500 square miles where it is believed to be uniform in thickness and in composition. In about a third of this area the shale is at a depth of less than 200 feet, but in most of the remainder it is at a depth of 1,000 feet or more. This area alone in Appalachia could, in theory, yield 30–35 billion barrels of oil, nearly half as much as already produced in the entire United States. If converted to gas instead of oil, the shale in the same area could theoretically yield 150–200 trillion cubic feet, more than 10 times the present annual production in this country. Equally suitable shale is quite certainly present under a far larger area, but has not been studied in as much detail. In these calculations no allowances have been made for wastage in mining or processing, which would be considerable and would vary greatly depending on methods used and the state of the technology.

The second study of the oil potential of the Devonian and Mississippian black shale was made in Kentucky. Reports prepared in the 1920's (Jillson, 1921; Crouse, 1925) give information about the distribution and composition of the Ohio and Sunbury Shales, and mention possible mining areas. Jillson stated (1921, p. 3) that the Sunbury ranges in thickness from about 4 to 16 feet, and the Ohio generally between 20 and 45 feet. Fischer assays that were made on samples from unspecified parts of these shales in 13 of the 20 counties in Appalachia where they crop out, gave an average yield of nearly 16 gallons of oil per ton (the later work by Crouse indicates a somewhat higher yield). The above reports do not state how the samples were taken, and it is, in fact, doubtful if these yields could be obtained by distillation from the entire thickness of the shale (Conant and Swanson, 1961, p. 69). It is known, however, that the Devonian and Mississippian black shale in Kentucky is considerably thicker than in Tennessee, and is much more widely exposed. If the Kentucky shale should prove to be as suitable for hydrogenation as preliminary experiments indicate (Shultz, 1965, p. 55), vastly greater quantities of oil and gas appear to be available in Kentucky than in Tennessee. Both Tennessee and Kentucky shales will apparently yield about as much gas by hydrogasification as would the oil shale in Colorado which gives twice as high a Fischer assay value (Shultz, 1965, p. 55).

In Ohio, black shales of both the Devonian and Mississippian and the Pennsylvanian coal-bearing sequences are present in large areas, and along with many of the coals, have been studied as possible sources of oil and gas. In general these studies have shown that by conventional distillation the Devonian and Mississippian sequence of black shale will yield less than 10 gallons of oil per ton, but that many of the impure coals will yield 20 to 40 gallons per ton. Further information on the distribution and potential oil yield of the Ohio deposits is given in reports by Ashley (1918), T. H. Kerr (1948), Krumin, Smith, and Bowen (1951), W. H. Smith and others (1952), and Krumin (1957).

The Devonian and Mississippian black shale crops out extensively in eastern Ohio and in parts of several other states of Appalachia, and probably underlies most of West Virginia, but little is known of its oil and gas potential in much of the area.

The Pennsylvanian black shales are associated chiefly with the coal beds, but some black shales are present in the upper part of the underlying beds of Mississippian age, and in the overlying strata of Permian age. Shale layers are present at various depths in large areas of Pennsylvania, Ohio, Kentucky, West Virginia, Tennessee, and Alabama, and are present in smaller areas of New York, Maryland, Virginia, and Georgia. Many of them consist of cannel shale—essentially very impure cannel coal. Some of these Pennsylvanian shales and impure coals have tested 20–45 gallons per ton, but many of them, especially the cannel shale, have insufficient continuity to support large operations (Ashley, 1918, p. 31–32; Fettke, 1923, p. 74). Some of these shale layers, along with the nearby beds of coal that have a higher organic content, may well be exploitable in the future as sources of oil or gas.

RESOURCE POTENTIAL

The widespread and abundant organic-rich black shale deposits in Appalachia are potential sources of enormous quantities of oil and gas for the heavily populated and industrialized eastern United States. Of greatest potential economic importance is the shale of the Devonian and Mississippian sequence variously known as the Chattanooga, New Albany, Ohio, Marcellus, and Sunbury Shales, which extends continuously from Alabama to New York. One of the most promising regions for future exploitation of this shale is along its outcrop belt in eastern Kentucky where large areas of relatively thick shale in a hilly region of notably poor soils could be readily mined by stripping. Some of the Pennsylvanian shale deposits will yield larger amounts of oil or gas, but they are reported to be much more limited in extent. In general, a square mile of either type of shale, having a thickness of 15 feet or more, might yield as much oil or gas as many oil or gas fields. If an in-place process can be developed that would require no mining or waste disposal, oil and gas would be available far in excess of quantities already found in the entire United States.

PEAT

By CORNELIA C. CAMERON, U.S. Geological Survey

INTRODUCTION

Peat differs greatly in physical and chemical properties, and an adequate classification system that will identify peat according to its specific properties has not yet been devised. For statistical purposes the U.S. Bureau of Mines has classified peat into three general types—moss peat, reed-sedge peat, and peat humus. Peat of sphagnum, hypnum, and other moss groups is classified as moss peat, whereas peat of reed-sedge, shrub, and tree groups is classified reed-sedge peat. Any peat so decomposed that the botanical identity is lost is classified as peat humus.

Peat consists of partly decayed vegetable matter, inorganic minerals, and water in varying proportions, the usual ratio being 10 percent solid matter to 90 percent water. Depending on the amount of water contained, peat ranges from 0.1 to 1.06 in specific gravity and weighs from 7 to 65 pounds per cubic foot. Aside from its high water content, peat is extremely variable, and scarcely any two deposits contain material having the same physical properties. Differences are due mostly to the variety of plants from which the peat is formed, and to differences in climate, age of the deposits, water level, and the quantity of sediment deposited during the accumulation of peat. Color ranges from light yellow through various shades of brown to jet black—the color representing in a measure the degree of decomposition. Peat that is newly exposed or has been well protected from the air is usually light yellow or brown. Well-decomposed humified peat is jet black. On drying in the air, most peat becomes lighter in color, except for very light varieties, which usually change to dark brown or black after being macerated and dried.

One of the chief substances formed by plants during their growth is cellulose which consists of carbon, hydrogen, and oxygen (Soper and Osbon, 1922, p. 6–7). If plant debris falls upon drained soil, it is vigorously attacked by fungi and bacteria, and the carbon and hydrogen of the cellulose unite with atmospheric oxygen and with each other to form carbon dioxide, water, and marsh gas. If oxidation is unhampered, the organic material will disappear in a relatively short time. If, however, the plant falls into water or upon saturated soil where atmospheric oxygen is largely excluded, decay is slow and, if the plant debris becomes buried, a large proportion of the fixed carbon is retained and peat is formed. By this means, peat, which essentially has the composition C_{62} H_{72} O_{24}, forms from cellulose (C_{72} H_{120} O_{60}) by the elimination of hydrogen and oxygen as water (H_2O) and carbon and oxygen as carbon dioxide (CO_2) and carbon and hydrogen as methane (CH_4) (Soper and Osbon, 1922, p. 6–7).

Peat is thus formed in swamps or bogs under conditions favorable to the profuse growth of plants and to the accumulation of plant debris without complete decomposition by bacterial and chemical action. Climate, topography, and changes in position of water table are the chief factors governing the formation and preservation of peat deposits. Low summer temperatures and sufficient humidity to offset evaporation facilitate the growth and accumulation of peat-forming plants in northern Appalachia and at high elevations in mountains and plateaus elsewhere.

The quality of peat is determined by several factors. The rate and type of water inflow and drainage determine the amount of inorganic material such as silt, sand, and gravel. Fluctuation of the water table permits air to come in contact with wet peat and causes rapid decomposition. Fluctuation is greatest near streams and drainage ditches where peat of the reed-sedge and moss types may be changed to humus or even destroyed.

If surface conditions are unchanged, carbonization is largely arrested with the formation of peat, and the accumulated organic matter may exist indefinitely as peat unless the land is drained and decomposition begins, or unless the peat is deeply buried beneath sediments and subjected to pressure and heat to form coal.

THE NATIONAL INDUSTRY

The production of peat in the United States for agricultural and horticultural purposes began about 1904 when 12 companies produced a few thousand tons of peat annually. Since then the industry has expanded greatly, and in 1964 there were 141 active operations in 26 states that produced almost 650,000 tons of peat. Tables 42 and 43 show 1964 production and sales of peat in the United States. In addition, 270,000 tons of peat moss valued at $12,253,000 was imported, mostly from Canada (table 44), in 1964.

All peat production is from surface pits, and most operators use conventional types of excavating and earth-moving machinery, including power shovels, bulldozers, draglines, and front-end loaders in drained bogs, and clamshells and dredges for submerged deposits. Peat is prepared for sale by shredding and screening; some is dried artificially.

Before 1955, most domestic peat was sold locally in bulk but since then large quantities have been packaged and distributed to all parts of the United States. Prices of domestic peat vary greatly, but in general the sales value depends chiefly on the type of peat, the degree of processing, and whether the peat is sold in bulk or packaged. The average price per ton for all domestic peat sold in 1964 was $9.69. The average price of bulk peat was $7.04 per ton whereas that of packaged peat was $12.05.

Peat is generally acceptable as an economic and lasting soil conditioner and substitute for animal manures when used in conjunction with fertilizers. In recent years it has been used extensively for this purpose. In 1964, 96 percent of the domestic peat sold was for general soil improvement (table 45). Peat is used chiefly by landscape gardeners and contractors, by homeowners, and by nurseries and greenhouses. The remainder is sold for uses such as preparation of potting soils and mixed fertilizers, for packing flowers, for preparing seed inoculant, and as a medium for growing mushrooms and earthworms (table 45).

Peat is still used for fuel in some countries, but none has been sold for fuel in the United States for several decades (Sheridan, 1965a).

The outlook for the U.S. peat industry is one of expected continued growth. Since 1945 the number of peat producers has more than doubled and domestic output has more than quintupled. Annual consumption is rapidly approaching 1 million tons.

TABLE 42.—*Peat produced in the United States in 1964, by type*

[In short tons. Source: U.S. Bur. Mines]

Type	Total	Unprepared	Processed	
			Shredded	Shredded and kiln-dried
Moss	144,899	11,952	111,958	20,989
Reed-sedge	361,025	21,065	336,873	3,087
Humus	143,109	59,897	79,942	3,270
Total	649,033	92,914	528,773	27,346

TABLE 43.—*Production and commercial sales of peat in the United States, by State, 1964*

[Source: U.S. Bur. Mines]

State	Active plants	Production (short tons)	Commercial sales		
			Short tons	Value	
				Total	Average price per ton
Alaska	1	2,350	2,350	$18,800	$8.00
California	5	35,391	35,391	442,941	12.52
Colorado	14	27,931	27,931	187,864	6.73
Connecticut, Massachusetts, New Jersey	5	22,431	22,431	254,334	11.34
Florida	7	19,813	19,813	102,152	5.16
Georgia, Maryland, South Carolina	5	16,101	14,624	151,075	10.33
Idaho	2	6,900	900	8,000	8.89
Illinois and Iowa	7	36,843	36,843	420,272	11.41
Indiana	8	66,548	66,568	543,046	8.16
Maine	3	6,300	6,350	170,750	26.89
Michigan	29	268,913	269,074	2,412,274	8.97
Minnesota	8	17,552	19,188	405,333	21.12
Montana, Nevada, North Dakota	4	634	634	29,381	46.34
New York	5	32,574	32,574	261,366	8.02
Ohio	8	6,636	6,363	82,608	12.98
Pennsylvania	10	43,500	39,500	397,123	10.05
Vermont	3	303	286	4,492	15.71
Washington	15	35,017	35,609	170,497	4.79
Wisconsin	3	3,296	3,261	136,518	41.86
Total	142	649,033	639,690	6,198,826	9.69

TABLE 44.—*Peat moss imported for consumption in the United States, by grade and by country, 1964*

[Source: U.S. Bur. Mines]

Country	Poultry and stable grade		Fertilizer grade		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
North America:						
Canada	3,764	$208,080	220,516	$10,360,374	224,280	$10,568,454
Mexico	25	4,345	257	11,800	282	16,145
Total	3,789	212,425	220,773	10,372,174	224,562	10,584,599
South America: Colombia	0	0	6	267	6	267
Europe:						
Belgium-Luxembourg	1	135	44	1,890	45	2,025
Denmark	0	0	25	876	25	876
Finland	0	0	124	3,332	124	3,332
France	0	0	181	4,832	181	4,832
Germany, West	993	38,706	32,000	1,178,560	32,993	1,217,266
Ireland	0	0	2,677	94,614	2,677	94,614
Netherlands	45	1,773	732	23,383	777	25,156
Poland and Danzig	0	0	7,428	242,177	7,428	242,177
Sweden	0	0	1,455	67,462	1,455	67,462
United Kingdom	0	0	140	7,827	140	7,827
Total	1,039	40,614	44,806	1,624,953	45,845	1,665,567
Asia: Japan	6	2,575	0	0	6	2,575
Grand total	4,834	255,614	265,585	11,997,394	270,419	12,253,008

TABLE 45.—*Commercial sales of peat produced in the United States in 1964, by use*

[Source: U.S. Bur. Mines]

Use	In bulk			In packages			Total		
	Short tons	Value		Short tons	Value		Short tons	Value	
		Total	Average price per ton		Total	Average price per ton		Total	Average price per ton
Soil improvement	285, 288	$2, 002, 654	$7. 03	326, 560	$3, 550, 753	$10. 87	611, 848	$5, 570, 892	$9. 08
Potting soils [1]	6, 684	43, 192	6. 46	6, 536	450, 068	68. 86	13, 220	493, 260	37. 31
Packing flowers, shrubs, etc	4, 352	40, 092	9. 21	2, 203	38, 997	17. 70	6, 555	79, 089	12. 07
Mushroom beds [2]	1, 649	16, 208	9. 83				1, 649	16, 208	9. 83
In mixed fertilizers	6, 418	39, 377	6. 14				6, 418	39, 377	6. 14
Total	304, 391	2, 141, 523	7. 04	335, 299	4, 039, 818	12. 05	639, 690	6, 198, 826	9. 69

[1] Includes small amount sold for seed inoculant.

[2] Includes small amount sold for earthworm culture and other uses.

INDUSTRY IN APPALACHIA

The peat industry in Appalachia began about 1958. In 1965, 15 plants in three States (table 46; fig. 47) were in production with reserves on hand estimated by the owners at considerably more than 3 million short tons of air-dried peat. In 1964, the total output of the Appalachian peat industry was 99,000 short tons valued at $906,000 (1958 constant dollars). This total represented 15.2 percent of the national production and 14.7 percent of the national value.

The greatest production comes from Pennsylvania, which in 1964 ranked third in production of peat in the United States. In that year, 43,500 short tons was produced at 10 plants, of which 39,500 short tons was sold for $397,123 at an average price of $10.05 per short ton (Sheridan, 1965a). These 10 plants held 428 acres of reserves which had an estimated maximum of 2,131,120 short tons of air-dried peat available in 1964 (Sheridan, 1956b, p. 11). In 1966 the number of plants had increased to 12 and reserve area was increased to 1,000 acres of peat bogs.

DEPOSITS IN APPALACHIA

Three general types of peat deposits can be recognized in Appalachia: (1) the filled basin, (2) the marsh or bog on flat or gentle slopes (built-up or climbing bog deposits), and (3) a composite type consisting of the built-up deposit underlain by peat of the filled-basin type. The first and third types are exploitable; the second type, though widespread on forest floors of the alpine areas, is not exploitable because it is thin, generally inaccessible, and covered with tree and shrub growths.

A section through a typical peat deposit of the filled-basin type shows (1) bedrock or glacial drift, (2) an overlying compact clay that settled to the bottom of the early pond or lake, (3) a swelling clay (called marl by peat producers), formed with the aid of algae, that grades upward into partially decayed remains of a reed-sedge flora which signifies an environmental change from pond to marsh, and (4) the peat deposit. Peat may accumulate to a thickness of many feet above the initial water level of the basin, and upward changes in plant composition commonly show that pond weeds such as water lilies and sedges were later displaced by mosses, grasses, herbs, shrubs, and trees. Further transition from marsh to damp woods may take place and the deposits finally become covered by a mixed broad- and needle-leafed forest. Some plants grow preferentially on peat bogs; tamarack, for example, is a peat bog indicator, particularly in northeast Pennsylvania.

Depressions and places of change in slope in glacial drift and bedrock are favored localities for development of peat bogs. Peat deposits south of the glaciated region of northern Pennsylvania are at high elevations in structurally controlled valleys developed on both synclines and breached anticlines in the Allegheny Mountain section of the Appalachian Plateaus and in the Valley and Ridge province. Such basins are generally underlain by sandstone and quartzite so resistant to erosion that downcutting of the streams was slowed and ponding facilitated.

All the peat deposits in Appalachia are of Quaternary age. Many are at the surface, but some are buried under glacial drift and sand, silt, and gravel washed from margins of the former glaciers. Flood-plain alluvium covers other peat deposits. Small deposits in sinkholes at the western base of the Blue Ridge are covered by terrace sand and gravel and by stony debris that accumulated at the foot of steep slopes.

TABLE 46.—*Peat bogs in active production*

No. (fig. 47)	Location	Producer	Size of bog (acres)	Peat				Products	Elevation (feet above sea level)	Geology	Section	
				Type	Analysis						Description	Thickness (feet)
					Organic content (percent)	pH	Absorption (percent)					
1	3½ miles north of Hinsdale, Cattaraugus County, N.Y.	Sue Peat Co	10	Humus	75+	5.9	800+	Bulk and package.	2,000	Bog is in cirquelike depression at margin of continental glaciation. Drainage is to Gull Brook flowing south to Ischua Creek.	Woody peat humus containing pine logs. Marl Clay overlies gently inclined bedrock (Devonian shale and siltstone of Conneaut Group of Chadwick).	22. 12.
2	2 miles northeast of Belmont, Allegany County, N.Y.	Genesee Valley Peat Products Co.	8½	Reed-sedge	95	3.4–4.1	1,000	do	1,600	Bog represents filled glacial pond on broad terrace 100–120 ft above Phillips Creek flowing south to Genessee River.	Peat Marl Clay Glacial drift (Wisconsin) overlies gently inclined bedrock (Devonian shale, siltstone, and sandstone of Canadaway Group of Chadwick).	25. 6.5. 0–1.
3	Corry, Erie County, Pa.	Corry Peat Products Co.	50	Humus, reed-sedge.	65–95	5.5	500–600	do	1,500±	Bog represents filled glacial pond in depression within glacial drift.	Reed-sedge peat, upper few feet humus. Marl Clay Glacial drift (Wisconsin) overlies horizontal bedrock (Devonian shale, sandstone, and limestone).	30. 3.4. 15.
4	2 miles southeast of Leesburg, Mercer County, Pa.	Walker (formerly Moore's) Humus & Nursery Co.	3 bogs, each about 2 acres.	Humus	88–90	4.5	500	Bulk	1,180±	Bogs in elongate depression draining northward to Neshonnock Creek. Bogs are filled ponds in a preglacial valley choked by glacial drift.	Humus Clay Glacial drift (Wisconsin) overlies horizontal bedrock (coal beds of Allegheny Group of Pennsylvanian age).	0–8. Undet.
5	2 miles southeast of Leesburg, Mercer County, Pa. (adjacent to No. 4).	D. M. Boyd	8–10									
6	2¾ miles east of Stillwater, Columbia County, Pa.	Benton Peat, Inc.	Several	Moss peat, some humus.	96	4.5	1,200	Bulk and package.	1,100	Bog, part of Wenner Swamp, is on crest of divide between Pine Creek and Fishing Creek which drain southward 200–300 ft below bog. Swamp is developed on Devonian shale and sandstone along the axis of an anticline within margin of Wisconsin glacial drift.	Humus Moss peat Reed-sedge Sandy clay with organic debris. Clay, overlying Devonian shale and sandstone.	2. 4. 1–16. Undet.

7	Near White Haven, Luzerne County, Pa. (1 mile downstream from head of Nescopeck Creek).	Stiller's Blue Ridge Co.	2	Humus	94	5.83	840	Bulk	1,200	Bogs in pockets along valleys of Nescopeck Creek (7, 8) and Linesville Creek (9) within margin of Wisconsin glacial drift, resting on Mississippian shale and sandstone on nose of a syncline.	Upper 3 ft burned off by fire in 1912. Reed-sedge peat Clay, overlies red shaly sandstone (Mississippian).	 8–10.
8	1.5 miles northwest of White Haven, Luzerne County, Pa. (head of Nescopeck Creek).	Pennsylvania Peat Moss, Inc.	58	Moss peat, reed-sedge, humus.	96	4.5	1,000	Bulk and package.	1,300		Humus Sphagnum moss and reed-sedge peat. Marl Sand, overlies red shaly sandstone (Mississippian).	1–3. 32 (avg.). 0–1.
9	White Haven, Luzerne County, Pa.	Blue Ridge Soil Pep Co.	11	Humus	94	5.83	840	Bulk	1,280		Muck Sphagnum and reed-sedge peat. Marl and gray clay Overlies red shaly sandstone (Mississippian).	1. 1–20. 1–2.
10	5 miles east of Wilkes-Barre, Luzerne County, Pa. (south of Mill Creek Pond).	Bald Mountain Peat Corp.	160±	Reed-sedge				Bulk and package.	1,580	Bog is within area of Wisconsin glaciation; overlies Pocono formation along rim of syncline. Peat, about 20 ft thick, discovered while building a lake.		
11	3 miles east of Fleetville, Lackawanna County, Pa.	Lake Linda Peat Co.	45	Reed-sedge	85–95	4.7–5.5	800–1,300	Package	1,260±	Lake Linda, drained in 1960 to permit peat excavation, formed in a depression in glacial drift (Wisconsin) deposited against a ridge of Devonian red shale and sandstone. Peat as thick as 60 ft, average 45 ft.		
12	1.1 miles north of Gouldsboro, Lackawanna County, Pa.	Wayne Peat-Humus Co.	500	Humus, reed-sedge.	94–98		764–1,000	Bulk and package.	1,980	Bog lies in a depression on the top of a hill blanketed by Wisconsin glacial drift.	Humus Reed-sedge peat Marl Glacial drift, overlies Devonian shale and sandstone.	0–4. 1–40. 0–8.
13	Near Blakeslee on Route 115, Monroe County, Pa.	Pocono Moss Products Co.	300	do	86–87	±4.5			1,800±	Bog in glacial drift (Wisconsin) Reed-sedge peat 0–60 ft thick overlies marl which rests on Devonian shale and sandstone.		
14	Skytop, Monroe County, Pa.	Blue Ridge Soil Pep Co., Inc.	185	Moss, reed-sedge.	±90	5.1	725–1,000	Bulk	1,500±	Bog formed an island in a lake of glacial origin. When lake level was artificially raised to improve resort area, island began to break up and floating peat interfered with resort use. Water level has been dropped 22 ft to permit removal of peat.		
15	4.5 miles southeast of Accident, Garrett County, Md.	Garrett County Processing & Packaging Co.	100	Reed-sedge (some humus).	95–97	3.6–4.5	600–1,200	Bulk and package.	2,680–2,700	Bog is part of the Glades and is on the floor of Castleman Basin on the divide between Castleman River and Cherry Creek. Basin is a structural trough with beds of sandstone and shale on either side. The Glades is a plain possibly caused by lateral erosion while vertical downcutting was slowed as streams flowed over sandstone of greater resistance. Ponding probably was aided by beavers and by blockage of stream channels with sediments.	Muck (74 percent organic material). Reed-sedge peat Peat mixed with clay Blue clay, overlies shale and coal of Pennsylvanian age.	1.5. 2–3. 1–1.5.

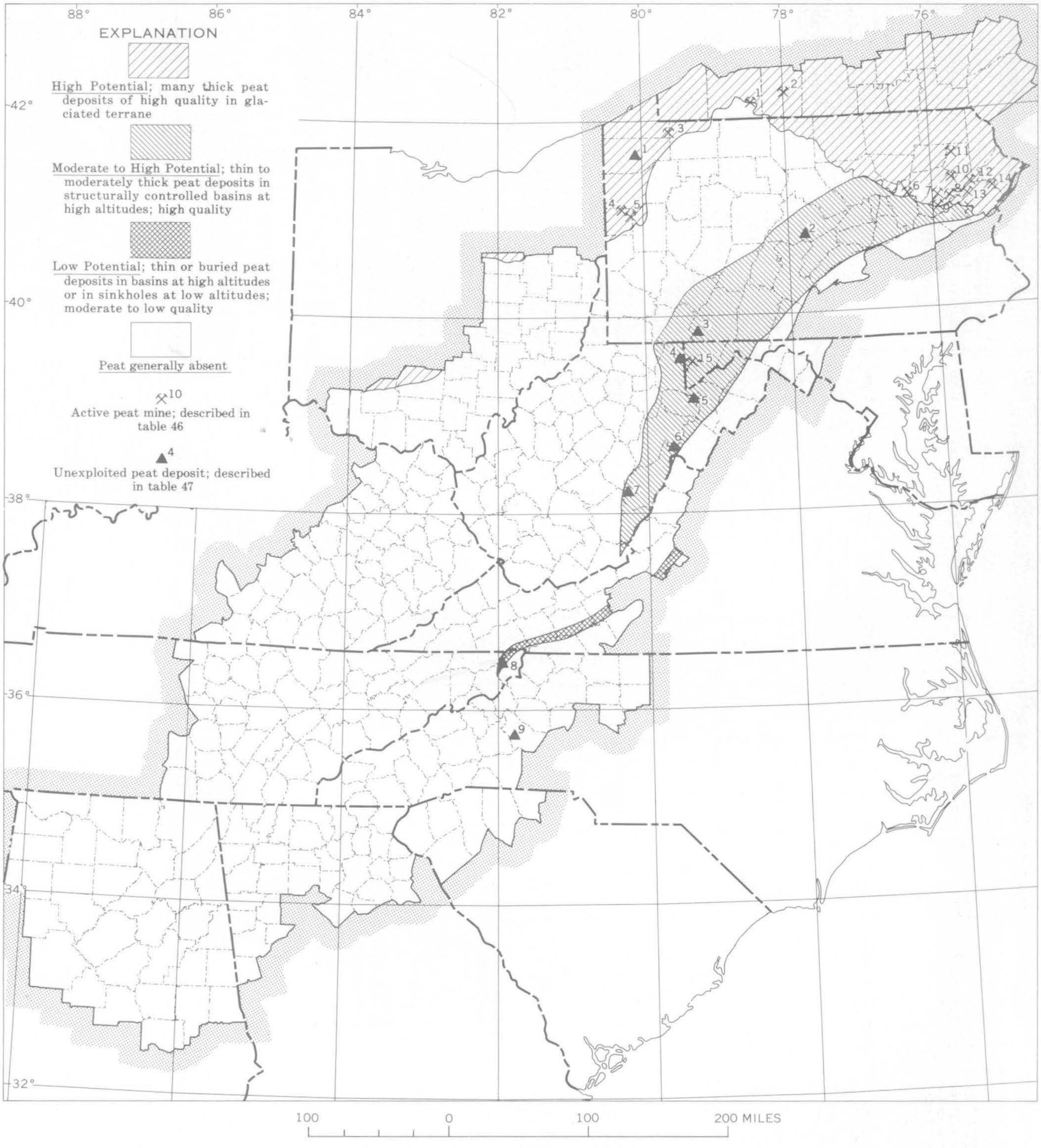


FIGURE 47.—Peat prospecting in the Appalachian Region.

Tables 46 and 47 briefly describe the known peat deposits of Appalachia. Figure 47 shows locations of these peat deposits and also shows the potential prospecting areas. The glaciated section of the northern parts of both the Appalachian Plateaus and Valley and Ridge provinces contains the most peat. Fourteen of the 15 peat bog (table 46) in production are in this area. Some of the peat in this region is very thick. Deposits in Cattaraugus and Allegany Counties, N.Y., have as much as 25 feet of peat (table 46). The three peat bogs in production in Lawrence and Erie Counties, Pa., contain humus and reed-sedge peat as much as 30 feet thick. Test borings in Conneaut Outlet Marsh in nearby Crawford County (table 47, No. 1) show 50 feet of reed-sedge peat under 3 feet of water and muck.

TABLE 47.—*Representative unexploited peat deposits*

No. (fig. 47)	Geologic setting	Location and description
1	Marsh in poorly drained, glacial terrane represents a filled lake in part of preglacial valley from which drainage was diverted by glaciation.	Conneaut Outlet Marsh, Crawford County, Pa. Marsh, 12 miles long and ¼–1 mile wide, locally contains peat. Test boring for proposed bridge on Interstate Highway 89 showed 50 ft of reed-sedge peat under 3 ft of water and muck. Peat overlies silty clay and gravel.
2	Bog in structurally controlled erosional depression—Valley and Ridge province. Bog at 1820 ft elevation, adjacent ridges at 2400 ft.	Bear Meadows Bog, Centre County, Pa. Bog, 1¼ miles long and ½ mile wide, is in a depression on nose of breached anticline plunging southwest, 60 miles southwest of nearest glacial moraine. According to Stingelin (1965) 9.2 ft of sphagnum moss peat overlies peaty clay and silty clay resting on Ordovician shale and sandstone. Adjacent ridges are Tuscarora Quartzite (Silurian).
3	Marsh in structurally controlled erosional depression; Allegheny Mountain section of Appalachian Plateaus. Marsh at 2470 ft elevation, adjacent ridges at 3000 ft.	Mount Davis Marsh, Somerset County, Pa. Bog, 1 mile long and 0.1–0.5 miles wide, is in a depression on axis of anticline plunging northeast. Stingelin (1965) reports 7 ft 8 in. of peat, mostly reed-sedge, overlying sand and silt, resting on Pocono Formation (Mississippian). Adjacent heights are capped by shale and sandstone of the Mauch Chunk Formation (Mississippian).
4	Swamp in structurally controlled erosional depression; Allegheny Mountain section of Appalachian Plateaus. Swamp at 2570 ft elevation, ridges 300–400 ft higher.	Cranesville Swamp, Preston County, W. Va. Swamp, 2 miles long and 0.5 mile wide, is in a depression just east of the axis of a breached anticline plunging northeast. Stingelin (1965) reports 41 in. of peat overlying light-gray to dark-brown clay and interbedded sandy layers resting on Greenbrier Limestone (Mississippian); bordering ridges underlain by Pocono and Mauch Chunk Formations (Mississippian).
5	Marsh and swamp in structurally controlled erosional depression; Allegheny Mountain section of Appalachian Plateaus. Marsh and swamp at 3150–3250 ft elevation, the surrounding mountains at 3900–4000 ft.	Marsh and swamp in Cannan Valley, Tucker County, W. Va. Most extensive area is about 2.5 miles long and 0.2–1 mile wide; valley is a boat-shaped basin on the axis of Blackwater anticline. According to Phillips (1925) at least 3 ft of black humus over brown moss peat and reed-sedge peat resting on Greenbrier Limestone (Mississippian).
6	Swamp in solution-formed depression on flank of syncline; Valley and Ridge province. Swamp at 3640 ft elevation, the surrounding mountains at 4000 ft.	Blister Swamp, Pocahontas County, W. Va. Swamp has about 50 acres of peat (Williams and Fridley, 1933) of undetermined thickness, resting on thin shale stratigraphically between Greenbrier and Pocono Formations (Mississippian). Depression formed by solution of Greenbrier Limestone during time stream erosion was slowed by flowing on resistant Pocono Sandstone.
7	Poorly drained basin developed on nonresistant shale in northwest dipping monoclinal strata, overlain and underlain by resistant sandstone; Appalachian Plateaus. Basin at 3400 ft elevation, the mountains 1000–1500 ft higher.	Cranberry Glades, Pocahontas County W. Va. Basin contains 250–300 acres of peat as much as 11 ft thick. Rigg and Strausbaugh (1949) report a section including 2 ft of sphagnum moss peat, 3 ft of mixed sphagnum and sedge, and 2 ft of reed-sedge peat, overlying 4 ft of algal ooze, 3 ft of marl and more than 1 ft of clay resting on shale of the Mauch Chunk Formation.
8	Poorly drained basin along trough of synclinal valley; best and thickest peat at upland edge of valley floor, where effects of artificial drainage on fluctuations of groundwater table and accompanying oxidation of organic matter are slight. Valley and Ridge province, valley at 2800 ft elevation, mountains 1400 ft higher.	Shady Valley in Johnson County, Tenn. Oval basin with floor 2 miles long and 1 mile wide, contains swamp and marsh land. Section along a central drainage ditch shows 12–14 in. of humus and reed-sedge peat underlying sand and gravel and overlying 2 ft of clay and a foot or two of sand. Bedrock is Shady Dolomite (Cambrian) and Erwin Quartzite (Cambrian?).
9	Pond or swamp on former flood plain of Catawba River; Piedmont province.	Railroad cut 2.45 miles west of Glen Alpine, Burke County, N.C. Bed of peat and driftwood 15 ft. thick, overlain by flood plain deposits and underlain by saprolitized schist and gneiss reported by Kerr (1875) and J. C. Reed, Jr., and others (1964).

The greatest concentration of peat bogs in active operation is in northeastern Pennsylvania where glacial drift and preglacially eroded fields of bedrock provide terrane suited for accumulation and preservation of thick deposits of peat. Typical deposits of good quality peat of all types, reaching thicknesses of as much as 60 feet, are mined in Columbia, Luzerne, Lackawanna, and Monroe Counties (table 46, Nos. 6–14). Many of these deposits are at the heads of valleys and on nearby ridges and hilltops where fluctuation of the ground-water table is slight. Moreover, these deposits are relatively free from contamination by silt, clay, sand, and gravel.

The peat bog being mined in Garrett County, Md. (table 46, No. 15) and unexploited peat deposits in Centre and Somerset Counties, Pa., and Preston, Tucker, and Pocahontas Counties, W. Va., (table 47, Nos. 2–7) are typical of peat deposits in structurally controlled valleys outside the areas of glaciation. These valleys occupy breached anticlines and synclines at high altitudes in the folded parts of the Appalachian Plateaus and Valley and Ridge province where slightly permeable shale and sandstone or quartzite underlie the peat deposits. The quality is best near the upland margins of the deposits; near the streams much of the peat has been destroyed by oxidation.

The unexploited peat deposit in Shady Valley, Tenn. (table 47, No. 8), represents the type of occurrence in structurally controlled basins at high altitudes in lower latitudes of Appalachia. Shady Valley is an oval basin with a floor 2 miles long and 1 mile wide, 2,800 feet above sea level. The swamps and marshes that occupy the floor are underlain with peat of the humus and reed-sedge type between sand and gravel above and sand and clay below. Severely oxidized peat can be observed along a central drainage ditch where amount of rise and fall of the water table is maximum. Twelve to fourteen inches of humus is all that remains in the banks of the ditch of an appreciably greater peat thickness shown near the valley walls where water-table fluctuation is minimal.

Peat deposits of Quaternary age, in valleys similar to that of Shady Valley and in sinkholes caused by solution of dolomite, extend along the base of the Blue Ridge. In the sinkholes the peat deposits are buried by slope wash and by terrace deposits and generally do not have economic potential.

A bed of peat 15 feet thick in Burke County, N.C. (table 47, No. 9), formed in swamps of former flood plains of rivers in the Piedmont province. Such deposits are generally too small, too widely scattered, or too inaccessible to be exploited profitably. Peat presently forming on the forest floors in the highest parts of the Blue Ridge and the Appalachian Plateaus also has little economic potential.

PROSPECTING FOR PEAT IN APPALACHIA

Although swamps, marshes, and flood plains abound in many parts of Appalachia, especially in the glaciated part, not all contain peat deposits of commercial value. For example, only about 5 percent of the swamps, marshes, and flood plains in glaciated northwestern Pennsylvania have economic or potentially economic deposits. The growing importance of peat increases the demand for a systematic study of the location, size, and quality of deposits preparatory to development.

FEDERAL SPECIFICATIONS AS A GUIDE IN SELECTING PEAT DEPOSITS

General Services Administration Federal Specification Q–P–116e, dated May 10, 1961, deals with peat for agricultural use and may serve as a guide in the prospecting of deposits for exploitation. Although the specification is for the use of Federal agencies, the following standards deserve consideration:

> Sphagnum moss peat shall consist of a least 75 percent of partially decomposed stems and leaves of sphagnum in which the fibrous and cellular structure is still recognizable. Its texture may vary from porous fibrous to spongy fibrous, and it shall be either crumbly or compact, but fairly elastic. It shall be nearly free from decomposed colloidal residue, wood, etc., and shall be essentially brown in color.
>
> Other moss peat shall consist of at least 75 percent of partially decomposed stems and leaves of hypnum, polytrichum, and other mosses in which the cellular structure is still recognizable. Its texture may vary from porous fibrous to spongy fibrous, and it shall be either crumbly or compact, but fairly elastic. It shall be nearly free from decomposed colloidal residue, wood, etc., and shall be essentially brown to black in color.
>
> Humus peat (peat muck) shall be finely divided plant debris so decomposed that its biological identity is lost. It shall be furnished in granular form, of uniform composition and size, free from hard lumps. It shall be low in wood and other extraneous matter, and shall be brown to black in color.
>
> Reed-sedge peat shall be the moderately decomposed stems, leaves and roots of rushes, coarse grasses, sedges, reeds, cattails, and similar plants. It shall be coarse or finely fibrous, and brown to black in color. It shall be low to moderately low in decomposed colloidal plant residue and low in wood or other extraneous materials.

The Federal specification states that the approximate pH should be determined by the purpose for which the peat is to be used. For instance, acid peat, pH 3.5–4.5, should be used for acid-loving plants. The acidity characteristic for each of the peat types is listed as 3.2–4.5 for sphagnum moss peat, 3.2–7.0 for other moss peat, and 4.0–7.5 for humus peat and reed-sedge peat.

LOCATING DEPOSITS

Economic value of a peat deposit depends not only on its quality but also on its size and its accessibility and the availability of markets for the prepared product. Most of the favorable peat-bearing areas in Appalachia, especially near-surface peat in basins, may be delineated by studies of large-scale topographic maps, aerial photographs, infrared imagery and radar surveys, maps of bedrock geology, glacial drift, and data on ground water, flooding, soils, and vegetation coordinated with studies in the field of the bedrock, surficial and ground-water geology, geomorphology, and ecology.

Peat deposits of good quality are especially abundant in northern Appalachia in basins at the heads of streams and on adjacent hill and ridge tops where water-table fluctuation is slight and where silt and sand have not been introduced through flooding. Deposits of good quality also occur at lower altitudes in parts of valleys dammed by glacial drift or from which streams have been diverted, or in structurally controlled valleys, if throughout the period of peat formation they have been free from flooding and excessive water-table fluctuation. Some deposits are covered with muck and water, some with marsh grasses, some with swamp trees and shrubs, and some with a dryer broad- and needle-leaf forest.

The three-dimensional shape of a peat deposit must be known in order to estimate peat reserves. According to Davis (in Dachnowski, 1912, p. 149), the quantity of peat in a given deposit may be determined for practical purposes by finding its total area and average depth and by then assuming that at least 200 tons of air- or machine-dried peat can be made per acre for each foot in depth. Material having an organic content of less than 75 percent must, of course, be eliminated from the calculation. Probing has long been used to determine depths of shallow deposits. Coring is required to obtain samples for peat analysis data. The cores should penetrate to the underlying glacial drift or bedrock to furnish information on the history of bog development to be used in further prospecting.

Mintzer (1962, p. 59–64) described the successful use of geophysical surveys for studies of peat bogs. A seismic-refraction survey related to highway construction showed the presence of an anomaly in a glaciated region of Logan County, Ohio, which was identified by borings as a peat bog. An electrical-resistivity survey combined with air-photo interpretation accurately delineated the areal extent and depth of the bog. Infrared radiometry was successful in determining the presence and depth of a peat bog buried by glacial outwash to a depth of 6–8 feet near Bellfontaine, Ohio. T. R. Ory (oral commun., 1965) reported that in this study anomalies appearing in infrared imagery correlate with bedrock, glacial drift, and depth of peat. Darker tones on the infrared image were found to correspond to areas underlain by peat, and darkest tones were correlated with the deepest part of the peat deposit. Results of such studies as these encourage further research in methods of quantitative prospecting.

RESOURCE POTENTIAL

The mining of peat, primarily for use as a soil conditioner, is a growing industry in the United States and especially in northern Appalachia. Annual national consumption is rapidly approaching 1 million tons. In 1964 the domestic production of peat was about 650,000 tons which was sold for nearly $6¼ million; an additional 270,000 tons was imported, chiefly from Canada.

Although the peat industry in northern Appalachia is only about 7 years old, by 1964 it contributed 15.2 percent of the total national production of peat. In 1965, fifteen plants produced peat from deposits in Maryland, Pennsylvania, and New York. Additional large deposits of peat probably occur in many glaciated areas of northern Pennsylvania and southern New York as well as in valleys at high altitude in central and south-central Pennsylvania, western Maryland, and eastern West Virginia.

On the whole, known and potential peat resources of Appalachia are large and the outlook for the Appalachia peat industry is for continued growth. There is a good demand for peat in the suburban areas of the cities of northeastern United States, where price is controlled in part by distance the peat must be transported. Peat in northern Appalachia is near these markets and, being cheap to mine and process, is in a favorable competitive position.

Prospecting is needed for the purpose of assisting local producers to plan expansion of output and to attract new producers. To assist in the expansion of the peat industry, techniques of making reliable estimates of size and quality of peat deposits should be developed. Most important is a clear understanding of the relation between the deposits and the vegetation, drainage conditions, water table, topography, glacial drift, and bedrock existing at present and during the formation of the peat.

PETROLEUM AND NATURAL GAS

By Richard F. Meyer, U.S. Geological Survey, and Curt D. Edgerton, Jr., U.S. Bureau of Mines.

INTRODUCTION

Petroleum and natural gas are among the most important and widespread mineral commodities of Appalachia. In 1964 they accounted for $187 million and ranked second to coal in value of the mineral commodities produced in the region. Oil and gas fields are found in all parts of Appalachia except in the Carolinas and Georgia (figs. 48, 49). However, the most extensive fields are in, and the greatest production has come from, Pennsylvania, West Virginia, and Kentucky. Production is from Paleozoic rocks, mostly in the Appalachian Plateaus, Interior Low Plateaus, and Central Lowland provinces; some natural gas is produced in the Valley and Ridge province.

Studies of petroleum production in Appalachia are difficult because of the paucity of statistical information, especially for the earlier years. Primary sources of information include Derrick Publishing Co. (1898, 1900, 1916, 1920), Arnold and Kemnitzer (1931), the American Petroleum Institute (1965 and earlier editions), and U.S. Bureau of Mines Minerals Yearbooks. Annual production in individual fields is not reported, although much information is available in the above reports and in Ver Wiebe (1938, 1949), Fettke (1952), and Whieldon and Eckard (1963). Little information is available about production according to geologic formation or to regions smaller than States. In the present report the production solely from Appalachia in Kentucky, New York, Ohio, and Tennessee is partly estimated.

The oil- and gas-field maps (figs. 48, 49) were compiled on a base developed from the oil- and gas-field map of the United States (Vlissides and Quirin, 1964).

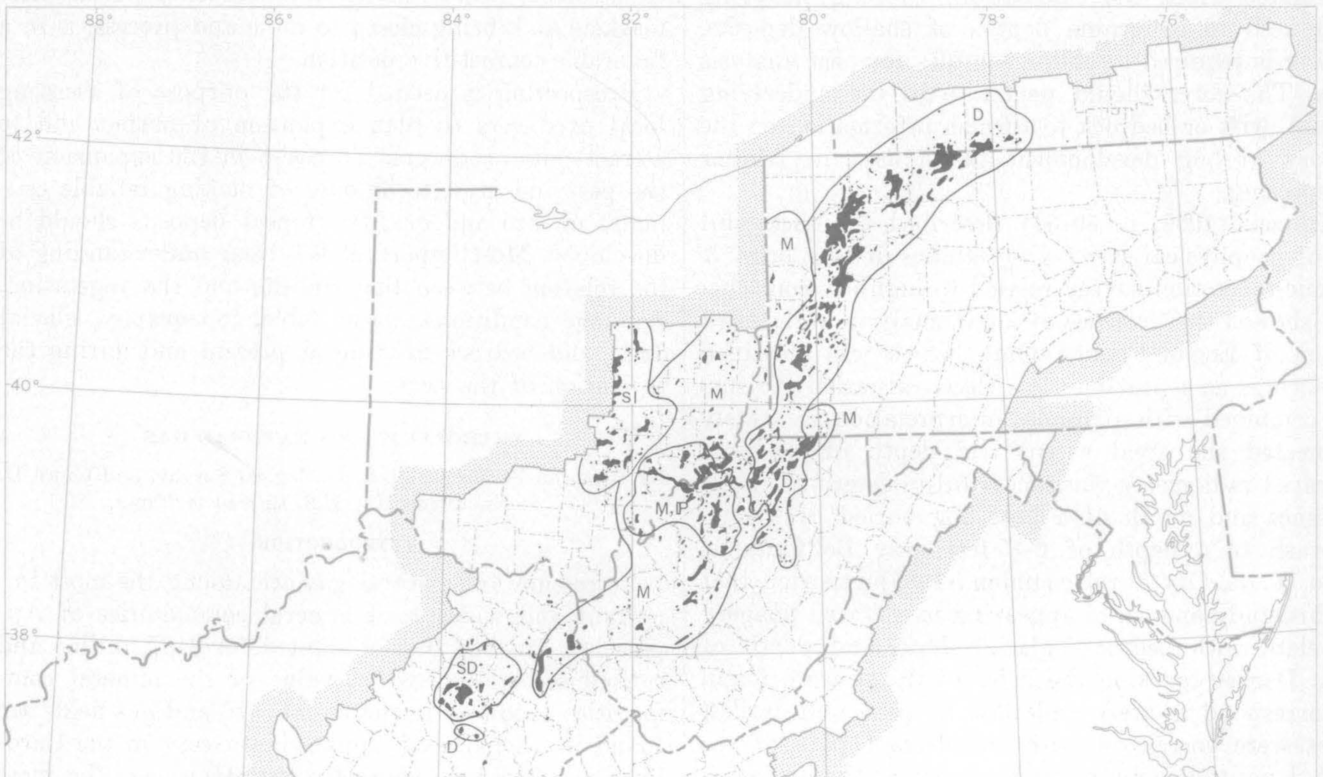


FIGURE 48.—Oil fields of the Appalachian Region. Modified from Vlissides and Quirin (1964).

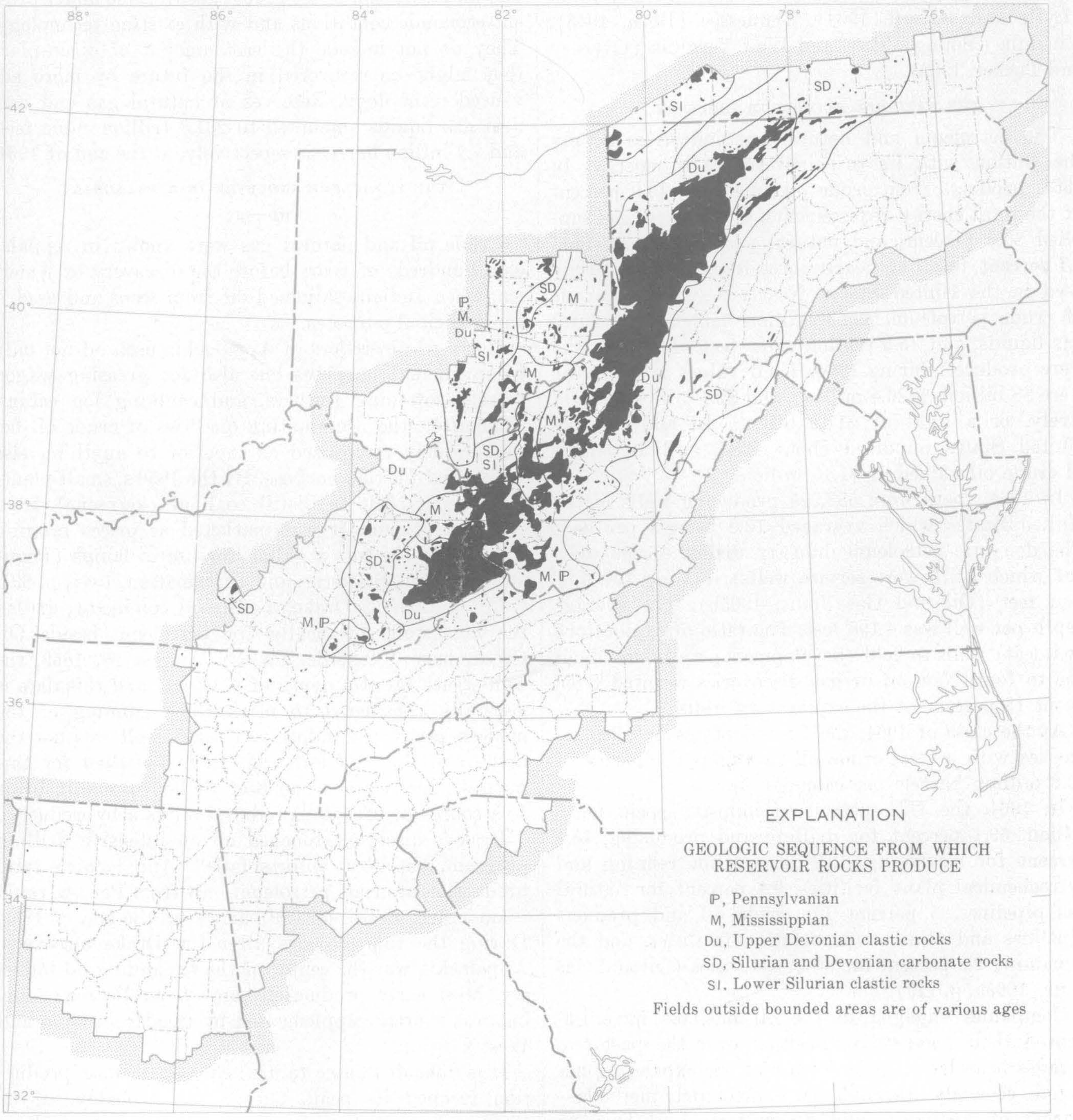


FIGURE 49.—Gas fields of the Appalachian Region. (Modified from Vlissides and Quirin (1964).

Information on individual States was derived as follows: Alabama (Semmes, 1920), Kentucky (E. B. Wood and Walker, 1954), New York (Kreidler, 1953, 1959, 1963), Ohio (Calvert, 1964), Pennsylvania (Lytle and Fairall, 1964), Tennessee (Born, 1943), Virginia (Young, 1955), and West Virginia (Overbey and Tucker, 1962).

THE NATIONAL PETROLEUM INDUSTRY

The petroleum and natural gas industries supply the Nation with its principal source of energy. In 1964, products from crude oil furnished 40.0 percent of the total energy requirements, dry natural gas supplied 30.0 percent, and natural gas liquids provided 3.4 percent, totalling nearly three-fourths of all energy used in the United States. Nearly 2.8 billion barrels of crude petroleum, 422.5 million barrels of natural gas liquids, and 15.5 trillion cubic feet of natural gas were produced during 1964. Their values in that year were $8 billion, $826.4 million, and $2.4 billion, respectively, or a total of $11.2 billion. In addition the United States imported about 438.6 million barrels of crude oil valued at $1.15 billion.

In 1964, there were 588,225 producing wells in the United States which averaged 12.9 barrels per day. The domestic petroleum industry drilled 45,236 wells (of which 2,273 were service wells) totaling 190 million feet (Oil and Gas Jour., 1965b). The average depth per well was 4,198 feet. The ratio of exploratory (wildcat) wells to field (development) wells was about one to four. New oil or gas discoveries resulted from about 15 percent of the exploratory wells.

At the close of 1964, the United States had 300 refineries with a total crude oil throughput capacity of 10.8 million barrels per calendar day.

In 1964, the U.S. petroleum industry spent $6.36 billion, 59.1 percent for drilling and producing, 13.4 percent for marketing, 10.2 percent for refining and petrochemical plant facilities, 9.4 percent for natural gas pipelines, 5 percent for crude oil and products pipelines and other transportation facilities, and the remaining 2.9 percent for other activities (Oil and Gas Jour., 1965a, p. 129).

Companies engaged in the oil business have improved their competitive position over the past two decades in order to keep abreast of the expanding national economy through two principal methods—merger of companies and diversification of business activities. Although not all attempted mergers have materialized, this avenue of economic growth is, nevertheless, utilized with increasing frequency. Companies have diversified by investing in such industries as petrochemical and fertilizer manufacture, real estate, mining, and shipping.

Crude petroleum reserves in the United States at the end of 1964 were estimated to be 31 billion barrels (Am. Gas Assoc., Am. Petroleum Inst., and Canadian Petroleum Assoc., 1965) recoverable under present economic conditions and with existing technology. They do not include the vast amount of oil-in-place that might be recovered in the future by more advanced technology. Reserves of natural gas and natural gas liquids amounted to 281.3 trillion cubic feet, and 7.7 billion barrels, respectively, at the end of 1964.

THE PETROLEUM INDUSTRY IN APPALACHIA

HISTORY

Crude oil and natural gas were known in Appalachia hundreds of years before the discovery of America, when Indians skimmed oil from seeps and used it for medicinal purposes.

Early white settlers in Appalachia used oil not only for medicinal purposes but also for greasing wagon wheels, softening leathers, and caulking log cabins. Thereafter, the illuminating qualities of crude oil became widely recognized as superior to anything else being used for this purpose. By the 1850's, small plants were being built to distill coal oil (kerosene) from crude petroleum. It was marketed at prices ranging from 60 to 70 cents a gallon for use in lamps (Pennsylvania Bur. Statistics and Information, 1944, p. 89).

Col. Edwin L. Drake, a railroad conductor, drilled the first well specifically for petroleum beside Oil Creek, near Titusville, Pa. On August 29, 1859, the well struck oil at a depth of 69½ feet and this date is generally considered to mark the beginning of the modern petroleum industry. Drake's well was not the first to produce oil but was the first drilled for this purpose; many wells had been drilled to obtain brine as a source of salt and produced oil as a byproduct.

Drake's discovery touched off an intensive drilling program, but many efforts failed. Appalachia's total production of crude petroleum—all from Pennsylvania—amounted to about 2,000 barrels by the end of 1859. During the four decades after the Drake discovery, Appalachia was the center of the expanding oil industry. Most early production came from Pennsylvania, but was shortly supplemented by that from Ohio and West Virginia.

It is difficult to ascertain when Appalachian production reached its peak, but it was probably in the 1890's, when production was at a maximum of about 40 million barrels per year. Thereafter, production declined except for occasional increases resulting from the discovery of large new fields or the introduction of technologically advanced production methods.

By 1917, annual petroleum production in Appalachia was down to slightly more than 22 million barrels. Increased business activity resulting from World War I boosted production to 29 million barrels, which dropped to about 24 million barrels during the mid-1920's. Surprisingly, the depression of 1929 and subsequent years had only slight effect on Appalachian crude oil production, although production of natural gas and natural gas liquids was adversely affected.

Appalachian oil producers were unable to take advantage of the increased demand for petroleum brought about by World War II because most fields had reached the stage of development where little could be done to reverse the decline of production experienced by all older fields. In the 1940's, natural gas production fluctuated widely from year to year, and natural gas liquids production continued a general increase begun some years earlier. From 1951 to 1961 the value of petroleum production in Appalachia declined. Since 1962 production has increased, but the cumulative increase was less than a million barrels during the period of 1962–64. At the end of 1964, annual production was slightly less than 17 million barrels (table 48).

Production of natural gas in Appalachia in 1964 totaled 374 billion cubic feet; since 1949, only one other year has been lower. Production of natural gas liquids, however, reached a peak in 1964, at 15 million barrels.

The following chronological review of the Appalachian petroleum industry provides a historical perspective for the industry as it is today. Data are derived principally from Derrick Publishing Co. (1898) and Williamson and Daum (1959).

Earliest petroleum leases were issued in 1853, to cover an oil spring, and in 1857 for a boring for oil. During 1859 and 1860 the lease form was simplified and evolved into the familiar one of royalty payments and bonuses.

Most cable-tool drilling equipment had been developed by brine well drillers by the early 1860s. Casing was in use and a technique had been worked out for sealing off formation water with sacks of seed, a method of "cementing." Foot-operated spring-pole drilling had been replaced by steam-operated machinery. About 1861 a hight-explosive torpedo was used to stimulate well production.

Transportation of crude oil to the primitive refineries of the day was a problem; much oil was hauled by wagon in open vats, wooden barrels and kegs, or any other available containers. Where both refineries and producing wells were located along navigable streams, crude petroleum commonly was shipped by barge. Such transportation resulted in much loss, not only from seepage and spillage, but from the evaporation of the lighter, more volatile fractions of crude oil. In 1861, 12 bulk boats (barges) were built to carry the product from Oil City, Pa., down the Allegheny River to Pittsburgh.

Several unsuccessful attempts were made during the early 1860's to transport crude oil by pipeline. The first successful pipeline was probably the one constructed in 1864 by Samuel Van Syckle who organized the Oil Transportation Association to build and operate a pipeline from producing wells on Miller's farm, near Titusville, Pa., to Pithole, about 5 miles away. The 2-inch line was capable of transporting 81 barrels of crude petroleum per hour, and the transportation charge was $1.00 per barrel, a considerable reduction from the $3.00 per barrel generally charged for wagon transport. The first natural gas pipeline was laid in 1875.

By 1892, iron storage tanks totaling 13 million barrels capacity were in use. Agreement had been reached that a barrel was to consist of 42 U.S. gallons; earlier, barrels ranged from 40 to 50 gallons.

Samuel M. Kier built the first petroleum refinery, of 5 barrels daily capacity, at Pittsburgh in 1854. He

TABLE 48.—*Estimated production and values of crude petroleum, natural gas, and natural gas liquids in the Appalachian Region, 1955–64*

[Source: U.S. Bur. Mines]

Year	Crude petroleum, including field condensate			Natural gas			Natural gas liquids			Total	
	Production (thousand barrels)	Value (thousands)	Value in 1958 constant dollars (thousands)	Production (million cubic feet)	Value (thousands)	Value in 1958 constant dollars (thousands)	Production (thousand barrels)	Value (thousands)	Value in 1958 constant dollars (thousands)	Value (thousands)	Value in 1958 constant dollars (thousands)
1955	18,655	$62,078	$67,547	404,189	$101,352	$110,281	9,372	$17,595	$19,145	$181,025	$196,973
1956	18,788	73,029	76,951	401,743	104,072	109,661	10,821	28,869	30,419	205,970	217,031
1957	18,949	79,083	80,372	394,791	101,624	103,280	9,799	27,897	28,352	208,604	212,004
1958	16,612	57,882	57,882	393,159	100,175	100,175	8,897	28,802	28,802	186,859	186,859
1959	18,341	64,892	63,996	399,460	105,060	103,610	12,081	31,242	30,811	201,194	198,417
1960	16,629	64,201	63,630	421,253	115,132	114,107	13,283	29,513	29,250	208,846	206,987
1961	16,173	63,850	63,467	405,541	110,954	110,288	13,704	31,311	31,123	206,115	204,878
1962	16,436	63,688	63,242	371,125	105,610	104,871	13,595	30,046	29,836	199,344	197,949
1963	16,554	64,384	64,126	397,050	102,592	102,182	14,894	30,219	30,098	197,195	196,406
1964	16,807	61,802	61,493	374,234	96,912	96,427	15,101	29,360	29,213	188,074	187,133

produced an oil for lamps which was unsatisfactory, however, because it smoked excessively when burned. Other refineries were built in the following years and by 1873 there were 101 refineries in operation in 21 different cities.

Between 1875 and 1877, H. L. Taylor & Co. evolved into the first integrated oil company when it acquired leases, producing wells, and pipelines.

During the early years of the petroleum industry, prices of crude oil varied widely, some sales being reported at $20.00 per barrel (Williamson and Daum, 1959, p. 103). Much crude oil sold for prices ranging from $8.00 to $14.00 per barrel. During the later 1860's, and throughout the 1870's, a price of $12.00 seems to have prevailed throughout much of Appalachia. Such high prices stimulated the drilling needed to keep the young industry alive.

PRODUCTION AND VALUE

Only a small part of domestic production of crude oil, natural gas, and natural gas liquids originates in Appalachia. Total value of U.S. production in 1955 was $9.2 billion (1958 constant dollars); production from Appalachia was $197 million, or 2.1 percent of the U.S. total. In 1964, the Appalachian industry produced only 1.7 percent of the U.S. total. Low productivity per well, relatively shallow depths, and a preponderance of small, independent companies and operators using outmoded equipment (figs. 50, 51) characterize the Appalachian crude oil industry.

The chart of annual crude oil production (fig. 52) shows several aspects of the petroleum industry. Until 1885 almost all U.S. production came from Appalachia. Between 1885 and 1900, when Appalachian production reached its peak, the effects of new producing regions began to show strongly and since 1900 the divergence between national and Appalachian production has steadily widened.

Secondary recovery of oil from wells in Appalachia has been an important factor in maintaining a fairly steady production during most of this century. The vacuum method was most extensively used from 1918 to 1925. This method was generally successful but had the disadvantage that only the more volatile hydrocarbons were extracted and a high-viscosity oil residue was left in the rock (Lytle, 1955, p. B33). Secondary recovery by air and gas injection was first attempted in 1916 and the amount of petroleum recovered by these methods steadily increased to a maximum in 1929. In 1953, 79 percent of production in Pennsylvania was by water flooding (Lytle, 1955, p. B34).

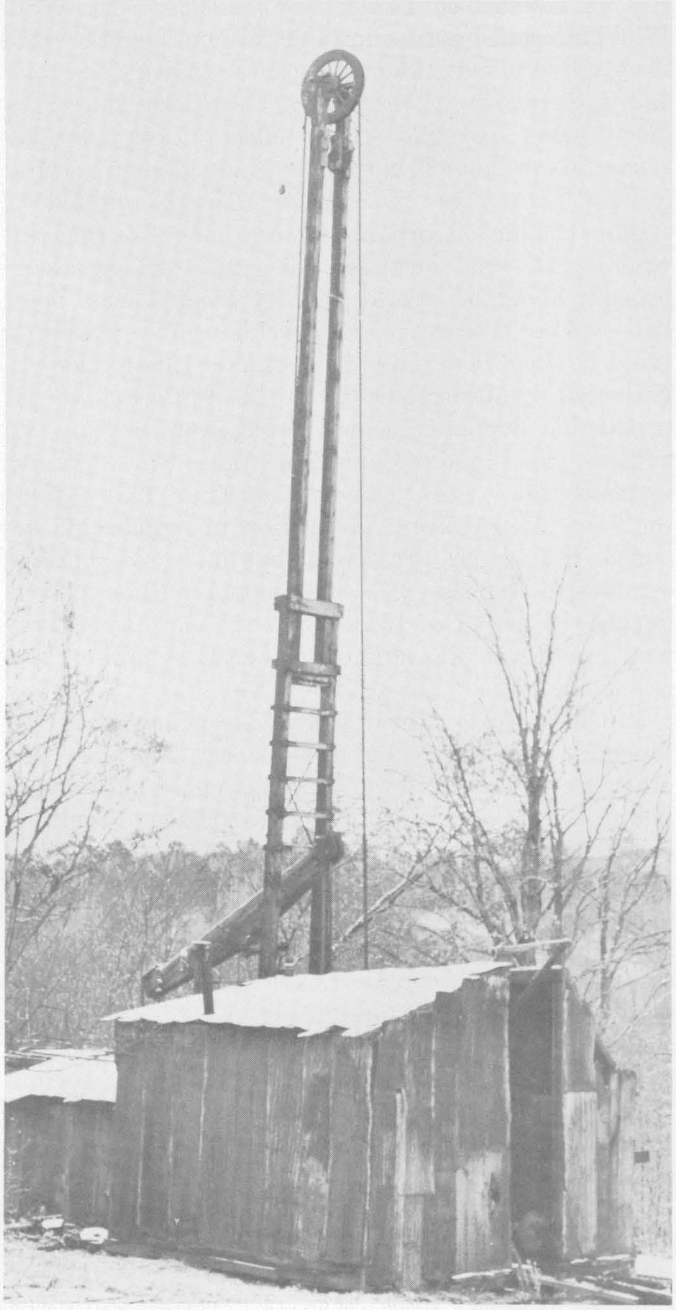


FIGURE 50.—Cable-tool rig drilling in an Appalachian field.

Natural gas production in the area has remained at an even level since 1918 (fig. 53) but discovery in 1965 of five gas pools in Pennsylvania has resulted in an increase in production. In 1964 Appalachia produced 15 million barrels of natural gas liquids (fig. 54), which represented 3.6 percent of the national production.

During the past 10 years (1955–64) production and value of crude petroleum, natural gas, and natural

FIGURE 51.—Disconnected pumping well with outmoded jack of a type common in Appalachian fields.

gas liquids in Appalachia have varied somewhat from year to year, in general showing an overall decline (fig. 55; table 48). Average annual value of production during the period was $200.5 million (1958 constant dollars). The values of both crude petroleum and natural gas were lower in 1964 than in 1955; crude petroleum declined $6 million to $61.5 million, and natural gas $13.9 million to $96.4 million. An increase in the value of natural gas liquids by $10 million to $29.2 million offset some of the decline in value of the others.

Some fields in Appalachia, notably the Bradford district of northwestern Pennsylvania and southwestern New York, produce exceptionally high-quality crude petroleum that contains large amounts of paraffin lubricating-oil fractions. Although prices vary according to characteristics, location, and quantity, this crude oil commands the highest price in the domestic market. In 1964 the average value of this high-quality crude petroleum was $4.44 per barrel in New York compared with the national average of $2.88 per barrel; in Pennsylvania it was $3.32 and in West Virginia, $3.85. Production was from old fields where secondary recovery methods were used; average daily production per well was less than 1 barrel.

Appalachia does not produce enough oil to supply its own refineries, so most of the crude oil is imported. Most existing fields are producing at capacity and it is doubtful that production can be increased materially now. However, the potential for discovery of new fields and deeper reservoirs is good, and such discovery could lead to important increases in production. Future development of more efficient secondary and tertiary recovery methods should bring about rejuvenation of some of the older fields.

NATURAL GAS STORAGE

Natural gas is stored in abandoned gas reservoirs to enable distribution and utility companies to supply peak demand more efficiently during periods of cold weather. Virtually all natural gas stored in this manner is recoverable.

Natural gas storage capacity in Kentucky, New York, Ohio, Pennsylvania, and West Virginia (outside as well as inside Appalachia) is estimated to be 1,700 billion cubic feet, or about 44 percent of U.S. total. At the end of 1964, an estimated 1,400 billion cubic feet of natural gas was in storage, or about 70 percent of capacity. At the beginning of 1965, West Virginia ranked third in natural gas storage in the Nation, with 306 billion cubic feet of stored gas. The gas was stored in 38 reservoirs, of which 23 are in rocks of Mississippian and 15 in rocks of Devonian age. In 1964, Kentucky had three natural gas storage installations in water sands (aquifers), a storage method rapidly coming into use in regions of the country where few exhausted dry-gas reservoirs are available.

PETROLEUM REFINING

Fourteen companies operated 18 petroleum refineries in Appalachia in 1964 ranging in operating capacity from 450 bpcd (barrels per calendar day) to 80,000 bpcp. The capacity of four refineries was above U.S.

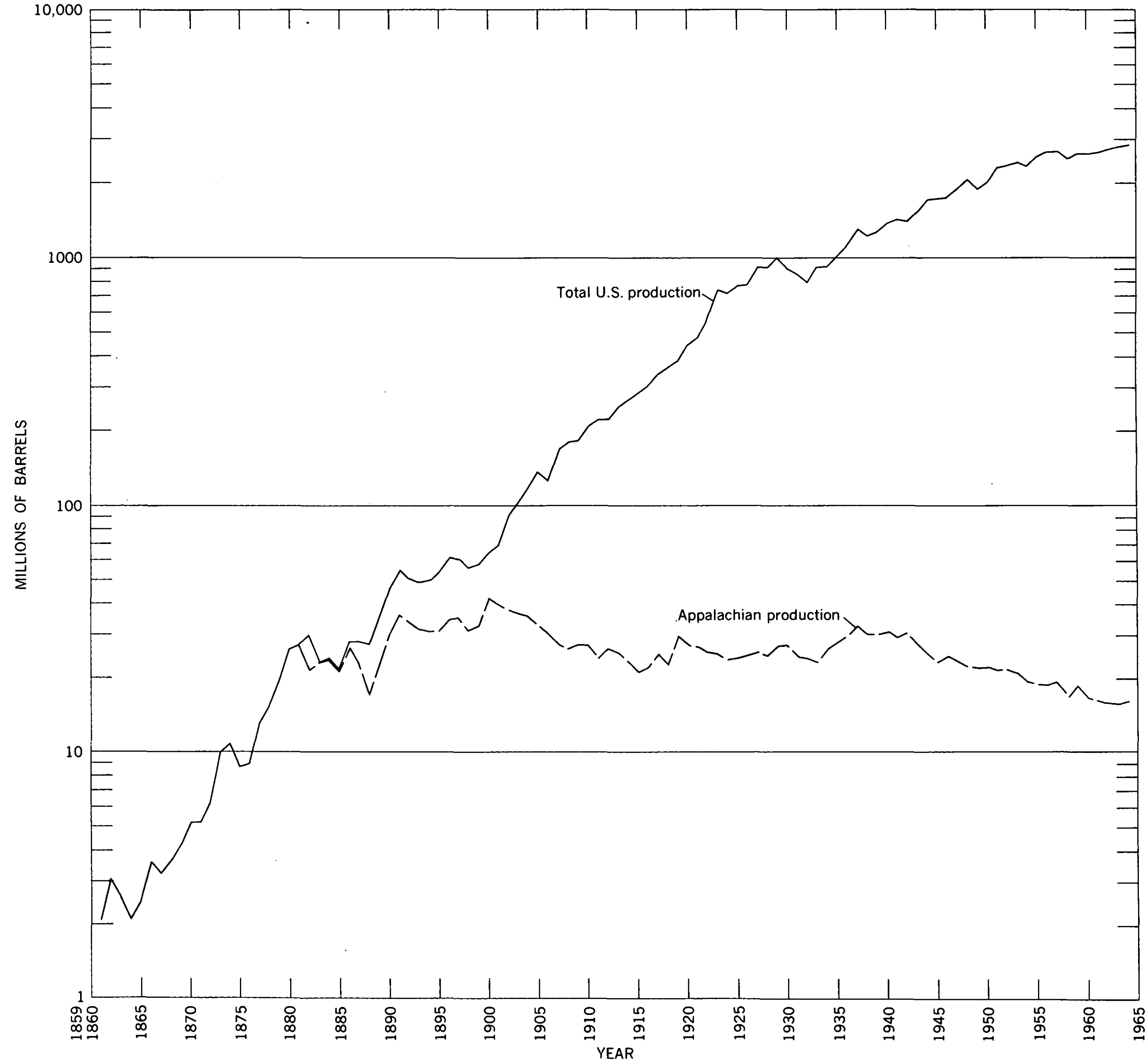


FIGURE 52.—Annual production of crude oil in the United States and in the Appalachian Region, 1859–1964.

average, 14 were below the average. Appalachian refineries represented 1.7 percent of the Nation's total operative refining capacity and 6 percent of the total number of refineries. A slightly greater percentage of the total refining capacity (operative and shut-down—"shut-down refining capacity" being that which is considered inoperable without extensive reconditioning) in Appalachia was shut-down at the end of 1964 than in the rest of the United States, 7.7 percent compared with 6.0 percent. Table 49 lists refineries operating in Appalachia and table 50 shows petroleum refining capacities of Appalachia and the United States.

PETROLEUM GEOLOGY

Petroleum and natural gas are produced from many stratigraphic zones in the Paleozoic (Cambrian to Pennsylvanian) sedimentary rocks of Appalachia. The hydrocarbons are found in porous or cavernous rocks where they have accumulated in traps formed by faults, folds, unconformities, and wedges of petroleum-bearing units. Comparison of figures 48 and 49 with the geologic and physiographic maps (pl. 2, and

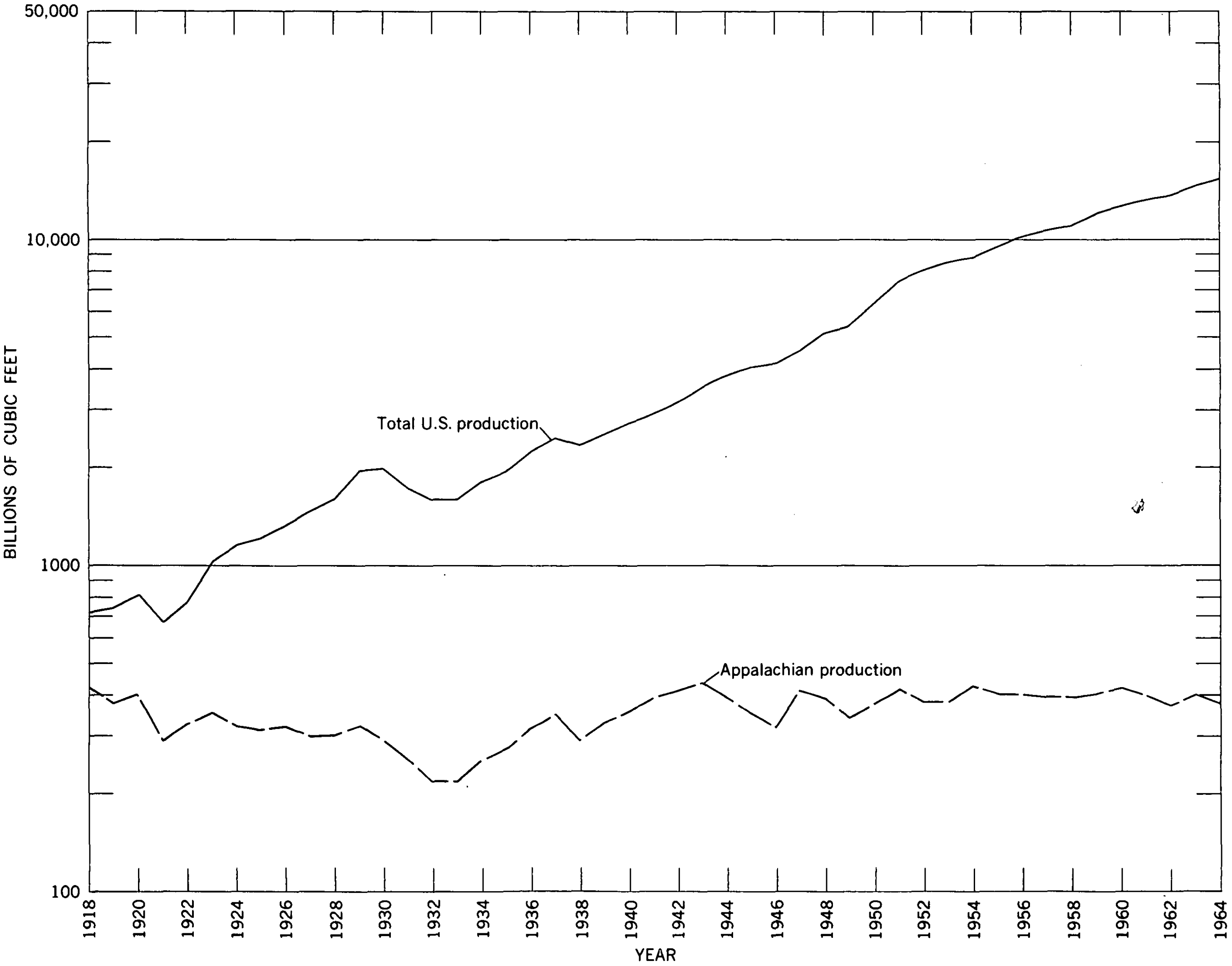


FIGURE 53.—Annual production of natural gas in the United States and in the Appalachian Region, 1918–64.

fig. 6 *A*, *B*,) shows that most of the oil and natural gas fields are in regions of relatively flat-lying sedimentary rocks of the Appalachian Plateaus, Interior Low Plateaus and Central Lowland. Little petroleum and natural gas has been produced from the folded rocks of the Valley and Ridge province. None has been produced from the Blue Ridge and Piedmont provinces, which are almost wholly underlain by metamorphic and igneous rocks.

Petroleum producing zones of the Appalachian petroleum basin are indicated in table 51 (in pocket); units believed to be equivalent in age are placed on the same horizontal line. Many of the zones have the same name in different states and although they may or may not be of the same age they are stratigraphically equivalent. The zones and formations are arranged as accurately as could be determined within the framework of standard geologic systems and series and the lithologic sequences of Colton (1961).

The broad structural framework of the area is apparent on a map of the configuration of the Precambrian basement rocks (Colton, 1961, fig. 4), schists, gneisses, and intrusives which crop out in the Piedmont and Blue Ridge provinces. Immediately west of the Blue Ridge, in the Valley and Ridge province, the basement is depressed as much as 35,000 feet. It rises gradually westward to elevations of less than 4,000 feet below sea level on the west margin of Appalachia, along the flank of the Cincinnati arch. The elongate depression thus formed is filled with a variable sequence of sedimentary rocks chiefly of Paleozoic age of which parts are petroleum bearing.

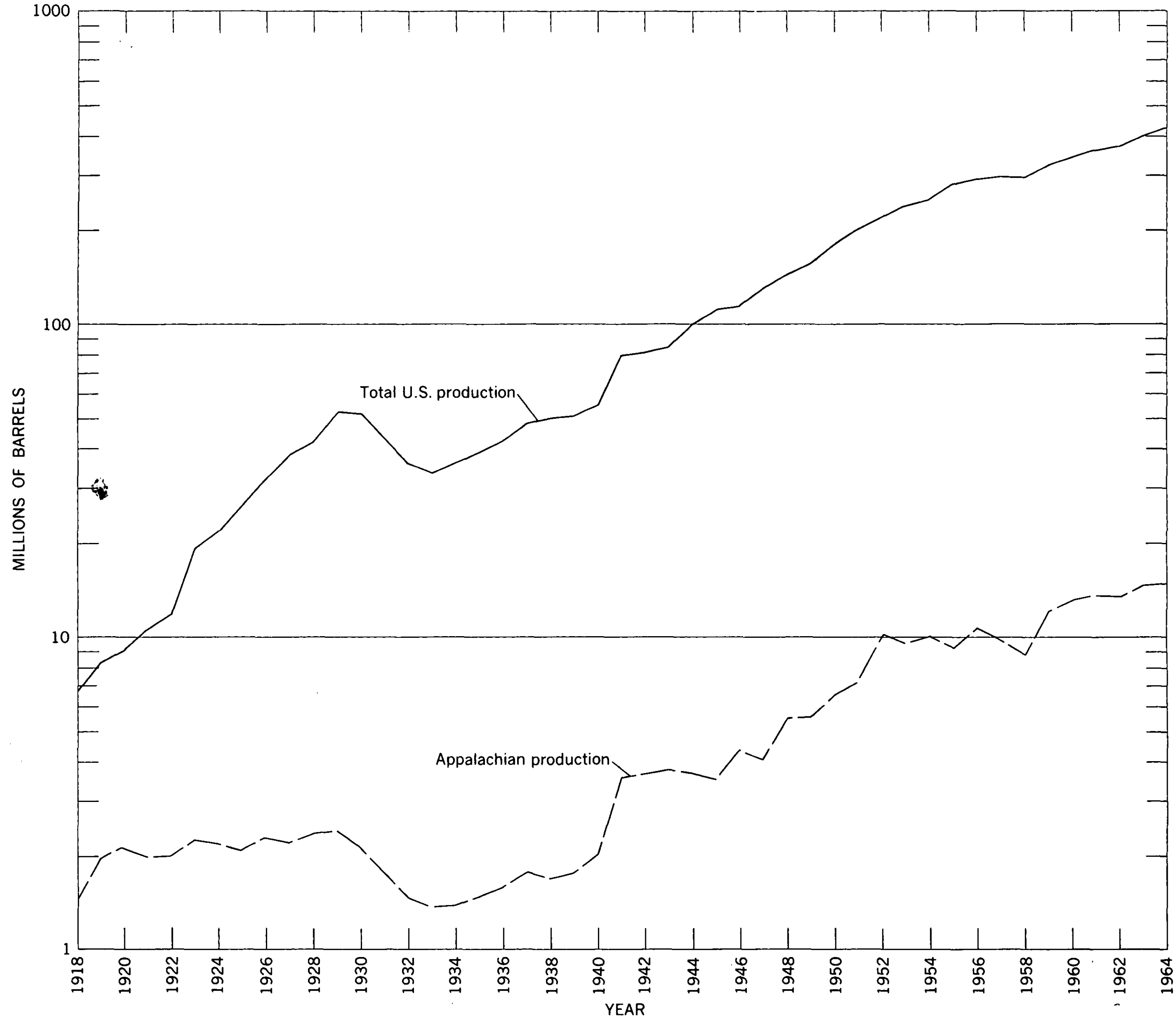


FIGURE 54.—Annual production of natural gas liquids in the United States and in the Appalachian Region, 1918–64.

The sedimentary rocks in the basin and on the west side of it, along the Cincinnati arch, are unmetamorphosed. On the east side of the basin the present limits of the stratified rocks are not the original depositional limits. The sedimentary rocks once extended an indeterminate distance farther east and their lateral equivalents in this direction may be found in the metamorphic complex of the Piedmont province. The uplift of Precambrian strata of the Blue Ridge, and subsequent erosion of the overlying Paleozoic rocks has destroyed the link between the sediments of the present basin and their metamorphosed equivalents.

Most of the petroleum produced to date in Appalachia has come from stratigraphic traps, of which the best known are those in the Upper Devonian and the Pennsylvanian. These traps consist typically of lenses of sandstone enclosed in thick shale sequences. Other sandstone traps are dependent upon the wedging out of the sandstone into less permeable rocks, as typified by some accumulations of gas in the Lower Devonian Oriskany Sandstone of Ohio. Stratigraphic traps in carbonate rocks occur in porous zones associated with reefs, as in the Greenbrier Limestone in eastern Kentucky.

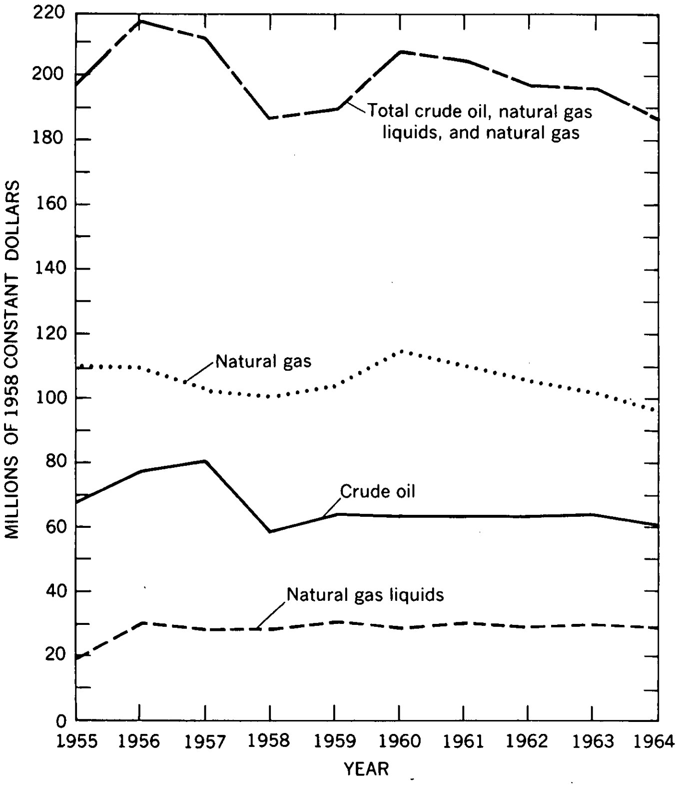


FIGURE 55.—Values of crude petroleum, natural gas, and natural gas liquids produced in the Appalachian Region, 1955–64.

Angular unconformities and disconformities form important petroleum and natural gas traps. At least five in the Paleozoic rocks of Appalachia have yielded oil and gas. In eastern Tennessee a disconformity separates the Knox Group from overlying rocks (Rodgers, 1953, p. 123). The upper surface of the Knox carbonate rocks has been eroded and channeled, and a secondary porosity has resulted. In New York, an angular unconformity separates Silurian from deformed Upper Ordovician strata. The next youngest unconformity in the stratigraphic section, described by Fettke (1952, p. 73), occurs at or above the Silurian-Devonian boundary. In West Virginia Lower Devonian rocks (Coeymans Limestone) rest upon Upper Silurian and Lower Devonion beds (Keyser Limestone). In western New York, Middle Devonian rocks (Onondaga Limestone) overlie the Upper Silurian Akron Dolomite. In eastern Kentucky, rocks of Onondaga age (Boyle Limestone) overlap rocks of early Late Silurian age (Greenfield Dolomite of Orton, 1871) and of Middle Silurian age (McFarlan, 1938, p. 1448).

Widespread epeirogenic uplift that occurred before Late Devonian time (Colton, 1961, p. 16) is marked by an erosional disconformity in southern Appalachia. This disconformity overlies progressively older rocks westward until over the Nashville dome the Upper Devonian Chattanooga Shale rests upon Middle Ordovician rocks; similarly, this disconformity overlies progressively older rocks eastward, across eastern Tennessee. Before deposition of Pennsylvanian strata or at least early in Pottsville time, the region of northwestern Appalachia was pushed upward, tilted, and eroded. As a result, Pennsylvanian strata truncate progressively older Mississippian beds from south to north in Pennsylvania.

Most of the oil fields in Appalachia are along three linear zones (fig. 48). The most southerly zone lies along the Kentucky-Tennessee boundary. There is no obvious structural control for this zone but it may be related to a fault in basement rocks. Another zone is related to the Kentucky River fault zone to the north. The third, or northernmost, oil-producing zone is arcuate and parallels the folded Appalachians. Most pools along the northern zone appear to result from stratigraphic entrapment.

PRINCIPAL PRODUCING FORMATIONS

Petroleum and natural gas have been produced from one or more formations or zones in each of the Paleozoic systems except the Permian. The relative amounts produced from each system or formation, however, cannot be estimated with accuracy because few data are available on production of the individual zones. This lack of information is a handicap to the evaluation of future production for individual petroleum- and gas-producing zones and for the Appalachian Region as a whole.

At present (1966), production from rocks of Cambrian age is restricted to the Gatesburg Formation in Erie County, Pa., from which a small amount of gas is obtained. Ordovician production is mostly oil derived from the "Black River," Trenton, and Leipers Limestones in Kentucky and Tennessee. Principal Silurian producing units include the Clinton Formation, Medina and Big Six sands, the Lockport and Salina Formations, and Newburg sand. Major production from these formations has been in northern Appalachia.

The Middle Devonian Onondaga Limestone and Lower Devonian Oriskany Sandstone have yielded substantial amounts of natural gas in southwestern Pennsylvania, western Maryland, and northeastern West Virginia, large amounts of gas in south-central New York, southwestern Virginia, and north-central Pennsylvania, and gas and oil in east-central Ohio.

TABLE 49.—*Location and capacity of petroleum refineries in the Appalachian Region, January 1, 1965*

[Source: U.S. Bur. Mines (1965b)]

Company	Location	Crude oil capacity (barrels per calendar day)		Type of refining process	Cracking and reforming capacity (barrels per calendar day)			Other products
		Operating	Shutdown		Charge, operating and shutdown	Gasoline output		
						Operating	Shutdown	
Principal product asphalt:								
Hunt Oil Co.	Tuscaloosa, Ala.	9,000	0					None.
Vulcan Asphalt Refining Co.	Cordova, Ala.	3,000	0					Do.
Warrior Asphalt Co.	Holt, Ala.	1,500	0					Do.
Kentucky Oil & Refining Co.	Betsy Layne, Ky.	450	0					Do.
Franklin Refinery, Div. of Sonneborn Sons, Inc.	Franklin, Pa.	1,500	0					Lubricants.
Pennsylvania Refining Co. (Pennzoil).	Karns City, Pa.	2,000	0					Lubricants, wax.
Valvoline Oil Co., Div. of Ashland Oil & Refining Co.	Freedom, Pa.	5,500	0					Lubricants.
Principal product gasoline:								
Ashland Oil & Refining Co.	Catlettsburg, Ky.	80,000	10,000	Catalytic cracking.	32,000	15,500	0	Lubricants, asphalt.
Louisville Refining Co., Inc.	Louisville, Ky.	17,000	0	do.	5,500	2,600	0	Asphalt.
Somerset Oil, Inc. (Formerly The S. D. Jarvis Co.).	Somerset, Ky.	2,000	0	Catalytic reforming.	400	0	400	None.
Kendall Refining Co.	Bradford, Pa.	6,000	0	do.	1,650	1,500	0	Lubricants, wax.
Pennzoil Co.	Rouseville, Pa.	10,000	3,000	Catalytic cracking.	3,060	0	1,530	Do.
Quaker State Oil Refining Corp.	Emlenton, Pa.	2,540	0	Catalytic reforming.	760	608	0	Do.
Do.	Farmers Valley, Pa.	4,000	0	do.	1,500	1,500	0	Do.
United Refining Co.	Warren, Pa.	15,000	0	Catalytic cracking.	6,000	3,840	0	Asphalt, wax.
Wolf's Head Oil Refining Co., Inc.	Reno, Pa.	2,000	0	Catalytic reforming.	450	450	0	Lubricants, wax.
Elk Refining Co.	Falling Rock, W. Va.	4,500	0	do.	1,800	1,800	0	Do.
Quaker State Oil Refining Corp.	St. Marys, W. Va.	2,500	0	do.	900	850	0	Do.
Total		168,490	13,000		54,020	28,648	1,930	

TABLE 50.—*Petroleum refining in the Appalachian Region and the United States, 1964*

[Source: Adapted from U.S. Bur. Mines (1965b)]

Area	Crude oil throughput capacity				Operating gasoline-output capacity	
	Operative		Shutdown			
	Barrels	Percent of total	Barrels	Percent of operative capacity	Barrels	Percent of operative capacity
Appalachia	168,490	1.7	13,000	7.7	28,648	17.0
United States exclusive of Appalachia	9,999,282	98.3	600,284	6.0	3,753,184	37.5
Total	10,167,772	100.0	613,284	6.0	3,781,832	37.2

Approximately a trillion cubic feet of gas was marketed from the Oriskany Sandstone reservoir of the Sissonville field, central West Virginia. In Kentucky, the "Corniferous" limestone of local usage, which includes carbonate rocks of Late Silurian and Early Devonian age, is the main oil-producing zone. Upper Devonian sandstone beds have yielded more than 80 percent of Pennsylvania's crude oil and much of the oil from West Virginia and New York. The same sandstone beds have produced large amounts of natural gas in the same States, the so-called "shallow" gas. The Devonian and Mississippian shale of eastern Kentucky and southwestern West Virginia, the "Brown shale" has been productive of large amounts of natural gas. Shale of equivalent age has yielded some gas in Ohio.

Petroleum reservoirs of Mississippian age occur largely in sandstone, most importantly the Berea Sandstone and Big Injun sand and to a lesser extent the Weir, Squaw, and Maxon sands. The Greenbrier Limestone and equivalent limestone formations have yielded significant amounts of oil and gas. Gas and oil have been produced from Pennsylvanian sandstones in southeastern Ohio, western Pennsylvania, northwestern West Virginia, and eastern Kentucky, and small amounts of gas in Virginia and Alabama. The "Maxton," Salt, Macksburg, Cow Run, and Dunkard sands have been notably productive.

Most of the gas fields (fig. 49) are alined with the northernmost oil-producing trend. However, several gas fields produce from fractured sandstone reservoirs associated with folds of the Valley and Ridge province at a considerable distance from the principal oil-producing areas.

STRATIGRAPHY

Lower Cambrian clastic sequence

Rocks of the Lower Cambrian clastic sequence crop out in the Valley and Ridge province (pl. 2), where they are locally as much as 10,000 feet thick (Colton, 1961, fig. 6). They form a wedge-shaped deposit that thickens eastward. The source area of these sediments was somewhere to the east of Appalachia and the main depositional basin probably lay in the area of the present Piedmont province. Well-known strata in this sequence, some of which possibly are older than Cambrian, include the Hardyston and Antietam Quartzites, Tomstown and Shady Dolomites, Chilhowee Group, and Loudoun, Weverton, Harpers, and Rome Formations.

At present, petroleum is not produced from the Lower Cambrian clastic sequence. In places in the Valley and Ridge province these rocks are deeply buried, the top of the sequence being as much as 30,000 feet below present sea level; however, near its western limit this upper surface is at a depth of only 3,000 feet below sea level. Petroleum originating in the center of the depositional basin and moving up dip could still be preserved in traps formed along the western edge of the clastic rocks.

Cambrian and Ordovician carbonate sequence

Thickness of rocks of the Cambrian and Ordovician carbonate sequence (Colton, 1961, fig. 7) range from 2,000 to 10,000 feet, increasing eastward in the Valley and Ridge province and decreasing westward. The carbonate sequence contains clastic rocks that attain their greatest thickness in eastern Kentucky and Tennessee. Included in the Cambrian and Ordovician carbonate sequence are the Elbrook, Conococheague, and Beekmantown Limestones, the Knox, Conasauga, and Trenton Groups, and, in the lower part, the Mt. Simon, Franconia, and Dresbach Sandstones.

Comparison of a thickness map with a structural contour map of this sequence, such as those shown by Colton (1961, figs. 7, 8), indicates that the axis of the present basin is far to the west of the original axis of the basin of deposition. Equivalent rocks deposited in the area of the Blue Ridge province and farther eastward have been uplifted and eroded.

Small amounts of oil and gas have been produced from several different formations in this sequence; most of it has come from Lower and Middle Ordovician carbonate rocks of eastern Kentucky and Tennessee. The Rose Hill oil field in southwestern Virginia produces from Trenton Limestone (R. L. Miller and Fuller, 1954, p. 301) or limestone of Black River age (McGuire and Howell, 1963, p. 5–13) in an anticline revealed in a window in an overthrust fault slice. Gas is produced from the Gatesburg Formation in Crawford County, Pa. Porous zones are common in the Gatesburg and Copper Ridge Formations, and the latter has proven highly productive of oil in north-central Ohio just west of Appalachia. The Trenton Limestone, which contains the productive zone of the Lima-Indiana field west of the northern part of Appalachia, has yielded half a billion barrels of oil from that field alone (Fettke, 1948, p. 1489), but has yielded little oil or gas in Appalachia.

The petroleum deposits in Kentucky and Tennessee result from a combination of structural and stratigraphic controls. The oil pools obviously are peripheral to a wedge of Cambrian and Ordovician clastic rocks in southeastern Kentucky. Structures such as the Cincinnati arch, Kentucky River fault zone, and in southwestern Virginia, a local Valley and Ridge anticline controlled the accumulation of oil and gas. The Lower Ordovician carbonate reservoir rocks are porous and cavernous at the unconformity with overlying Middle Ordovician strata.

Upper Ordovician clastic sequence

Included in the Upper Ordovician clastic sequence are the Martinsburg, Utica, Reedsville, Queenston, Oswego, Juniata, and Sequatchie Formations, and rocks of Cincinnation age near the Cincinnati arch. The Late Ordovician Taconic disturbance affected the distribution, thicknesses, and lithology of rocks of this sequence, as is well shown by Colton (1961, fig. 9). A land area then existed to the east of the present Valley and Ridge province, and from this source area were eroded the sediments which form the red Queenston Shale. The red shale interfingers with black shale over much of Appalachia and, to the west, the black shale interfingers with carbonate rock. Strata are thickest in the northeastern part of Appalachia, where they consist chiefly of red beds. They thin to the south and west and contain abundant interbedded limestone along the Cincinnati arch. In the west the strata are at depths of less than 5,000 feet below sea level, but in eastern Pennsylvania they are probably at more than 25,000 feet below sea level.

Petroleum generated in the black shale would likely have migrated westward, up the regional dip, into porous zones in the limestone. The environmental setting of the Upper Ordovician clastic sequence strongly suggests the likelihood that petroleum has accumulated along the carbonate-black shale transition zone, as it has in both the Permian and Paradox basins of western United States. However, drilling in this zone in the Appalachian basin has not yet located commercial quantities of oil or gas.

The Upper Ordovician sequence is not very productive at present although gas is obtained from it in Tennessee and, formerly, in Alabama. Recently, prolific oil production at very shallow depths has been obtained from the Leipers Limestone on the Cincinnati arch in Monroe County, Ky., the oil occurring mainly in porous zones in otherwise impermeable rocks.

Lower Silurian clastic sequence

The oldest rocks in Appalachia that have produced significant amounts of petroleum are those of the Lower Silurian clastic sequence (Colton, 1961, figs. 10, 11). Most important of these strata are the Clinton and Medina sands in New York, Ohio, and Pennsylvania, the Big Six sand in Kentucky and its equivalent, the Keefer Sandstone in West Virginia.

Rocks of this sequence attain a maximum thickness of about 2,400 feet in eastern Pennsylvania but in most places are much thinner. Included in the sequence are the Albion Group, Tuscarora Quartzite, Clinch Sandstone, Red Mountain Formation and, in the upper part, the Clinton Group or Formation and Rochester Shale.

The source of the clastic rocks lay north and east of Appalachia at no great distance. Deposition of clastic debris from the erosion of a highland in this region produced a lithofacies pattern consisting of dominantly clastic rocks in the east and north and nonclastic rocks in the west. However, several individual sandstone units extend over the entire area and indicate periods of strong relative uplift of the source area and dominance of clastic deposition.

The structural axis of the Lower Silurian roughly coincides with that of the previously described Cambrian and Ordovician carbonate sequence. The paucity of wells that penetrate the formation outside the limits of known oil fields prevents precise location of this axis.

The oil and gas occur in stratigraphic traps in sandstone. The Ohio fields lie along the transition zone between sandstone to the east and carbonate rocks to the west. The Kentucky pools in the Big Six sand apparently also are controlled by the Kentucky River fault zone.

Silurian and Devonian carbonate sequence

The Silurian and Devonian carbonate sequence includes important producing zones, especially of gas (table 51). It is thickest in northwestern Pennsylvania, about 3,400 feet, and in northeastern West Virginia and adjacent Maryland, about 2,400 feet (Colton, 1961, fig. 12). The axis of maximum thickness approximately coincides with the structural axis of the basin (Colton, 1961, fig. 14); the axis of deposition has thus shifted westward from its position in earlier times. Included in the Silurian and Devonian carbonate sequence are such well-known lithostratigraphic units as the Lockport and Hancock Dolomites, Cayuga and Salina Groups, Bloomsburg Red Beds, Helderberg and Oriskany Groups, and Onondaga Limestone.

In eastern Kentucky, petroleum and natural gas are produced mainly from Devonian limestone and dolomite (Boyle and equivalent formations); lesser amounts are produced from Silurian carbonate rocks known collectively as the "Corniferous" limestone. Production is from porous zones at least partly controlled structurally by the Kentucky River fault zone. North of this area almost all natural gas fields produce from the Oriskany Sandstone. Most of the gas accumulations are in stratigraphic traps associated with wedging out of the sandstone but a few are in structural traps. Systematic exploration may reveal petroleum-bearing reefs in the transitional zone between the carbonates and the salt-bearing strata of the Silurian System.

Devonian clastic sequence

The rocks of the Devonian clastic sequence consist largely of many named units of shale, mudstone, siltstone, and sandstone, some of which may actually be correlative (table 51). The sequence includes the Hamilton and "Portage" Groups, the Ohio and Chattanooga Shales, and the Chemung and Catskill Formations of the Susquehanna Group. The rocks are at least 11,000 feet thick in the northeastern part of Appalachia, become thinner southward, and finally wedge out in southern Appalachia. The axis of the depositional basin (Colton, 1961, fig. 15) was in eastern Appalachia, east of the axis of deposition of the older Silurian and Devonian carbonate sequence. The axis of the present structural basin lies considerably west of the axis of deposition and is clearly marked by a concentration of oil and gas fields (Colton, 1961, fig. 14).

The Devonian clastic sequence was derived from a landmass to the east of the present States of Pennsylvania and New York as indicated by crossbedding showing that sediment transport was from east to west (Burtner, 1963, p. 22). Lithofacies analysis by Ayrton (1963, p. 4) also shows eastward thickening of the sequence. The fact that Ayrton found only one small area where the sequence is more than 80 percent sandstone further indicates a source area some distance east of Appalachia. The red beds of the Catskill Formation in northeasternmost Appalachia grade westward and southward into dark-colored shale interbedded with lenses of sandstone which are exploited for petroleum in Pennsylvania and adjacent States. In Ohio, Kentucky, Tennessee, West Virginia and southwestern Virginia the Devonian clastic sequence consists entirely of black shale. In Kentucky and West Virginia it is known as the "Brown shale" and produces gas from zones perhaps having fracture porosity.

The lenticular sandstone units of the main oil and gas producing area are of small extent and erratic distribution. One the of the largest, the reservoir of the Music Mountain oil pool, is 4 miles long and 800–2,000 feet wide, and averages 35 feet in thickness (Fettke, 1941). Although the many individual sandstone units shown in table 51 for Pennsylvania and West Virginia probably cannot be correlated, they appear to occupy similar stratigraphic positions. Other sands, such as the Benson, Fifth, Balltown, Elizabeth, Snee, and Speechley, appear to be widespread sheet sands.

Mississippian sequence

Strata of the Mississippian sequence (table 51) are or have been productive of petroleum nearly everywhere in Appalachia where they crop out. Plate 2 shows the distribution of these rocks. The sequence is thickest (more than 6,000 feet) in the Valley and Ridge province and thins westward. Some well known lithostratigraphic units in the Mississippian sequence are the Pocono, Murrysville, and Berea Sandstones, Price and Mauch Chunk Formations, Fort Payne Formation, Pennington Shale, and Ste. Genevieve, Girkin (Gasper), and Greenbrier Limestones. In most places the Greenbrier Limestone constitutes the top of the "Big Lime," an important petroleum zone.

Two Mississippian units, the Berea Sandstone and Greenbrier Limestone, have yielded the greatest amounts of oil and gas. The Berea Sandstone has been the most productive unit in southeastern Ohio (Stout, 1951, p. 57) and in the western half of West Virginia (Haught, 1959, p. 16). The Big Injun sand, from which oil has been produced since 1889, is at present (1966) by far the most important oil producing sand in West Virginia; the main area of Big Injun production lies near the geographical center of the State. Limestone reefs (Thaden and others, 1961) and dolomitic and oolitic zones (Youse, 1964) in the Greenbrier Limestone have yielded important amounts of oil and gas in eastern Kentucky, being second only to that from Silurian and Devonian "Corniferous" rocks. Locally these zones are called the Beaver or Beaver Creek sand, terms which are used elsewhere for other stratigraphic units.

Pennsylvanian sequence

Pennsylvanian rocks are widespread (pl. 2) and compose a thick sequence generally divided into the Pottsville, Allegheny, Conemaugh, and Monongahela Groups. (See section on "General Geology," p. 55.) In Alabama as much as 10,000 feet of Pennsylvanian is preserved, all Pottsville in age. In southern Virginia there is 6,000 feet of strata of Pottsville and Allegheny age. Farther north, in southwestern Pennsylvania and adjacent areas, the Pennsylvanian System includes the four groups and is about 1,500 feet thick. In part of this area it is overlain by Permian strata.

The Pennsylvanian sequence consists of shale, claystone, siltstone, sandstone, and limestone, both marine and nonmarine, as well as many coal layers. Petroleum and natural gas occur commonly in stratigraphic traps formed by lenses of sandstone enclosed in thick shale units.

The Pennsylvanian sequence of Appalachia has been one of the greatest sources of energy in the world, having yielded large quantities of petroleum in addition to enormous amounts of coal. The petroleum has come from many different zones in the sequence, from the oldest parts to the youngest, and from all parts of the region, but by far the greatest production has been in Kentucky, Ohio, Pennsylvania, and West Virginia. Sandstones of the Pottsville Group or Formation have been the major producing zones although considerable amounts of oil and gas have been produced from the overlying sequences as well.

EXPLORATION

Large quantities of petroleum and natural gas have been produced in Appalachia and the potential for new discoveries and increased future production is good. A systematic exploration program is needed and should include regional studies of structure and stratigraphy to establish broad controls of distribution of fields as well as detailed investigation and drilling to search for new deposits. There is need for increased exploratory drilling in Appalachia in order to evaluate potential resources of petroleum and natural gas.

The amount of exploratory and development drilling in Appalachia is known only approximately because of the difficulty of obtaining precise figures solely for Appalachia. Total footage of exploratory wells drilled (fig. 56) has been about 800,000 feet per year, although it has declined somewhat in recent years. The total number of exploratory wells drilled ranges from about 200 to 300 annually, and since 1957 the ratio of successful to unsuccessful wells has declined. In 1964 the average well was drilled to a depth of about 2,600 feet.

Most of the known oil and gas zones in Appalachia are at shallow depths in the relatively flat-lying sedimentary rocks west of the Valley and Ridge province and north of Tennessee. Knowledge of petroleum and natural gas in Appalachia is largely based on traditional methods of exploration in this region. Shallow exploration in the known oil and gas region undoubtedly will result in discovery of new reserves but enough is known of the region, because of density of drill holes, to estimate that new, very large shallow fields will not likely be found. On the other hand, deep drilling, of which very little has been done in this region, offers excellent possibilities for finding new, perhaps very large petroleum reserves.

In contrast to northern Appalachia, comparatively little drilling has been done in the flat-lying rocks to the south in Alabama and to a lesser extent, in Tennessee. Shallow, as well as deep, drilling offers possibilities for significant new discoveries in these States.

Geophysical exploration undertaken in Appalachia during 1964 (Am. Petroleum Inst., 1965, p. 8) included 81 gravity crew months, or 27 percent of the United States total, and 367 seismic crew months, 9 percent of the national total, mostly in Ohio outside the boundaries of Appalachia. A cooperative project between the U.S. Geological Survey and the Pennsylvania Geological Survey resulted in an aeromagnetic map of western Pennsylvania and eastern Ohio (Popenoe, Petty, and Tyson, 1964).

There is no reason to suppose that petroleum and natural gas were not generated in the Valley and Ridge province as they were to the west in Appalachia. Much exploration is needed to assess the potential of this province. Occurrence of oil and gas would most likely be determined by whether they were retained during and after folding and faulting in a geologic environment subjected to relatively high temperatures and pressures. Many geologists have considered that oil and gas would be largely destroyed under these conditions and that the Valley and Ridge province is not generally favorable for petroleum.

An isocarb map, such as figure 57, is helpful in assessing the potential for petroleum and natural gas in the Valley and Ridge province. This map shows the amount and distribution of fixed carbon in coal and can be compared with the oil and gas maps (figs. 48, 49). Such comparison reveals a relation between distribution of fixed carbon in coal and distribution of oil and gas fields. Almost without exception, the oil fields (fig. 48) lie along or west of the 55-isocarb, and most gas fields (fig. 49) follow or are west of the 65-isocarb. In theory, fixed carbon is a measure of the degree of metamorphism of coal, and all oil and gas would be expected to be volatilized and dissipated in areas where fixed carbon values are high, such as the folded belt of northern Appalachia. In fact, however, such a relation does not appear to exist, for gas is found in the northern belt where isocarb values are as high as 75–80. Because they are fluids, oil and gas are probably not affected to the same degree as coal. The isocarb map indicates that the anticlines of the folded belt of northern Appalachia might be favorable to accumulation of natural gas but not petroleum, whereas the anticlines beneath thrust sheets in the Valley and Ridge in southern Appalachia might be favorable to accumulation of petroleum.

It is concluded that there is need of systematic exploration for petroleum and natural gas in Appalachia. In addition to study required in the regions of known shallow fields, the following features or areas should be investigated:

1. Deep zones below the present main oil-producing shallow reservoirs of Pennsylvania and northern West Virginia.
2. Transition zones, mainly in northern Appalachia, between the black shale and carbonate rocks of the Upper Ordovician clastic sequence, the clastic

and carbonate rocks of the Lower Silurian clastic sequence, and the salt beds and carbonate rocks of the Silurian and Devonian carbonate sequence.

3. Systematic study of strata that are or may become major producers, including, in descending stratigraphic order, Greenbrier Limestone, Devonian and Mississippian shale, Onondaga Limestone, Oriskany Sandstone, Clinton sand, Medina sand, and dolomites of the Knox Group.
4. Unconformity between Lower and Middle Ordovician strata in the western part of Appalachia.
5. Deep zones in the Valley and Ridge province, particularly the thrust fault region in the southern part where fixed carbon ratios (see fig. 57) are relatively low.
6. Truncated edge of the Lower Cambrian clastic sequence of the southern Valley and Ridge province.

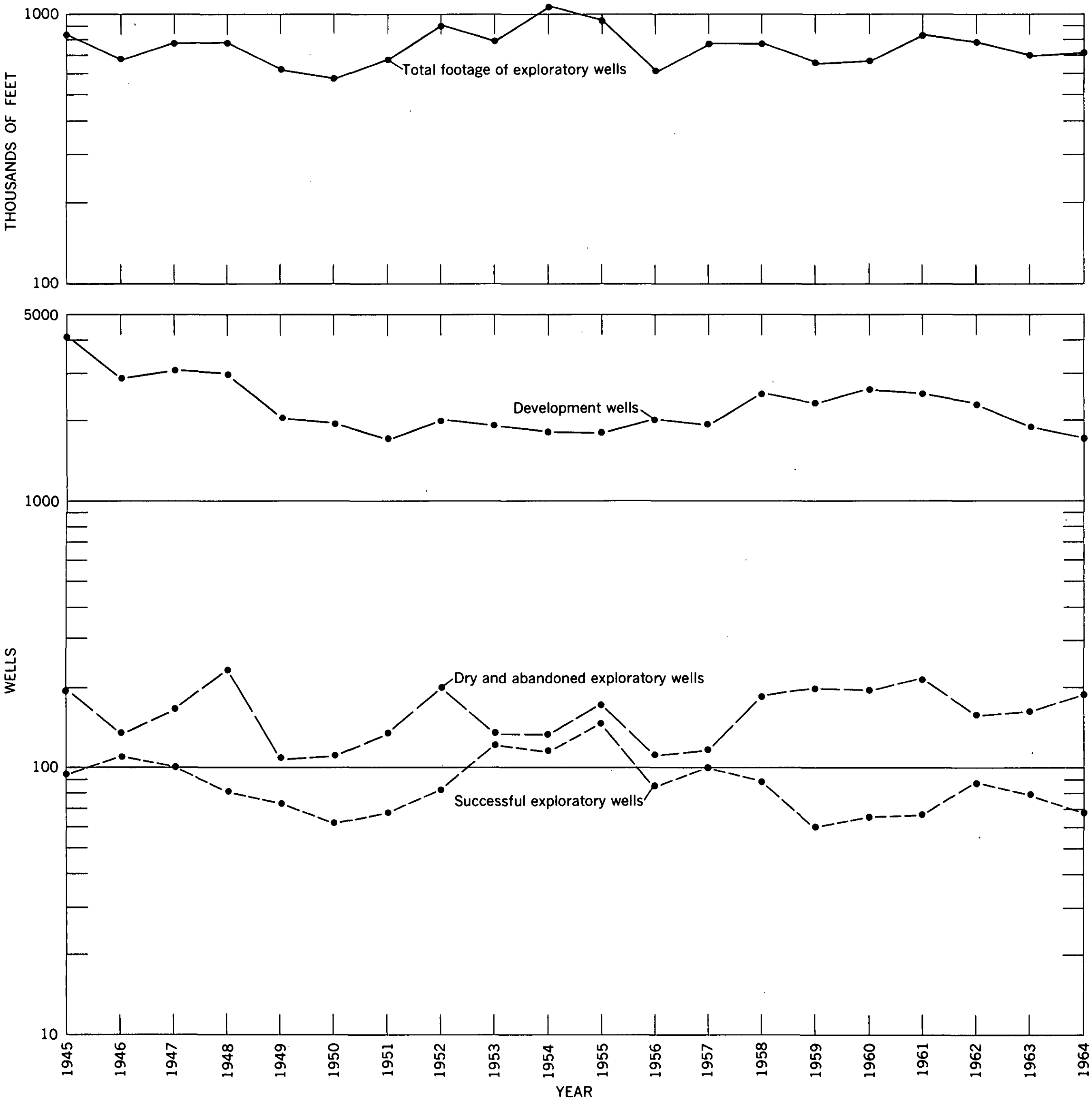


FIGURE 56.—Numbers of exploratory and development wells and total footage of exploratory wells drilled in the Appalachian Region, 1945–64.

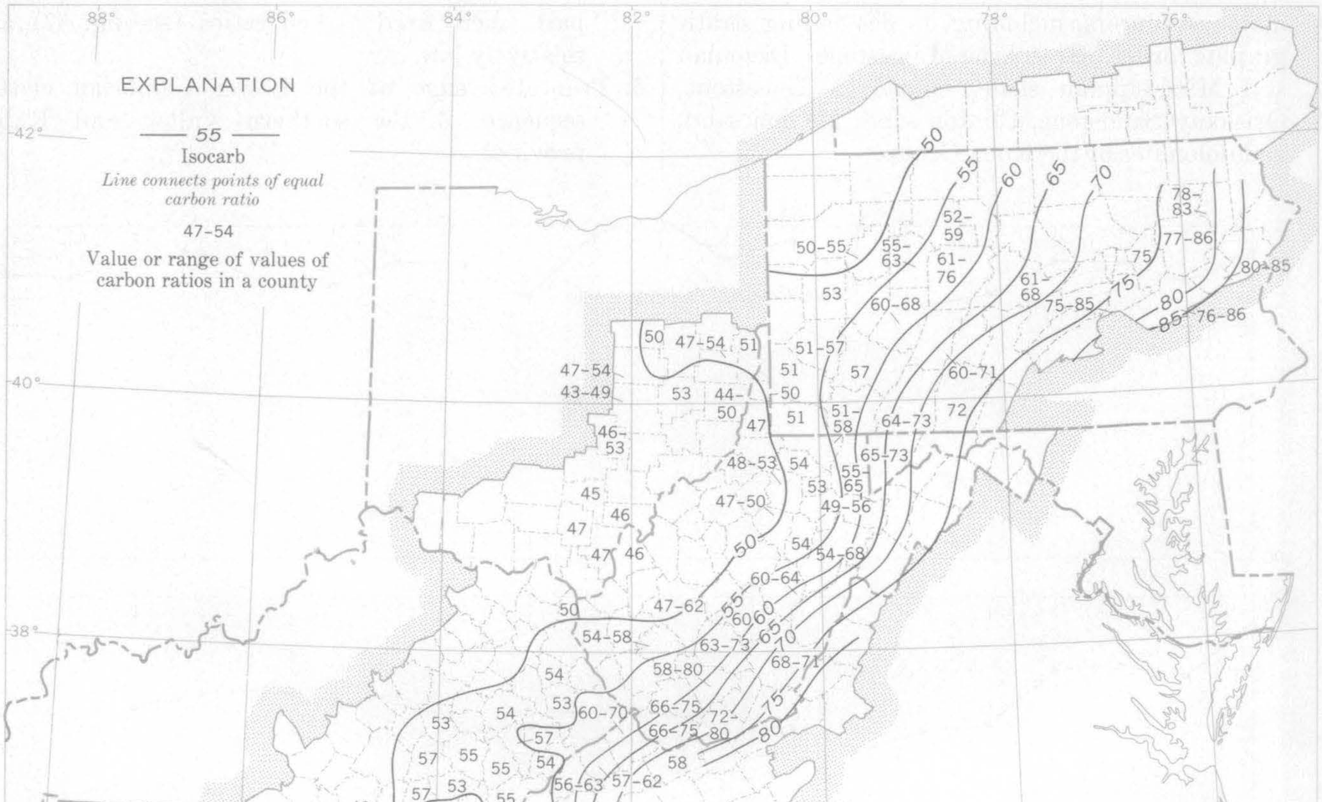


FIGURE 57.—Generalized isocarb map of the Appalachian Region.

RESERVES AND RESOURCE POTENTIAL

The following table gives only an approximation of petroleum reserves in Appalachia. The reserves of Tennessee and Virginia are excluded, because they are not separately reported; the reserves of Kentucky and Ohio are for the entire States and hence are probably as much as 50 percent too high.

Estimated proved reserves of crude oil

[Compiled from Am. Gas Assoc,. Am. Petroleum Inst., and Canadian Petroleum Assoc. (1965). In thousand barrels]

Area	Proved reserves, as of Dec. 31, 1964	Change in 1964
Kentucky	117, 861	17, 405
New York	13, 561	−4, 874
Ohio	99, 562	11, 784
Pennsylvania	86, 621	−5, 113
West Virginia	58, 710	1, 407
Total Appalachia	376, 315	20, 609
Total United States	30, 990, 510	20, 521

Recoverable natural gas liquids were 125,744,000 barrels as of December 31, 1964.

Approximations of reserves of natural gas are given in the table below. Alabama, Maryland, and Tennessee reserves are not reported separately and are excluded; Kentucky, New York, and Ohio reserves include data from the parts of these States outside as well as within the boundaries of Appalachia.

Estimated proved recoverable reserves of natural gas

[Compiled from Am. Gas Assoc., Am. Petroleum Inst., and Canadian Petroleum Assoc. (1965). In million cubic feet]

Area	Proved recoverable reserves, as of Dec. 31, 1964	Part in underground storage at end of 1964
Kentucky	1, 094, 355	45, 224
New York	133, 489	95, 170
Ohio	709, 421	391, 325
Pennsylvania	1, 243, 575	521, 514
Virginia	32, 180	0
West Virginia	2, 347, 945	350, 125
Total Appalachia	5, 560, 965	1, 403, 358
Total United States	281, 251, 454	2, 939, 763

Although Appalachia has been producing petroleum and natural gas for more than 100 years, its resources are still imperfectly known. The shallow oil and gas fields of northern Appalachia (figs. 48, 49), from which most production has come, have been extensively drilled and are well known. The gas and oil potential of the remainder of Appalachia, with the exception of a few local areas, is unknown. Perhaps the greatest opportunity is for discovery of important new resources in zones at greater depth than most of those now productive. It is likely that important new fields will be found at depth in regions of known shallow fields and perhaps in the flat-lying rocks of Alabama and Tennessee, in areas where little or no petroleum and natural gas have yet been produced. The Valley and Ridge province, which has yielded little oil and gas to date, requires extensive exploration, particularly deep drilling, to determine whether oil accumulations exist; shallow drilling should lead to discovery of new gas resources.

It can be concluded that future production from traditional shallow zones in Appalachia will continue to decline slowly as the petroleum and gas resources are exhausted. Exploration will discover new shallow fields, but individually these will probably not be large. In contrast, deep zones might prove to have major resources and their discovery to result in greatly expanded production from the region.

CONSTRUCTION MATERIALS

CEMENT

By GEORGE E. ERICKSEN, U.S. Geological Survey, and ROBERT D. THOMSON, U.S. Bureau of Mines

INTRODUCTION

Cement plants are found in the Appalachian parts of all the States except Kentucky and New York, but the greatest number of plants and the largest production are near the two industrial centers of Pittsburgh, Pa., and Birmingham, Ala. (fig. 58). In addition to the plants within Appalachia, many plants in bordering areas in southeastern Pennsylvania, central Ohio, and New York supply cement products to the nearby Appalachian Region. Elsewhere along the borders of Appalachia only a few cement plants (three in Ohio, one in Kentucky, two in Maryland, and one each in Virginia, Tennessee, Georgia and Alabama) compete with the plants in Appalachia for local markets. The Appalachian Region is self-sufficient in cement, and exports considerable amounts to the bordering areas.

The cement history of the United States began with the manufacture of natural cement from cement rock near Fayetteville, N.Y., for construction of the Erie Canal in 1817 (Bogue, 1955, p. 12). Natural cement was first produced in the famous Lehigh Valley district of southeast Pennsylvania in 1826 (Bogue, 1955, p. 12) from a cement rock which continues to be used in the manufacture of portland cement. Portland cement was first manufactured in the United States in 1875 at Coplay (in Lehigh Valley), Pa., more than 50 years after the process for its manufacture was first patented in England (Alexander, 1942). The Lehigh Valley district along the border of Appalachia has become one of the leading producers of portland cement in the world. In 1965, this area had 13 operating plants having a total capacity of about 36 million barrels of cement (Pit and Quarry, 1965). (The marketing unit of portland cement is the 376-pound

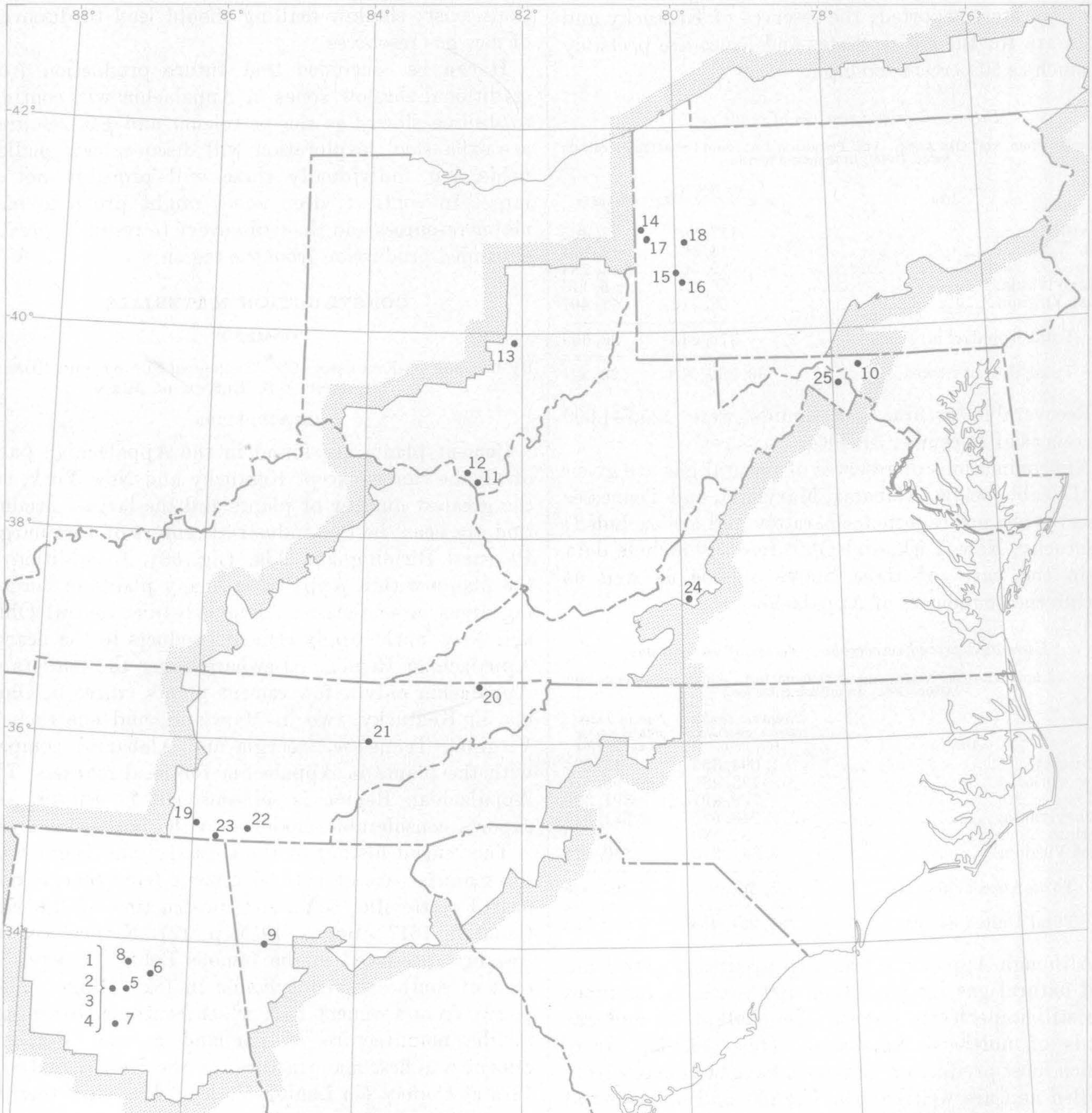


FIGURE 58.—Cement plants in the Appalachian Region. Numbers refer to table 53 (p. 166).

barrel; however, the cement is sold in bulk or in 94-pound paper bags, four of which are equivalent in weight to a barrel. The marketing unit of masonry cement is the 276–280 pound barrel. In this report all figures are given in terms of the 376-pound barrel; masonry cement figures are converted to this unit.)

THE INDUSTRY IN APPALACHIA

The cement industry is one of the important industries in Appalachia and is one of the mineral industries of the region that has had a marked increase in production during the past 20 years. Cement production has nearly tripled during the period 1945–64, from about 15.8 million barrels valued at $31.6 million in 1945, to 44.1 million barrels valued at $142.5 million in 1964 (table 52). In 1964, 23 portland cement plants having a total capacity of about 49.5 million tons, were operating in Appalachia (table 53). In addition, two plants produced slag-lime cement.

TABLE 52.—*Total shipments of cement (portland, masonry, and slag) from plants in the Appalachian Region, 1945–64*

Year	Shipments (376-lb barrels)	Value (1958 constant dollars)
1945	15, 823, 844	31, 578, 578
1946	26, 740, 951	57, 961, 429
1947	29, 913, 131	63, 233, 141
1948	30, 719, 280	72, 261, 446
1949	28, 680, 606	73, 023, 107
1950	31, 360, 024	81, 266, 836
1951	51, 864, 229	88, 908, 629
1952	35, 045, 078	90, 538, 360
1953	35, 812, 952	98, 328, 288
1954	36, 362, 018	103, 605, 698
1955	41, 566, 214	127, 362, 110
1956	43, 243, 681	138, 089, 130
1957	40, 489, 426	131, 408, 110
1958	42, 251, 200	131, 972, 868
1959	44, 137, 311	142, 734, 400
1960	39, 566, 748	133, 282, 123
1961	40, 614, 950	135, 228, 228
1962	41, 456 606	137, 524, 444
1963	41, 403, 620	134, 796, 926
1964	44, 069, 255	142, 493, 788

Portland cement (including a small amount of slag-lime cement) amounted to 39,503,367 barrels valued at $125,281,590 (1958 constant dollars). Masonry cement produced by nearly all the plants amounted to 4,565,888 barrels valued at $17,212,196 (1958 constant dollars). Two plants produced slag-lime cement for which production figures are withheld to avoid disclosing individual company data. The calculated unit value, based on these 1964 production figures, is $3.17 per barrel for portland cement and $3.77 per barrel for masonry cement.

TYPES OF CEMENT

Of the many types of cement, only portland, slag, and masonry cements are produced in Appalachia. Natural cement, made by burning a cement rock, was an important product during the last century and early part of this century but is no longer produced in the region. ("Cement rock" is argillaceous limestone containing the proper proportions of calcium oxide, alumina, and silica to make a hydraulic cement, one which hardens or sets under water.)

Portland cement is a hydraulic cement made by burning (in a rotary kiln) a finely ground, carefully proportioned mixture of limestone and aluminous and siliceous materials such as clay and sand. W. R. Barton (in U.S. Bur. Mines, 1965a, p. 191) gave the composition of typical kiln feed mixture as follows: 75 percent calcium carbonate ($CaCO_3$), 14 percent silica (SiO_2), 4 percent magnesium carbonate ($MgCO_3$), 5 percent alumina (Al_2O_3), and 1 percent iron oxide (Fe_2O_3). The chemical composition of the kiln feed differs somewhat according to type of cement produced and natural variations in the principal components and impurities in the raw materials. The mixture is burned at a temperature of about 2,700°F to produce a clinker made up of hydraulic calcium silicates ($3CaO \cdot SiO_2$ and $2CaO \cdot SiO_2$), tricalcium aluminate ($3CaO \cdot Al_2O_3$), and tetracalcium aluminoferrite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$), and minor amounts of calcium sulfate ($CaSO_4$), magnesia (MgO) and lime (CaO) (W. R. Barton, in U.S. Bur. Mines, 1965a, p. 191). The clinker is mixed with specified small amounts of either calcined or uncalcined gypsum (to control rate of hardening) and pulverized to make portland cement.

Five types of portland cement are marketed in the United States, each of which has special properties or uses. W. R. Barton (in U.S. Bur. Mines, 1965a, p. 191) described these five types as follows:

> In 1940, ASTM grouped portland cements under five types, based partly upon the proportions of tricalcium silicate, dicalcium silicate, and tricalcium aluminate in the cement. Specifications for Type I, general-purpose cement, and Type II moderate-heat cement, are so similar that many companies make only one type that will meet the requirements of either. Type III, high-early-strength cement containing a greater quantity of tricalcium silicate, is made by many companies for use where time cannot be allowed for Type I or II to develop strength. Types I, II, and III together constitute more than 97 percent of all the portland cement in the United States. Type IV, low-heat cement containing less tricalcium silicate and tricalcium aluminate and Type V, high-sulfate resistant cement containing the least amount of tricalcium aluminate, are usually made only upon order (ASTM Specification C 150–63).

TABLE 53.—*Cement plants, products, and raw materials in the Appalachian Region, 1964*

[Source: U.S. Bur. Mines]

No. (fig. 58)	Location		Plant name	Company	Plant capacity (376-lb. barrels)	Process	Products	Raw materials
	State	County						
1	Alabama	Jefferson	Birmingham	Alpha Portland Cement	1,800,000	Wet	Portland and masonry cements.	Conasauga Limestone; residual clay.
2	do	do	do	Lehigh Portland Cement	1,810,000	do	do	Conasauga Limestone; Pottsville Formation (shale).
3	do	do	do	Lone Star Cement	1,900,000	do	do	Conasauga Limestone; Pottsville Formation (shale).
4	do	do	North Birmingham	Southern Cement			Slag-lime and masonry cements.	Blast furnace slag; hydrated lime; portland cement.
5	do	do	Leeds	Universal Atlas Cement Div., U.S. Steel.	1,880,000	Wet	Portland and masonry cements.	Chickamauga Limestone; Floyd Shale.
6	do	St. Clair	Ragland	National Cement Div., Woodward Iron.	1,450,000	Dry	do	Little Oak Limestone; Floyd Shale.
7	do	Shelby	Roberta	Southern Cement	3,000,000	do	do	Bangor Limestone; shale.
8	do	Blount	Graystone	Cheney Lime and Cement			Slag-lime and masonry cements.	Blast furnace slag; limestone(?).
9	Georgia	Polk	Rockmart	Marquette Cement Manufacturing.	1,280,000	Dry	Portland and masonry cements.	Conasauga Formation (limestone); shale.
10	Maryland	Washington	Hagerstown	Marquette Cement Manufacturing.	2,050,000	do	do	Conococheague Limestone; Martinsburg Shale.
11	Ohio	Lawrence	Ironton	Alpha Portland Cement	1,200,000	do	do	Maxville Limestone; sandstone.
12	do	do	Superior	Marquette Cement Manufacturing.	1,370,000	do	do	Vanport Limestone; Maxville Limestone; Allegheny Group (shale).
13	do	Muskingum	Jonathan	Columbia Cement	3,200,000	Wet	do	Maxville Limestone; Allegheny Group (shale).
14	Pennsylvania	Lawrence	Bessemer	Bessemer Cement	3,000,000	do	do	Vanport Limestone; Allegheny Group (shale).
15	do	Allegheny	Neville Island	Marquette Cement Manufacturing.	2,000,000	do	Portland slag and general use cements, and masonry cement.	Blast furnace slag; Vanport Limestone(?).
16	do	do	Universal	Universal Atlas Cement Div., U.S. Steel.	2,600,000	Dry	do	Do.
17	do	Lawrence	Wampum	Medusa Portland Cement	2,500,000	do	Portland and masonry cements.	Vanport Limestone; Allegheny Group (shale).
18	do	Butler	West Winfield	Penn-Dixie Cement	1,908,000	Wet	do	Vanport Limestone; Allegheny Group(?) (shale).
19	Tennessee	Franklin	Cowan	Marquette Cement Manufacturing.	950,000	do	do	Ste. Genevieve and Girkin ("Gasper") Limestones; residual clay.
20	do	Sullivan	Kingsport	Penn-Dixie Cement	1,620,000	do	do	Rockdell Limestone (quarry in Scott County, Va.); Sevier Shale.
21	do	Knox	Volunteer Div	Ideal Cement	2,800,000	do	do	Lenoir Limestone and Holston Formation; Ottosee Shale.
22	do	Hamilton	Chattanooga	General Portland Cement	2,000,000	do	do	Ste. Genevieve, Girkin ("Gasper") and Glen Dean Limestones; Alluvial clay.
23	do	Marion	Richard City	Penn-Dixie Cement	1,584,000	do	Portland cement	Ste. Genevieve, Girkin ("Gasper") and Glen Dean Limestones; Pennington Shale.
24	Virginia	Botetourt	Virginia Div	Lone Star Cement	3,400,000	Dry	Portland and masonry cements.	Mosheim Member of Lenoir Limestone; shale.
25	West Virginia	Berkeley	Martinsburg	Capitol Cement	4,000,000	Wet	do	Mosheim Member of Lenoir Limestone; cement rock; shale.

The variation in chemical composition of the five types of portland cement is not great. Bogue (1955, p. 32) shows typical compositions of the following ranges for the five types: 62.3–64.3 percent CaO, 1.8–2.9 percent MgO, 20.4–25.0 percent SiO_2, 3.4–6.0 percent Al_2O_3, 2.7–4.3 percent Fe_2O_3, and 1.6–2.3 percent SO_2.

Two plants in Appalachia produced portland-slag cement and two others a slag-lime cement. The portland-slag cement is prepared by pulverizing a mixture of granulated blast-furnace slag and portland cement clinker; the slag-lime cement (also called puzzolan cement) is made by mixing powdered slaked lime and finely ground blast-furnace slag.

Masonry cement, produced by nearly all cement plants in Appalachia, is made by grinding a mixture of portland cement clinker or finished portland cement together with limestone and an air-entraining agent to a fineness greater than portland cement. The finished masonry cement makes a mortar having a high degree of plasticity and water retention. Varying amounts of gypsum are added to control setting time.

RAW MATERIALS

The principal raw materials used in the manufacture of cement, limestone—clay or shale—sand or sandstone, are only briefly mentioned here. Distribution, geology, and composition of these materials are described in the sections on "Clay," "Limestone and Dolomite," and "Sand and gravel" (p. 167, 227, 254).

The most critical requirements for cement limestone are that it be low in $MgCO_3$ and impurities such as phosphorous, sodium, and potassium and that it meet specifications for maximum amounts of silica and alumina. Availability of high quality limestone generally determines the location of a cement plant within a given market area. Good-quality cement limestone deposits are moderately abundant in Appalachia with the exception of the central Appalachian Plateaus region of West Virginia and parts of bordering States covered mainly by rocks of Pennsylvanian and Permian age (pl. 2). Aluminous and siliceous materials such as clay, shale, slate, sand, and sandstone are widespread and generally can be found near limestone deposits of suitable grade.

Limestone formations used for manufacture of cement in Appalachia are listed in table 53 and are described in the section on "Limestone and Dolomite" (p. 227). They range in age from Cambrian to Pennsylvanian. The limestones most extensively used are the Conasauga Limestone (Cambrian) of Alabama and Georgia, the Ste. Genevieve, and Girkin (Gasper), Limestones (Upper Mississippian) of Tennessee, and the Vanport Limestone (Pennsylvanian) of western Pennsylvania and southern Ohio. Other limestones being used are those of Middle and Late Ordovician age, including the Chickamauga, Little Oak, Holston, and Lenoir Limestones of Alabama, Tennessee, Virginia, and West Virginia; limestone of the Conococheague Group (Upper Cambrian) of western Maryland, the Bangor Limestone (Upper Mississippian) of Alabama, and the Maxville Limestone (Upper Mississippian) of Ohio. O'Neill (1964, p. 6–7) reported that the Valentine Member (of Field, 1919) of the Curtin Formation (of Kay, 1943) (Ordovician) and the Tonoloway and Keyser Limestones (Silurian and Devonian?) were exploited in central Pennsylvania for cement limestone.

Depending upon available markets for cement, the above-mentioned formations could be exploited more extensively for cement limestone and other formations also could be used. Middle Ordovician limestones could be used much more widely in Alabama, Georgia, Tennessee, Virginia, West Virginia, and Maryland. The Greenbrier Limestone offers good possibilities as a cement limestone in southwestern Virginia and in eastern West Virginia. Good cement limestone is widespread in the Upper Mississippian rocks extending from northern Alabama to Kentucky ("Limestone and Dolomite," section on p. 227). The Brassfield Limestone of southern Ohio is a potential source of cement limestone; this formation is mined for cement limestone in southwestern Ohio to the west of the Appalachian Region. O'Neill (1964, p. 3, 6, 7) reported the Pleasant Hill Limestone (Cambrian), parts of the Curtin Formation of Kay (1943) (Ordovician), and the Coburn Formation of Field (1919) (Ordovician) to be potential sources of cement rock in central Pennsylvania.

Most cement plants use clay or shale (table 53) in addition to limestone, and, although not indicated in the table, many of the plants also use sand or sandstone to furnish part of the needed silica. Shale, clay, and sandstone suitable as sources of alumina and silica are abundant and widespread in the Paleozoic rocks in Appalachia. Residual clay is also widespread as are alluvial deposits of clay and sand.

Low-cost blast-furnace slag is available for cement manufacture in the steel-producing centers of Birmingham, Ala., Pittsburgh, Pa., and regions along the Ohio River in Kentucky and Ohio.

RESOURCE POTENTIAL

Cement limestone is widespread and abundant in Appalachia except in some parts of the Appalachian Plateaus province and in the Piedmont and Blue Ridge provinces in the southeastern part of the region. Resources are large enough to sustain the present cement industry and to supply any expanded industry of the future. Other cement raw materials (sandstone, sand, shale, and clay) are abundant in all parts of Appalachia.

The Appalachian Region is capable of producing all the cement it needs and of exporting large amounts of cement to bordering areas. Nevertheless, some areas accessible to cheap river transportation, as for example the regions of Charleston and Huntington, W. Va., now import large amounts of cement from outside Appalachia and will probably continue to do so in the future. Elsewhere the cement industry of Appalachia will continue to compete for internal and external markets with nearby outside plants.

CLAY

By John W. Hosterman and Sam H. Patterson, U.S. Geological Survey, and John W. Sweeney and John W. Hartwell, U.S. Bureau of Mines

INTRODUCTION

Clay is a natural, earthy, generally plastic material composed of very fine crystalline particles (clay minerals) that are principally hydrous aluminum silicates, but may contain varying amounts of iron, magnesium, potassium, sodium, or other ions. All clay contains nonclay minerals that are rare in some clay deposits and abundant in others. The most common nonclay minerals are quartz, feldspar, mica, iron oxide minerals, and carbonate minerals. Titanium-bearing minerals and gypsum are abundant in some clay deposits, and organic matter is abundant in others.

The suitability of clay for different uses depends on physical properties controlled by the mineral and chemical composition. Physical properties of clay include plasticity, bonding strength, color, vitrification range, deformation with drying and firing, resistance to high temperatures, gelation, viscosity of slurries, ion-exchange capacity, particle size, and absorbent properties. The structure and composition of the various clay minerals are complex; for further information the reader is referred to a summary by Murray (1960) and to books by Grim (1953, 1962); a report by Klinefelter and Hamlin (1957) outlines many of the laboratory procedures used in evaluating clay.

Some types of clay are suitable for many unrelated uses, and some industries use more than one type of clay for the same purpose; thus a satisfactory classification of clay based either on mineral type or industrial use is difficult. Clay is classified in this report according to the usage of the U.S. Bureau of Mines (J. D. Cooper, 1965a). Kaolin, fire clay, and miscellaneous clay and shale are mined in Appalachia. Kaolin is used for some purposes for which other types of clay are not suitable, but it is also used as fire clay and in heavy clay products. (The terms "heavy clay products" and "structural clay products" are used interchangeably for all forms of brick, tile, and other fired clay products used in construction; both terms exclude fire brick and other types of refractory products.) Fire clay is so named because of its principal use in refractory products; however, major proportions of the fire clay mined in Appalachia are used for heavy clay products of the same type as made from miscellaneous clay and shale. Potassium-bentonite, a form of bentonite having little value, was once mined on a small scale. The pottery and stoneware industry uses several different types of clay, most of which come from outside of Appalachia. Clayey tripoli, which is not true clay, is discussed in this section because it is reported as fire clay in Bureau of Mines statistics; it is also discussed in the section on "Abrasives" (p. 261). Ball clay and fuller's earth, classified separately by the Bureau of Mines, are not mined in Appalachia.

During the preparation of this report, J. W. Hosterman visited many plants producing clay products and several State geological surveys in the northern part of Appalachia, and S. H. Patterson visited the southern part of the region. Officials of many companies supplied information on the clay resources used by their plants and the products they are making. These officials are too numerous to list individually, but appreciation is hereby expressed to all who contributed information. State organizations contributed much valuable information on clay resources in their respective States, and their assistance is also gratefully acknowledged.

Directories of the following organizations were extremely useful in compiling this report: Refractories Institute (1961); Geological Survey of Alabama (Cook and others, 1963); Ohio Department of Industrial Relations (Kefauver, 1963); Georgia Dept. of Mines, Mining and Geology (1964); Structural Clay Products Institute (1964); American Ceramic Society (1965); National Clay Pipe Institute (1965); Pennsylvania Bureau of Topographic and Geologic Survey (O'Neill, 1965); and Virginia Division of Mineral Resources (Le Van and Pharr, 1966).

MISCELLANEOUS CLAY AND SHALE

Miscellaneous clay and shale resources and the industries that use them are widely scattered throughout Appalachia (fig. 59, table 54). They are used chiefly in making fired clay products, but some clay and shale are used in unfired form. The unfired uses are as follows: shale for filler in paint and asphalt; clay for abrasives, termed "rottenstone"; shale for "clay dummies" used to pack dynamite in blasting holes; and clay used for plugging dry oil and gas holes. These products are easily processed, requiring only drying, grinding, and bagging. Fired products made from miscellaneous clay and shale include face and structural brick, vitrified sewer pipe, drain tile, flue tile, conduit, pottery, stoneware, and floor, wall, and roofing tile. In addition to these uses, miscellaneous clay and shale are used in the manufacture of portland cement and lightweight aggregate.

Miscellaneous clay and shale are produced in parts of every State within the limits of Appalachia. The total miscellaneous clay and shale, including that used for cement (table 53) and lightweight aggregate (table 79), produced in the region from 1945 through 1964, amounted to 71 million short tons (table 55), valued at $86 million (1958 constant dollars). During this period the production was distributed as follows: Pennsylvania, 25 percent; Ohio, 17 percent; Tennessee, 13 percent; Alabama, 12 percent; West Virginia, 8 percent; Virginia, 6 percent; North Carolina and Georgia, 5 percent; and Kentucky, Maryland, New

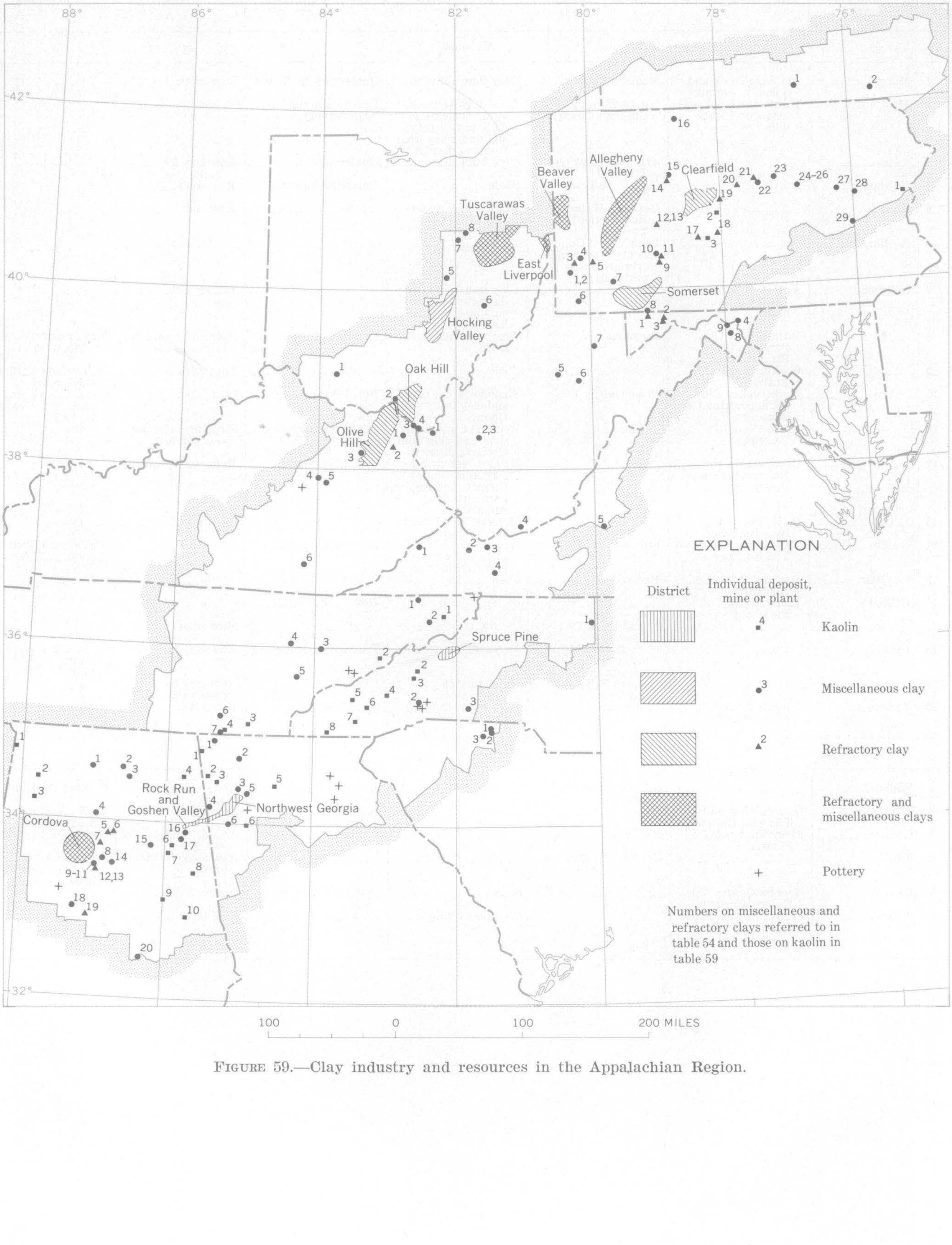


FIGURE 59.—Clay industry and resources in the Appalachian Region.

TABLE 54.—*Clay and shale industry and resources in the Appalachian Region, exclusive of major districts*

No. (fig. 59)	County or district	Plant name, location	Mine or pit location	Raw material	Geologic formation or age	Product	Reference
				Alabama			
1	Morgan	Alabama Brick and Tile Co., Decatur.	Madison County	Clay from alluvium	Quaternary to Recent	Face brick	
2	Madison	Huntsville Brick and Tile Co., Huntsville.	Huntsville and Cullman County.	Local clay from alluvium, shale from Cullman County, and underclay from Cordova district.	Clay in alluvium is Quaternary.	do	
3	do		Alabama Brick and Tile Co.	Clay from alluvium	Quaternary	Raw clay for face brick.	
4	Cullman		Huntsville Brick and Tile Co.	Shale	Pottsville Formation	Raw shale	
5	Blount		Harbison-Walker Refractories Co., Thermal.	Black Creek underclay	do	Raw clay	
6	do		Lehigh Coal Co., Lehigh (clay mine operated intermittently).	do	do	do	
7	Jefferson	A. P. Green Fire Brick Co., Kimberly.		Clay from Cordova district and from outside of Appalachia.		Refractories	
8	do	Birmingham Clay Products Co., Birmingham.	Birmingham	Weathered and fresh shale.	Pottsville Formation	Face and common brick.	McVay and Toulmin (1945, p. 80–81).
9	do	Watkins Brick Co., Ensley.	Ensley	Shale	do	Face brick	McVay and Toulmin (1945, p. 83).
10	do	W. S. Dickey Clay Manufacturing Co., Bessemer.	Bessemer	Shale mined at plant and clay from Bibb County.	Floyd Shale	Clay pipe	O. M. Clarke (oral commun., October 13, 1965).
11	do	Natco Corp., Bessemer.	do	Weathered and fresh shale and clay from Cordova district.	Pottsville Formation	Structural tile and clay conduit.	Do.
12	do	Harbison-Walker Refractories Co., Bessemer.		Black Creek underclay from Blount County, and clay from outside of Appalachia.		Refractory products	Do.
13	do	H. K. Porter Co., Inc., Bessemer.		Material from outside of Appalachia.		do	Do.
14	do	Stephenson Brick and Tile Co., Lovick.	Lovick	Weathered and fresh shale and clay from Cordova district.	Pottsville Formation	Face brick	McVay and Toulmin (1945, p. 75–80).
15	St. Clair	Ragland Brick Co., Ragland.	Ragland	Shale	do	do	
16	Calhoun	Frame Brick Co., Piedmont.		do	Rome Formation	do	
17	do		Frame Brick Co., Weaver.	do	do	Raw shale	
18	Bibb		W. S. Dickey Manufacturing Co., Schultz Creek.	Montmorillonitic clay	Tuscaloosa Group	Raw clay for clay pipe.	O. M. Clarke (oral commun., Oct. 13, 1965).
19	do		Norman E. Smith, Lawley.	Refractory clay	do	Raw clay for refractories.	Do.
20	Elmore	Jenkins Brick Co., Montgomery.	Montgomery	Clay from alluvium	Quaternary	Face brick	Do.
				Georgia			
1	Walker		General Shale Products, Inc.	Shale	Red Mountain Formation.	Red shale for face brick.	Cressler (1964, fig. 2).
2	Whitfield	Dalton Brick and Tile Co., Dalton.	Dalton	do	Conasauga Formation.	Face brick	R. W. Smith (1931, p. 181–182).
3	Gordon	Plainville Brick Co., Plainville.	Plainville	do	do	do	R. W. Smith (1931, p. 232–236).
4	Floyd		Chattahoochee Brick Co., Coosa.	do	do	Raw shale for face brick.	J. W. Smith (oral commun., Oct. 11, 1965).
5	Bartow	Georgia Quarry Tile Co., Adairsville.		Shale	Shale of Paleozoic age.	Quarry Tile	
6	Polk	Chattahoochee Brick Co.		Weathered slate	Rockmart slate of Hayes (1891).	Face brick	J. W. Smith (oral commun., June 1, 1966).

TABLE 54.—*Clay and shale industry and resources in the Appalachian Region, exclusive of major districts*—Continued

No. (fig. 59)	County or district	Plant name, location	Mine or pit location	Raw material	Geologic formation or age	Product	Reference
Kentucky							
1	Boyd	Big Run Coal and Clay Co., Princess.	Princess	Underclay below Nos. 6 and 7 coal beds and shale.	Breathitt Formation	Face brick	Dobrovolny and others (1963).
2	Carter		General Refractories Co.	Underclay below one of the Princess series coal beds.	do	Raw plastic clay used in making refractory products.	
3	Rowan	Lee Clay Products Co., Clearfield.	Clearfield	Shale and Olive Hill clay bed.	Lee Formation	Clay pipe and other structural products.	
4	Powell		Big Run Coal and Clay Co., Clay city	Shale	New Providence Fm. (as used by the Kentucky Geological Survey).	Raw shale used in brick plant at Lexington.	Preston McGrain (oral commun., Oct. 18, 1965).
5	do	H. B. Sipple Brick Co., Stanton.	Stanton	do	do	Face brick	Do.
6	Whitley	Corbin Brick Co., Corbin.	Woodbine	Soil, alluvium, and weathered shale.	Breathitt Formation	do	Puffett, (1963).
Maryland							
1	Garrett	Harbison-Walker Refractories Co., Grantsville.	Ohiopyle, Fayette County, Pa.	Clarion flint and plastic clay.	Allegheny Group	Refractories.	
2	Allegeny	Kaiser Refractories and Chemical Corp. Zihlman.	Ohipyle, Fayette County, Pa. Frostburg.	Clarion flint and plastic clay. Mount Savage flint and plastic clay.	do	do	
3	do	Mount Savage Refractories Co., Mount Savage.	Rockwood, Somerset Co., Pa.	Upper and lower Kittanning plastic clay.	do	do	
4	Washington	Victor Cushwa & Sons, Inc., Williamsport.	Williamsport	Shale	Martinsburg shale (Ordovician).	Face brick	
New York							
1	Chemung	Binghamton Brick Co., Horseheads.	Horseheads	Shale	Devonian	Face brick	Brownell and others (1951, p. 85, 227).
2	Broome	Binghamton Brick Co., Inc., Binghamton.	Binghamton	do	do	do	Brownell and others (1951, p. 86, 226).
North Carolina							
1	Stokes	Pine Hall Brick and Pipe Co., Pine Hall.	Pine Hall	Shale	Triassic	Face brick	Stuckey and Steel (1953, p. 15).
2	Henderson	Moland-Drysdale Inc., Fletcher.	Fletcher	Sericite schist	Brevard schist	do	Do.
3	Rutherford	Bostic Brick Co., Bostic.	Bostic	Slope wash and alluvium from saprolite (sericite schist from outside Appalachia is also used).	Recent	Brick	
Ohio							
1	Highland	Mowerystown Brick and Tile Co., Mowerystown.	Mowerystown	Clay and shale	Elkhorn Formation (Ordovician) Pleistocene clays.	Clay pipe	David Webb (oral commun., October 1965).
2	Scioto	Harbison-Walker Refractories Co., Portsmouth.	Greenup Co., Ky.	Olive Hill flint clay	Lee Formation (Pennsylvanian).	Refractories.	
3	Lawrence	The Carlyle Tile Co., Coal Grove.	Coal Grove	Lawrence clay, Lower Kittanning clay.	Pottsville Formation	Tile	Stout (1916, p. 352).
4	do		Jess Brammer, Waterloo and Gateway.	Shale	do	Raw clay for tile.	
5	Muskingum		The Bowerstown Shale Co., Frazeysburg.	Middle Mercer shale	do	Raw clay for face brick.	Stout (1918, p. 80).
6	Noble	Ava Brick Corp., Ava.	Ava	Cow Run shale	Conemaugh Formation.	Face brick	Kefauver (1963, p. 191).
7	Holmes		Clark Clay Co., Millersburg.	Brookville clay	Allegheny Formation.	Raw clay for well plugging.	G. W. White (1949, p. 163).
8	do		The Holmes Limestone Co., Salt Creek Township.	do	do	Raw clay for face brick, well plugging, filler, refractories.	G. W. White (1949, p. 161).

TABLE 54.—*Clay and shale industry and resources in the Appalachian Region, exclusive of major districts*—Continued

No. (fig. 59)	County or district	Plant name, location	Mine or pit location	Raw material	Geologic formation or age	Product	Reference
				Pennsylvania			
1	Washington	Saglime Brick and Tile Co., Vance.	Vance	Shale	Washington and Greene Formations (Pennsylvanian and Permian).	Face brick	John Roen (oral commun., October 1965).
2	do	Donley Brick Co., Washington.	Washington	do	Washington Formation (Pennsylvaian and Permian).	do	Do.
3	do	Haws Refractories Co., Cannonsburg.	Lemont Furnace	Underclay	Conemaugh Formation.	Refractories	
4	Allegheny	Kirwin Brick Co., Inc., Bridgeville.	Bridgeville	Shale	Monongahela Group	Face brick	Leighton (1941, p. 53).
5	do	Hiram Swank's Sons, Inc., Large.	Holsopple, Clearfield	Lower Kittanning clay, Mercer flint clay.	Allegheny Group, Pottsville Group.	Refractories.	
6	Greene	Greene County Clay Products Co., Waynesburg.	Waynesburg	Shale	Washington Formation (Pennsylvaian and Permian).	Face brick	Leighton (1941, p. 113).
7	Fayette	Layton Fire Clay Co., Layton.	Layton	do	Conemaugh Formation.	do	
8	Somerset	Otto Brick and Tile Works, Inc., Springs.	Springs	Clay	Alluvium (Quaternary).	do	O'Neill and others (1965, p. 329).
9	do		Hiram Swank's Sons, Holsopple.	Lower Kittanning? clay.	Allegheny Group	do	
10	Cambria	Hiram Swank's Sons, Inc., Johnstown.	Hopsopple, Clearfield	Lower Kittanning clay, Mercer flint clay.	Allegheny Group, Pottsville Group.	Refractories	
11	do	Triangle Clay Products, Co.	Johnstown	Shale and underclay	Allegheny Group	Face brick	Shaw (1928, p. 33).
12	Indiana	Hiram Swank's Sons, Inc., Clymer.	Clymer, Osceolo Mills.	Lower Kittanning clay, Mercer flint clay.	Allegheny Group, Pottsville Group.	Refractories	
13	do		L. H. Foehrenbach, Clymer.	Lower Kittanning clay.	Allegheny Group	Raw clay for refractories.	Do.
14	Jefferson	Falls Creek Refractories, Co., Falls Creek.	Curwensville	do	do	Refractories	
15	do	Brockway Clay Co., Brockway.	Brockway	Shale and Lower Kittanning clay.	do	Clay pipe	O'Neill and others (1965, p. 186).
16	McKean	Hanley Co., Lewis Run.	Lewis Run	Shale	Oswego Sandstone (Ordovician).	Face brick	
17	Blair	Blair Clay Products Co. (Div. of RESCO), Altoona.	Curwensville	Lower Kittanning clay.	Allegheny Group	Refractories	
18	Huntingdon	Maryland Refractories Co., Alexandria.		Grinds refractory		Refractories	
19	Centre	J. H. France Refractories Co., Clarence.	Anderson Creek	Mercer flint clay	Pottsville Group	do	
20	do	F. E. Fink and R. H. Stackhouse, Monument.	Farrandville	do	do	do	
21	Clinton		F. E. Fink and R. H. Stackhouse, Farrandville.	do	do	Raw clay for refractories.	
22	do	Mill Hall Clay Products, Inc., Mill Hall.	Castanea	Shale	Rose Hill Formation (Silurian).	Clay pipe	G. W. Colton (oral commun., October 1965).
23	Lycoming	Penn Paint and Filler Co., Antes Fort.	Oriole	do	Reedsville shale (Ordovician).	Abrasive	Do.
			Montoursville	do	Onondaga Formation (Devonian).	Filler	W. D. Carter (oral commun., October 1965).
24	Northumberland.	Glen-Gery Shale Brick Corp., Watsontown.	Watsontown	Red shale	Bloomsburg Red Beds (Silurian).	Face brick	
			White Deer	Shale	McKenzie Formation (Silurian).		
25	do	Watsontown Brick Co., Watsontown.	Watsontown	Red shale	Bloomsburg Red Beds (Silurian).	do	
26	do	Watsontown Products Co., Watsontown.	do	do	do	Filler	
27	Columbia	Alliance Clay Products Co., Mifflinville.	Mifflinville	do	do	Face brick	
28	Luzerne	Hazelton Brick Co., Hazel Village.	Hazel Village	Shale	Mauch Chunk Formation (Mississippian).	do	O'Neill and others (1965, p. 261).
			McAdoo	L. Kittanning clay (Buck Mountain).	Post-Pottsville age	do	
29	Schuylkill	Auburn Brick Co., Auburn.	Auburn	Shale	Onondaga Formation (Devonian).	do	

TABLE 54.—*Clay and shale industry and resources in the Appalachian Region, exclusive of major districts*—Continued

No. (fig. 59)	County or district	Plant name, location	Mine or pit location	Raw material	Geologic formation or age	Product	Reference
				South Carolina			
1	Cherokee		Bennett Brick and Tile Co., near Kings Mountain State Park.	Weathered sericite schist and manganifereous schist.	Paleozoic	Raw clay for face brick.	
2	do		Broad River Brick Co., near Kings Mountain State Park.	do	do	do	
3	do	Broad River Brick Co., Gaffney.	Gaffney	Slope wash and alluvium from saprolite and sericite schist (underclay from Cordova, Ala., Triassic shale from North Carolina are also used).	Slope wash and alluvium are Recent.	Face brick	
				Tennessee			
1	Sullivan	General Shale Products, Inc., Kingsport.	Kingsport	Shale	Sevier Shale	Face brick	
2	Washington	General Shale Products, Inc., Johnson City.	Johnson City	do	Athens and Sevier Shales.	do	Whitlatch (1938, p. 3).
3	Knox	General Shale Products, Inc., Knoxville.	Knoxville	do	Rome Formation	do	
4	Anderson?		General Shale Products, Inc., Oliver Springs.	Underclay	Lee Group	Raw clay	
5	Loudon	Old Hickory Brick Co., Greenback.	Greenback	Residuum and manganiferous clay.	Chapman Ridge Sandstone.	Face brick	S. W. Maher (oral commun., Oct. 5, 1965).
6	Hamilton	B. Mifflin Hood (Federal Ceramics, Inc.), Daisy.	Daisy	Shale	Pennington Formation.	Quarry tile	Swingle and Luther (1964a).
7	do	General Shale Products Inc., Chattanooga.	Walker County, Ga.	do	Red Mountain Formation.	Face brick	
				Virginia			
1	Dickenson	Combs Dummie Co.	Georges Fork	Shale	Norton Formation (Pennsylvanian).	Clay dummies	
2	Tazewell	General Shale Products Corp., Richlands.	Richlands	do	Brallier Shale (Devonian).	Face brick	S. S. Johnson and others (1965, p. 144).
3	do	Tazewell Clay Products Co., Tazewell.	Tazewell	Residual clay	Beekmantown Dolomite (Ordovician).	Clay dummies	S. S. Johnson and others (1965, p. 147).
4	Smyth	General Shale Products Corp., Atkins.	Atkins	Shale	Rome Formation (Cambrian).	Face brick	S. S. Johnson and others (1965, p. 119).
5	Botetourt	Webster Brick Co., Inc., Webster.	Webster	do	do	do	Calver and others (1964, p. 107).
				West Virginia			
1	Cabell	Barbourville Clay Manufacturing Co., Barbourville.	Barbourville	Red shale	Conemaugh Formation.	Face brick	Cross and Schemel (1956, p. 50).
2	Kanawha	Charleston Clay Products Co., Charleston.	Charleston	Bakertown clay	do	do	
3	do	West Virginia Brick Co., Charleston.	do	do	do	do	
4	Mercer	Virginia Brick and Tile Co., Princeton.	Princeton	Red shale	Mauch Chunk Formation (Mississippian).	do Clay pipe	McCue and others (1948, p. 57).
5	Lewis	Weston-Jane Lew Brick and Tile Co., Weston.	Weston	Shale, Pittsburgh clay.	Conemaugh Formation.	Face brick	McCue and others (1948, p. 51).
6	Upshur	Buckhannon Brick Co., Buckhannon.	Buckhannon	Red shale	do	do	
7	Taylor	Grafton Brick Co., Thornton.	Thornton	do	do	do	
8	Berkeley	Continental Clay Products Co., Martinsburg.	Martinsburg	Weathered shale	Martinsburg shale (Ordovician).	do	McCue and others (1948, p. 27).
9	do	United Clay Product Co., North Mountain.	North Mountain	do	do	do	

York, and South Carolina, 14 percent. The miscellaneous clay and shale mined for building brick, vitrified sewer pipe, and other heavy clay products in 1964 amounted to 3 million short tons. Relatively small tonnages of miscellaneous clay and shale were produced for other uses.

TABLE 55.—*Production of miscellaneous clay and shale, 1945–64*

[Includes material sold or used for cement and lightweight aggregate. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	1,405	1,928	10,849	12,878
1946	2,807	3,247	20,190	20,862
1947	2,581	2,641	21,774	21,068
1948	2,893	2,879	24,747	23,654
1949	2,753	2,610	23,726	22,607
1950	3,115	3,111	26,400	26,472
1951	3,471	3,997	27,649	31,522
1952	3,105	3,957	26,508	32,683
1953	2,890	3,724	28,268	34,365
1954	3,442	4,425	29,852	38,950
1955	4,201	4,453	32,838	38,422
1956	4,384	5,673	34,274	43,643
1957	4,123	5,457	30,408	38,124
1958	3,605	4,652	30,674	38,216
1959	4,087	5,089	34,731	40,884
1960	4,658	5,836	34,300	40,997
1961	4,337	5,306	33,788	40,021
1962	4,344	5,076	34,392	40,977
1963	4,390	5,419	35,968	44,017
1964	4,488	6,217	38,125	46,718
Total	71,079	85,697	579,461	677,080

In recent years, miscellaneous clay and shale have been mined throughout the United States except Alaska, Nevada, and Rhode Island. The leading producing States in 1964 were California, Pennsylvania, Texas, and Ohio. The total miscellaneous clay and shale sold or used by producers in the United States in 1964, including the clay and shale used in cement and lightweight aggregate, was 38 million short tons (J. D. Cooper, 1965a, p. 372) valued at $47 million (1958 constant dollars). The miscellaneous clay and shale mined in Appalachia in 1964 amounted to 12 percent of the tonnage and 13 percent of the value of the total domestic production.

The production of miscellaneous clay and shale in Appalachia is related to the general economy of the country. About 80 percent of the output of these materials is consumed in the building and construction industries. The increase in new homes, other types of buildings, and highways in the region during the last 20 years has resulted in a threefold expansion in production. Low-cost transportation is essential to the industry because most of the products made from miscellaneous clay and shale are heavier than the competing materials. Therefore, most structural clay products are sold to conusmers within a distance of about 200 miles of any given plant, though some of the products having special market value or influenced by unusual local conditions are shipped farther than 200 miles.

TYPES AND OCCURRENCE

Many different fine-grained rocks are classified as miscellaneous clay and shale and are used in making brick, tile, and other structural clay products. Although most contain appreciable quantities of clay minerals, several are neither clay nor shale but are included in Bureau of Mines statistics for these materials. The rocks used for structural clay products in Appalachia include both fresh and weathered shale, slope wash and alluvium, alluvium in stream bottoms, montmorillonitic clay, ferruginous saprolite, and weathered and fresh schist. Underclay and kaolin are also used in structural clay products, and some production of these clays is reported as miscellaneous clay by the Bureau of Mines.

Some brick plants use only one type of miscellaneous clay or shale, and others use several different types. Plants using only one type ordinarily are capable of producing only one or very few types of common or face brick. Plants using two or more types of raw materials are able to produce bricks having many different shades and textures. Least control of raw material is required where common red brick is made because most clay and shale contain sufficient iron oxide to burn red; a few companies find it necessary to add hematite to their clay or shale.

The production of the more costly types of face brick requires more stringent control of raw materials to obtain the desired colors and textures. Common products in this category are light-gray, light-yellowish-gray, or buff face brick and glazed face brick having many colors. The material used in such bricks must be either very low in iron oxide or the iron present must be in minerals that will not oxidize and turn red when fired. Underclay is the most common material used for buff brick in Appalachia. Small quantities of locally mined kaolin are used for buff brick by one plant near Piedmont, Ala. Several plants in North and South Carolina make buff brick from sericite schist mined locally and minor quantities of underclay shipped from the Cordova district, Alabama. Face brick of many different colors and textures are made by mixing, in varying proportions, the materials from which buff brick are made with those used for the more common red and brown brick. A deep-purple face brick is made in plants in the Carolinas by using manganiferous sericite schist and in Tennessee by using manganiferous clays.

Shale and clay used in making brick and other structural clay products occur in formations ranging in age from Cambrian to Recent (table 54). The shale deposits used most extensively in various regions in Appalachia are: red beds in the Rome Formation of Cambrian age in Virginia, Tennessee, and Alabama; shale beds in the Conasauga Formation of Cambrian age in Alabama and Tennessee; weathered shale in the Martinsburg Shale of Ordovician age in Maryland and Virginia; Sevier Shale of Ordovician age in Tennessee; red shale in the Bloomsburg Red Beds of Silurian age in eastern Pennsylvania; the New Providence Formation of Mississippian age; in Kentucky; shale beds in the Pennington Formation of Mississippian age in Tennessee; the Floyd Shale of Mississippian age in Alabama; shale of Pennsylvanian age in Pennsylvania, Ohio, Kentucky, and Alabama; and the Washington and Greene Formations of Permian age in southwestern Pennsylvania. Slopewash and alluvium of Pleistocene and Recent ages are mined at several places in Alabama and the Carolinas.

Many rocks used as raw materials in structural clay products are similar in mineral composition, but some have distinctive compositions that impart desirable properties to products. Investigations by X-ray diffraction methods show that illite is the most abundant clay mineral in most shale used for brick in Appalachia; kaolinite and montmorillonite occur in much smaller quantities. Amounts of kaolinite and montmorillonite are approximately equal in most shale, but in some shale one or the other is absent or occurs only in trace quantities. Nonclay minerals vary appreciably in shale and commonly are more abundant than clay minerals. Quartz is the most abundant and feldspar the second most abundant nonclay mineral in most shale; most red shale contains appreciable quantities of hematite. Most shale will develop sufficient plasticity when ground and wet to be workable and will fuse at suitable temperatures to form products of desired density and strength.

Montmorillonitic clay, such as found in the Tuscaloosa Group in Alabama, has other desirable physical properties. It characteristically becomes extremely plastic when wet and forms a strong bond when dry. Small quantities of Tuscaloosa clay are added to shale to obtain the properties required in making clay pipe (O. M. Clarke, oral commun., Oct. 14, 1965).

RESOURCE POTENTIAL

Resources of miscellaneous clay and shale are virtually inexhaustible in many areas of Appalachia, but a few plants in the metropolitan areas have raw-material supply problems. In many areas scattered throughout the region, beds of shale several tens of feet thick and suitable for use in structural clay products crop out over areas of many square miles. The suburban spread of several large cities has engulfed a few brick and tile plants and their clay and shale resources. Some of these plants must be relocated or face increasing costs of transporting raw materials from more distant sources.

Future demands for products made from miscellaneous shale and clay can be expected to increase at a rate lower than the rise in the gross national product, and this growth probably will be unevenly distributed in Appalachia. Requirements for building materials resulting from the population growth should cause continued growth in the markets for structural clay products, although competition from building materials made of wood, aluminum and other metals, glass, and cement also will continue to increase. The greatest growth in demands for products made from miscellaneous clay will be in the growing centers of population such as Birmingham, Ala., and Pittsburgh, Pa. Uncommonly large local demands also can be expected in such areas as the Piedmont belt of the Carolinas which is attracting an increasing number of rural industrial plants and is in a phase of unprecedented economic growth.

FIRE CLAY

Fire clay is used extensively in Appalachia for refractory and heavy clay products by an industry widely scattered throughout the region (fig. 59, table 54). Fire clay, by definition, can be made into products that are resistant to high temperatures. The products vary appreciably in quality, and the temperatures they are capable of withstanding range from about 2,770°F to nearly 3,250°F. Refractory products are made by drying, grinding, and blending the clay, molding it into shapes by either extrusion or press or a combination of both and by hand if the shapes are complicated, and firing it in a periodic or tunnel kiln. The products include brick and special-shaped blocks for furnace linings, pouring-pit refractories, mortar mixes, and other miscellaneous items. The heavy clay products include building and face brick, vitrified sewer pipe, and flue tile.

HISTORY AND PRODUCTION

The first fire-clay production in Appalachia was probably along the Ohio River and the first plant using fire clay in Appalachia may well have been one that was built near New Cumberland, W. Va., in 1830 (Stout, 1923, p. 10). The manufacture of fire brick in Ohio began in 1841 near East Liverpool (Stout, 1930, p. 29). Fire clay was discovered in western Maryland in 1837, and the first plant at Mount Savage began operation in 1841 (Clark and others, 1900, p. 181). The manufacture of fire brick from the Sciotoville flint clay began in 1863 at Scioto County, Ohio. The Lower Kittanning underclay of Tuscarawas County, Ohio, was first used in large amounts about 1868 when a three-kiln plant was built at Dover. The historical records of the early fire-clay industry in Pennsylvania are scanty, but several companies began producing refractories from the Mercer flint clay in Clearfield County, Pa., about 1870 (Chance, 1884, p. 168–176). A brick company using fire clay near Lucinda, Clarion County, Pa., began operating in 1872. Underclay in the Oak Hill district, Jackson County, Ohio, was first used in 1873 when two plants were erected. The first record of fire-clay production in Kentucky was in 1883 when flint clay was shipped from the Olive Hill district to Scioto County, Ohio, for use in making fire brick (Crider, 1913, p. 592–594).

The total fire clay produced in Appalachia in the 20-year period 1945–1964 was 86.8 million short tons valued at $419 million (1958 constant dollars, see table 56). During this period, production was distributed as follows: Pennsylvania, 40 percent; Ohio, 38 percent; West Virginia, 8 percent; Kentucky, 7 percent; Maryland, Alabama and Tennessee, the remaining 7 percent. Fire-clay mining in Maryland declined considerably during the past 10 years; the three refractories in western Maryland are now mainly supplied from clay deposits in southern Pennsylvania. In 1964, Appalachian production was 42 percent of the tonnage and 52 percent of the value of the total domestic output. More than half was used in making refractories; approximately 46 percent was used in making structural clay products; and minor tonnages were used for other products (table 57).

Most economic factors influencing the fire clay industry are directly related to the activity of the construction and steel industries. Those pertaining to the miscellaneous clay and shale industry also apply to fire clay production, because 46 percent of the fire clay is made into structural clay products for building. About half of the fire clay is used in refractory products; 65 percent of these products are used by the steel industry.

TABLE 56.—*Production of fire clay, 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value in 1958 constant dollars (thousands)	Short tons (thousands)	Value in 1958 constant dollars (thousands)
1945	3, 114	11, 166	6, 090	20, 536
1946	3, 971	14, 847	7, 908	27, 119
1947	4, 375	16, 626	9, 039	31, 691
1948	4, 811	17, 527	9, 850	34, 094
1949	4, 154	15, 241	8, 572	29, 216
1950	4, 504	17, 259	9, 536	33, 053
1951	5, 752	16, 606	11, 853	51, 743
1952	5, 287	24, 772	11, 285	50, 716
1953	4, 857	18, 030	10, 267	40, 773
1954	4, 325	18, 610	8, 797	35, 873
1955	5, 180	25, 587	10, 840	45, 830
1956	5, 689	34, 281	11, 803	56, 636
1957	4, 553	30, 206	10, 805	52, 147
1958	3, 765	21, 706	8, 808	40, 420
1959	4, 278	23, 806	9, 862	44, 567
1960	4, 344	23, 380	9, 915	44, 828
1961	3, 623	20, 174	8, 690	38, 569
1962	3, 187	17, 310	8, 065	35, 557
1963	3, 449	20, 644	8, 390	39, 400
1964	3, 622	21, 324	8, 549	40, 788
Total	86, 840	419, 102	188, 924	793, 556

TABLE 57.—*Fire clay sold or used in the Appalachian Region*

[In short tons. W, withheld to avoid disclosing individual company data. Source: U.S. Bur. Mines]

Use	1963	1964
Architectural terra cotta	266	247
Building brick	1, 048, 985	1, 147, 571
Chemicals, plastics	4, 800	------
Clay crucibles	W	W
Firebrick	1, 474, 131	1, 510, 671
Floor and wall tile	W	W
Foundries	350, 858	402, 904
High alumina brick	W	W
Mortar	W	W
Other heavy clay products	125, 162	75, 153
Other refractories	88, 033	117, 343
Pottery and stoneware	W	W
Rotary drilling mud	W	W
Saggers	W	W
Vitrified sewer pipe	248, 908	186, 805
Total	3, 449, 435	3, 621, 514

Since 1957, both the United States and Appalachian fire clay production has remained nearly constant, even though the demand for fire clay products has been increasing. Improvements in quality of products have been made possible by selective mining, upgrading the raw material by blending different types of clay, better methods of manufacturing, and by other means. These changes have resulted in the shutting down of some obsolete plants and the expansion and modernization of others. In a few areas, high-grade clay that is inexpensive to mine and transport has been depleted and the local plants now depend on clay from other areas. An example is the western Maryland area, where much of the clay is now obtained from deposits in Pennsylvania.

TYPES AND OCCURRENCE

Underclay beds of Pennsylvanian age, most of which underlie coal beds, are the chief source of fire clay mined in Appalachia. Most underclay is plastic, but some is hard, nonplastic, and flintlike and is known as "flint clay"; a variety intermediate between the two is called "semiflint clay." The plastic clay is similar to some shale in composition because it contains kaolinite and illite in approximately equal amounts (Schultz, 1958, p. 374–380), but plastic clay generally contains less iron than shale. Most flint clay consists of nearly pure kaolinite, and semiflint clay is intermediate between flint clay and plastic clay in mineral composition. A variety of flint clay called nodular clay consists chiefly of a matrix of kaolinite in which are masses and nodules consisting chiefly of diaspore, AlO(OH), and minor quantities of boehmite, AlO(OH) (Bolger and Weitz, 1952, p. 83). Boehmite also occurs in some other flint clay (Hosterman and Patterson, 1961). Nonclay minerals in underclay are chiefly quartz, siderite, feldspar, and rarely anatase.

Plastic underclay is widely distributed throughout most of Appalachia. Flint clay occurs chiefly in northeast Kentucky, southern Ohio, and Pennsylvania and is present in parts of West Virginia. Nodular clay occurs only in the Clearfield district, Pennsylvania. Some plastic clay is suitable for use in low- or moderate-heat-duty refractories; flint clay commonly is used for products capable of withstanding higher temperatures than those made from plastic clay; the nodular clay is the most refractory of all the kinds of fire clay in Appalachia and is made into high-quality products.

The underclay used most commonly in Pennsylvania, Ohio, and part of West Virginia for both refractory and heavy clay products occurs below the following coal beds: Tionesta of the Pottsville Group; Brookville, Clarion, Lower Kittanning, and Middle Kittanning of the Allegheny Group; and Pittsburgh and unnamed coal beds of the Conemaugh Formation. Underclay beds associated with the Princess Group of coal beds in Kentucky and coals of Pottsville age in Tennessee are mined for use in several types of structural clay products. Underclay below the Mary Lee and Black Creek beds of Pottsville age in Alabama is used in both refractories and structural clay products. The Sciotoville flint clay in Ohio, Mercer flint clay in Pennsylvania, and the Olive Hill clay in Kentucky, all of Pottsville age, are used for making refractory products almost exclusively.

RESOURCE POTENTIAL

Resources of fire clay suitable for use in low- and moderate-heat-duty refractory and heavy clay products are very large, but high-quality clay for high-heat duty products is more limited. Resources of low- and moderate-heat-duty clay in the northern part of Appalachia amount to several billion tons, according to estimates by the U.S. Bureau of Mines. In addition, large resources of this type of clay occur in Alabama. Resources of fire clay suitable for use in making high-heat-duty refractories occur chiefly in the Olive Hill district, Kentucky, and the Clearfield and Somerset districts, Pennsylvania. Although information is not available on which to base accurate estimates of the resources of this type of clay in Appalachia, total resources are known to be much smaller than those of the low- and moderate-heat-duty type. The few estimates of the high-heat–duty-type clay that have been made are given in the discussions of districts.

The future demands for fire clay are difficult to predict because many economic factors are involved, and both the heavy clay products and refractories industries consume fire clay. In 1964 the heavy clay-products industry used 46 percent and the refractories industry used 49 percent of the fire clay mined in the United States (Cooper, 1965a, p. 366). The future potential of fire clay used in making heavy clay products is about the same as that of miscellaneous clay, because both types are used by the manufacturers in the same manner. The demand for some grades of fire clay probably will decrease and for other grades likely will increase. Clay having low- or moderate-heat-duty refractory properties will continue to be used by the metallurgical industries for pouring pit linings, ladles, and uses other than for furnace linings, and demands for this type of product should increase as the production of metals expands. This type of clay is also used for such products as the fire brick for fireplaces and heating furnaces, and demands for these products should increase as the Nation's population and economy grow.

DISTRICTS

Clay mining and processing plants in Appalachia are concentrated in arbitrarily defined districts (fig. 59). Districts producing only clay for refractories are Clearfield, Pennsylvania; Oak Hill, Ohio; Olive Hill, Kentucky; and Somerset, Pennsylvania. Districts producing both refractory and heavy clay products are Allegheny Valley and Beaver Valley, Pennsylvania; Cordova, Alabama; East Liverpool, Ohio and West Virginia; and Tuscarawas Valley, Ohio. The Hocking Valley district, Ohio, produces only heavy clay products. All are presently active in mining and processing clay; inactive areas and districts are not described in this report. Scattered plants and mines not located within the above districts are listed in table. 54.

Clearfield district, Pennsylvania

The Clearfield district, probably the most important producer of refractory clay products in the Appalachia region, is in parts of Clearfield, Clinton, and Centre Counties; small deposits not shown on figure 59 occur in Cameron County (Bolger and Weitz, 1952, p. 81; Pennsylvania Geol. Survey, 1964). The two most important clay beds mined within the district are the Mercer flint clay in the Pottsville Group and the Lower Kittanning clay of the Allegheny Group.

The Mercer clay, containing large resources of flint and nodular clay, ranges in thickness from 3 to 12 feet, averaging about 5 feet (Leighton, 1941, p. 81–102). According to Conley and others (1947, p. 11), the Curwensville and Morgan Run areas contain about 70 million tons of Mercer flint clay. Although much of this clay has been mined since these estimates were made, other large deposits have been proved in the nearby Anderson Creek basin. The reserves of flint clay for use in the refractory industry are probably adequate to sustain the present rate of mining for several decades.

The Lower Kittanning plastic underclay is used extensively to make low- to intermediate-grade refractory products. It is blended with Mercer flint clay to improve its workability, particularly to achieve the required plasticity and bond strength; the ratio of plastic clay to flint clay determines the refractoriness of the fired product. Leighton (1941, p. 81–102) indicated that the clay bed ranges in thickness from 3 to 18 feet and averages about 6 feet. The reserves of Lower Kittanning in the Clearfield district are probably adequate for the refractories industry, despite the fact that the dam on the west branch of the Susquehanna River will flood part of the area containing minable Lower Kittanning clay.

Individuals and companies mining clay in the Clearfield district are A. P. Green Fire Brick Co., Artie K. Baughman, Augenbaugh Coal Co., Inc., Bartell Excavating, Inc., General Refractories Co., Geynet Lansbury Coal Co., Reese Brothers Coal Co., and Thomas Bros. The companies producing refractory clay products are Clearfield Clay Products Co., Harbison-Walker Refractories Co. (3 plants), Hiram Swank's Sons, Inc., North American Refractories Co., Osceola Fire Brick Co., and Williamsgrove Clay Products Co. The Gem Clay Products Co. at Windburne is a small producer of face brick using Lower Kittanning underclay.

Oak Hill district, Ohio

The Oak Hill district, an important producer of low- to intermediate-grade refractory clay products, is in parts of Lawrence, Scioto, and Jackson Counties, southern Ohio, and is just north of the Olive Hill district, Kentucky. Two underclay beds of Pennsylvania age are mined and processed within the district—the Sciotoville in the Pottsville Formation and the Lower Kittanning of the Allegheny Formation.

The Sciotoville flint clay occurs in small, irregularly shaped isolated pockets in eastern Scioto and Jackson Counties. It is believed to be equivalent in age and similar in origin to the Olive Hill flint clay. Many deposits have been mined out, so the remaining reserves of flint clay in southern Ohio are considered to be small. Only two underground mines—operated by Pyro Clay Products at Gephart and W. and J. Belcher at Scioto Furnace—are currently producing Sciotoville flint clay. As a result, many of the refractories plants in Ohio are using flint clay from the Olive Hill district, Kentucky.

The Lower Kittanning semiflint and plastic clay is the most important economic clay bed in the district. According to Stout (1916, p. 228), the clay bed averages 5–6 feet in thickness, and covers an area of about 200 square miles. The clay is used chiefly in making ladle brick, hot tops, and mortar mixes. The following individuals and companies are mining the Lower Kittanning clay bed: Cecil W. Chaney, Harbison-Walker Refractories Co., F. H. House and Sons, W. E. Engle Stone, and Waterloo Coal Co. The following companies are producing refractory clay products using varying proportions of Sciotoville flint clay, Olive Hill flint clay, and Lower Kittanning semiflint and plastic clay: A. P. Green Fire Brick Co., Cedar Heights Clay Co. (2 plants), Davis Fire Brick Co. (5 plants), International Minerals and Chemicals Corp. (2 plants), and North American Refractories Co.

Olive Hill district, Kentucky

The area referred to as the Olive Hill district extends over parts of Greenup, Carter, Rowan, and Elliott Counties; clay also occurs in Lewis, Magoffin, and Morgan Counties (Hosterman, 1963). The fire clay in this district is in the Olive Hill bed (Crider, 1913, p. 594–595) in the lower part of the Lee Formation of Pottsville age. The bed is locally more than 20 feet thick but is only 3–5 feet thick at most places where mined. It consists chiefly of flint clay and semiflint clay, but small quantities of plastic clay are also present. Large resources of clay are present in the district. The total clay of all grades in two 7½-minute quadrangles alone is estimated to be as much as 275 million tons (Patterson and Hosterman, 1962, p. 78), and the total in the entire district is several times this figure. Much of this clay cannot be mined profitably now, either because it is too high in iron oxide and silica to be used in high-quality refractories or because it is under thick overburden and too costly to mine.

In 1965, fire brick was made in the district in plants operated by General Refractories Co. at Olive Hill and Hitchins and by Louisville Fire Brick Co. at Grahn. In addition to the companies operating plants, fire clay was mined by Harbison-Walker Refractories Co., Davis Fire Brick Co., Harry Hatfield and Co., and M. N. McCoy and Sons Clay Co. Several of these companies ship fire clay to the Portsmouth and Oak Hill areas, Ohio. Mullite refractories were produced by the Chas. Taylor Sons Co., subsidiary of National Lead Co., at a plant at South Shore, Ky., from kyanite and bauxite from outside Appalachia.

Somerset district, Pennsylvania

The Somerset district is an important producer of raw clay used to make refractory products. The boundary of the district has been arbitrarily drawn (fig. 59) to include the clay deposits that occur in south Somerset County and eastern Fayette County. This district is north of the Mount Savage clay district in Garrett and Allegany Counties, Md. (Waagé, 1950, p. 5), now virtually depleted of accessible good clay. Harbison-Walker Refractories Co. and Kaiser Refractories Division, Kaiser Aluminum and Chemicals Corp., are both strip mining flint clay (Clarion clay according to operators) near Ohiopyle, Fayette County, and shipping the raw material about 25 miles to their plants in Maryland. General Refractories Co. is strip mining clay that is correlated with the Clarion clay (Flint, 1965, p. 179–196) near Fort Hill and Rockwood, Somerset County, and shipping the raw material to Salina, Westmoreland County, a distance of about 70 miles. Clarion flint clay was formerly mined at present (1966) and that reserves are adequate of Berlin and near Meyersdale. Both Waagé (1950, p. 26) and Flint (1965, p. 182) correlate the Clarion clay of Pennsylvania with the Mount Savage clay of western Maryland. The Eureka Fire Brick Works at Mount Braddock is using the Mahoning underclay of the Conemaugh Formation (Hickok and Moyer, 1940, p. 449) to make low-grade refractory clay products.

Poor outcrops of the underclay beds in the Somerset district and problems in identifying and correlating the many underclay beds make an appraisal of the reserves and resources very difficult. However, it is very probable there are many commercial bodies of both plastic and flint clay in addition to those being mined at present (1966) and that reserves are adequate for several decades of mining at the present rate.

Allegheny Valley district, Pennsylvania

The Allegheny Valley district extends along the Allegheny River and its tributaries in parts of Allegheny, Armstrong, Clarion, Jefferson, and Westmoreland Counties. Both refractory and heavy clay products are produced in the district. Small tonnages of Mercer flint clay of the Pottsville Group are mined, but Lower Kittanning plastic clay is the principal local raw material used in making low- and high-heat-duty refractory products. The Lower Kittanning and Clarion underclays of the Allegheny Group and shale beds from both the Allegheny Group and Conemaugh Formation are used in making face brick, sewer pipe, and flue tile. The Mercer bed crops out only along Red Bank Creek where it consists of plastic clay about 2 feet thick overlain by flint clay 8–10 feet thick (Leighton, 1941, p. 68). The Lower Kittanning plastic clay, ranging in thickness from 3 to 10 feet, is mined underground along the Allegheny River valley.

Companies operating refractories plants in the district are A. P. Green Fire Brick Co. at Climax, H. K. Porter Co. at Saint Charles, General Refractories Co. at Salina, Harbison-Walker Refractories Co. at Templeton, Haws Refractories Co. at West Mosgrove, Howe Sound Refractories Division, Howe Sound Co. at Kittanning, Freeport Brick Co. at Freeport, and Kittanning Brick Co. at Reesdale. Only one company mines local Mercer flint clay; four companies use clay shipped from the Clearfield district; one company ships clay from the Somerset district. Four companies use Lower Kittanning clay as a blend with flint clay, and four companies are using chiefly Lower Kittanning underclay. The Allegheny Brick Co. and Continental Clay Products Co. use Lower Kittanning clay in making face brick.

Shale beds from the Allegheny Group and Conemaugh Formation are strip mined and processed into heavy clay products by Glassmere Brick and Tile Co., Milliken Brick Co. (2 plants), Graff-Kittanning Clay Products Division of Logan Clay Products Co., Monroeville Brick Co., and New Bethlehem Tile Co. The Hanley Co. at Summerville makes glazed face brick from Clarion underclay mined underground.

Nearly all flint clay in the Mercer bed in the Allegheny Valley district, except that requiring costly underground mining, is virtually exhausted. Companies, therefore, find it more profitable to ship raw clay from the Clearfield and Somerset districts than to mine local flint clay. The potential resources of the Mercer clay in the district, at depths of several hundred feet, are probably large but will have little value until reserves in other districts are depleted. Reserves of Lower Kittanning plastic underclay, though considerably larger than those of the Mercer clay bed, are also limited, and most clay in this bed has to be mined underground. Large resources of underclay occur in several beds other than the Mercer and Lower Kittanning, but presumably the clay is of too low quality to be used by the refractories industry. Reserves of shale and underclay of the type now used in heavy clay products are virtually inexhaustible.

Beaver Valley district, Pennsylvania

The Beaver Valley district, in parts of Beaver and Lawrence Counties, Pa., produces both refractory and heavy clay products. The only clay bed mined and used in the district is the Lower Kittanning. The underclay contains good plastic clay 4–6 feet thick that grades downward into more sandy plastic clay about 5 feet thick (Leighton, 1941, p. 77). Many companies are strip mining underclay along with the overlying coal and are selling the clay to consumers as much as 50 miles away. These companies are Davis Coal Co., Interstate Fire Clay Co., Negley Fire Clay Co., Ralph A. Voen, Inc., American Fire Clay and Products Co., and McQuiston Coal Co. The New Castle Refractories Co. is the only company producing refractory products. The following companies are producing face brick: Colonial Clay Products Co., Darlington Brick Co. (Division of General Dynamics Corp), Eastvale Clay Products Co., Fenati Brick Co., Metropolitan Brick, Inc., and Standard Clay Manufacturing Co.

Cordova district, Alabama

The Cordova district is one of the most productive refractory and miscellaneous clay areas in the eastern United States. It is located in the central part of the Warrior coal basin in Walker and Jefferson Counties, Ala. Most of the clay mined is plastic underclay below the Mary Lee coal of Pottsville age (O. M. Clarke, oral commun., Oct. 13, 1965), and commonly both coal and clay are extracted from the same mine. The few samples of Mary Lee underclay that have been analyzed (Metzger, 1964, p. 6) consist chiefly, in order of abundance, of illite, kaolinite, vermiculite, and mixed-layer clay minerals. Two samples of this clay for which test data are available (McVay and Toulmin, 1945, p. 142–144) show it to be suitable for low- to intermediate-heat-duty refractories. Although the Mary Lee clay is unsuitable for high-heat-duty fire brick, large tonnages are shipped to the Birmingham area for use in moderate- and low-heat duty refractories, and as a binder for refractories made of calcined bauxite and kaolin mined outside of Appalachia. Clay having moderate-heat-duty properties is adequate for several types of refractory products, and some plants make high-heat-duty products by mixing Cordova clay with better grades of clay shipped from outside Appalachia. The Mary Lee underclay is also used extensively in making buff- and cream-colored face brick, because it is sufficiently low in iron content to fire to light shades at the temperatures used in making this type of brick. Clay from the Cordova district is shipped to several plants in Alabama, South Carolina, and North Carolina for making face brick.

Companies that have mined clay in the Cordova district in recent years include the following: Aaron Clay Co., A. P. Green Fire Brick Co., Baird Coal & Clay Co., Banks Coal Co., Cane Creek Clay Co., Contract Mining Co., Harbison-Walker Refractories Co., Harris Clay & Coal Co., Natco Corp., Riceton Coal & Clay Co., Russell Coal & Clay Co., Taft Coal & Clay Co., T. & S. Coal Co., and Bibby Coal, Shale, & Clay Co. Clay resources in the Cordova district have not been estimated, but the clay remaining is presumably adequate to sustain the present rate of production for several decades.

East Liverpool district, Ohio and West Virginia

The East Liverpool district is in parts of Hancock County, W. Va., and Jefferson County, Ohio, and extends northward into Columbiana County, Ohio, outside the Appalachian Region. The district produces both refractory and heavy clay products. Two underclay beds—the Tionesta and Lower Kittanning—are mined underground along both banks of the Ohio River. In Hancock County, the Lower Kittanning clay ranges in thickness from 7 to 20 feet and averages about 16 feet (Cross and Schemel, 1956, p. 49). In Jefferson County, the Lower Kittanning clay ranges in thickness from 5 to 14 feet and averages about 9 feet (Lamborn, 1930, p. 43). The Clarion clay is used by H. K. Porter Co. at Irondale to make low-heat duty refractories. The Lower Kittanning underclay is mined and processed into low- and intermediate-heat duty refractory products by Fredrick J. Dando Co. and Globe Brick Co. The clay is also mined and made into sewer pipe and flue tile by the Kaul Clay Co. The Peerless Clay Corp. and Union Clay Manufacturing Co. produce sewer pipe and flue tile from Lower Kittanning clay hauled from the Beaver Valley district, Pennsylvania.

Tuscarawas Valley district, Ohio

The Tuscarawas Valley district is the largest district in Appalachia producing both refractory and heavy clay products, and it is referred to as the "sewer pipe capital of the world." The district includes parts of Tuscarawas, Carroll, and Harrison Counties (fig. 59), and it extends northward into Stark County outside the Appalachian region. The two most important clay beds are the Brookville of the Pottsville Formation and Lower Kittanning of the Allegheny Formation.

The Brookville underclay, used chiefly for making heavy clay products, ranges in thickness from 1 to 12 feet but averages about 4 feet (Lamborn, 1956, p. 54). No figures are available on reserves of the Brookville clay; however, it occurs extensively throughout the district and to the north in Stark County.

The Lower Kittanning, used primarily for making clay pipe and refractories, ranges in thickness from 2 to 20 feet, the average thickness being about 9 feet. It consists of a bed of irregular lenses of semiflint clay embedded in plastic clay. Although the Lower Kittanning underclay has been mined for many decades, the reserves in the district and in Stark County are large enough to last for many more decades at the present rate of consumption.

The following companies are mining clay in the Tuscarawas Valley district: Arthur S. Henry Coal Co., Davis Mining Co., Eberhart Coal, Inc., F. H. Minerals, Inc., Fox Valley Mining Co., James and James Coal & Clay Co., and D. M. Coal Co. The following companies are producing building and face brick: Metropolitan Brick, Inc., Natco Corp., Whitacre-Greer Fireproofing Co., Bowerston Shale Co., Belden Brick Co. (2 plants), Claycraft Co., Evans Brick Co., Goshen Brick & Clay Corp., Shepfer & Moomaw Brothers, Inc., and Stone Creek Brick Co. The following companies are producing sewer pipe and flue tile: American Vitrified Products Co., Malvern Flue Lining, Inc., Larson Clay Pipe Co., Ross Clay Products Co., Superior Clay Corp., and U.S. Concrete Pipe Co. The following companies are producing low- to intermediate-grade refractories: Columbia Fire Brick Co., Corundite Refractories, Inc., Evans Pipe Co., H. K. Porter Refractories Co., North American Refractories Co., and Robinson Clay Products Co. The Federal Ceramics Corp. is making stoneware from Brookville underclay.

Hocking Valley district, Ohio

Large amounts of miscellaneous clay products and pottery are produced in the Hocking Valley district occupying parts of Hocking, Perry, and Muskingum Counties. The pottery industry does not use local clay but at least six shale beds and five underclay beds are mined and used by 14 companies producing face brick, stoneware, clay pipe, and tile. The shale beds are Quakertown, Massillon, Tionesta, Brookville, Clarion, and Middle Kittanning. They are 8–42 feet thick (Flint, 1951) and average about 25 feet. The underclay beds are Massillon, Tionesta, Brookville, Lower Kittanning, and Middle Kittanning; they range from 6 inches to 12 feet in thickness and average 4–5 feet.

Clay is mined by the Nutter Brothers Coal Co., Ivan L. Hammer, E. K. Coal Co., and Tharp Coal Co. Face brick is made by the Belden Brick Co., General Hocking Brick Co., Natco Corp., Claycraft Co., and Straitsville Brick Co. Stoneware products are made by the Zanesville Stoneware Co., Maurice A. Night Sons Co., Nelson McCoy Pottery Co., and Robinson Ransbottom Pottery Co. Clay pipe is made by the Logan Clay Products Co., Junction City Clay Co., and Rush Creek Clay Co. The Mosaic Tile Co. makes wall tile, and the Ludowic-Celado Co. makes roofing tile.

CLAYEY TRIPOLI

Clayey tripoli, a granular silica material consisting of a natural mixture of tripoli and clay, is mined and processed for use chiefly as a gunning refractory. It is being produced in Alabama and also occurs in Georgia and Tennessee. The material mined in Alabama contains much more tripoli than clay, but producers call themselves clay companies, and the product is reported with fire clay by the Bureau of Mines. Tripoli also is used for abrasives and is described in the "Abrasives" section (p. 266).

Clayey tripoli is being produced by the Alabama Refractory Clay Co., Montevallo; Riverside Clay Co., Pell City; Donoho Clay Co., Anniston; and Dixie Clay Co., Jacksonville. A fifth company is reported to be constructing a plant at Talladega. Total annual production of clayey tripoli in Alabama is estimated to be approximately one-third of a million tons. Much of it sells for $9–10 per ton in bulk form and about $15 bagged, f.o.b. plant. Most of it is used as a gunning mix that is sprayed under pressure into linings of cupolas, furnaces, and steel and iron ladles. It is used in most, if not all, of the iron and steel centers in the United States and Canada, and some is shipped overseas. The product is prepared by drying, grinding, and screening; it ranges from pea size or a little coarser to −200 mesh.

Clayey tripoli in Alabama occurs as an earthy clayey plastic material filling sinkholes or other depressions in limestone or dolomite. Most is light gray or gray, but the upper parts of some deposits are colored dark gray by organic matter; dark-colored zones occur at depth locally. Lumps of thoroughly weathered chert, so soft that they can be crushed between one's fingers, are common, but nodules of weathered chert retaining most of their original hardness are abundant in some zones. The deposits mined near Montevallo lie on the Copper Ridge Dolomite of Late Cambrian age (Butts, 1940b, p. 18), and probably most other deposits now mined in Alabama are on this formation (O. M. Clarke, Jr., oral commun., Oct. 14, 1965). Similar deposits are likely to occur on other chert-rich carbonate rocks of the Knox Group.

Clayey tripoli deposits vary appreciably in purity, but according to producers most market-grade material ranges from 85 to 92 percent SiO_2; approximately half of the balance consists of Al_2O_3, and half of varying amounts of Fe_2O_3, MgO, CaO, TiO_2, and alkalies. Samples from the Jacksonville and Pell City areas were examined by the U.S. Geological Survey and found to contain 70–80 percent fine-grained thoroughly weathered or "rotten" chert; most of the remainder consists of the clay minerals kaolinite and montmorillonite.

No systematic geologic investigations of the clayey tripoli have been made, and little information exists on which to summarize the extent of the deposits. Nevertheless, large areas in northeastern Alabama, northwestern Georgia, and eastern Tennessee are favorable for the occurrence of such deposits.

Three of the plants now in operation in Alabama are supplied by deposits within a belt underlain by the Knox Group, extending from southwestern Talladega County, Ala., northeastward into Georgia. Deposits mined at Montevallo, Ala., are near the southern end of a narrow Knox Group outcrop belt that also extends into Georgia. Other linear areas underlain by the Knox Group lie northwest of this belt. Extension of these belts in Georgia and Tennessee cover large areas.

Many clayey tripoli deposits in Georgia are described by Butts and Gildersleeve (1948, p. 155), who stated, "The tripoli deposits have a wide distribution throughout northwest Georgia. Some of the better known occurrences are in the vicinities of Lyerly and Harrisburg, Chattooga County; Silver Creek, Floyd County; Spring Place, Murray County; and Dalton, Whitfield County." Other occurrences of clayey tripoli in that part of Appalachia lying in Georgia are listed by Veatch (1909, p. 279–281), who also notes that material of this type in Walker County was once used for fire brick. A summary of all known Georgia tripoli deposits and a history of their use, for purposes other than gunning refractory, is contained in a Georgia Department of Mines, Mining, and Geology Information Circular (Crickmay, 1937).

Deposits of tripoli similar to those mined in Alabama occur at several localities in Tennessee. Deposits southwest of Cleveland, Bradley County, Tenn., are 87.84 percent SiO_2 and 8.84 percent Al_2O_3 (Swingle, 1959, p. 77). Deposits near Evensville, Rhea County, Tenn., described by Swingle and Luther (1964b, p. 3–4) as clay are probably clayey tripoli, inasmuch as they contain weathered chert and are 89.19 percent SiO_2 and 5.87 percent Al_2O_3. Deposits at both localities occur in the Knox Group and some are in depressions in carbonate rock. The deposits near Cleveland were mined many years ago presumably for use other than as gunning mix, and those near Evensville have been mined intermittently on a small scale and used as refractory clay. Other deposits of clayey tripoli may occur in residual siliceous material of the Rome ("Watauga") Formation near Butler, Johnson County, Tenn. (Whitlatch, 1937, p. 6–8).

Most geologic guides used in prospecting for bauxite can also be applied to the search for tripoli. Some depressions favorable for accumulation of tripoli may show on topographic maps, and others might be located by stereographic study of aerial photographs. Because such depressions are likely to be poorly drained and swampy, they may contain soils appreciably different from those in surrounding well-drained areas; therefore, detailed soil maps may be exceedingly useful in prospecting.

The clayey tripoli industry in Alabama has expanded appreciably in the last few years in response to the growing use of gunned silica refractories in the iron and steel industries. The demand for the Alabama tripoli will probably continue to grow and perhaps the deposits in Tennessee and Georgia will also be mined. The industry now consists of vigorous independent companies capable of locating new deposits and supplying the increased demand for their product.

KAOLIN

COMPOSITION AND USE

Kaolin is a clay consisting chiefly of the clay mineral kaolinite or related minerals. The term "china clay" is used more or less synonymously with kaolin by the U.S. Bureau of Mines, particularly for raw material used for ceramic materials other than refractories. The structural formula of kaolinite is $(OH)_8Si_4Al_4O_{10}$ and its theoretical composition is 39.50 percent Al_2O_3, 46.54 percent SiO_2, and 13.96 percent H_2O. Most kaolin is white, or nearly so, and plastic when wet, but some is hard and flintlike. Some is red and brown, depending on the quantity and type of impurities that are mixed with it.

Two other minerals of the kaolin group, halloysite and its hydrated form endellite, are common in the clay deposits in Appalachia. Halloysite has the same composition as kaolinite, but endellite contains twice as much water. Endellite is more common than halloysite, but inasmuch as dehydration takes place at room temperature, most endellite converts to halloysite before identification is made, and probably most halloysite referred to in this section occurs in place as endellite. Because the kaolin group minerals differ in preparation required for specific uses, constituent minerals of given deposits must be accurately identified. The moisture in endellite causes excessive cracking in ceramic products, whereas it is a usable raw material after dehydration to halloysite. Most endellite has a porcelainlike appearance and parts with a conchoidal fracture; it commonly becomes chalky as it converts to halloysite.

According to U.S. Bureau of Mines records, kaolin was mined in Appalachia in 1963 and 1964 for use in fertilizers, firebrick, insecticides and fungicides, refractories other than firebrick, paper filler, and whiteware. Kaolin in this region is also used in making white portland cement. In recent years, kaolin has also been mined for use in making alum and has been blended with other types of clay to lighten the color of face brick. Kaolin is mined outside of Appalachia for many additional uses including paper coating, foundry sand bond, catalysts, porcelain enamels, roofing granules, bleaching and absorbent agents, filter aids, and chemicals; as fillers in rubber, ink, adhesives, medicines, foods, cosmetics, crayons, pencil leads, detergents, paste, sizing, linoleum, and textiles; and for other purposes. Paper coating is the largest single use for kaolin, constituting about one-third of its total consumption. Paper coating and filling kaolin together used more than half the domestic production in 1964.

PRODUCTION

Kaolin is reported to have been mined by Indians in western North Carolina and exported to England in the early part of the 17th century (Parker, 1946, p. 17), and 5 tons was mined near Franklin, N.C., and shipped to Josiah Wedgewood in England in 1767–68 (Griffiths, 1929). Organized kaolin mining began near Webster, Jackson County, N.C., in 1888, and kaolin has been mined intermittently in the western part of the State since that date (Broadhurst, 1955, p. 35–41). Within the limits of Appalachia, kaolin was mined in Alabama as early as 1898, halloysite was mined in Georgia in 1885, and mining of deposits in Pennsylvania now known to be chiefly kaolin was mentioned in several reports of the Second Pennsylvania Geological Survey, during the period 1874–77.

In 1964, 3.3 million short tons of kaolin valued at $64 million (1958 constant dollars) was produced in the United States. Georgia was the leading producing State, accounting for 78 percent of the total domestic production; South Carolina was second with 16 percent. Other States reporting production in 1964 were Alabama, California, Florida, Georgia, Idaho, North Carolina, Pennsylvania, Texas, Utah, and Vermont. The major kaolin districts of Georgia and South Carolina are outside Appalachia, and districts within Appalachia produce only a small part of the Nation's total kaolin. From 1945 through 1964 about 1.9 percent of the Nation's kaolin output came from Appalachia (table 58), and in 1964 the region produced 1.3 percent of the total kaolin output. The leading States in order of kaolin production in Appalachia during the period 1945–64 were North Carolina, Alabama, Pennsylvania, and Georgia. The districts in Appalachia in which kaolin was mined in 1964 are Chalk Bluff and Anniston in Alabama; northwest Georgia; and Spruce Pine in North Carolina. Kaolin was also produced in the Kunkletown and Stormstown areas of Pennsylvania, but this clay was classified as miscellaneous clay and fire clay in Bureau of Mines statistical records.

TABLE 58.—*Production of kaolin, 1945–1964*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value in 1958 constant dollars (thousands)	Short tons	Value in 1958 constant dollars (thousand)
1945	25,910	480	939,988	11,954
1946	35,635	676	1,322,303	17,648
1947	38,107	716	1,425,106	20,687
1948	42,786	724	1,568,848	22,892
1949	40,015	602	1,415,537	21,899
1950	43,105	728	1,750,858	27,272
1951	50,666	760	1,866,299	26,885
1952	40,054	634	1,829,102	26,421
1953	64,130	1,116	1,883,974	28,729
1954	37,861	505	1,873,000	30,160
1955	43,781	576	2,166,400	34,692
1956	45,861	700	2,249,920	36,357
1957	43,936	680	2,183,685	36,178
1958	34,761	507	2,222,185	36,421
1959	29,739	433	2,535,474	41,107
1960	34,621	443	2,730,451	45,271
1961	33,460	443	2,739,816	46,651
1962	30,818	436	2,998,157	53,120
1963	30,477	421	3,163,573	59,531
1964	41,729	467	3,331,342	64,282
Total	787,452	12,047	42,196,018	688,157

DEPOSITS

Kaolin deposits of several different types and origin occur in Appalachia (fig. 59; table 59). The most extensive are at or near the present land surface; they probably formed by weathering of residual material during the Tertiary and Quaternary Periods. Deposits of this type include: (1) fillings of sinkholes or other depressions in carbonate rock, (2) blanket or lenslike residual masses that occur on sedimentary rocks in Pennsylvania, and (3) residual deposits developed on granite and pegmatite. A second group of kaolin deposits is overlain by sedimentary rocks and is older than the weathered residual deposits. This group includes the bedded halloysite in Georgia, Tennessee, and Kentucky and kaolin deposits along the contact of the Tuscaloosa Group and Paleozoic rocks in Alabama. Much of the flint clay associated with coal beds is nearly pure kaolin; its use for refractories was described on page 175.

Kaolin in depressions or sinkholes in carbonate rocks occur as irregular pockets or lenses. Some deposits consist of nearly pure kaolin, but many contain appreciable quantities of iron oxide or quartz sand and some are rich in lignite or other organic matter. Many de-

TABLE 59.—*Kaolin in the Appalachian Region*

[Some deposits for which no estimates have been made are designated as small or moderate in size. Most deposits considered to be small contain only a few thousand or tens of thousand tons. Deposits of moderate size probably contain several hundred thousand or a few million tons]

No. (fig. 59)	District or deposit; county	Occurrence	Uses	Resources	Remarks
			Alabama		
1	Margerum; Colbert	Kaolin associated with bauxite occurs in small lenses or pockets in Upper Cretaceous rocks (Bergquist and Overstreet, 1965). Most deposits are at or near the present land surface.	Probably suitable for several products in which kaolin is used.	Resources are estimated to be approximately 100,000 long tons of kaolin and low-grade bauxite (Bergquist and Overstreet, 1965, p. 23).	No deposits mined (Clarke, 1964, p. 505).
2	Russellville; Franklin	Impure kaolinitic clay associated with brown iron ore deposits occurs in depressions on Mississippian limestone and below Cretaceous (Tuscaloosa) gravels (Clarke, 1964, p. 504).	Fire clay	Presumably small to moderate in size.	Now mined for fire clay.
3	Chalk Bluff; Marion	Nearly pure kaolin with minor quartz and other mineral impurities occurs in irregular beds or lenses having a maximum thickness of 27 ft (Clarke, 1964, p. 503). The deposits overlie weathered shale along the contact of Pennsylvanian rocks and the Tuscaloosa Group (Bramlette and McVay, 1940, p. 209).	Ceramic glazes and ware, carrier for insecticides, and for face and refractory brick (Clarke, 1964, p. 506). This kaolin is also used for filters and other products.	Presumably of moderate size.	Deposits now mined by Thomas Alabama Kaolin Co.
4	Fort Payne area; DeKalb.	Kaolin and lignitic clay occur at the Ladd mine (W. B. Jones, 1940, p. 32) and at the Stout mine (Cloud, 1966a). Deposits at Ladd mine are in residuum filling sinkholes in the Longview Limestone, and the Stout deposit is on the Chepultepec Dolomite. Similar clay also occurs near Valley Head, DeKalb County (Ries, 1900, p. 123–126, 147–150).	Mined for fire clay prior to 1915.	Presumably small	No recent mining reported.
--------	Rock Run and Goshen Valley area; Cherokee.	Many small kaolin deposits are associated with bauxite. Deposits occur with residuum in depressions on carbonate rock.	Suitable for use in refractory products (Ries, 1900, p. 137–147).	Kaolin resources, part of which are on old mine dumps, are estimated to be 752,000 long tons (Cloud, 1966b).	Do.
6	Weaver; Calhoun	Small kaolin deposit probably occurs in a depression on carbonate rock.	Light-colored face brick	Very small(?)	Mined in recent years by Frame Brick Co.
7	Anniston area; Calhoun	Small kaolin deposits, some of which are associated with bauxite and brown iron ore, occur in the city of Anniston and surrounding area (Cloud, 1966a). The kaolin is partly lignitic and is in irregularly shaped bodies in residuum on carbonate rock.	Small tonnages are used in porcelain insulators and other ceramic products.	Small	Mined intermittently on a small sclae for many years. This kaolin is reported as fire clay in U.S. Bureau of Mines statistics.
8	Dixie mines; Randolph	Weathered pegmatite. Tailings after removal of scrap mica are 20–35 percent kaolin (Clarke, 1963, p. 51–54).	Clay has potential use as filler in paint and plastics if beneficiated.	Small(?)	Scrap mica is recovered but clay is now discarded.
9	Reams property; Clay	Weathered granite sill containing 34 percent clay, chiefly kaolinite (Clarke, 1963, p. 44).	Clay is potentially suitable for ceramic whiteware and refractories if beneficiated.	do	No mining reported.
10	Allen property; Tallapoosa.	Weathered pegmatite, 85–90 percent kaolin (Clarke, 1963, p. 55–56).	Clay has several potential uses if beneficiated.	do	Do.
			Georgia		
1	Rising Fawn; Dade	Halloysite occurs in a bed 2–4 ft thick, presumably in the Armuchee Chert (Butts and Gildersleeve, 1948, p. 114).	Used as a filler in food (Veatch, 1909, p. 284).	Small(?)	Small tonnages were mined between 1889 and 1894.
2	Summerville; Chattooga	White and pink kaolin clays occur in association with small bauxite deposits in depression on carbonate rocks.	Probably suitable for use in refractories.	No reserve estimates have been made; however, kaolin occurs at several places and one auger hole penetrated kaolin 40 ft thick (Veatch, 1909, p. 282, 283).	Presumably no clay has been mined from these deposits.
3	Gore; Chattooga	Halloysite occurs in a bed 1–6 ft thick and having an average thickness of 28 in. This bed is in the Armuchee Chert.	Used for aluminum sulphate.	Reserves of all grades of halloysite are estimated at more than 1 million tons (Broadhurst and Teague, 1954, p. 61).	Production in about 1913 is estimated to have been 500–600 tons.
	Northwest Georgia; Floyd, Bartow, and Polk.	Many kaolin deposits occur in association with small bauxite bodies in fillings of sinkholes or other depressions on carbonate rocks of the Knox Group (W. S. White and Denson, 1952).	Used chiefly in aluminous chemicals. Small quantities are used in refractories.	No estimates of total resources have been made. Deposits are irregular in size and shape, and many are small.	Kaolin is shipped by American Cyanamid Co. after drying at Halls Station, Bartow County.
5	Jasper; Pickens	Kaolin occurs in thoroughly weathered pegmatite.		No estimates have been made, but kaolin is present in pegmatite at several localities (Veatch, 1909, p. 259–260).	No mining reported.
6	Turner mica mine; Paulding.	Kaolin occurs in weathered granite		No estimates have been made, but granite is decomposed at depth of 87 ft (Veatch, 1909, p. 258).	Do.

TABLE 59.—*Kaolin in the Appalachian Region*—Continued

No. (fig. 59)	District or deposit; county	Occurrence	Uses	Resources	Remarks
		North Carolina			
-------	Spruce Pine; Avery, Mitchell, and Yancey.	Both kaolin and halloysite occur as alteration products of weathered feldspar in alaskite masses. Many deposits are scattered throughout the district.	Kaolin is prepared by water washing and used chiefly in porcelain and pottery. Flake mica and quartz sand are byproducts of kaolin washing.	The crude kaolin in the Spruce Pine district was estimated to be 51 million tons (C. E. Hunter, 1940, p. 102) from which 3-7 million tons could be washed (Parker, 1946, p. 26).	Kaolin and halloysite have been produced in the Spruce Pine district since about 1904. Several companies operated mines and plants in the past, but the only one now active is the Harris Clay Co.
2	Arrowood mine; Buncombe.	White halloysite occurs in a weathered pegmatite. Exposed pegmatite is 390 ft long and 40-90 ft wide and is weathered to depths of 25-50 ft.	Washed kaolin that was produced was probably used chiefly for china clay.	Measured, indicated, and inferred halloysite is 17,500 tons (C. E. Hunter and Hash, 1949, p. 23).	Fifteen carloads of halloysite was produced in 1947 and 1948.
3	Alexander deposit; Buncombe.	White halloysite occurs in weathered pegmatite.	Suitable for use as china clay(?).	Measured, indicated, and inferred halloysite is 10,000 tons (Hunter, C. E., and Hash, 1949, p. 27).	No mining reported.
4	Woodrow area; Haywood.	Kaolin occurs in thoroughly weathered igneous dikes near Woodrow and in other nearby areas.	Washed kaolin that was produced was probably used chiefly for china clay.	Small(?)	Kaolin was produced during and after World War I (W. S. Bayley, 1925, p. 76-84).
5	Bryson City area; Swain.	Several deposits of kaolin in weathered dikes occur north and south of Bryson City.	do	do	Kaolin was produced from several deposits in the early 1900's (W. S. Bayley, 1925, p. 34-43).
6	Lttle Savannah Creek area; Jackson.	Halloysite occurs in several weathered pegmatites.	do	do	Kaolin was produced in the early 1900's (C. E. Hunter and Hash, 1949, p. 27).
7	Franklin area; Macon.	Kaolin occurs in several weathered granitic rock masses in the vicinity of Franklin.	do	do	Kaolin was produced from at least 2 deposits in early 1900's (W. S. Bayley, 1925, p. 43-61).
8	Hayesville area; Clay.	Halloysite and kaolin occur in weathered pegmatites (C. E. Hunter and Hash, 1949, p. 29).	do	do	Kaolin was produced probably in about the same period as in the Franklin area.
		Pennsylvania			
1	Kunkletown; Monroe.	Inpure residual kaolin derived from weathered Buttermilk Falls Limestone of Willard (1938) and New Scotland Formation.	Used in making white portland cement.	No resource estimates have been made; however, deposits have been mined for more than 60 years, and resources are probably adequate to sustain present production at present rate for several decades.	Deposits are now mined by the Universal Atlas Cement Co. The production is reported as miscellaneous clay in U.S. Bureau of Mines statistics.
2	Stormstown; Centre.	Impure residual kaolin occurring on the Gatesburg Formation (Leighton, 1941, p. 67). These deposits probably occur as sinkhole fillings.	Refractory clay products.	Deposits are small and irregular.	Deposits are now mined by Harbison-Walker Refractories Co. The production is reported as fire clay in U.S. Bureau of Mines statistics.
3	Oreminea; Blair.	Impure residual kaolin occurring on Gatesburg Formation (Leighton, 1941, p. 38).	do	do	Deposits are now mined for refractory clay.
		Tennessee			
1	Elizabethton; Carter.	Nine small lenticular bodies of kaolin occur in residuum in sinkholes and other depressions in the Shady Dolomite in an area north and northeast of Elizabethton (King and Ferguson, 1960, p. 91). Some deposits contained small masses of bauxite.	-------	-------	Presumably no kaolin has been produced from these deposits.
2	Del Rio; Cocke.	A deposit of kaolin 50 ft wide and 250 ft long occurs 3.5 miles southwest of Del Rio (Gildersleeve, 1946a, p. 16). The deposit is developed on weathered shale and slate near the base of the Sandsuck Formation (Ferguson and Jewell, 1951, p. 227).	-------	Small	A plant for processing this kaolin was built in Del Rio in the late 1950's but significant production was not attained.
3	Whiteoak Mountain; Bradley.	A small deposit of halloysite occurs in the Fort Payne Chert (Swingle, 1959, p. 75).	-------	do	Deposits were explored by bulldozer trenching in early 1950's, but no halloysite has been produced.
4	Chattanooga; Hamilton.	Many small kaolin deposits are revealed in prospect pits and in association with bauxite in five small inactive mines on Missionary Ridge and Summit Knobs (Dunlap and others, 1965). Kaolin occurs in sinkholes and other depressions on Copper Ridge Dolomite.	May have been mined for fire clay or other uses.	Many deposits are present, but most are small and some are on valuable lands close to Chattanooga.	No recent production, but presumably some kaolin was mined when bauxite was worked from 1907 to 1928.

posits of this type enclose masses of bauxite or bauxitic clay. Sinkhole-fill deposits occur in eastern Tennessee, northeastern Alabama, and northwestern Georgia. Kaolin is mined from sinkhole fills for use in aluminous chemicals in Floyd and Bartow Counties, northwest Georgia. Deposits in the Margerum district, Alabama, may be of the sinkhole-fill type, but are underlain by sandy beds (Bergquist and Overstreet, 1965, p. 6), and their origin is not definitely known.

Blanket or lenslike kaolin deposits of the residual type occur on the Gatesburg Formation of Cambrian age and the Buttermilk Falls Limestone of Willard (1938) and New Scotland Formation of Devonian age in Pennsylvania. They differ from the sinkhole-fill deposits in that they are more continuous and are derived from sandstone and shale as well as from carbonate rocks. Relict bedding and textures of parent rocks are retained in some deposits, but the fact that in others all evidence of parent material has been destroyed suggests that some reworking or transportation of kaolin may have taken place. Although much kaolin in this type of deposit is white, it commonly contains more impurities than the better grades in other types of deposits. It is used to make white portland cement and is mixed with other types of clay to make refractory products.

Deposits of residual kaolin derived from granite and pegmatite are scattered throughout the belt of crystalline rocks underlying the Blue Ridge and Piedmont provinces from western North Carolina to eastern Alabama. Kaolinite is the only clay mineral in some deposits, but mixtures of kaolinite and endellite occur in others. In all deposits the clay is intermixed with nonclay minerals, chiefly quartz and mica, and washing is necessary to recover the kaolin. Kaolinite occurs as an alteration product of feldspathic rock rich in mica (Sand, 1956, p. 37–39), and endellite is chiefly a product of feldspathic rock containing little mica. Endellite is commonly so intermixed with kaolinite that it cannot be separated profitably, but in some deposits it is sufficiently concentrated to make the production of an almost pure halloysite product possible. Endellite is much more abundant than kaolinite in the Spruce Pine district, North Carolina, but farther south kaolinite tends to be the most abundant clay mineral in weathered igneous rocks (Sand, 1956, p. 37).

Deposits of kaolin in the Chalk Bluff district and other localities in northwestern Alabama occur along the contact between the Tuscaloosa Group of Cretaceous age and the underlying beds of Paleozoic age (Clarke, 1964, p. 504). These deposits may represent a residuum that accumulated during the long erosional interval of late Paleozoic and most of Mesozoic time (Mellen, 1937, p. 29), or they may be the lowermost Tuscaloosa deposits.

Two deposits of bedded halloysite in northwestern Georgia were mined in the past (Butts and Gildersleeve, 1948, p. 112–115). One deposit is located 6 miles north of Gore, Chattooga County, and the other is near Rising Fawn, Dade County. The halloysite bed ranges from 1 to 6 feet thick, and averages 28 inches in thickness. The deposits are in the Armuchee Chert of Early and Middle Devonian age. An estimated 500–600 tons was mined about 1913 from the Gore deposits for making aluminum sulphate. The deposits near Rising Fawn were worked on a small scale between 1889 and 1894 and are reported to have been used as a filler or extender in food (Veatch, 1909, p. 284). Deposits remaining near Gore contain more than 1 million tons of all grades of halloysite (Broadhurst and Teague, 1954, p. 61). The size of the deposits near Rising Fawn has not been estimated. Other minor occurrences of halloysite in Georgia are listed by Veatch (1909, p. 259–260).

A small deposit of halloysite occurs near Lewis Gap on Whiteoak Mountain, Bradley County, Tenn. (Swingle, 1959, p. 75) in a pocketlike depression in the Fort Payne Chert. It was trenched by bulldozer in the early 1950's (R. A. Laurence, written communi., Jan. 12, 1966), but according to Swingle (1959, p. 75), the size of the deposit still was not determined. None of this clay has been mined.

Small lenses of porcelaneous halloysite occur beneath the New Albany Shale of Devonian and Mississippian age near Halls Gap, Lincoln County, Kentucky (Crawford and McGrain, 1964). The deposits are probably very small and therefore are not listed in table 59 or located on figure 59.

RESOURCE POTENTIAL

Production and resources of high-grade kaolin in Appalachia are small as compared to other regions in the United States. The total kaolin associated with bauxite in Appalachia is estimated to be approximately 1 million tons (Overstreet, 1964, p. 17). The potentially recoverable kaolin, composed of both kaolinite and halloysite, in 51 million tons of weathered rock in the Spruce Pine district, North Carolina, was calculated to be 3–7 million tons (J. M. Parker, 1946, p. 26). Other deposits are relatively small. In comparison to annual U.S. production of kaolin, now more than 3 million tons, resources of Appalachia are small. Nevertheless, reserves in districts now producing kaolin on comparatively small scales are probably adequate to sustain the present rate of production for several decades.

The possibilities for the use of low-grade and impure kaolin are somewhat brighter than for high-grade kaolin. Although resources in blanket-type deposits in Pennsylvania have not been accurately estimated, some deposits are known to extend over several square miles and a few are more than 100 feet thick (Leighton, 1941, p. 66). Supplies for the present consumers of this type of kaolin are adequate for many years. Low-grade kaolin is also a potential source of a better grade of kaolin which might be recovered by washing. In addition to the deposits in Pennsylvania, sandy and cherty kaolin having little present value occurs at several places in southern Appalachia.

Though the halloysite deposits in Appalachia are not large, they probably will be exploited at an increasingly greater rate in the future, because minable deposits occur only at a very few places outside the region. Halloysite will probably continue to be in demand for use as china clay in the manufacture of certain ceramic products. Halloysite increases translucency in ceramic ware (H. P. Hamlin, written commun., May 1963), and it is this property that enhances its value. Resources of halloysite in the Spruce Pine district, North Carolina, are probably adequate for several years' production at the present rate. Other deposits occur in weathered igneous rocks in other districts in western North Carolina (Hunter and Hash, 1949), and these areas are favorable for the discovery of new deposits. The bedded halloysite deposits in Georgia have not been tested and evaluated for all of the uses for which halloysite is now produced; they may contain larger resources than are known now.

POTTERY AND STONEWARE CLAY

Indians first mined and used clay for pottery in Appalachia long before the discovery of America, and undoubtedly several potteries were in operation before the 19th century. At the present time, there are many small and a few large potteries scattered throughout Appalachia (fig. 59). Most small potteries are operated by the owner alone or with one or two employees. The largest is the Scio Pottery Co. at Scio, Harrison County, Ohio, which employs as many as 1,500 people. The Shenango Refractories Co., Lawrence County, Pa., has nearly 1,000 employees; the Iron Mountain Stoneware, Inc., at Laurel Bloomery, Tenn., employs 45 people, and several people work at the Pigeon Forge Pottery, Pigeon Forge, Tenn. The products made by the Appalachia pottery industry include tableware, stoneware, chemical and gasoline filters, chemical stoneware, flower pots and art ceramic objects primarily for tourist trade.

Zanesville, Muskingum County, and Roseville, Perry County, Ohio, are the major centers of the pottery industry of Appalachia; potteries were first established here more than a century ago. Currently, more than 20 plants make tableware and stoneware in these two areas but the demand for better quality pottery, the competition from plastics, and the decreasing use of stoneware have forced most companies to use ball clay and kaolin imported from outside of Appalachia; local clay is consequently now mined at a reduced rate. Only five plants in these two areas are now producing stoneware products from Ohio clay. The local clay deposits in the Hocking Valley clay district (fig. 59) are the Tionesta underclay in the Pottsville Formation and the Brookville and Lower Kittanning underclays of the Allegheny Formation. All this clay is supplied by the I. L. Hammer estate, and each plant uses 200–500 tons annually. The principal products are stoneware filters used in the gasoline and chemical industries.

Only a small quantity of the kaolin used in the better grades of pottery and stoneware is mined in the southern part of Appalachia, and most kaolin and ball clay is imported from the western parts of Kentucky and Tennessee and from the Coastal Plain region of Georgia and South Carolina. The pottery at Laurel Bloomery, Tenn., which makes tableware, uses kaolin from the Spruce Pine district, North Carolina. It also uses a very small amount of kaolin from residual deposits on the Shady Dolomite from abandoned manganese mines near the plant (R. A. Laurence, written commun., Oct. 12, 1965). Possibly other potteries in Appalachia use minor quantities of kaolin from Spruce Pine, N.C.

Most of the small scattered potteries making artware for the tourist trade use low- or moderate-grade clay and such clay is also used by the largest flower pot manufacturer in Appalachia. Residual and alluvial clays are the principal raw material used by the small potteries; they contain appreciable quantities of silt and sand and so much iron oxide that they fire red. Silty clay mined from alluvial deposits is also used by the Friedi-Elverson Pottery Co., New Brighton, Beaver County, Pa., in making clay pots of many sizes and shapes.

The pottery industry in Appalachia is not as dependent on local sources of clay as are the other clay industries of the region. Resources of clay in Appalachia suitable for the better grades of pottery are limited, and most clay used for this type of product will probably continue to be imported. Clay suitable for making the lower grades of pottery and stoneware occurs at many places, and whether or not it can be used depends more on the availability of markets rather than raw material. Probably the future demand for pottery for the tourist trade will increase steadily and many of the small potteries will find additional markets. Nevertheless, part of the pottery industry has suffered severely recently from competition from plastics, wood, metal, and glass industries, and this competition probably will continue and tend to retard production of some products.

POTASSIUM-BENTONITE

Potassium-bentonite, a potassium-bearing clay also referred to as metabentonite, occurs in many places in Appalachia. Potassium-bentonite beds of Ordovician age crop out in many places in Tennessee and adjacent States (Fox and Grant, 1944) and several places in Pennsylvania (Weaver, 1953, p. 922). Beds of Devonian age (Weaver, 1956, p. 359) occur at several places in New York, Pennsylvania, Maryland, West Virginia, and Virginia, and potassium-bentonite has been recognized in all other Paleozoic Systems except the Cambrian (Lounsbury and Melhorn, 1964, p. 557).

Most potassium-bentonite occurs in beds that are only a few inches thick but in places are 2–3 feet thick; and at a few localities where thickened by deformation they are as much as 20 feet thick (Butts and Gildersleeve, 1948, p. 90). Most beds are tan, gray, or yellowish gray, and appreciably softer than associated rock.

All bentonite, by definition, is composed of clay that formed from the alteration of glassy igneous materials in volcanic ash or tuff. Potassium-bentonite, although related in origin to the Wyoming or sodium-type and southern or calcium-type bentonites, differs appreciably in mineral content and physical properties. Wyoming and southern bentonites consist chiefly of montmorillonite, whereas most potassium-bentonite is chiefly illite or other micalike clay minerals and contains only minor quantities of montmorillonite (Weaver, 1953). Because of its composition, potassium-bentonite does not swell appreciably in water and does not tend to dissaggregate into extremely fine particles. These properties are valuable in other types of bentonite.

The only potassium-bentonite mined in Appalachia was the 5–6 carloads shipped for refining lard by the Dixie Mineral Products, Inc., about 1928 (Gildersleeve, 1946a). It occurs as a bed, as much as 3 feet thick, in limestone of Ordovician age near Dayton, Rhea County, Tenn.

Presumably, the deposits of potassium-bentonite more favorably situated for mining include those near Dayton, Rhea County, Tenn. (Gildersleeve, 1946a), and at the following localities in Georgia (Butts and Gildersleeve, 1948, p. 90–91): (1) south of Trenton, Dade County; (2) south of Chickamauga, Catoosa County, and (3) south of Rossville, Walker County. Though the only attempt to use potassium-bentonite in Appalachia was unsuccessful, some use may still be found for this clay. Preliminary tests show that it might have some value for use as foundry sand bond (F. A. W. Davis, 1936). Some potassium-bentonite bloats at high temperatures into an extremely lightweight material that might be used as an insulating material or low-strength lightweight aggregate.

CRUSHED STONE

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THE NATIONAL INDUSTRY

Crushed stone is the term applied to rock that has been crushed or ground to standard sizes after quarrying. Included in this classification are large, irregular stone blocks, known as riprap, used chiefly for protection against the wave and current action of water. For statistical purposes, commercial crushed stone produced in Appalachia is classified into the following groups: limestone, granite, marble, sandstone, and miscellaneous stone.

The largest use of crushed stone is for concrete aggregate and roadstone. In 1964, 63 percent of the national production was used for this purpose. Crushed limestone for cement manufacture ranked second composing 14 percent of total output. Considerable quantities of stone are also used for riprap, railroad ballast, roofing granules, and filtration beds. Additional uses of limestone, the most important of the crushed stones, are: fluxstone, agricultural limestone (agstone), lime manufacture, asphalt and fertilizer fillers, alkali manufacture, glass manufacture, stone sand, whiting, sugar refining, and refractory (dolomite) uses. Table 60 shows quantity and value (1958 constant dollars) of crushed stone sold or used by producers in Appalachia, in 1963 and 1964.

In areas where they are readily available, sand and gravel and blast furnace slag can be substituted for crushed stone for most construction purposes. Since the end of World War II, blast furnace slag has largely replaced limestone in the manufacture of mineral wool. Slag is also substituted for limestone in the manufacture of cement. Lightweight aggregate can be used instead of stone in some concrete, where the higher costs can be justified.

The growth of the crushed stone industry in the United States resulted chiefly from the increased use of concrete in construction and from the expansion of road and highway systems. From the turn of the century until World War I, production increased

TABLE 60.—*Crushed and broken stone sold or used by producers in the Appalachian Region, by uses*

[Source: U.S. Bur. Mines]

Use	1963		1964	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
Agriculture	3,689	6,015	3,516	6,255
Cement	10,657	14,001	11,368	13,224
Concrete and roadstone	57,751	80,622	60,695	86,199
Flux	4,130	7,548	4,904	8,019
Lime	3,497	6,007	4,323	8,359
Railroad ballast	1,204	1,496	1,465	1,761
Refractory	339	1,930	358	2,349
Riprap	598	879	275	423
Roofing gravel, aggregates, chips, and terrazzo	269	2,653	324	3,284
Other uses	6,512	17,754	4,478	18,387
Total	88,646	138,905	91,706	148,260

slowly. Highway and building construction grew rapidly in the prosperous era before 1929. Demand declined in the depression years but was sustained to some extent by Federal projects (Bowles and Jensen, 1943, p. 6, 7). Just before and during the early years of World War II, the demand for cement and for other crushed stone products increased greatly for the construction of airfields, manufacturing plants, military establishments, and shipyards. In the past two decades, accelerated highway and general construction activity resulted in remarkable additional growth in the crushed stone industry.

Annual domestic production of crushed stone increased 360 percent from 1945 to 1964 and Appalachian output expanded 280 percent. For the 20-year period, Appalachia produced 1,059 million tons (table 61), or about 13 percent of the U.S. production. In 1964, Alabama, Pennsylvania, and Tennessee contributed slightly more than one-half the total Appalachian output and Georgia, Virginia, and West Virginia produced about one-fourth of the output.

THE INDUSTRY IN APPALACHIA

LIMESTONE

Limestone (here used to include dolomite) is by far the most important type of crushed stone. It was one of the earliest materials utilized by the pioneer settlers, being used for building stone and burned for lime more than 200 years ago. In the last two decades, 86 percent of total Appalachian crushed stone output was limestone. Table 62 shows the annual production of crushed limestone in Appalachia and the United States for the period 1945–64. In 1964, the record year, Appalachia produced 15 percent of the national total.

Limestone was produced in all Appalachia States in 1964. The three major States producing about 60 percent of the output were Tennessee, 17.2 million tons; Alabama, 14.3 million tons; and Pennsylvania, 13.5 million tons. Combined production of Virginia, West Virginia, Kentucky, and Ohio constituted 33 percent of total output.

TABLE 61.—*Production of crushed stone, 1945–64*

[Includes: granite; basalt (traprock); limestone and dolomite; marble; sandstone, quartz, and quartzite; slate: calcareous marl; and miscellaneous stone. United States totals excludes limestone used for cement and lime for 1945–53; excludes shell.]

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (millions)	Value, in 1958 constant dollars (millions)	Short tons (millions)	Value, in 1958 constant dollars (millions)
1945	24	37	153	218
1946	24	38	178	269
1947	29	47	207	308
1948	35	58	225	333
1949	32	57	223	340
1950	36	65	250	339
1951	37	67	284	383
1952	36	62	300	415
1953	41	74	305	455
1954	50	87	398	539
1955	54	91	453	616
1956	60	101	485	667
1957	62	102	512	714
1958	61	102	514	714
1959	65	108	562	779
1960	72	118	596	826
1961	77	123	592	825
1962	83	135	634	897
1963	89	139	667	939
1964	92	148	704	1,002
Total	1,059	1,759	8,242	11,578

TABLE 62.—*Production of limestone and dolomite (crushed and broken stone), 1945–64*

United States totals excludes limestone used for cement and lime for 1945-53. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	21,864	31,708	112,240	156,698
1946	21,553	31,974	134,213	195,016
1947	26,026	38,774	149,866	216,842
1948	31,497	49,479	166,135	237,381
1949	28,887	47,079	163,066	241,759
1950	32,116	52,720	180,111	267,609
1951	33,131	52,101	204,673	285,940
1952	31,981	49,075	216,319	293,184
1953	36,068	60,269	224,327	302,476
1954	42,754	67,038	315,325	403.768
1955	48,579	75,907	360,341	464,402
1956	53,709	81,187	379,972	495,991
1957	55,110	81,318	382,069	520,226
1958	53,035	78,006	390,468	516,765
1959	54,775	79,175	433,003	571,803
1960	60,269	87,771	450,393	600,901
1961	64,721	94,074	437,398	587,853
1962	69,449	102,284	460,953	628,370
1963	71,114	103,943	488,348	659,278
1964	75,833	110,022	510,247	691,257
Total	912,471	1,373,904	6,159,467	8,337,519

In 1964, 63 percent of Appalachian limestone production was used for concrete aggregate and roadstone. Use for manufacture of cement, about 15 percent, ranked second. Most of the remainder went into fluxstone, agriculture limestone, railroad ballast, riprap, refractory stone, and for lime manufacture.

GRANITE

Granite ranked second in Appalachian crushed stone production, the 73.2 million tons produced during the 1945–64 period (table 63), was 7 percent of total crushed stone output. The annual rate of production has steadily increased to the maximum of 9.6 million tons in 1964 which was 17 percent of the total U.S. output (table 63). Georgia, North Carolina, and South Carolina, listed in order of output, accounted for the bulk of Appalachian production.

TABLE 63.—*Production of granite (crushed and broken stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	292	672	7,378	10,634
1946	546	1,216	10.585	16,641
1947	599	1,331	11,922	17,948
1948	707	1,288	13,124	16,622
1949	1,057	1,856	16,458	24,483
1950	1,018	1,884	21,387	28,694
1951	1,108	1,816	19,765	27,063
1952	1,063	1,756	21,770	31,533
1953	2,152	3,225	22,888	33,211
1954	2,189	3,702	22,816	34,660
1955	2,626	3,846	25,462	38,964
1956	2,958	4,230	29,095	42,203
1957	4,242	5,573	41,097	50,351
1958	5,195	7,398	31,377	45,432
1959	6,140	7,776	36,917	51,113
1960	8,191	10,703	42,118	60,881
1961	7,250	10,012	43,396	62,921
1962	8,107	11,533	49,156	70,390
1963	8,162	11,614	48,040	70,554
1964	9,646	13,534	55,488	80,413
Total	73,248	104,965	570,239	814,711

More than 95 percent of 1964 production was used for concrete aggregate and roadstone. Other uses included riprap, railroad ballast, stone sand, and poultry grit.

SANDSTONE

Sandstone, a category that includes quartz and quartzite, constituted 5 percent of Appalachian crushed stone production during the last two decades. Annual quantities and values of production in Appalachia and the United States for that period are presented in table 64. Record Appalachian production was in 1963, partly because of increased demand for sandstone in the construction of a rock-fill dam in West Virginia. In 1964, Appalachia produced 15 percent of the total domestic output of crushed sandstone.

The three principal sandstone-producing States, accounting for about 81 percent of Appalachian output in 1964, were: Pennsylvania, 2.7 million tons; West Virginia, 0.5 million tons; and Tennessee, 0.2 million tons. The remaining 19 percent of output originated in the Appalachian parts of Ohio, Virginia, North Carolina, Alabama, and Georgia.

In 1964, 83 percent of production was used for concrete aggregate; most of the remainder was used for refractories (ganister). Smaller quantities were used for riprap, cement, glass manufacture, railroad ballast, foundry sand, and abrasives.

TABLE 64.—*Production of sandstone, quartz, and quartzite (crushed and broken stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	1,555	3,564	4,323	10,507
1946	1,285	3,316	4,093	11,823
1947	1,938	5,020	6,622	15,636
1948	1,865	4,732	7,086	16,084
1949	1,884	5,838	6,729	17,565
1950	2,492	7,153	8,835	20,104
1951	2,233	7,677	8,501	18,824
1952	1,808	6,167	8,297	18,265
1953	1,608	5,556	8,301	20,822
1954	4,214	11,270	11,717	27,314
1955	1,522	4,194	12,605	26,385
1956	2,065	8,282	12,823	33,699
1957	1,695	7,388	15,739	37,845
1958	1,358	5,686	24,484	42,364
1959	2,027	6,894	17,080	34,243
1960	2,975	8,068	20,574	36,899
1961	3,413	8,258	22,995	37,752
1962	3,814	9,393	25,687	39,933
1963	7,331	12,014	28,566	46,386
1964	4,231	9,382	27,738	51,215
Total	51,313	139,852	282,795	563,665

MARBLE

Marble made up 1.5 percent of Appalachian crushed stone production during the 1945–64 period. Annual production and values in Appalachia and the United States for that period are presented in table 65. Maximum production was in 1964, when output in Appalachia was 77 percent of the national total and was 20 times the Appalachian production of 1945.

Marble production was reported in 4 of the 12 Appalachian States in 1964. In order of output, these are: Georgia, Alabama, North Carolina, and Tennessee. In 1964, about 30 percent of production was sold or used as roadstone, the largest use. Other uses included terrazzo, paint and putty, neutralizer, and roofing gravel or chips.

MISCELLANEOUS STONE

Small amounts of slate, basalt, calcareous marl and others rocks are used in Appalachia for crushed stone. Slate was less than 1 percent of Appalachian crushed stone production during the 1945-64 period; annual production and value in Appalachia and the United States for that period are presented in table 66. The principal use was for lightweight aggregate. From 1945–54, basalt (traprock) was less than 1 percent of Appalachia crushed-stone production and was used for concrete aggregate. The combined calcareous

TABLE 65.—*Production of marble (crushed and broken stone), 1945–64.*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	76	344	111	763
1946	73	474	128	1, 092
1947	80	459	142	1, 227
1948	333	1, 324	193	1, 525
1949	399	1, 802	137	1, 313
1950	491	2, 772	178	1, 738
1951	630	4, 586	169	1, 844
1952	630	4, 659	149	1, 687
1953	621	4, 052	378	3, 987
1954	751	4, 582	454	4, 240
1955	782	6, 088	976	7, 890
1956	1, 038	6, 946	842	6, 619
1957	1, 014	7, 160	1, 274	9, 792
1958	1, 019	9, 430	1, 269	12, 025
1959	1, 436	11, 585	1, 758	13, 988
1960	1, 184	10, 384	1, 515	13, 198
1961	1, 127	9, 596	1, 435	12, 320
1962	1, 282	10, 562	1, 623	14, 277
1963	1, 349	9, 515	1, 752	13, 511
1964	1, 505	13, 251	1, 963	17, 361
Total	15, 820	119, 571	16, 446	140, 397

TABLE 66.—*Production of slate (crushed and broken stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	53	439	482	4, 858
1946	89	716	664	7, 064
1947	93	719	763	7, 990
1948	75	543	659	6, 968
1949	67	486	608	6, 642
1950	87	688	761	8, 515
1951	73	559	648	6, 929
1952	83	644	593	6, 415
1953	94	735	546	6, 313
1954	124	755	609	7, 117
1955	159	750	619	6, 890
1956	173	665	526	5, 125
1957	190	647	512	4, 481
1958	206	1, 206	523	5, 028
1959	230	1, 319	537	4, 855
1960	225	1, 295	413	2, 888
1961	184	935	372	2, 569
1962	218	1, 229	393	2, 640
1963	241	1, 382	749	3, 297
1964	337	1, 899	1, 139	4, 586
Total	3, 001	17, 611	12, 116	111, 170

marl and other stone output also accounted for less than 1 percent of the total Appalachian crushed stone production during the same period.

RESOURCE POTENTIAL

Rocks suitable for crushed stone are abundant and widespread in Appalachia and constitute a vital resource for present and future industrialization and urbanization. The crushed stone industry of Appalachia has grown steadily during the past two decades and, with the economic development expected during the next decade or two, should grow even more rapidly. Future use patterns will probably remain about the same, most crushed stone being utilized by the building industry and in highway construction.

DIMENSION STONE

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INTRODUCTION

The early settlers in Appalachia used slabs of surface stone, field stone, and boulders for building foundations, basement walls, dams for mill ponds, bridge abutments and piers, and similar types of basic construction. As the demand for building material increased with the expansion of population and industrial centers, reliable sources of useful stone were sought. Numerous deposits were found within short haulage distances, and quarrying became an important industry. Some quarries produced stone of such excellent quality that they attained early fame throughout the construction industry and attracted widespread markets. These sources have continued to supply stone for many of the Nation's important buildings and monuments.

Dimension stone includes blocks and slabs of natural stone that satisfy requirements for use as building stone, monumental stone, paving blocks, curbing, and flagging (Currier, 1960, p. 7). Structural uses of stone include foundations, walls, chimneys, sills, steps, and trim in buildings, and in engineering structures such as retaining walls, sea walls, and bridges. Bowles (1917, p. 23–25) lists four principal forms of building stone: cut or finished stone, ashlar, rough building stone, and rubble. Cut or finished stone has been shaped and sized accurately and may even be carved and surface tooled or polished; ashlar is stone that has been squared into rectangular blocks with rock-faced (broken), sawed, or planed surfaces. Rough building stone consists of rock-faced blocks of various shapes and sizes. Rubble, the cheapest form of building stone, consists of irregular blocks having one good face. Monumental stone may be considered as the finest quality of cut or finished dimension stone. Uniformity of texture, attractive coloration, freedom from flaws, and suitability for carving and polishing are the principal requisites. Paving blocks are small brick-shaped blocks used for roads, docks, freight yards and other surfaces subjected to heavy abrasive traffic. Curbing consists of long slabs of stone used for edging roadways and sidewalks. Flagging consists of thin slabs used for walks, driveways, and paved areas such as patios, carports, and courtyards.

According to their particular uses, dimension stones are chosen for such qualities as strength, hardness, durability or resistance to weathering, and ornamental features, and these qualities depend, in turn, upon mineralogic composition, texture, structure, and color. Consumers have developed a variety of specifications for dimension stone, which are described in reports of the American Society for Testing and Materials. In addition to these qualities, other factors are considered in selecting sites for quarry operations. The stone must be sound and not fractured and shattered nor extensively cut by mud seams or shale splits. There must be a sufficiently large volume of sound stone which is easy to quarry and transport to mills and markets.

In Appalachia where supplies of dimension stone of nearly every type are virtually inexhaustible, economic factors limit production. The volume of production depends largely upon the rate of industrial activity, particularly in the building trades, and cost is always an overriding consideration. A rise in dimension stone production characterizes the prosperous years; depressed economic conditions lead to stagnation of the industry. The demand for stone is generally created by architects and designers and by the vagaries of the consuming public, and style trends dictate, to a marked degree, the kinds of dimension stone that are quarried and how they are to be used in construction. Formerly, walls were constructed chiefly of massive blocks of stone carefully shaped and fitted to bear the entire weight and stresses of the structure; but a growing practice is to use natural stone as veneer or thin panels, fixed and keyed upon a basic framework of steel and concrete. A current trend in stone veneer is the use of precast panels of concrete faced with exposed quartz-pebble aggregate.

Dimension stone is commonly shipped long distances to satisfy special architectural demands, and the cost of transportation is an important factor in competitive marketing. The amount of handwork required in quarrying and shaping building stone also places it at a disadvantage when compared to the production methods in the manufacture of concrete block, brick, and cast "stone."

In former years dimension-stone quarries often were opened just to supply stone for a local project. Architects today, however, prefer to utilize stone of proven suitability because tests to forecast the durability of untried stone are not generally accepted. The American Society for Testing and Materials is developing specifications and test methods for a variety of dimension stones, which in time may alter the situation.

At the beginning of this century, dimension stone was produced in much greater tonnage than crushed stone. However, by 1964, dimension stone was only one-half of 1 percent of the total tonnage of domestic stone production, largely because of the growth of the crushed stone industry to supply stone for concrete highways and buildings. Even in 1925, the year of greatest U.S. production of dimension stone (4.8 million tons), the building stone output, which was the major segment of dimension stone production lagged behind the pace set by construction because of the increasing use of concrete and steel in commercial buildings. The record low production year of this century was 1942. Since World War II, domestic production of dimension stone has shown a gradual increase. Table 67 shows annual production, with quantities and values, of dimension stone produced in Appalachia and the United States for the period 1945–64.

During the 20 years covered in table 67, dimension stone produced in Appalachia accounted for 22 percent of the value and 14 percent of the tonnage of U.S. production. All Appalachian States reported output, but Virginia production was from outside the Appalachian area. Tennessee, Ohio, and Georgia, listed in order of output, accounted for 65 percent of Appalachian production, while Pennsylvania, New York, North Carolina, and Alabama contributed 34 percent.

TABLE 67.—*Production of dimension stone, 1945–64*

[Includes granite, marble, limestone, sandstone, and miscellaneous stone. Excludes basalt and slate. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	63	4, 671	855	23, 172
1946	150	7, 741	1, 324	42, 840
1947	176	10, 545	1, 379	49, 359
1948	186	10, 633	1, 536	55, 557
1949	238	13, 654	1, 584	59, 503
1950	257	13, 075	1, 815	66, 469
1951	260	13, 574	1, 820	63, 755
1952	280	13, 107	1, 828	59, 623
1953	292	12, 643	1, 891	61, 265
1954	335	15, 193	2, 330	71, 839
1955	405	17, 713	2, 473	83, 202
1956	362	17, 502	2, 449	79, 863
1957	397	16, 659	2, 275	78, 198
1958	367	16, 514	2, 285	73, 252
1959	370	19, 066	2, 309	79, 713
1960	330	18, 431	2, 124	78, 618
1961	321	18, 749	2, 178	80, 350
1962	297	17, 057	2, 475	82, 019
1963	327	21, 546	2, 370	87, 292
1964	340	17, 890	2, 336	86, 910
Total	5, 753	295, 963	39, 636	1, 362, 799

MARBLE AND LIMESTONE

Marble is limestone or dolomite that has been metamorphosed or recrystallized into a rock composed mainly or wholly of crystals of the minerals calcite or dolomite or mixtures of both. Some unmetamorphosed limestone is sufficiently pure and crystalline to take a high polish and in the trade is called "marble." This type of limestone is included with true marble for purposes of this report. Impurities, chiefly iron oxides, produce various colored patterns which lend life or tone to the marble. The valuable varieties of marble are distinguished chiefly on the basis of color. Statuary marble is the purest and whitest, architectural marble has the most uniform tones of color, and ornamental marble is distinguished by striking effects of varied colors.

Deposits of the various kinds of marble occur throughout long narrow belts within the Valley and Ridge, Blue Ridge, and Piedmont provinces in the southeastern part of Appalachia (fig. 60). Descriptions of the important belts follow.

Nearly all limestone used as dimension stone in Appalachia is obtained from small quarries developed to supply local building needs. Because they lack the special decorative or ornamental qualities that marble generally possesses, the limestone products are seldom transported great distances nor are unusual demands created for them by vogue or style trends. Nevertheless, suitable limestone is widespread throughout Appalachia and it has, in the past, provided vast amounts of building stone.

TENNESSEE MARBLE BELTS

Tennessee marble, a very pure nonmetamorphic limestone of the Holston Formation of Middle Ordovician age, is quarried from beds in the Valley and Ridge province in eastern Tennessee that crop out in a series of roughly parallel belts that trend northeastward over an area 12–16 miles wide and about 125 miles long (fig. 60).

The repetition of the marble beds is caused by complex folding and faulting and subsequent exposure through erosion. The width of each belt generally does not exceed one-fourth mile, but in places a belt may attain widths of a mile or more. The thickness of the Holston Formation may be as much as 400 feet, but, owing to variation in texture and structural defects, its workable beds are generally not more than 60–80 feet thick. According to C. H. Gordon (1924, p. 28), the marble ranges in color from light pink and gray to deeper shades of red and chocolate, is coarse textured, and is relatively impervious to stains and soiling. There is no practical limit to the amount of marble available in the beds, but supplies of certain colors or grades of marble may be limited.

Gordon (1924, p. 30) identified several major belts of marble, shown in figure 60: the Luttrell belt, the Galbraith belt, the Black Oak belt, which is inter-

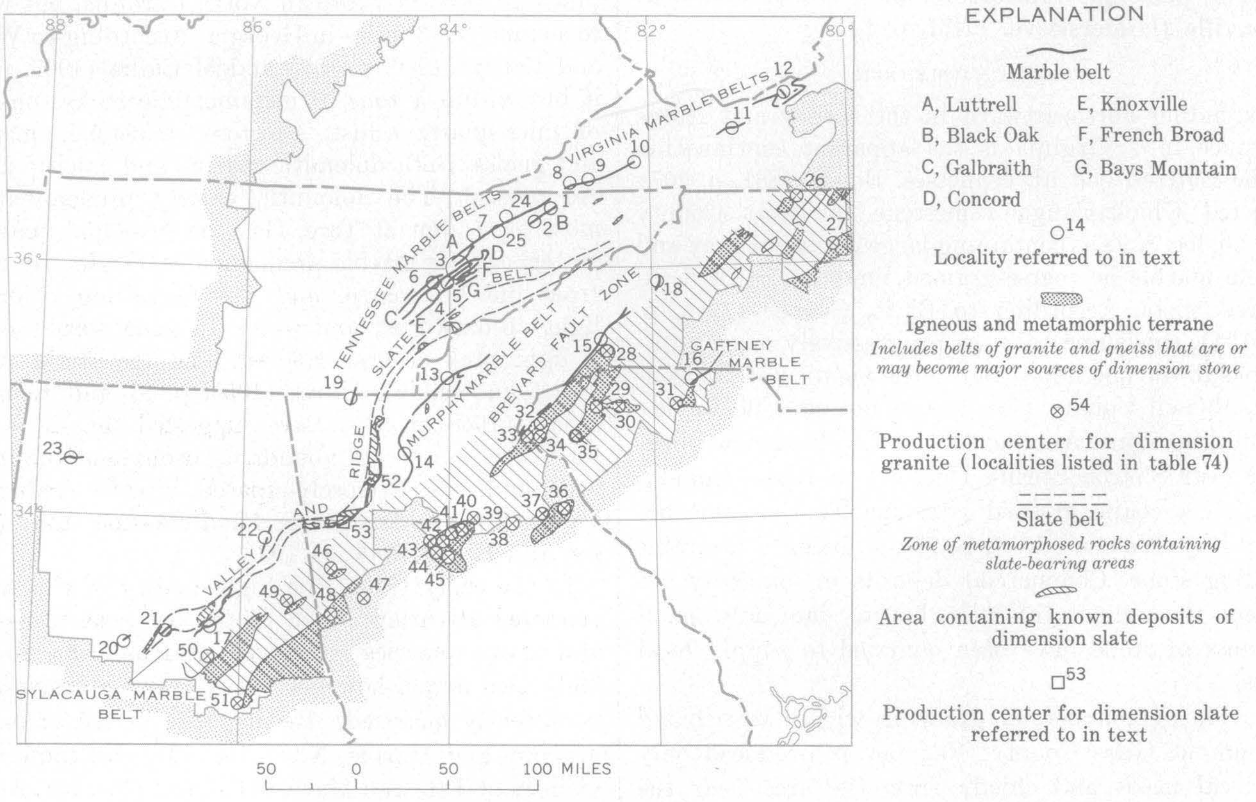


FIGURE 60.—Distribution of marble, granite, and slate in the southern part of the Appalachian Region.

rupted by faulting and erosion, the Concord belt, the Knoxville belt, the French Broad belt, and the Bays Mountain belt. The beds of marble are not of commercial grade throughout the various belts. Gordon (1924, p. 31) stated that the best and most productive deposits are found near the middle of the area.

The Meadow belt, not shown because of scale limitations, parallels the Knoxville belt at a distance of about half a mile. Lenses of marble also occur irregularly within the overlying Tellico and Ottosee Formations, and the marble of the Meadow belt may represent such lenses. Attempts to work them have generally proved unsuccessful because of their small size and inferior quality of stone.

According to Maher and Walters (1960, p. 1), the first development of Tennessee marble was the opening of a quarry in Hawkins County, Tenn., in 1838 (fig. 60, loc. 1). Subsequently, marble from this area (loc. 2) was used in the construction of the National Capitol in Washington, D.C., In 1852, a quarry was opened in the Knoxville, Tenn., area (loc. 3) where the marble is generally flat lying and outcrops are extensive. The quality of the marble plus favorable quarrying conditions helped establish Knoxville as the center of the marble industry in Tennessee. Other important quarries are located at Friendsville (loc. 4), Louisville (loc. 5), Concord (loc. 6), and Luttrell (loc. 7). The principal fabricating mills are at and near Knoxville (Gildersleeve, 1946f, p. 6).

VIRGINIA MARBLE BELTS

Extending northeastward in the Valley and Ridge Province into Virginia is the apparent continuation of the Luttrell belt of Tennessee. Boyd (1881, p. 207) reported Chickamauga Limestone in Scott County (fig. 60, loc. 8, 9) as containing large masses of gray and purple marble or coarse-grained limestone with flesh-colored spots. According to B. N. Cooper (1945, p. 133–134), this stone becomes progressively more argillaceous to the northeast, and in the vicinity of Hansonville, Russell County (loc. 10), is not suitable for use as building stone. Another belt of Chickamauga Limestone near Sharon Spring (loc. 11) in Bland County, contains a coarse-grained gray marble that was described by Watson (1907, p. 77) as being a desirable building stone. Commercial deposits undoubtedly are present throughout this belt, but to date only small amounts of stone have been quarried to supply local needs.

Marble of commercial grade is widely distributed throughout Giles County, Va., but is produced only for local needs and chiefly from the area near the junction of Walker Creek and New River (loc. 12). All rocks in the area have been subjected to intense deformation, and limestone of at least four formations has been, in places, metamorphosed into marble. The formations are: (1) Copper Ridge and Nittany Dolomites of Cambrian and Ordovican age, (2) the Murfreesboro Limestone of Ordovician age, (3) the Moccasin Limestone of Ordovician age, and (4) the Romney Shale of Devonian age (Mathews, 1934, p. 7). The Moccasin Limestone is the most important and, according to Mathews (1934, p. 11), consists of an upper red member and a lower marble member that ranges in thickness from 60 to 121 feet. The uppermost part of the lower member is thin bedded and dark reddish brown. The lower beds are much thicker, more compact, and variable in color, ranging from a variegated carnelian and light Nile-green to gray with golden bands. Commercial-grade marble is distributed throughout the base of the member, and Mathews (1934, p. 31–32) listed many localities favorable for prospecting.

MURPHY MARBLE BELT

Elongate, lens-shaped masses of metamorphic marble occur within the Murphy marble belt in the Blue Ridge and Piedmont provinces of North Carolina and Georgia extending from Swain County, N.C., southwestward about 100 miles into central Cherokee County, Ga. (fig. 60). The belt ranges from 1,000 feet to a half mile in width in North Carolina, but widens to as much as 3 miles in Georgia. According to Watson and Laney (1906, p. 192) and McCallie (1907, p. 32), it lies within a zone of metamorphic rocks consisting of mica-quartz schist, schistose sandstone, quartzite, and gneiss. Both dolomitic marble and calcitic marble are present. The dolomitic variety predominates in most places but at Tate, Ga., the principal quarrying center, calcitic marble predominates. Grain size ranges from fine to coarse, and the prevailing colors are light- to dark-gray and white. In some areas the stone is light pink or flesh colored. The age of the marble is not known, but Hurst (1955, p. 8) and King and others (1958, p. 965) have suggested that it is early Paleozoic. Joints are abundant throughout the marble beds and where closely spaced, greatly reduce the amount of marble suitable for dimension stone (Watson and Laney, 1906, p. 193).

In the early 1900's, the high quality of this marble attracted attention, much of the belt was prospected, and many quarries were worked from time to time. Only two areas, however, have been extensively and persistently quarried: the deposits in the vicinity of Murphy and Marble, N.C. (loc. 13), and those in the vicinity of Tate and Marble Hill, Ga. (loc. 14). According to Broadhurst (1955, p. 72), the Murphy marble in Cherokee County, N.C., has a maximum thickness of about 500 feet and contains white, blue, red, pink, and dark-banded dolomitic marbles which are excellent for monumental, decorative, and building stone. Conrad (1960, p. 13) stated that a quarry near Murphy produced a very attractive mottled blue and white marble that was widely known as Regal Blue Marble.

The most important producing deposits in the Murphy marble belt are those centering about Tate and Marble Hill, Ga. Figure 61 shows the extensive workings at the White Cherokee Quarry of the Georgia Marble Co. at Tate. Fairley (1965, p. 27), and W. S. Bayley (1928), recognized several distinct marble-bearing areas within a complexly folded series of schists and gneisses in this part of the belt. Most of the marble is white, nearly pure calcite, but parts are dolomitic. Furcron (1964–65, p. 27), in describing the deposits at Tate-Marble Hill stated that the marbles have been extensively quarried since 1840 for dimension stone, monumental stone, statuary, and other purposes. The stone has been used in public buildings all over the Nation and for Federal buildings and monuments in Washington, D. C., including the statue in the Lincoln Memorial.

MARBLE IN BREVARD FAULT ZONE

The Brevard fault zone is a narrow belt of schist that extends southwestward from Surry County, N.C., to Tallapoosa County, Ala., where it disappears beneath the Coastal Plain sediments. Bluish-white finely crystalline calcitic and dolomitic marble occurs within this zone, in Buncombe, Henderson, and Transylvania Counties, N.C., and is best developed near Mills River (fig. 60, loc. 15). Whether the marble occurs as disconnected lenses or as a continuous horizon is not known. Conrad (1960) and Reed and Bryant (1964, p. 1191) considered it to be part of an exotic tectonic slice. Although the marble beds have been utilized for well over 100 years, most, if not all, the stone has either been burned for lime or crushed for roadstone and concrete aggregate. The commercial possibilities for use as dimension stone are not known, although descriptions of many quarries suggest that the beds are badly fractured.

GAFFNEY MARBLE BELT

In the Piedmont province, east of the Brevard zone, a narrow belt of steeply dipping metamorphosed sedimentary rocks extends northeastward from just south of Gaffney, S.C. (fig. 60, loc. 16) to beyond the eastern edge of Appalachia. According to Conrad (1960, p. 39), the rocks in the belt consist of quartzite, schist, volcanics, crystalline limestone and dolomite, and calcareous metashale. The so-called "Gaffney Marble" (Keith and Sterrett, 1931, p. 6) occurs as discontinuous beds or lenses that range in thickness from 50 to 800 feet. The marble is, for the most part, very fine- to medium grained and varies in color from dark bluish gray to white. Its composition varies considerably; some is calcitic but most is dolomitic. Thin beds of mica schist are interbedded with the marble. Many quarries have been developed along the belt, but most of the marble has been sold as crushed stone or burned for lime.

SYLACAUGA MARBLE BELT

Beds of pure-white to cream-colored marble, in places streaked or clouded, crop out in a narrow northeast-trending belt called the Sylacauga marble belt, about 35 miles long and ranging from ½ to 1½ miles wide in east-central Alabama (fig. 60). According to Prouty (1916, p. 46), the belt is bordered on the southeast by slate and phyllite of the Talladega Slate but is separated from these rocks by a thrust fault. The belt is bounded by the Knox Group along most of its northwestern border. Prouty (1916, p. 48) stated that the marble is the metamorphosed equivalent of limestone units ranging in age from Cambrian through Silurian, and include the Beekmantown and Chickamauga Limestones.

The thickest deposits of marble occur toward the central and southwestern parts of the belt. Various quarries in the vicinity of Sylacauga (loc. 17), the area of chief development, show the marble to be at least 200 feet thick. Jones (1926, p. 50) reported that some quarries have produced stone more or less continuously since the Civil War. The marble is a fine-grained nearly pure calcite. It takes a high and brilliant polish, and is ideally suited for architectural and ornamental purposes; some is of statuary grade.

The deposits are deeply weathered, however, and laced with a large number of fractures, faults, and shear zones; the size of sound blocks that can be quarried is therefore limited. According to Jones (1926, p. 50), less than half the volume of stone quarried can be used as dimension stone, but all the broken and crushed material is used for various purposes such as terrazzo, furnace flux, and agriculture lime.

OTHER MARBLE BELTS

McDowell County, N.C.—Large disconnected masses of marble occur throughout a belt of limestone in the northern part of McDowell County near Clinchfield (fig. 60, loc. 18). Watson and Laney (1906, p. 202) reported that the color and texture of the marble makes it favorable for use as a general building stone, but that much of the marble now exposed is useless for building purposes because it is closely

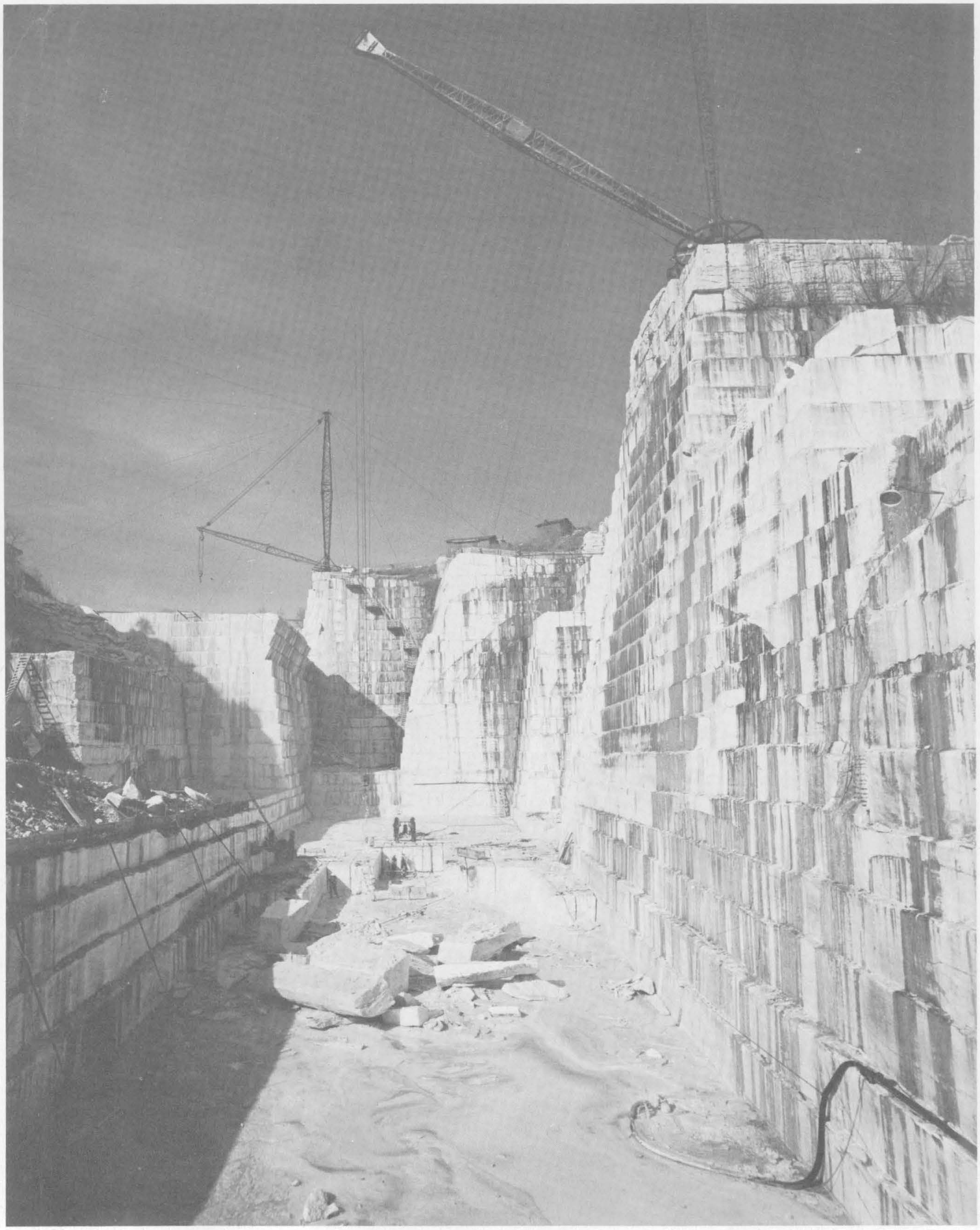


FIGURE 61.—Georgia Marble Co.'s White Cherokee quarry, Tate, Ga.

jointed. Early drilling records, however, indicate that some of the marble units are nearly 1,000 feet thick, and that some parts are fairly free from joints (Watson and Laney, 1906, p. 203).

Whitfield County, Ga.—A zone of dark-chocolate and gray, highly fossiliferous marble occurs within a narrow north-trending belt from Whitfield County, Ga., near Red Clay (fig. 60, loc. 19) into Bradley County, Tenn. The thickness of the marble beds is estimated to range from 30 to 60 feet (McCallie, 1907, p. 75). The marble probably belongs to the Holston Formation which is extensively worked in the vicinity of Knoxville, Tenn. In Georgia, however, the stone has been quarried and used only locally for tombstones, chimneys, and other building purposes; according to Butts and Gildersleeve (1948, p. 28), the stone probably has little value as a dimension stone.

Bibb County, Ala.—A light-gray marble, in places colored by deep-red veins, streaks, and irregular masses, has been quarried from a belt in the central part of Bibb County, Ala., along the Cohara River (fig. 60, loc. 20) for use as interior decoration and for monuments. According to Prouty (1916, p. 85, 86), the marble is metamorphosed Ordovician limestone and the amount available is very great. The marble in the center of the belt is more than 220 feet thick, but the beds thin to the southwest and become impure toward the northeast.

Shelby County, Ala.—A narrow belt of variegated marble is exposed in the southernmost part of Shelby County near Calera (fig. 60, loc. 21). The marble is reported by Prouty (1916, p. 86) to be metamorphosed limestone of Cambrian age. Butts (1910) described it as follows:

> The marble is thick bedded, the layers being 3 to 4 feet thick. They are cut by joints which divide them into blocks of considerable size, and it seems probable that under good cover even larger blocks exist * * * the rock is very fine grained and takes a high polish. Part of the layers are gray and part are variegated with deep red and pale pink, the whole stratum being composed perhaps of one-half of each kind * * * the variegation gives to the rock a highly ornamental effect when polished, and it would appear to possess superior qualities for decorative purposes.

Calhoun County, Ala.—An imperfectly known northeast-trending belt of black marble of probable Chickamauga age is exposed intermittently in the northern half of Calhoun County near Jacksonville (fig. 60, loc. 22). Prouty (1916, p. 93) described some of the exposures as thin-bedded marble, with few layers more than 2 feet thick; other exposures consist of much thicker layers. White calcite veins and streaks occur in the marble, enhancing its value as decorative stone.

Franklin County, Ala.—A bed of very light gray to white, almost pure oolitic limestone of the Rockwood Member of Jones (1928) of the Bangor Limestone of Mississippian age has been extensively quarried for use as dimension stone in the vicinity of Russellville, Ala. (fig. 60, loc. 23). Although technically not a marble, it is, according to Jones (1926, p. 43), "* * * remarkably uniform in texture, is hard and very durable and is, in part, massively bedded * * * which enables the quarrymen to take out as large blocks as their equipment will handle. Furthermore, these blocks will usually be without cracks or flaws, suitable for columns or any other use which requires absolute uniformity in grain, color, or texture." This bed of limestone trends roughly eastward across the County for a distance of almost 20 miles and has a rather wide zone of outcrop in spite of the fact that the bed averages only about 25–30 feet in thickness; in places it is much thicker (Jones, 1928, p. 14). The stone has been used for wall blocks, steps, door sills, window seats, and buttress caps.

Grainger County, Tenn.—Black limestone of Middle Cambrian age has been quarried for use as interior marble at two localities in Grainger County, Tenn. (R. A. Laurence, written commun., Nov. 19, 1965). The Imperial Black quarry, near Thorn Hill (fig. 60, loc. 24), in the Maryville Limestone, has been operated intermittently since 1935. The Craig quarry, in the Craig Limestone Member of the Rogersville Shale at Rutledge (loc. 25), was operated chiefly in the late 1930's, and then abandoned. The Maryville Limestone crops out extensively in this area, but black marble occurs only in limited amounts.

PRODUCTION

From 1945 to 1964, Appalachia produced about two-thirds of the dimension marble quarried in the United States. Quantities and values of annual production in the United States for the 20-year period are presented in table 68. Annual Appalachian production is withheld in order not to disclose individual company data. About 85 percent of Appalachian production in 1964 was sold as building stone and 15 percent as monumental stone.

The principal producing States in Appalachia during the last two decades have been Tennessee and Georgia; lesser production has been reported from Alabama and North Carolina.

Limestone accounted for 5 percent of the value and 7 percent of the tonnage of Appalachian dimension stone production from 1945 to 1964, and represented 2.4 percent of the dimension limestone quarried in the

United States during the period. Quantities and values of annual production in the United States for the 20-year period are given in table 69. Annual Appalachia production is withheld in order not to disclose individual company data. All the 1964 Appalachia production was sold or used as building stone.

The principal producing States in Appalachia during the last two decades have been Alabama, Pennsylvania, and Georgia. Minor production was reported from Kentucky, Maryland, West Virginia, and New York.

TABLE 68.—*Production of marble (dimension stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	60	6, 199
1946	77	9, 220
1947	85	11, 169
1948	82	10, 550
1949	102	12, 849
1950	89	10, 713
1951	87	9, 454
1952	89	9, 726
1953	76	8, 939
1954	84	10, 608
1955	116	13, 639
1956	105	12, 748
1957	148	14, 301
1958	136	15, 631
1959	137	17, 835
1960	129	17, 585
1961	157	18, 456
1962	146	18, 608
1963	150	20, 918
1964	130	19, 149
Total	2, 185	268, 297

SANDSTONE

Sandstone, a sedimentary rock composed chiefly of quartz grains cemented by silica, iron oxide, calcium carbonate, or clay, has been a popular building material in Appalachia. It is commonly used as ashlar blocks in walls, window sills, and fireplaces, as flagstones, and in massive blocks for piers, bridge abutments, and large foundations.

SANDSTONE BELTS AND AREAS

Although many sandstone-bearing formations have been extensively quarried from time to time, probably more than half the volume of sandstone quarried for building purposes has been produced from relatively few sandstone units that are generally either persistently thick bedded or persistently thin bedded, and are even textured, attractively colored, and durable. These units are listed in table 70. They crop out, (fig. 62) in the Valley and Ridge, the Appalachian Plateaus, and the Interior Low Plateaus provinces. In the Valley and Ridge, sandstone beds of Cambrian to Mississippian age dip steeply and form narrow belts of outcrops. The Appalachian Plateaus are characterized by flat-lying strata containing numerous sandstone beds of Pennsylvanian and Permian ages and, to the north, of Devonian age. Flat-lying beds of Mississippian sandstone crop out in the Interior Low Plateaus. A narrow belt of quartzite lies east of the Valley and Ridge province in the Talladega Belt.

TABLE 69.—*Production of limestone (dimension stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	334	3, 262
1946	504	7, 655
1947	543	8, 731
1948	607	12, 263
1949	680	14, 597
1950	808	20, 279
1951	807	19, 456
1952	787	15, 787
1953	799	16, 432
1954	1, 175	21, 372
1955	1, 183	26, 723
1956	1, 029	21, 807
1957	953	21, 685
1958	979	18, 757
1959	952	20, 407
1960	860	16, 987
1961	855	16, 589
1962	896	16, 729
1963	895	18, 061
1964	779	18, 944
Total	16, 425	336, 523

TABLE 70.—*Some sandstone units commonly quarried for dimension stone*

Unit	*Age*
Waynesburg Sandstone Member of Washington Formation.	Pennsylvanian.
Pottsville Formation	Do.
Homewood Sandstone Member of Pottsville Formation.	Do.
Buena Vista Sandstone Member of Cuyahoga Formation.	Mississippian.
Price and Pocono Sandstones	Do.
Hartselle Sandstone	Do.
Berea Sandstone	Devonian or Mississippian.
Catskill Formation	Devonian.
Oriskany Sandstone	Do.
Tuscarora and Clinch Sandstones	Silurian.
Tusquitee Quartzite	Cambrian.
Nottely Quartzite	Do.
"Basal clastics," including Weisner Quartzite.	Do.

The locations of some of the areas known to have produced dimension stone are shown in figure 62 and identified in table 71. A selected group of quarry sites briefly described below are typical of the kinds of sandstone beds exploited for dimension stone.

Scioto County, Ohio.—Several sandstone-bearing formations crop out along the Ohio River in the vicinity of Buena Vista (fig. 62, loc. 71); they are in ascending order the Bedford Shale and Berea Sandstone of Devonian or Mississippian age and the Buena Vista Sandstone Member of the Cuyahoga Formation of Mississippian age. Rocks exposed attracted attention of pioneers, and quarrying began in the early 1800's. Although both the Berea Sandstone and Bedford Shale contain suitable sandstone units, almost all dimension stone has been quarried from beds of the Buena Vista Member. Stone from a certain layer became so popular with architects and builders at Cincinnati that it was known as the City ledge (Bownacker 1915, p. 125). The City ledge usually ranges from 3 to 4 feet in thickness, has a uniform bluish-drab color and a medium grain, is strong and durable, and carves well. Blocks containing as much as 300 cubic feet were quarried and shipped, but the average has been about 45 cubic feet. The blocks are sawed into pieces of various sizes to meet the market demand. In addition to a large use for architectural purposes, this ledge has provided stone for bridges, culverts, flagging, and curbing.

Beaver County, Pa.—The Homewood Sandstone Member of the Pottsville Formation of Pennsylvanian age has been extensively quarried in the vicinity of Koppel (fig. 62, loc. 29). The sandstone bed, 20–60 feet thick, is massive, coarse grained, and tan to gray in color. Widely spaced joints permit blocks of any desired size to be quarried. Sound blocks 2 feet thick and as much as 3 feet wide and 6 feet long have been obtained for use in constructing piers and abutments, retaining walls, and extra large foundations (Stone, 1932, p. 46). Curbstones have also been produced.

Rockcastle County, Ky.—Within the Borden Formation of Mississippian age, a northeast-trending lens of sandstone 16–20 miles long, has been quarried since 1896 in the vicinity of Wildie and Mount Vernon (fig. 62, loc. 131, 132). The sandstone of the Wildie Member of the Borden is argillaceous, bluish drab, fine grained, and even textured. It splits freely in all directions and in the trade is known as the "Rockcastle freestone;" it is remarkably free from iron, weathers uniformly, and is worthy of its interstate reputation as a building stone (Richardson, 1923, p. 96–97).

Cumberland County, Tenn.—Thin-bedded sandstone of the Pottsville Formation of Pennsylvanian age, especially the Crossville Sandstone Member of Wanless (1946) is extensively quarried throughout an area near Crab Orchard (fig. 62, loc. 149). According to Gildersleeve (1946f, p. 9), the stone is a medium to fine-grained dense silica-cemented quartzitelike sandstone. It occurs in beds ranging from less than an inch to about 18 inches in thickness. The beds are horizontal and of uniform thickness. The stone separates readily along bedding planes and may be quarried in many sizes; much of it is stained by iron oxides to form intricate variegated patterns in gold, purple, mauve, blue, gray, and pink. This highly colored stone is used in wall panels, as veneer for exterior walls, floors, copings, roofing, flagstones, and for similar decorative purposes. Most of the light-colored unstained stone is produced in bricklike shapes for use in exterior walls and heavy construction. Fabricating plants are located near the quarries.

Barbour County, W. Va.—Highly colored sandstone from beds totalling as much as 60 feet in thickness has been quarried for building stone in the vicinity of Junior and Laurel (fig. 62, loc. 116). The beds are part of the Homewood Sandstone Member of the Pottsville Formation of Pennsylvanian age (Grimsley, 1909, p. 510–511). This fine- to coarse-grained sandstone shows a variety of colors, including blue, buff, yellow, pink, and red; some yellow sandstone has an irregular red banding and is called Calico stone. Yellow or red spots give a mottled appearance to some beds. The sandstone has been popular for trimming fronts of buildings; the variety of colors permits its use with any color of brick.

Ritchie County, W. Va.—Beds of buff to yellowish-brown sandstone of the Waynesburg Sandstone Member of the Washington Formation of Pennsylvanian age have been extensively quarried for building stone in the vicinity of Cornwallis (fig. 62, loc. 91). Mica flakes occur sparingly, and the rock has abundant white kaolin particles that impart a speckled appearance. The quarry, one of the largest in West Virginia, has provided some stone for buildings, but most of the stone has been used for bridge piers and "is regarded as one of the best bridge stones in the State" (Grimsley, 1909, p. 446).

Susquehanna County, Pa.—Greenish-gray hard thin-bedded, nearly flat-lying sandstone of the Catskill Formation of Devonian age has been extensively quarried for flagstones in the vicinity of Brandt (fig. 62, loc. 61). Stone (1932, p. 269) reported that "in outcrop these sandstones look massive and crossbedded but when a quarry is opened it is common to find that the stone will lift in even layers 2 to 5 inches thick and

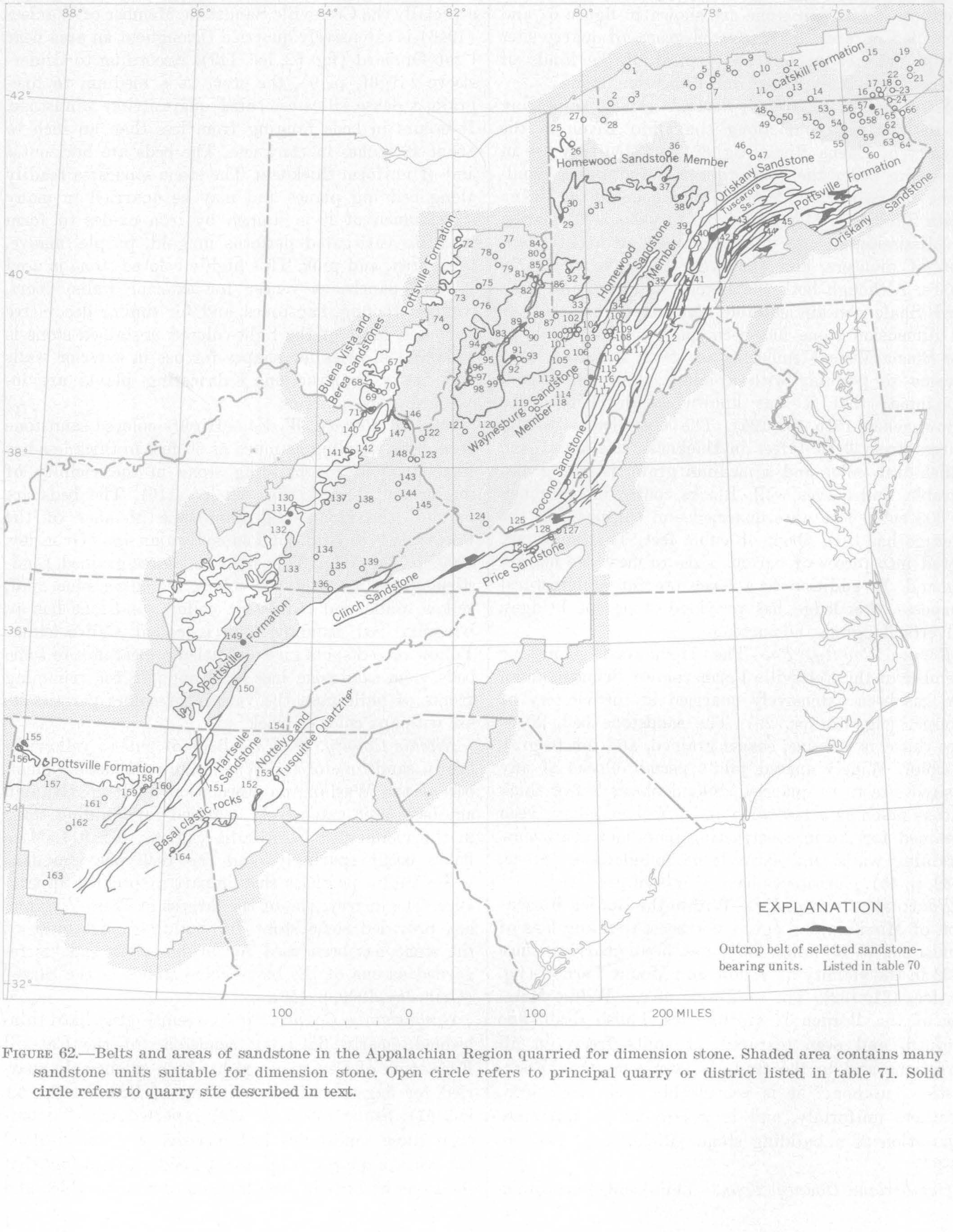


FIGURE 62.—Belts and areas of sandstone in the Appalachian Region quarried for dimension stone. Shaded area contains many sandstone units suitable for dimension stone. Open circle refers to principal quarry or district listed in table 71. Solid circle refers to quarry site described in text.

TABLE 71.—*Areas containing dimension sandstone quarries*

No. (fig. 62)	Location	No. (fig. 62)	Location
	New York		
1	Leona	13	Elmira
2	North Clymer	14	Waverly
3	Jamestown	15	Oxford
4	Cuba	16	Oquaga
5	Rockville	17	Deposit
6	Angelica	18	Hale Eddy
7	Belmont	19	Oneonta
8	Hornellsville	20	Delhi
9	Cohocton	21	Hamden
10	Bath	22	Walton
11	Corning	23	Apex
12	Watkins	24	Hancock
	Pennsylvania		
25	Conneautville	46	Slate Run
26	Meadville	47	Jersey Mills
27	Le Boeuf	48	Tioga
28	Correy	49	Mansfield
29	Koppel	50	Mainesburg
30	Ellwood City	51	Towanda
31	Butler	52	Durrell
32	Washington	53	LeRaysville
33	Waynesburg	54	Auburn
34	Ohiopyle	55	Meshoppen
35	Somerset	56	Montrose
36	Johnsonburg	57	Alford
37	Falls Creek	58	Kingsley
38	Curwensville	59	Nickelson
39	Dysart-Dean	60	Scranton
40	Holidaysburg	61	Brandt
41	Bedford	62	Waymart
42	McVeytown	63	Honesdale
43	Lewistown	64	White Mills
44	McAlisterville	65	Equinunk
45	Richfield	66	Stalker
	Ohio		
67	Waverly	76	Cumberland
68	Rarden	77	Sherrodsville
69	Henley	78	Uhrichsville
70	McDermott	79	Tippicanoe
71	Buena Vista	80	Steubenville
72	Millersburg	81	Martins Ferry
73	Zanesville	82	Bellaire
74	Corning	83	Newport
75	Cambridge		
	West Virginia		
84	Kings Creek	102	Barracks-Underwood.
85	Wellsburg		
86	Wheeling	103	Fairmont
87	Hundred	104	Rivesville
88	New Martinsville	105	Clarksburg
89	Sisterville	106	Grafton
90	Middlesbourne	107	Zeverly
91	Cornwallis	108	Kingwood
92	Harrisville	109	Albright
93	Pullman	110	Rowlesburg
94	Briscoe	111	Aurora
95	Parkersburg	112	Bloomington
96	Lone Cedar	113	Weston
97	Sherman	114	Buckhannon
98	Ravenswood	115	Philippi
99	Burning Springs	116	Junior-Laurel
100	Mannington	117	Kingsville
101	Farmington	118	Gassaway
	West Virginia—Continued		
119	Frametown	123	Saltpetre
120	Charleston	124	Gary
121	Sattes	125	Bluefield
122	Dickenson	126	Greenbrier
	Virginia		
127	Blacksburg	129	Pulaski
128	New River		
	Kentucky		
130	Berea	140	Vanceburg
131	Wildie	141	Farmers
132	Mt. Vernon	142	Bluestone
133	Day Ridge	143	Paintsville
134	Barbourville	144	West Prestonburg
135	Pineville	145	Pikeville
136	Middlesboro	146	Mandy
137	Willow	147	Ashland
138	Jackson	148	Louisa
139	Harlan		
	Tennessee		
149	Crab Orchard	150	Morgan Springs
	Georgia		
151	Cloudland	153	Jasper
152	Rydal	154	Mineral Bluff
	Alabama		
155	Cherokee	160	Albertville
156	Allsboro	161	Cullman
157	Phil Campbell	162	Jasper
158	Guntersburg	163	Tuscaloosa
159	Big Spring Valley	164	Anniston

make excellent flagstones." Quarries have produced a wide range of sizes and shapes of stone for various uses, including 3–4 inch coping as much as 8 feet long, flagstones and curbstones of various sizes, and landscape flagstones in irregular shapes. Some of the stone is dressed to rock-face random ashlar.

Marshall County, Ala.—Thin-bedded sandstone of the Pottsville Formation of Pennsylvanian age has been quarried at irregular intervals in the vicinity of Guntersville (fig. 62, loc. 158, 159). The beds have an aggregate thickness of approximately 50 feet (Hunter, 1940, p. 7). According to Gildersleeve (1946f, p. 10), the " * * * sandstone suitable for building purposes is characterized by thin, horizontal beds, clay parting seams, and grains of such nature that the stone is easily split and shaped." The quartz grains of the stone are cemented by silica, and the stone has great strength. The sandstone is generally gray, grading into or blended with gray and pink, light-tan or buff, reddish-pink, white to bluish-gray, and light-brown and mauve stone (Gildersleeve, 1946f, p. 10). In some places the quality of the stone is impaired for building purposes by crossbedding, abundant closely spaced joints, and iron-stained spots (Hunter, 1940, p. 7). Almost all stone produced from this area has been in the form of blocks and slabs for local construction.

PRODUCTION

During the period 1945–64, sandstone ranked first, being 56 percent of the dimension-stone tonnage quarried in Appalachia; in value it ranked second, accounting for 31 percent of total sales. During the same period, 44 percent of dimension sandstone quarried in the United States was produced in Appalachia. Quantities and values of annual production in Appalachia and the United States for the 20-year period are presented in table 72.

TABLE 72.—*Production of sandstone (dimension stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	28	489	64	971
1946	68	1,329	161	3,030
1947	88	1,790	187	4,420
1948	99	2,388	204	4,829
1949	115	2,832	226	5,369
1950	144	3,661	266	6,989
1951	158	4,234	291	7,693
1952	173	4,026	352	7,944
1953	185	4,628	354	9,155
1954	201	5,561	402	10,706
1955	242	6,802	503	13,317
1956	216	6,916	624	15,181
1957	224	5,184	555	12,057
1958	198	5,251	489	11,313
1959	194	6,109	473	11,583
1960	190	6,213	439	11,438
1961	158	6,053	391	11,067
1962	156	6,078	390	10,828
1963	175	6,415	412	11,397
1964	198	5,580	431	10,562
Total	3,210	91,539	7,214	179,849

TABLE 73.—*Sandstone (dimension stone) sold or used by producers in the Appalachian Region, by uses*

[Source: U.S. Bur. Mines]

Use	1963		1964	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
Building:				
Rough construction	21,286	276	29,522	334
Rubble	10,364	109	10,700	116
Rough architecture	41,793	920	39,274	707
Dressed stone	61,277	3,941	71,211	2,855
Curbing and flagging	40,194	1,169	47,607	1,568
Total	174,914	6,415	198,314	5,580

The principal producing States in Appalachia during the last two decades have been Ohio, Tennessee, New York, and Pennsylvania. Some production was reported from West Virginia, Georgia, North Carolina, Kentucky, Maryland, and Alabama.

Uses of sandstone produced in Appalachia for 1963 and 1964 are shown in table 73. About 76 percent of the production in both years was sold for building stone; the remainder was used as curbing and flagging.

GRANITE

A wide variety of crystalline igneous rocks are used for dimension stone because of their great strength, durability, coloration, and high polishing characteristics, but commercially all varieties are called granite. The light-colored varieties include true granite, granodiorite, quartz monzonite, and related rock types, whereas dark-colored varieties, commonly called "black granites" include diorite and gabbro. True granite is a visibly granular rock consisting of feldspar, quartz, and mica or hornblende. Granodiorite and quartz monzonite differ from true granite only in the kinds and amounts of feldspar contained in the rock. Quartz monzonite, for example, contains as much or more sodic feldspar as it does potassic feldspar. Diorite and gabbro contain varying amounts of both sodic and calcic feldspars as well as more abundant ferromagnesian minerals such as hornblende, augite, and olivine, giving a darker color. Crystalline rocks in which the alignment of certain minerals, commonly mica or hornblende, is roughly parallel because of metamorphic effects are called gneiss. The term "granite gneiss" or simply "gneiss" identifies rocks of this type.

Granite is one of the hardest stones used for building purposes; consequently, it is expensive to quarry and shape into usable forms. Most granite masses contain parallel systems of joints or cracks and, to keep costs at a minimum, sites for the production of stone are selected where joint systems facilitate quarrying operations. The most favorable condition for quarrying is one in which the joints occur in three systems, approximately at right angles to each other and spaced several feet apart. Where joints are too numerous and closely spaced, the granite will not yield sound blocks large enough for building purposes. The stone generally splits in certain directions with greater ease than in others. The direction of easiest splitting is known as the rift. A second, less-marked tendency to split, generally at right angles to the rift, is known as the grain. A well-defined rift and grain are of great assistance to the stonecutter in shaping massive blocks.

GRANITE BELTS AND AREAS

Granite and related rock types occur throughout large areas in the Piedmont province of southeastern Appalachia, and most of the granite produced in Appalachia for building purposes has come from this region. The Piedmont province is almost entirely underlain by Precambrian and Paleozoic metamorphic rocks, chiefly gneiss and schist, that have been intruded by various-sized masses of granite. Within this igneous and metamorphic terrane, many areas contain large deposits of both granite and gneiss suitable for use as dimension stone. Most quarry sites, however, are located within the granite masses forming rather narrow northeast-trending belts (fig. 60). Selection of sites is further guided by the distribution of a thick residual mantle of earthy clay and decayed rock called saprolite. Where saprolite is thick, the expense of removal to expose fresh rock is generally prohibitive. Sites are selected, therefore, in areas where the saprolite is thin or absent.

The locations of some areas containing granite quarries are shown in figure 60 and identified in table 74. Four of these areas, selected as having representative types of commercial granite, are briefly described.

Surry County, N.C.—Granite occurs in two narrow belts trending northeastward across the eastern half of Surry County. The rest of the county is underlain by various types of gneisses and schists. Deep weathering has rendered much of the granite unsuitable as a convenient source of dimension stone, but at Mount Airy (loc. 26), fresh unjointed granite is exposed for about 5,000 feet along the crest of a rather conspicuous hill (Councill, 1954, p. 45). This granite, a very light gray to almost white, medium-grained stone composed of feldspar, quartz, and mica, has been extensively quarried since 1904. Blocks of stone are obtained by lifting layers of granite, and subdividing them into blocks by the plug and feather method, as described in detail by Councill (1954, p. 51–53). The blocks are slabbed, shaped, and polished in nearby shops for use in building and trimming mausoleums, in bridge construction, as architectural stone, and for curbing. They are also used for statuary and monuments. The quarries of this area lead the Nation in output of stone used in mausoleums (Councill, 1954, p. 45).

Spartanburg County , S.C.—According to Sloan (1908, p. 198), a gray medium-fine-grained biotite granite with excellent working qualities and susceptible to high polish has been quarried near Pacolet (fig. 60, loc. 31). This granite underlies an area of at least 100 acres, and has been extensively quarried for use in monuments.

TABLE 74.—*Areas containing dimension granite quarries*

No. (fig. 60)	Location	No. (fig. 60)	Location
North Carolina			
26	Mount Airy	28	Hendersonville
27	Winston Salem		
South Carolina			
30	Greenville	33	Tugaloo
31	Pacolet	34	Westminster
32	Walhalla	35	Pendelton
Georgia			
36	Elberton	43	Stone Mountain
37	Carlton	44	Lithonia-Pine Mountain
38	Athens		
39	Winder	45	Calloway
40	Bay Creek	46	Carrollton
41	Snellville	47	Newnan
42	Centerville	48	Franklin
Alabama			
49	Wedowee	51	Tallassee
50	Rockford		

Anderson County, S.C.—Biotite granite gneiss, ranging in color from dark gray with a reddish cast to bright gray is reported by Sloan (1908, p. 177) to have been extensively quarried in the vicinity of Pendelton (fig. 60, loc. 35) and used to make culverts, abutments, and piers. The granite has good working qualities under chisel and chipping hammers and takes a fine polish.

Gwinnett County, Ga.—An extensive belt of highly contorted biotite granite gneiss begins just south of the border of Appalachia in north-central Georgia, extends northeastward across the southern half of the county, and terminates in Barrow County. Within this belt the granite gneiss is exposed both as a surface pavement and as dome-shaped masses that rise in places several hundred feet above the surrounding lowlands. Many quarries throughout the belt have produced dimension stone, particularly at Winder, Bay Creek, Snellville, Centerville, and Lithonia-Pine Mountain (fig. 60, loc. 39–44). According to Watson (1902, p. 142) the first stone quarried in the area was at Pine Mountain, in 1883. Herrmann (1954, p. 8) described the stone as being medium grained, extremely hard, gray white and showing banding due to concentrations of light- and dark-colored minerals in alternating bands ranging in thickness from one-tenth to one-half inch. The stone is well suited for general building purposes and for curbing because of its ease in quarrying and ability to withstand weathering.

PRODUCTION

Granite constituted 12 percent of the tonnage and 9 percent of the value of Appalachian dimension-stone production from 1945 to 1964. The Appalachian output of 678,000 tons during this period amounted to 6 percent of the total dimension granite quarried in the United States. Quantities and values of annual production in the United States for the 20-year period are given in table 75. Annual Appalachian production is withheld in order not to disclose individual company data. Leading producing States in Appalachia were North Carolina and Georgia. Of the 1964 Appalachian production, 52 percent was sold as building stone and the remainder as curbing, flagging, monumental stone, and paving blocks.

TABLE 75.—*Production of granite (dimension stone), 1945–64*

[Source: U.S. Bur. Mines]

Year	United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	362	$11, 832
1946	535	21, 761
1947	521	23, 315
1948	562	25, 866
1949	486	24, 557
1950	548	25, 932
1951	523	24, 652
1952	509	23, 477
1953	597	23, 829
1954	634	26, 377
1955	617	26, 658
1956	545	26, 758
1957	539	26, 873
1958	621	24, 059
1959	654	26, 221
1960	600	28, 517
1961	662	30, 389
1962	902	31, 788
1963	753	32, 665
1964	843	33, 583
Total	12, 013	519, 109

SLATE

Slate, consisting essentially of quartz and silicate minerals, is a microgranular crystalline rock derived by metamorphism of shale. Slate's distinguishing characteristic is its tendency to cleave easily along nearly parallel and very closely spaced planes; this is the main basis for its industrial value. Other important properties are color, hardness, toughness, and electrical and chemical resistivity. Slate is used either as a dimension stone or in crushed or finely ground form. Dimension shapes are used for roofing, for blackboards, for mounting electrical equipment, and as "mill stock" for making stair treads and risers, flooring and flagstones, building-facing panels, mantles and hearths, sinks and drainboards, grave vaults and covers, table tops, and for decorative stone of various kinds. Slate crushed to granule size has been used to coat composition roofing and siding, and presently is used for surfacing tennis courts and driveways. Finely ground slate is used as inert filler in a variety of products ranging from paint to rubber and in abrasive soaps and polishes.

The color of slate is of considerable commercial importance. The colors most desirable for roofing are deep brick red, grayish purple, olive green, gray green, dull-bluish green, brown, or mottled in various color combinations. Color differences are due to the presence of various mineral constituents, such as hematite in red slate, chlorite in dark-green slate, sericite in light-green and gray slate, and carbon in black slate. In deposits of slate, cleavage, grain, shear zones, and joints are of primary importance. Cleavage determines how well the slate will split into large very thin slabs such as blackboards. The grain, a plane of breakage usually at right angles to the cleavage, determines the ease with which usable blocks of slate can be broken out of a quarry. Widely spaced joints are an aid in quarrying, but numerous shear zones and closely spaced joints generally make the slate worthless as dimension stone.

In the region of Appalachia, most slate occurs in long sinuous belts associated with other metamorphic rocks, chiefly argillite, phyllite, schist, quartzite, and marble.

VALLEY AND RIDGE SLATE BELT

Most of the slate in Appalachia occurs in a long narrow belt which extends from Unicoi and Washington Counties, Tenn. southwestward through Georgia, and into Bibb and Chilton Counties in central Alabama (fig. 60). This belt coincides in a general way with the eastern boundary of the Valley and Ridge province, but encroaches to a limited extent the southwestern part of the Blue Ridge province. The belt is bordered on the southeast along most of its length by major thrust faults, and is delineated on the northwest by a somewhat arbitrarily drawn line, west of which slaty cleavage is absent or poorly developed in the rocks.

Slate deposits within the Tennessee part of the belt occur in the Ocoee Series of Precambrian age in Blount, Monroe, and Sevier Counties. The slate in Blount County is light to dark bluish gray, pale green and pale purple, and even grained, with good cleavage and moderate strength. Most cleavage surfaces are rough and lusterless. Virtually all the former workings in Blount County are now included in the Great Smoky Mountains National Park.

Several quarries have been opened in Monroe County, but most of the slate appears to have been used locally. This slate is micaceous and exhibits various colors and types of cleavage including dark-bluish gray with lustrous ribboned cleavage faces, dark-purplish gray and green with smooth lusterless cleavage faces.

Sevier County slate has not been mined and few data are available about it.

In the Georgia part of the belt, slate has been quarried from two separate formations; the Conasauga Formation of Cambrian age in Bartow County, and the so-called "Rockmart Slate," a lens within the Chickamauga Limestone of Ordovician age (Hayes, 1902) in Polk County. The slate-producing area in Bartow County is nearly 5 miles wide and, although it extends northward into Gordon and Murray Counties (Shearer, 1918, p. 99), most slate has been produced from the vicinity of Fairmount (fig. 60, loc. 52) near the Gordon County line where the slate is green. Until World War I, the slate was quarried extensively for roofing material. Later, according to Furcron (1964–65, p. 20), the use of green slate for roofing granules caused a revival of the industry, and the deposits have provided a steady flow of slate granules and flour. However, dimension slate is no longer produced.

The slate-bearing areas in the vicinity of Rockmart, Polk County (fig. 60, loc. 53), are bounded on the southeast by a large thrust fault. The commercial deposits, consisting of very dark bluish-gray slate with smooth to rough and uneven cleavage, lie in a zone a few miles wide. The material within a half mile of the bounding thrust fault is badly crumpled and schistose (Shearer, 1918, p. 57) and therefore unsuitable for use as dimension stone. Material more than a few miles away from the fault has imperfect slaty cleavage that makes it unsuitable for most uses. The slate is weathered to depths ranging from 15 to more than 40 feet. Quarrying of Rockmart slate began about 1850 (Furcron, 1964–65, p. 29), and most of it was used as roofing material. Since then, the quarries have been worked intermittently, but none of the slate is now used for dimension stone.

Slate-bearing areas in the Alabama segment of the belt, chiefly in Talladega, Shelby, and Chilton Counties (fig. 60), have been prospected and some material has been quarried for local use. Jones (1926) reported that the slate appears to be of good quality. The slate occurs in several different formations: the Talladega Slate of Precambrian(?) to Carboniferous(?) age, the Weisner and Rome (Montevallo) Formations of Cambrian age, and the Chickamauga Limestone of Ordovician age. The best deposits occur in the Weisner Formation in the southwestern part of Talladega County, and in the Rome (Montevallo) Formation in Chilton County. Butts (1940b) reported the presence of rock suitable for use as roofing material in the Waxahatchee Slate in Shelby and Chilton counties. He described it as light gray with good cleavage but containing numerous closely spaced joints.

WEST VIRGINIA SLATE BELT

Dark-gray to black carbonaceous clay-slate of doubtful quality occurs within a belt of Martinsburg Shale of Ordovician age in Berkeley County, W. Va. According to Dale (1906, p. 119), the northeast-trending belt is 14 miles long and 2–3 miles wide. The slate is generally unsuitable for most uses but some may find use as mill stock items for inside use.

PENNSYLVANIA SLATE BELT

The Pennsylvania slate belt, described by Behre (1927, 1933), Ashley (1931), Stone (1932), and B. L. Miller and others (1939, 1941), trends northeastward parallel to, but, for the most part, just outside the southeastern boundary of the Pennsylvania part of Appalachia. The slate, formed within the Martinsburg Shale, has been extensively quarried. The belt is one of the largest slate-producing regions in the United States. A small part extends into Carbon County where, according to Dale and others (1914, p. 108–109), dark-bluish-gray slate with finely banded texture and rough lusterless cleavage surfaces has been quarried for roofing slate and mill stock.

OTHER SLATE-BEARING AREAS

Sullivan and Washington Counties, Tenn.—Two areas containing small deposits of slate lie north of the Valley and Ridge slate belt, one in Sullivan County, the other in Washington County (fig. 60). Both deposits are in the Athens Shale of Ordovician age. The slate is very dark gray to black with fair cleavage (Dale and others, 1914, p. 118–119).

Fannin County, Ga.—Several quarries have produced slate for flagstones and crushed rock from the Nantahala Slate of early Paleozoic(?) age and the Brasstown Schist of Cambrian age, in the eastern part of Fannin County (fig. 60). The slate is greenish gray to grayish black, strongly banded and ribboned, and relatively coarse grained. It has good slaty cleavage and breaks readily into thin sheets many feet across (Hurst, 1955, p. 50–51, 127).

MISCELLANEOUS DIMENSION STONE

Miscellaneous varieties of dimension stone (local varieties not reported to U.S. Bur. Mines according to rock type) accounted for 0.1 percent of the value and 0.5 percent of the quantity of Appalachian dimension stone production from 1945 to 1964. Production during this period represented 2 percent of the miscellaneous dimension stone quarried in the United States. Quantities and values of annual production in Appalachia and the United States for the 20-year period are given in table 76. Pennsylvania was the major producing State. Production from Appalachia, last reported in 1963, was used as rubble and flagging.

TABLE 76.—*Production of miscellaneous varieties of dimension stone, 1945–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	1	5	35	908
1946	2	13	47	1,174
1947	(1)	(1)	42	1,724
1948	(1)	2	80	2,049
1949	(1)	1	90	2,131
1950	(1)	1	104	2,556
1951	----------	----------	112	2,500
1952	2	21	91	2,689
1953	(1)	13	65	2,910
1954	1	25	35	2,776
1955	5	74	54	2,865
1956	5	45	146	3,369
1957	3	26	79	3,282
1958	3	43	60	3,492
1959	4	55	93	3,667
1960	3	44	96	4,091
1961	----------	----------	113	3,849
1962	----------	----------	141	4,066
1963	1	14	160	4,251
1964	----------	----------	153	4,672
Total	30	382	1,796	59,021

[1] Production less than 500 tons or $500.

GYPSUM AND ANHYDRITE

By C. F. WITHINGTON, U.S. Geological Survey and GEORGE E. FISH, JR., U.S. Bureau of Mines

INTRODUCTION

The calcium sulfate minerals gypsum and anhydrite occur in beds formed by precipitation from saline waters, generally in partly isolated arms of the sea. Gypsum is hydrous calcium sulfate ($CaSO_4{\cdot}2H_2O$); when pure it contains 32.5 percent lime (CaO), 46.6 percent sulfur trioxide (SO_3), and 20.9 percent water. Pure gypsum is white or light gray; impurities may color it dark gray, black, pink, green, or yellow. The most common form is massive rock gypsum, a compact aggregate of small crystals occurring in beds as much as 100 feet thick. Alabaster is a compact very fine grained rock gypsum. Other varieties, of mineralogic interest only, include satin spar and selenite.

Anhydrite is calcium sulfate ($CaSO_4$); when pure it contains 41.19 percent CaO and 58.81 percent SO_3; it is slightly heavier and harder than gypsum. Pure anhydrite may be gray, bluish gray or white; impurities may color the mineral red, pink, gray or black. Anhydrite may occur as isolated crystals or lenses within a gypsum deposit; bedded gypsum deposits pass into anhydrite at depth.

TABLE 77.—*Uses of United States gypsum products*

[Source: U.S. Bur. Mines]

Use	1963		1964	
	Quantity (thousand short tons)	Value, in 1958 constant dollars (thousands)	Quantity (thousand short tons)	Value, in 1958 constant dollars (thousands)
Uncalcined:				
Portland-cement retarder	2,898	12,931	3,034	12,997
Agricultural gypsum	1,262	4,372	1,475	5,518
Other uses [1]	49	563	53	623
Total	4,209	17,865	4,562	19,138
Calcined:				
Industrial:				
Plate-glass and terra-cotta plasters	46	778	50	788
Pottery plasters	50	1,115	53	1,218
Dental and orthopedic plasters	13	484	14	541
Industrial molding, art, and casting plasters	90	1,945	99	2,165
Other industrial uses [2]	80	2,774	76	2,796
Total	279	7,094	292	7,508
Building:				
Plasters:				
Base-coat	1,036	19,158	972	18,667
Sanded and premixed perlite	477	11,837	455	11,515
To mixing plants	1	21	(3)	3
Gaging and molding	123	2,649	121	2,703
Prepared finishes	9	821	9	817
Roof-deck	325	4,622	352	5,438
Other [4]	19	1,033	22	1,108
Keene's cement	36	963	34	936
Total	2,026	41,104	1,965	41,187
Prefabricated products [5]	[6] 8,214	348,027	[6] 8,642	363,884
Total	----------	389,131	----------	405,071
Grand total, value	----------	414,090	----------	431,717

[1] Includes uncalcined gypsum for use as filler and rock dust, in brewer's fixe, in color manufacture, and for unspecified uses.

[2] Includes dead-burned filler, granite polishing, and miscellaneous uses.

[3] Less than ½ unit.

[4] Includes joint filler, patching, painter's, insulating, and unclassified building plasters.

[5] Excludes tile.

[6] Includes weight of paper, metal, or other materials.

Gypsum is the more useful of the two minerals; most gypsum mined in the United States is calcined for use as plaster, principally in the manufacture of wallboard and other prefabricated gypsum products (table 77). Uncalcined or raw gypsum is used as a set retarder for portland cement and as a soil conditioner. Annual production of gypsum in the United States has exceeded 10 million tons in the past few years, about 25 percent of world production. Gypsum for use as a soil conditioner was first imported from Nova Scotia; it was not until 1790 that uncalcined gypsum was produced in the United States, and

TABLE 78.—*Historical growth of the gypsum industry in the United States, for selected years, 1890–1964*

[Data from Barton (1965) and Barton, in U.S. Bur. Mines (1965a, p. 418)]

Year	Crude gypsum production (thousand short tons)	Gypsum products sold or used					
		Uncalcined except land plaster		Land plaster		Calcined	
		Thousand short tons	Value per ton, in 1958 constant dollars	Thousand short tons	Value per ton, in 1958 constant dollars	Thousand short tons	Value per ton, in 1958 constant dollars
1890	183	19	4.43	57	11.00	79	22.61
1919	2,420	470	4.55	40	7.46	1,596	14.31
1929	5,016	1,028	3.33	38	7.50	3,362	15.41
1939	3,227	793	4.28	75	10.57	3,224	29.67
1949	6,608	1,564	3.93	426	4.84	6,359	27.47
1959	10,900	2,801	4.38	1,188	3.05	10,657	34.45
1963	10,388	2,947	4.56	1,262	3.45	10,519	37.52
1964	10,684	3,087	4.39	1,475	3.72	10,899	37.66

calcined gypsum was not produced here until about 1835. From 1790 to 1964, about 305 million tons of gypsum was produced in the United States of which about 45 percent was produced in the last 25 years. Table 78 shows production of gypsum for selected years.

Domestic production of gypsum may possibly reach 13 million tons by 1970, and perhaps 20 million tons by 1980. Gypsum imports may also increase from the present 5–6 million tons to perhaps 8 million tons in 1970.

The amount of anhydrite produced annually in this country is not known but probably amounts to only a few hundred thousand tons. It is used primarily as a soil conditioner and to a lesser extent as a retarder for portland cement. In Europe, anhydrite is used in making sulfuric acid and ammonium sulfate.

Calcium sulfate minerals occur in considerable quantities in the United States. It is estimated that potentially exploitable deposits contain 50 billion tons of rock of 85 percent or more gypsum. The amount of anhydrite available is many times that of gypsum. Although the United States has adequate reserves of gypsum, the deposits are not evenly distributed throughout the country. Appalachia is deficient in known commercial gypsum deposits and obtains most of its gypsum from outside the region.

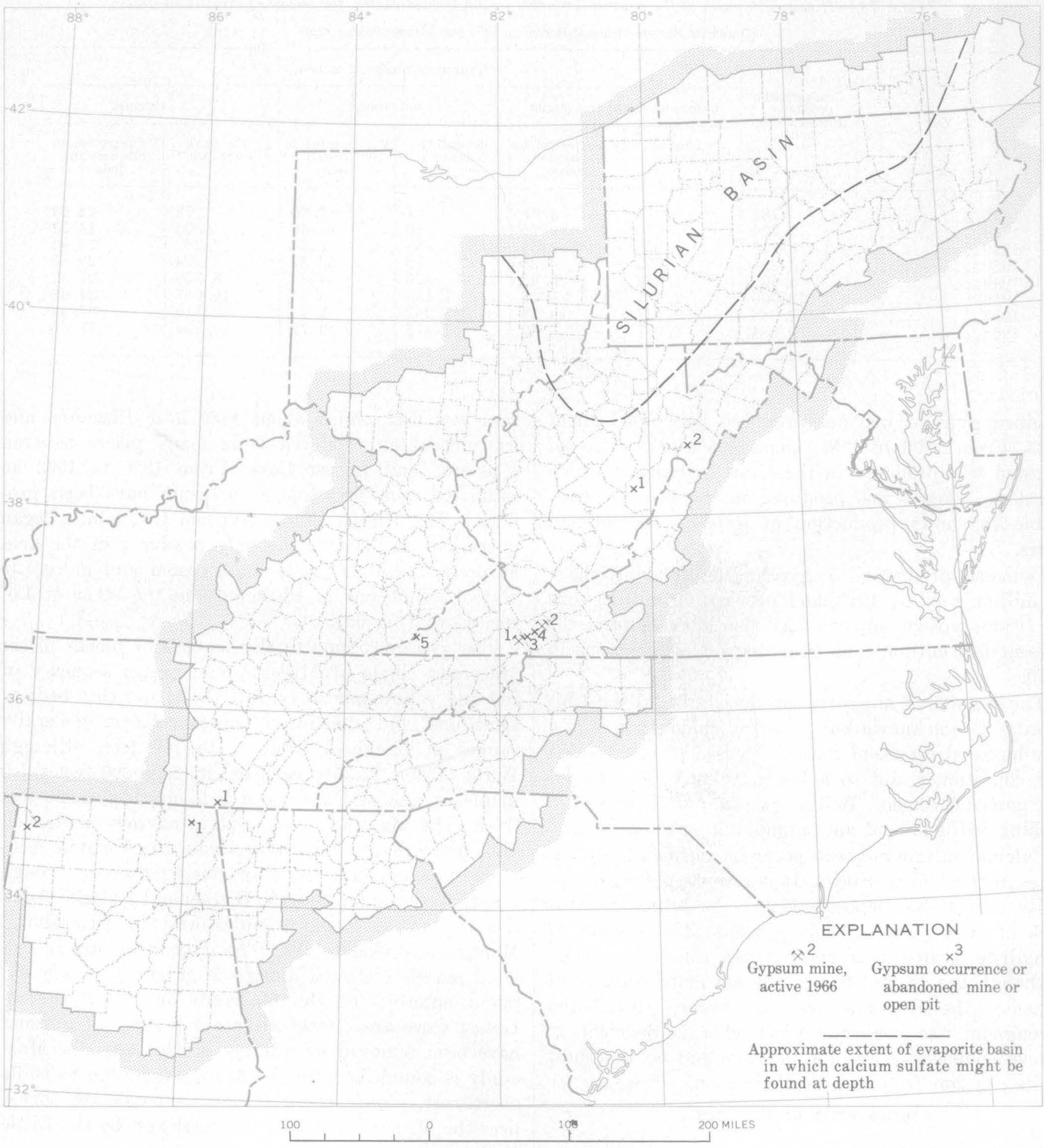
DESCRIPTION OF DEPOSITS

VIRGINIA

Although gypsum and anhydrite have been found throughout much of Appalachia, the only deposits of gypsum that have been worked are in the southwestern part of Virginia. These deposits crop out for 20 miles along the valley of the North Fork of the Holston River from Plasterco, Washington County, northeastward to Locust Cove, Smyth County. Gypsum was first mined about 1830 near Plasterco and has since been produced from many places between Plasterco and Locust Cove. From 1830 to 1963 an estimated 5 million tons of gypsum have been produced. The United States Gypsum Co., which began operations in 1909, is the only producer in the area at present, and is producing gypsum and anhydrite at two mines, one at Plasterco and the other at Locust Cove (fig. 63).

The gypsum occurs locally as beds or blocks in the Maccrady Shale of Mississippian age, a sequence of red and yellow mudstone, soft shale, and thin beds of sandstone and dolomite. This formation generally ranges in thickness from 50 to 100 feet, although Butts (1940a, p. 354) reported it to be 800 feet thick in places, and at Plasterco it is as much as 2,000 feet thick. The Maccrady crops out in narrow bands, seldom more than a mile wide, from the Virginia-Tennessee line, northeastward for about 120 miles through Scott, Washington, Smyth, Wythe, and Pulaski Counties to a point about 3 miles west of Blacksburg, Montgomery County, Va. The gypsum occurs in isolated masses scattered along the generally poorly exposed outcrops of the Maccrady in the Plasterco-Locust Cove area; most surface exposures of gypsum have been removed by mining. In this area the Maccrady is bounded on the southeast side by the Saltville overthrust, along which Cambrian rocks are thrust over the Maccrady, and on the northwest by the Little Valley Limestone.

The Maccrady Shale as exposed in the mine and drill holes of the United States Gypsum Co. at Plasterco is more than 2,000 feet thick and consists predominantly of detached masses or blocks (called boulders by the miners) of gypsum, anhydrite, salt and limestone in a matrix of red and green clay or shale. Some bedded gypsum is found near the upper



LIST OF LOCALITIES

ALABAMA
1 Estells Fork, Jackson County
2 Colbert County
TENNESSEE
1 Hales Bar Dam, Marion County

VIRGINIA
1 Plasterco, Washington County
2 Locust Cove, Smyth County
3 Saltville, Smyth County
4 North Holston, Smyth County
5 Hagan, Lee County

WEST VIRGINIA
1 Edray, Pocahontas County
2 Hardy County

FIGURE 63.—Gypsum and anhydrite in the Appalachian Region.

contact of the formation and veins of satin spar are scattered through the clay. The calcium sulfate is mainly gypsum to a depth of about 1,000 feet; below that it is predominantly anhydrite. Blocks of gypsum exposed in mining are typically 50–100 feet long, 20–80 feet high and 15 feet wide, and contain 1,000–15,000 tons each. The largest reported are more than 200 feet long, 10–30 feet wide and 150 feet high, and contain 50,000–75,000 tons of gypsum each (Appleyard, 1965).

The gypsum in the blocks is white and medium- to fine-grained, and in places is laminated with shale. The gypsum laminae are as much as 5 mm thick and the shale as much as 1 mm thick. The laminae represent an original depositional feature of the calcium sulfate. Locally the gypsum contains lenses and masses of petroliferous shale and black magnesian limestone. Some blocks of gypsum contain crystals of clear to slightly stained selenite as much as an inch long in a matrix of fine-grained gypsum.

The Plasterco mine is 1,000 feet deep, the deepest gypsum mine in the United States, and is developed by a vertical shaft, with drifts and inclines to the individual blocks of gypsum. The Locust Cove mine, which went into production in 1964, consists of a 1,200-foot-long incline to a depth of more than 600 feet below the surface. The gypsum, being mined from three levels, is shipped to Plasterco for milling. When this mine is in full production, the output is expected to be 1,000 tons per day and will eventually replace the mine at Plasterco (Appleyard, 1965). Major deposits that have been worked in the past between Plasterco and Locust Cove include one at Saltville, where a considerable amount of gypsum is present but where only a little mining has been done, and another at North Holston (formerly called Plasterburg). The gypsum at North Holston is in lenticular masses that parallel the bedding of the Maccrady. Mining was started in this deposit in 1906, and continued intermittently until World War II; both open-pit and underground mining methods were used. In 1938, the mine was 100 feet deep; no anhydrite was reported at that depth (J. S. Cullison, Tennessee Valley Authority, Unpubl. data, 1938).

The origin of the evaporites in southwest Virginia has been the subject of much speculation. Several early writers regarded the gypsum as an alteration product of limestone, possibly of very recent age (Lesley, 1862; Rogers, 1884, p. 141–142; Stevenson, 1885, p. 157–160). E. C. Eckel (1903, p. 402) concluded that both the salt and gypsum were deposited as part of the original sedimentary sequence through the evaporation of sea water, and he gave an early Carboniferous age to the deposits. Stose (1913) described the evaporite-bearing beds and named them the Maccrady Shale for exposures near Maccrady (now McCready) a town northeast of Saltville.

A discussion of the geologic setting of the gypsum in the Maccrady Shale in southwest Virginia and suggestions for prospecting for new deposits in the State is given in Withington (1965).

A 5–8-foot-thick gypsum bed in the Newman Limestone of Mississippian age has been reported north of Hagan, Lee County, Va. (fig. 63, loc. 5) (R. L. Miller, oral commun., 1965). The bed was exposed in the railroad tunnel between Hagan, Va., and Harlan County, Ky., about 2,700 feet from the south portal. The exposure is now covered, but, from the data available, Miller suggested that the gypsum-bearing beds dip 39° west and that if these beds were projected to the surface they would crop out about 550 feet above the south portal of the tunnel. No geologic maps of this area are available, but inasmuch as the bed was apparently hydrated where it was cut in the tunnel at least 500 feet below the surface, a considerable amount of gypsum may be present. If the gypsum is in a bedded deposit, it has probably been removed from the surface by solution, and drilling will be necessary to determine the exact nature of the deposit. A well in Tazewell County, Va. (United Production Co. J. M. Hoge Well 1–1532), penetrated gypsum in the Rome Formation at the intervals of 4833–4852 feet, 4964–5001 feet, and 5077–5118 feet (Virginia Minerals, 1965).

ALABAMA

E. C. Eckel (1935) reported stringers of rock gypsum in the Bangor Limestone of Mississippian age along Estells Fork in Jackson County and thin incrustations of gypsum interbedded with blue shale of Mississippian age in western Colbert County (fig. 63, loc. 1, 2). These occurrences are small but may represent the eroded outcrop of larger and more extensive subsurface beds. In Limestone County, gypsum occurs in isolated masses in the upper part of the Chickamauga Limestone. Although this material is not of commercial value, the Fort Payne chert which overlies the gypsum is highly contorted, and this contortion indicates that some gypsum might have been removed from the outcrop by solution (Geol. Survey of Alabama, written commun., 1966). Thin layers of gypsum of mineralogic interest occur south of Elkmont, Limestone County, scattered through a 1-foot-thick band a few feet below the Chattanooga Shale.

Isolated selenite crystals of mineralogic interest only have been reported from Franklin and Tuscaloosa Counties. One crystal from Franklin County, now in the collection of the Geological Survey of Alabama is a "magnificent large clear crystal on the inside of a black velvety lined dornick of brown iron ore" (Pallister, 1955, p. 27). Scattered selenite crystals occur in clay about 7 miles west of Northport, Tuscaloosa County (Alabama Geol. Survey, written commun., 1966).

TENNESSEE

According to a report in the files of the U.S. Geological Survey, J. M. Kellberg, geologist for the Tennessee Valley Authority, found gypsum in cores of four diamond-drill holes along the axis of Hales Bar Dam in Marion County (fig. 63, loc. 1). In one hole on the west bank, significant quantities of gypsum were scattered through about 70 feet of the Bangor Limestone of Mississippian age. Most are thin platy selenite and veinlets of satin spar, but Kellberg reported that "fairly solid" (massive?) gypsum was found about 180 feet below the surface. Its lateral extent is not known, for none of the other drill holes extended to the depth of the gypsum horizon. Extensive drilling might uncover gypsum of sufficient quantity to be minable.

WEST VIRGINIA AND OTHER AREAS

Minor quantities of gypsum have been reported in West Virginia, and although these occurrences are not economic, their presence might indicate commercial gypsum deposits of importance at depth. At Edray, Pocahontas County (fig. 63, loc. 1), the gypsum occurs as rounded masses, 2–4 inches in diameter, in the Greenbrier Limestone of Mississippian age (Martens, 1945, p. 12–13). Gypsum also is found in Hardy County (fig. 63, loc. 2) as lenses interbedded with shale (Price, Tucker, and Haught, 1938, p. 335).

In the Silurian saline basin, which underlies much of the northern part of Appalachia, calcium sulfate is associated with salt of Silurian age at depths of about 800–1,000 feet or more below the surface. Most calcium sulfate is anhydrite and is generally too deeply buried to be considered economic.

RESOURCE POTENTIAL

Although economic reserves of gypsum in Appalachia are known to be present only in the Saltville area of Virginia, other parts of the region have some promise of additional resources. Withington (1965) has indicated other promising areas in Virginia where the Maccrady Shale might be found in association with thrust faults; further geologic study and drilling in these areas and in other states, described on the preceding pages, may lead to discovery of new exploitable gypsum deposits.

LIGHTWEIGHT AGGREGATES

By A. L. Bush, U.S. Geological Survey, and John W. Sweeney, U.S. Bureau of Mines

INTRODUCTION

Since the first use of cinders in concrete some 75 or more years ago, many materials have been used as aggregates to lighten the weight of concretes and plasters; in loose form many of these materials are also used for thermal insulation. These materials may be natural or manufactured, or they may be byproducts from other operations. Materials as diverse as rice hulls, wax pellets, pumice, and expanded shale have been tried and tested; the mineral raw materials have proved to be most satisfactory.

A few mineral raw materials can be used in their natural state (pumice, scoria, and diatomite), but most require processing to decrease their unit weight. This processing may consist of heating the material under controlled conditions to cause expansion (clay, shale, slate, vermiculite, and perlite), or of burning an ingredient out of a mixture to leave voids (sintering clay materials or coal washery refuse), or of vesiculating a liquid during sudden cooling to form a solid froth (expanding blast furnace slag). Both the natural and the processed materials are light in weight because a high percentage of their volume consists of voids; ideally the voids should be spherical and unconnected, with strong and impervious shell walls. Actually the texture may be irregularly cellular as in sintered clay, spongelike as in pumice, or accordionlike as in vermiculite. Because of this cellularity, the mineral aggregates tend to make good thermal insulation. Their effectiveness generally increases with increasing porosity, but decreases with increasing unit weight and permeability. Many mineral aggregates also are desirable for their fire-resistant properties.

Lightweight and ultralightweight aggregates range in weight from about 5 to 75 pounds per cubic foot (Washa, 1956); expanded perlite and vermiculite (ultralightweight) weigh 5–20 pounds per cubic foot, and expanded clay, shale, slate, and slag weigh 30 or more pounds per cubic foot. J. E. Conley and others (1948, p. 8) pointed out that for concrete, the most economic results generally are obtained if the lightweight aggregate weighs about half as much as normal weight sand and gravel aggregate (about 110–120 lb per cu ft). Improving the workability of the concrete may require an increased amount of fine material (Kluge, Sparks, and Tuma, 1949, p. 628), so the weight may approach two-thirds or even three-quarters that of normal-weight aggregate. Depending on the grading of the aggregate and the mix proportions of cement, water, and aggregate, lightweight concrete and plaster range from 20 to 115 pounds per cubic foot (Washa, 1956, p. 379), compared with 140 to 160 pounds per cubic foot for normal-weight concrete.

The physical properties of suitable aggregates have been summarized by J. E. Conley (1942), Moyer (1942), Peterson (1949), Carlson (1956), Washa (1956), and Everhart and others (1958); the characteristics of lightweight concrete have been reported by J. E. Conley and others (1948), W. H. Price and Cordon (1949), Kluge (1956), Valore (1956), Shideler (1957), Gray and others (1961), Klieger and Hanson (1961), Beecroft (1962), and a host of others. The American Society for Testing and Materials (1965) has issued standard specifications and tests for lightweight aggregates and concrete.

The more commonly used materials for lightweight aggregates are clay, shale, slate, blast-furnace slag, vermiculite, and perlite, each in its expanded or sintered form, and volcanic pumice and scoria (and to a very minor extent diatomite or diatomaceous shale) in their natural state (Klinefelter, 1960). Appalachia has large reserves and resources of clay and shale. Moderate to large resources of slate, slag, and vermiculite are available in or near Appalachia. Perlite, pumice, and scoria are totally lacking.

All suitable lightweight-aggregate materials in Appalachia require heat treatment as well as crushing and grading, and so cost more per unit than normal-weight aggregates that need only grading or crushing and grading. The premium cost of the lightweights, therefore, must be offset by other direct or indirect cost advantages, as ease of handling, superior insulation qualities, or reduced steel framework costs. Lightweight aggregates are bulky materials of low unit value that usually cannot be transported long distances and still remain competitive. The result is that both the producing or processing plants and the sources of raw materials must be close to market areas. Because Appalachia has relatively few major market areas, wider development of its lightweight-aggregate resources depends on how well these resources can compete with other potential resources in markets adjacent to Appalachia.

A useful appraisal of Appalachia's potential in the highly competitive lightweight-aggregate market also must consider the nearby producers of similar materials. Expanded clay, shale, and slate compete with expanded slag, for they have generally similar bulk densities and compressive strengths. In the ultralightweight class, vermiculite competes with perlite; both have relatively low compressive strength. There is virtually no competition between the lightweight and the ultralightweight materials, for they are best suited for different applications.

Producing plants both in and near Appalachia are shown in figure 64, identified by the materials they process. Clay, shale, and slate are quarried in and adjacent to plants; the formations that are used also are identified on figure 64. Expanded slag plants are located only where the crude slag is produced. Vermiculite is shipped to processing and market areas for exfoliation, except for plants near the mines in northwestern South Carolina. All perlite is imported from the western United States; it is included in this discussion to give perspective to the vermiculite potential.

The amount of lightweight aggregate produced annually is tied very closely to the level of activity of the building and highway construction industries, the largest consumers of the aggregate. High transportation costs for the bulky low-unit-value materials and aggressive competition from normal-weight and by-product lightweight aggregates act as dampers on the growth of the industry. On the other hand, opportunities for substantial growth may be provided by the development of new markets for established uses, increased use in less common operations, and the introduction of new applications.

In many parts of the country, little or no use is made of lightweight or ultralightweight aggregates, largely because of inadequate knowledge of the suitable raw materials and their advantages. In 1962, only 54 percent of all concrete block produced in the United States were made with lightweight aggregate (James H. Davis, written commun., 1965). In Appalachia, suitable clay, shale, and slate are widely distributed, far more so than sources of blast-furnace slag or commercial quantities of cinders. Recognition of the availability of raw materials and the advantages of the lightweight product, particularly in insulation, can lead to the establishment of new industries in new market areas, both in and near Appalachia.

Lightweight structural concrete is one of the uses where a larger market could be developed. Properly designed, lightweight concrete has a wide variety of structural applications. Wider acceptance by architects, engineers, builders, and buyers can be expected, but this acceptance can be quickened by the imaginative and pioneering use of lightweight concrete in large-scale projects, such as stadiums, municipal redevelopment areas, fine-arts centers, and the like. The concept that concrete construction requires great bulk for high strength is waning. With this change in thinking, opportunity is great for broader use of lightweight structural concrete.

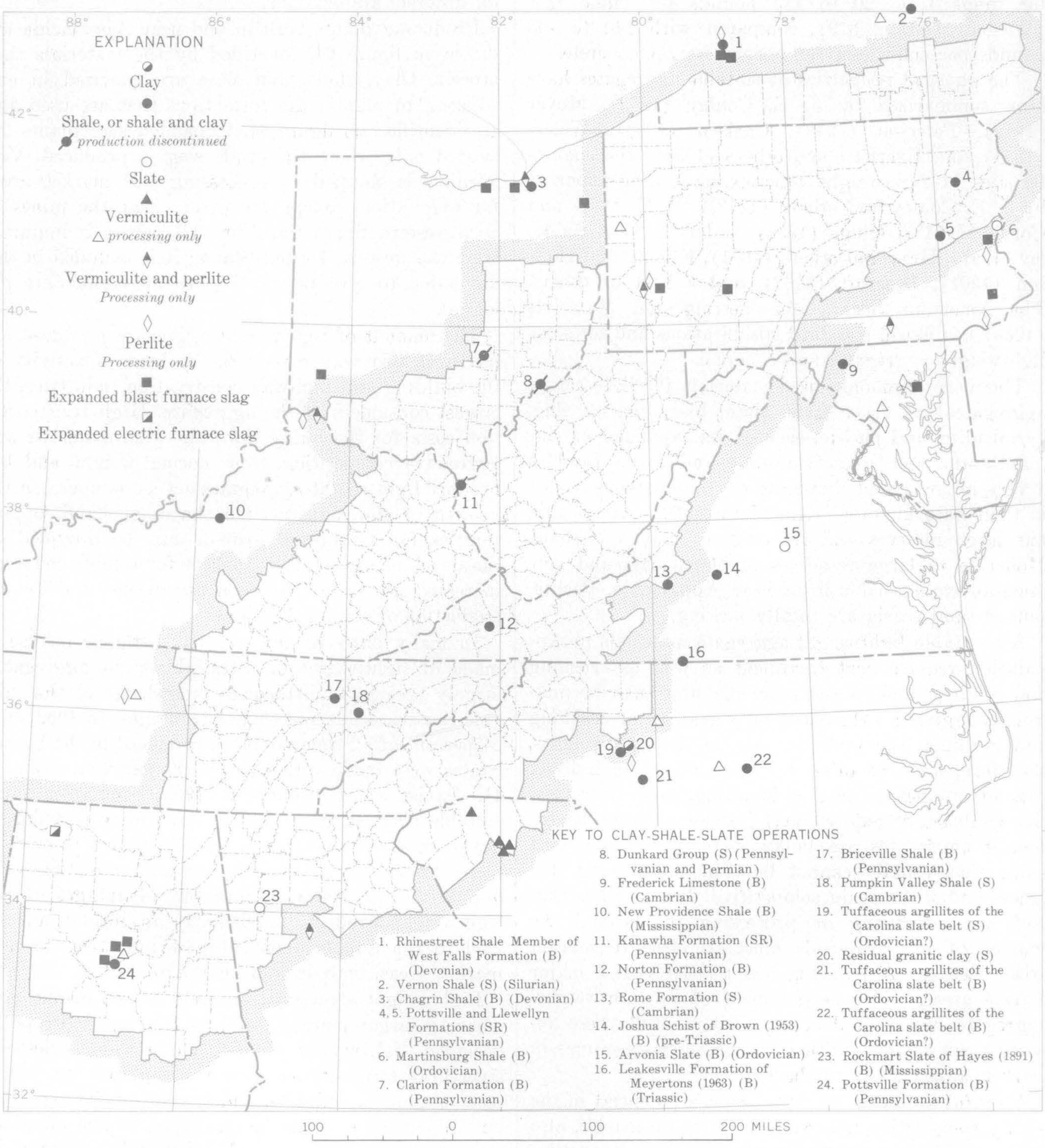


Figure 64.—Plants producing or processing lightweight aggregate in the Appalachian Region. Lettering indicates process: B, bloating; R, coal washery refuse; S, sintering.

A new application of lightweight aggregate as a skid-resistant surface for highways may develop a substantial new market. Recent research at the University of Tennessee's Engineering Experiment Station (E. A. Whitehurst, written commun., March 1966) and recent research in Texas (Gallaway, 1964) indicate that expanded shale aggregate in the seal coat makes a satisfactory highway surface, with respect to both traction and durability. A market developed for this use could be particularly significant in Appalachia, where there may be a large increase in the upgrading of present highways and in new highway construction.

There is a vital need for market analyses of the general type done by the Tennessee Valley Authority (1965a) for a part of the TVA region. Analyses such as these can indicate the raw-material sources and general competitive position for a prospective lightweight aggregate operation. Supplemental studies also are essential to analyze capital investment requirements, types of aggregates in current demand, future applications and the types of aggregate that will be needed, and the size of the potential market.

EXPANDED CLAY, SHALE, AND SLATE

Many types of clay, shale, and slate develop a bloated or vesicular structure on high-temperature heating. Austin, Nunes, and Sullivan (1942), Riley (1951), Ehlers and Richardson (1958), and many others have investigated possible causes of bloating and the conditions for most efficient and economical controlled expansion. J. E. Conley and others (1948), Klinefelter and Hamlin (1957), Hamlin and Templin (1962), and many others have described methods to evaluate possible raw materials.

Bloating results from the evolution of gases within the raw material; if the gas evolves in a temperature range where the material is beginning to be vitrified (pyroplastic) it will be trapped, and expansion will take place. Above and below this range the gas will escape. Small changes in composition of minor components of the material can affect the temperatures of gas evolution and of material softening, the width of the bloating range, and the amount of expansion. Commercial bloating is done in rotary kilns or in sintering beds, and if the temperature range between softening and liquefaction is narrow, the bloating is difficult to control. Production is usually most economical between 1,800°F and 2,200°F, but the temperature can be as low as 1,600°F or as high as 2,400°F. Materials with a wide variety of bloating temperatures are thus suitable.

The suitability of argillaceous materials is affected by the content of substances such as iron, alkali, carbonate, organic material, and silt. Too much of these materials may cause the bloating range to be too narrow, the firing temperature to be too high, or the expanded product to be too heavy. Within a lithologic unit the contents may vary greatly in short vertical distances but commonly they are more uniform laterally.

The relationships among composition, weathering, structure, and thickness affect the suitability, and units in one area that do not bloat, that bloat imperfectly, or that bloat only at uneconomically high temperatures, may be eminently suitable a short distance away. A thorough sampling and testing program is necessary to trace suitable beds and to outline areas of various degrees of favorability.

Clay, shale, and slate can also be ground, mixed with combustible material (ground coal), and sintered to produce lightweight aggregates. The argillaceous materials generally become pyroplastic and stick together, and voids are left as the combustibles are burned out; some bloating may occur, but it is incidental to the sintering. Thus units that may not bloat of themselves still can be sources for lightweight aggregate. It is hazardous, therefore, to classify units as unfit for lightweight aggregate unless they have been tested and found to be unsuitable for both processes.

So many kinds of argillaceous sediments and sedimentary rocks have been found to be suitable that it is difficult to single out characteristics that distinguish the favorable from the unfavorable. Illitic and montmorillonitic materials seem to be more consistently suitable than kaolinitic ones. Dark-colored (green, gray, black) clay and shale, particularly those with a moderate organic content, generally are more suitable than light colored (particularly reddish) ones, but some black shale does not bloat and some red shale does. Common or brick clay generally is more suitable than flint or ball clay. Marine, littoral, lacustrine, and fluviatile clays and shales all are possible raw materials, and they constitute a very large percentage of the bedded rocks of Appalachia. They occur in formations that range in thickness from a few feet to a 1,000 feet or more. Outcrop areas range from narrow bands of only a few acres to broad areas of many square miles. Suitable formations occur in the sedimentary rocks of every Paleozoic system, and they are particularly numerous in the Mississippian and Pennsylvanian rocks.

Because of the wide geographic and stratigraphic distribution, no attempt is made in this report to present a map showing sources of clay, shale, and slate. The geologic map of Appalachia (pl. 2) can best be used for this purpose, and the formations from which sampling and testing have identified suitable materials (table 79) are keyed to this map by letter symbols. Formations that have supplied material for commercial production of lightweight aggregate are indicated in table 79 and figure 64.

Much of the clay and shale extracted as waste in the course of coal-mining operations or separated in the coal washeries is suitable raw material. Much is bloatable in itself; some is suitable sinter feed with the addition of only small amounts of ground coal (Myers and others, 1964; Utley and others, 1965). As byproducts of coal extraction, the mining costs are low, so the raw material may be processed into a relatively low-cost lightweight aggregate. A future possibility may be the use as an aggregate of "spent" oil shale that could result from retorting of black shale such as the Upper Devonian Chattanooga Shale and its correlatives (U.S. Bur. Reclamation, 1952; Conant and Swanson, 1961, p. 69; Pray, 1965).

On the basis of the meager data available, meaningful calculations of total reserves and potential resources are not possible. However, it is obvious that the potential resources are ample for any foreseeable demand for an extremely long time. Reserves in the Appalachian deposits now being quarried amount to several million tons. Factors other than the quantity of crude material in the ground will control the utilization of clay, shale, and slate for lightweight aggregate.

TABLE 79.—*Known and potential clay and shale sources of lightweight aggregate in the Appalachian Region*

[Suitability for bloating or sintering based on: Commercial production (C); Rotary kiln tests (K); Laboratory tests (L); Similarity to known suitable materials (S); Test for nonaggregate properties (T). No sources in South Carolina.]

Rock unit	Age	Geologic map symbol (pl. 2)	Process		Commercial plant (fig. 64)	References and remarks
			Bloat	Sinter		
		Alabama				
Rome Formation	Cambrian	Ꞓml		L		Pallister and others (1964, p. 8).
Chattanooga Shale	Devonian	DSO	S			Suitable in nearby Tennessee. (Conant and Swanson, 1961, p. 69).
Girkin (Gasper) Formation	Mississippian	Mu	L			Tennessee Valley Authority (1965a, p. 7).
Pottsville Group or Formation	Pennsylvanian	ℙp	L,K			Conley and others (1948, p. 51), Pallister and others (1964, p. 2, 35).
Parkwood Formation	Mississippian and Pennsylvanian.	M	C		24	Truman Jones (oral commun., 1966).
Coker Formation	Cretaceous	K	L			Marginal suitability, (Pallister and others, 1964, p. 26).
Tuscaloosa Group	do	K	L			Pallister and others (1964, p. 27, 30).
		Georgia				
Rome Formation	Cambrian	Ꞓml	L			Furcron (1958, p. 11).
Conasauga Shale or Formation	do	Ꞓml	L			R. W. Smith (1931), Furcron (1958, p. 4, 11).
Rockmart Slate of Hayes (1891)	Ordovician or Mississippian.	Oum	C		23	Vallely and Peyton (1957, p. 324, 333).
Chattanooga Shale	Devonian	DSO	S			Suitable in nearby Tennessee. (Conant and Swanson, 1961, p. 69).
		Kentucky				
New Providence Shale	Mississippian	Ml, M	C		10	McGrain (1957, p. 23).
Pennington Shale	do	Mu, M	L			Do.
Breathitt Formation	Pennsylvanian	ℙp, ℙa	L			McGrain (1957, p. 23; 1958, p. 29).

TABLE 79.—*Known and potential clay and shale sources of lightweight aggregate in the Appalachian Region*—Continued

Rock unit	Age	Geologic map symbol (pl. 2)	Process		Commercial plant (fig. 64)	References and remarks
			Bloat	Sinter		
Maryland						
Martinsburg Shale	Ordovician	O	L	------	------	U.S. Geological Survey (1964).
			S	S	------	Suitable in Pennsylvania. (O'Neill and others, 1965, p. 400, 401).
Romney Shale	Devonian	D	L	------	------	M. M. Knechtel (oral commun., 1966).
Marcellus Shale Member	do.	D	S	S	------	Suitable in Pennsylvania. (O'Neill and others, 1965, p. 400, 401).
Rockwell Formation	Mississippian	M	L	------	------	M. M. Knechtel (oral commun., 1966).
Greenbrier Formation	do.	M	L	------	------	Do.
Allegheny Formation	Pennsylvanian	ℙap	L	------	------	Do.
			S	S	------	Suitable in Pennsylvania. (O'Neill and others, 1965, p. 400, 401).
Conemaugh Formation	do.	ℙc	L	------	------	M. M. Knechtel (oral commun., 1966).
			S	S	------	Suitable in Pennsylvania. (O'Neill and others, 1965, p. 400, 401).
Monongahela Formation	do.	ℙ	L	------	------	M. M. Knechtel (oral commun., 1966).
New York						
Sonyea Formation Middlesex Shale Member	Devonian	Du	L	------	------	Brownell and others (1951, p. 178).
West Falls Formation Rhinestreet Shale Member	do.	Du	L	------	------	Brownell and others (1951, p. 172).
			C	------	1	Used in nearby area, (Wallace and Slaypoh, 1958, p. 778; Davis, 1963, p. 9).
Perrysburg Formation Dunkirk Shale Member	do.	Du	L	------	------	Brownell and others (1951, p. 168–169).
North Carolina						
Rome Formation	Cambrian	Ꞓbc	L	------	------	Oriel (1950, p. 54–55).
Newark Group	Triassic	T̄R	C	------	16	Broadhurst (1955, p. 51–52); Stuckey and Conrad (1961, p. 9, 22). Used as Leakesville Formation in Virginia. (Meyertons, 1963, p. 5–12, 50).

TABLE 79.—*Known and potential clay and shale sources of lightweight aggregate in the Appalachian Region*—Continued

Rock unit	Age	Geologic map symbol (pl. 2)	Process		Commercial plant (fig. 64)	References and remarks
			Bloat	Sinter		
Ohio (nomenclature of Pennsylvanian units is that of the references cited and does not necessarily conform to that of the U.S. Geological Survey)						
Eden Group	Ordovician	Oum	L	------	------	Everhart and others (1958, p. 8, 9).
Olentangy Shale	Devonian	Du	L	------	------	Everhart and others (1958, p. 9).
Chagrin Shale	do.	Du	S, C	------	3	Suitable nearby, (J. W. Hosterman, oral commun., 1966).
Cuyahoga Group	Mississippian	M	L	------	------	Everhart and others (1958, p. 8).
Black Hand Formation	do.	M	S	------	------	Do.
Anthony Shale	Pennsylvanian	ℙp	S	------	------	Do.
Massillon Shale	do.	ℙp	S	------	------	Do.
Bear Run Shale	do.	ℙp	S	------	------	Do.
Lower Mercer Shale	do.	ℙp	L	------	------	Do.
Brookville Clay	do.	ℙp	L	------	------	Do.
Lower Kittanning Clay and Shale	do.	ℙa	L	------	------	Do.
Washingtonville Shale	do.	ℙa	C	------	7	Flint (1951, p. 49), Henry Brown (oral commun., 1966).
Middle Kittanning Shale	do.	ℙa	L	------	------	Everhart and others (1958, p. 8).
Putnam Hill Shale	do.	ℙa	L	------	------	Do.
Birmingham Shale	do.	ℙa	L	------	------	Do.
Mahoning Shale	do.	ℙc	S	------	------	Do.
Brush Creek Shale	do.	ℙc	L	------	------	Do.
Bellaire Shale	do.	ℙc	L	------	------	Do.
Cow Run Shale	do.	ℙc	L	------	------	Do.
Fishpot Shale	do.	ℙm	L	------	------	Do.
Dunkard Group	Pennsylvanian and Permian.	P	L	C	8	Bowen (1955), Everhart and others (1958, p. 8).
Minford Silt	Pleistocene	Not shown.	L	------	------	Do.
Pennsylvania						
Martinsburg Shale	Ordovician	O	K.	L	6	O'Neill and others (1965, p. 400, 401).
Rose Hill Formation	Silurian	S	------	L	------	O'Neill and others (1965, p. 335, 401).
Catskill Formation	Devonian	D	K	L	------	Do.
Hamilton Group	do.	D	K	------	------	Do.
Mahantango Formation	do.	D	K	L	------	Do.
Marcellus Shale	do.	D	------	L	------	O'Neill and others (1965, p. 111, 401).
Post-Pottsville rocks, undivided	Pennsylvanian	ℙ	C	------	5	Thomson and Otte (1958, p. 997).
				L	------	O'Neill and others (1965, p. 311, 401).
Clarion Sandstone	do.	ℙa	K	------	------	O'Neill and others (1965, p. 230, 400).
Kittanning Formation	do.	ℙa	K	L	------	O'Neill and others (1965, p. 400, 401).
Conemaugh Formation	do.	ℙc	K	L	------	Do.
Monongahela Formation or Group	do.	ℙm	K	------	------	O'Neill and others (1965, p. 353, 400).
Washington Formation	Pennsylvanian and Permian.	P	------	L	------	O'Neill and others (1965, p. 341, 401).
Greene Formation	Permian	P	K	------	------	O'Neill and others (1965, p. 337, 400).

TABLE 79.—*Known and potential clay and shale sources of lightweight aggregate in the Appalachian Region*—Continued

Rock unit	Age	Geologic map symbol (pl. 2)	Process		Commercial plant (fig. 64)	References and remarks
			Bloat	Sinter		
			Tennessee			
Rome Formation	Cambrian	Ꞓml	K	L	------	Conley and others (1948, p. 41–44), Scott (1953, p. 98, 116).
			L			Tennessee Valley Authority (1965a, p. 5).
Pumpkin Valley Shale	do	Ꞓml	L	C	18	Brick and Clay Record (1956), Finlayson (1965).
Conasauga Shale	do	Ꞓml	L	------	------	Tennessee Valley Authority (1965a, p. 5).
Nolichucky Shale	do	Ꞓml	S	S	------	Suitable in nearby Virginia (S. S. Johnson and others, 1965).
Reedsville Shale	Ordovician	Oum	L	------	------	Tennessee Valley Authority (1965a, p. 5).
Sequatchie Formation	do	Oum	L	------	------	Do.
Chattanooga Shale	Devonian	MD, MDS, MDSO	L	------	------	Conant and Swanson (1961, p. 69).
Pennington Formation	Mississippian	Mu, M	L	------	------	Milici (1965).
Briceville Shale	Pennsylvanian	ℙ	K	L	------	Conley and others (1948, p. 44–50), Scott (1953, p. 98, 116).
			C	------	17	Lenhart (1951).
Whitwell Shale	do	ℙp	L	------	------	Milici (1965).
Slatestone Group (shale members)[1]	do	ℙp	L	------	------	Tennessee Div. Geology unpub. data (1966).
Indian Bluff Group (shale members)[1]	do	ℙp	L	------	------	
			Virginia			
Rome Formation	Cambrian	Ꞓml	L	C	13	S. S. Johnson and others (1965), C. E. Smith (1963, p. 6).
Pumpkin Valley Shale	do	Ꞓml	L	------	------	S. S. Johnson and others (1965), R. A. Laurence (written commun. 1966).
Rogersville Shale	do	Ꞓml	L	------	------	S. S. Johnson and others (1965).
Nolichucky Shale	do	Ꞓml	L	L	------	Do.
Athens Shale	Ordovician	Oum	L	------	------	Do.
Edinburg Formation of Cooper and Cooper (1946)	do	Oum	S	------	------	Suitable nearby (Calver and others, 1964, p. 72).
Martinsburg Shale	do	O, Oum	S	S	------	Suitable nearby (Calver and others, 1964, p. 66, 70).
Clinton Formation	Silurian	MDS, S	L	------	------	S. S. Johnson and others (1965).
Brallier Shale	Devonian	MDS, DS, D, DSO	L	L	------	Calver and others (1964, p. 25, 130, 160).
Chemung Formation	do	D	L	------	------	Calver and others (1964, p. 30).
Chattanooga (Genesee) Shale	do	D	L	------	------	S. S. Johnson and others (1965).
Romney Shale	do	DSO, D, DS	L	S	------	Calver and others (1964, p. 40, 92).
Bluestone Formation	Mississippian	M	L	------	------	S. S. Johnson and others (1965).
Hinton Formation	do	M	L	------	------	Do.
Maccrady Shale	do	M	L	L	------	Calver and others (1964, p. 28).
Norton Formation	Pennsylvanian	ℙp	C	L	12	S. S. Johnson and others (1965), C. E. Smith (1963, p. 4).
Wise Formation	do	ℙp	L	L	------	S. S. Johnson and others (1965).
Leakesville Formation of Meyertons (1963)	Triassic	Ꞧ	C	------	16	C. E. Smith (1963, p. 3). Meyertons (1963, p. 5–12, 50).

See footnote at end of table.

TABLE 79.—*Known and potential clay and shale sources of lightweight aggregate in the Appalachian Region*—Continued

Rock unit	Age	Geologic map symbol (pl. 2)	Process		Commercial plant (fig. 64)	References and remarks
			Bloat	Sinter		
West Virginia						
Martinsburg Shale	Ordovician	O	T	------	------	McCue and others (1948, p. 27).
			S	S	------	Suitable in nearby Virginia (Calver and others, 1964, p. 66, 70).
Romney Shale	Devonian	D	S	S	------	Suitable in nearby Virginia (Calver and others, 1964, p. 40, 92).
Bedford Shale	Devonian or Mississippian.	D, M	S	------	------	Suitable in nearby Ohio (Bowen, 1955).
Sunbury Shale	Mississippian	M	S	------	------	Suitable in nearby areas (Conant and Swanson, 1961, p. 69).
Bluefield Formation	do	M	T	------	------	McCue and others (1948, p. 65).
Hinton Formation	do	M	T	------	------	McCue and others (1948, p. 57).
			S	------	------	Suitable in nearby Virginia (S. S. Johnson, and others, 1965).
Maccrady Shale	do	M	T	------	------	McCue and others (1948, p. 61).
			S	------	------	Suitable in nearby Virginia (Calver and others, 1964, p. 28).
Kanawha Formation	Pennsylvanian	ℙp	T	C	11	Myers and others (1964, p. 2).
				------	------	Coal Age (1950a, p. 93), McCue and others (1948, p. 27).
Norton Formation	do	ℙp	S	S	------	Used in nearby Virginia (C. E. Smith, 1963, p. 4; S. S. Johnson and others, 1965).
Wise Formation	do	ℙp	S	S	------	
Allegheny Formation	do	ℙa	T	------	------	McCue and others (1948, p. 37, 39).
			S			Suitable in nearby Ohio (Everhart and others, 1958, p. 8, 9).
Conemaugh Formation	do	ℙc	T	------	------	McCue and others (1948, p. 25, 34).
			S	------	------	Suitable in nearby Ohio (Everhart and others, 1958, p. 8, 9).
Monongahela Formation	do	ℙm	T	------	------	McCue and others (1948, p. 42, 63).
			S	------	------	Suitable in nearby Pennsylvania (O'Neill and others, 1965, p. 400).
Dunkard Group	Pennsylvanian and Permian.	P	S	S	------	Used in nearby Ohio (Bowen, 1955 and Everhart and others, 1958, p. 8).
Washington Formation	do	P	T	------	------	McCue and others (1948, p. 31, 33).
				S	------	Suitable in nearby Pennsylvania (O'Neill and others, 1965, p. 401).
Greene Formation	Permian	P	T	------	------	McCue and others (1948; p. 8, 81).
			S	------	------	Suitable in nearby Pennsylvania (O'Neill and others, 1965, p. 400).

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[1] Of the Tennessee Division of Geology.

During the last 10-year period for which records are currently available (through 1964), Appalachia has produced about 12 percent of all the clay, shale, and slate used for lightweight aggregate in the United States (table 80). In the mid-1950's the proportion was about 20 percent. Production in Appalachia has increased, but at a slower rate than elsewhere in the country, so in 1964 Appalachia's share of the market was only 10 percent. Total U.S. production in 1964 (Cooper, 1965a, p. 376) was about 7.5 million tons of lightweight aggregate produced from clay, shale, and slate in 70 plants in 33 states.

TABLE 80.—*Production of clay, shale, and slate used in the manufacture of lightweight aggregate, 1955–64*

[Source: U.S. Bur. Mines]

Year	Appalachia [1] (short tons)	United States [2] (short tons)
1955	553, 768	3, 092, 583
1956	767, 377	4, 087, 913
1957	507, 819	3, 752, 455
1958	466, 823	4, 456, 867
1959	530, 800	5, 270, 298
1960	699, 314	5, 504, 367
1961	686, 314	6, 047, 092
1962	698, 199	6, 769, 912
1963	753, 589	6, 796, 961
1964	732, 052	6, 753, 000
Total	6, 396, 055	52, 531, 488

[1] Includes slate used for the manufacture of lightweight aggregate.
[2] Excludes slate used for the manufacture of lightweight aggregate.

During 1964 only seven plants were operating within the borders of Appalachia. In addition, Birmingham Clay Division, Vulcan Materials Co., began producing expanded shale at Bessemer, Ala., late in 1965. Lightweight aggregate (expanded slate) was first produced in Georgia in 1954 by Georgia Lightweight Aggregate Co. at Rockmart, Ga. Production has been continuous from 1954 through 1964. Lightweight aggregate plants at Marietta and New Lexington, Ohio, operated from 1953 to 1960. They were inactive in 1964.

Two lightweight aggregate plants have operated in Pennsylvania, both utilizing shale from anthracite coal mine wastes. The Warner Company has operated a plant at Tamaqua since 1950. In 1964, a lightweight aggregate plant was put in operation by the Bylite Corp. at Pittston, Pa. Lightweight aggregate (expanded shale) was first produced in Appalachian counties of Tennessee in 1955 by two companies, Shalite Corp., Knoxville, and La-Lite Aggregate Co., Lake City. Production has been continuous from 1955 through 1964. In 1966, initial production of lightweight aggregate from expanded shale was reported by Tennlite, Inc., Greenbrier, Tenn., just west of the Appalachia border. Two lightweight aggregate plants are operating in the Appalachia section of Virginia. Webster Brick Co. operates a plant at Roanoke and reported production from 1955 through 1964. Lightweight Aggregate Division, Clinchfield Coal Corp. operates a plant at Dante and has reported production from 1960 through 1964. Trulite Corp. operated a lightweight aggregate plant at Ceredo, W. Va., using shale from bituminous coal mine wastes; this plant operated from 1955 through 1961.

EXPANDED SLAG

In Appalachia, expanded slag is produced at five iron-blast-furnace operations in western Pennsylvania and Alabama and at one phosphorus-electric-furnace plant in northwestern Alabama (fig. 64). In neighboring areas expanded blast-furnace slag is produced at nine other plants in Ohio, eastern Pennsylvania, and Maryland (fig. 64).

TABLE 81.—*Production of expanded blast furnace slag, 1954–64*

[Source: U.S. Bur. Mines from Natl. Slag Assoc.]

Year	Appalachia [1]		United States	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
1954	1, 222	2, 927	2, 599	6, 673
1955	1, 182	3, 421	2, 892	8, 662
1956	1, 270	3, 764	2, 990	8, 952
1957	1, 137	3, 269	2, 942	8, 572
1958	1, 071	3, 065	2, 985	8, 638
1959	1, 176	3, 122	2, 812	7, 926
1960	1, 043	2, 951	2, 626	7, 704
1961	848	2, 394	2, 275	6, 765
1962	812	2, 289	2, 249	6, 569
1963	781	2, 289	2, 251	6, 676
1964	782	2, 341	2, 426	7, 237
Total	11, 324	31, 832	29, 047	84, 374

[1] Includes production from plants at Youngstown and Middletown, Ohio, outside Appalachia.

Annual U.S. production of expanded blast-furnace slag for the past 4 years has been 2.2–2.4 million tons (table 81), valued at about $7 million. In Appalachia (table 81), production has decreased steadily over the past 6 years to about two-thirds of the 1959 production, from nearly 1.2 million tons to less than 0.8 million tons in 1963 and 1964. There was a very slight increase in 1964, but preliminary estimates indicate a continuing decrease in 1965. The decrease over the 6-year period reflects in large measure a local reduction in the supply of blast-furnace slag available for processing. The decrease is anticipated to continue for the next year or two, and production of expanded blast-furnace slag is likely to drop to about 0.5 million tons per year (W. R. Barton, oral commun., March, 1966). The economics of the byproduct iron-blast-furnace-slag industry are outside the scope of this paper, but it is likely that the expanded-slag segment of the production in Appalachia will continue to be several hundred thousand tons a year. An even greater amount is and will be available from the slag plants nearby; the total for the region shown in figure 64 is probably about a million and a quarter tons.

Expanded electric-furnace slag is produced in Appalachia at Wilson Dam, Colbert County, Ala. The slag is a byproduct of the manufacture of elemental phosphorus by the Tennessee Valley Authority (Scott and Sandberg, 1953). In 1965, nearly 200,000 short tons was sold for lightweight aggregate (R. A. Laurence, written commun., March 1966); a considerably greater tonnage is and probably will be available for many years to come.

VERMICULITE

Vermiculite is a lightweight-aggregate material found in significant quantity in Appalachia. It is a micaceous mineral that expands upon heating; the expansion (exfoliation) is accordionlike, perpendicular to the cleavage. In the laboratory the mineral expands to as much as 30 times it original volume; commercially, twentyfold expansion is about the maximum. In its expanded form, vermiculite has a bulk density of 5–10 pounds per cubic foot, classing it as an ultralightweight aggregate. In addition it has low thermal conductivity, is chemically inert, and is fairly refractory—qualities that make it suitable for loose-fill insulation, as well as aggregate for concrete and plaster.

Vermiculite characteristically is associated with ultramafic rocks, and the relationship is clearly demonstrated in southeastern Appalachia. Dunite, saxonite, and pyroxenite bodies have intruded Precambrian metamorphic rocks of the Blue Ridge province, in a belt that extends northeast from White County, Ga., to Floyd County, Va. (pl. 2; fig. 65). Scattered ultramafic intrusive bodies also are found as far southwest as Tallapoosa County, Ala., and northeast (outside the boundaries of Appalachia) in Virginia. Chromite, corundum, and olivine occur in many of these ultramafic rocks, and vermiculite is present with most of them. Many ultramafic rock bodies also occur in the Paleozoic metamorphic rocks of the inner part of the Piedmont province in western South Carolina and northeastern Georgia (pl. 2; fig. 65); vermiculite deposits are present in the South Carolina area.

HISTORY AND PRODUCTION

Most vermiculite deposits are in the intrusive ultramafic bodies of the Blue Ridge. The earliest sustained production of vermiculite in the southeast began in 1933 from the Swannanoa (Buncombe County) and Ellijay (Macon County) districts of North Carolina (fig. 65); these districts have also been the most productive in the Blue Ridge. Sporadic production that ended in 1955 came from many other deposits in these counties and in Jackson and Yancey Counties, N.C., and from a few in Towns and Rabun Counties, Ga. In part at least this sporadic production reflects the generally small size of most deposits and the spotty distribution of minable concentrations.

The most productive deposits, however, are those of the inner Piedmont of South Carolina. Production began about 1937, in the Tigerville district of Greenville County and has continued to the present in the Enoree district of Spartanburg and Laurens Counties.

Nearly all vermiculite deposits of the southeastern States that are or have been mined lie within the borders of Appalachia. The only exceptions are the Laurens and Union County deposits, and these are within about 10 miles of the border of Appalachia. The exceptions, however, include some of the largest and most productive deposits of the southeast.

In 1963 and 1964, more than 99 percent of all United States vermiculite production came from Montana, the largest producer, and from South Carolina. Total crude-ore production in 1964 was 226,000 tons, worth about $3.6 million (May, 1965a, p. 1151). All the substantial South Carolina production came from just outside Appalachia, but in 1965, production was resumed in Spartanburg County inside Appalachia.

During the past 11 years, total United States production of both crude and exfoliated vermiculite has increased (table 82). The production of exfoliated vermiculite in Appalachia has ranged from about 10,000 to 15,000 tons per year during this same period. The cumulative production for the years 1954–64 has been about 120,000 tons, worth more than $7 million.

TABLE 82.—*United States production of crude and exfoliated vermiculite, 1954–64*

[Source: U.S. Bur. Mines]

Year	Crude		Exfoliated	
	Short tons	Value (1958 constant dollars)	Short tons	Value (1958 constant dollars)
1954	196,000	2,732,000	145,000	11,633,000
1955	204,000	2,939,000	158,000	10,881,000
1956	193,000	2,685,000	159,000	10,194,000
1957	184,000	2,646,000	161,000	10,071,000
1958	191,000	2,727,000	155,000	9,785,000
1959	207,000	3,039,000	153,000	9,459,000
1960	199,000	3,080,000	151,000	10,213,000
1961	206,000	3,330,000	151,000	10,722,000
1962	205,000	3,270,000	152,000	11,074,000
1963	226,000	3,558,000	172,000	13,821,000
1964	226,000	3,595,000	177,000	13,793,000
Total	2,237,000	33,601,000	1,734,000	121,646,000

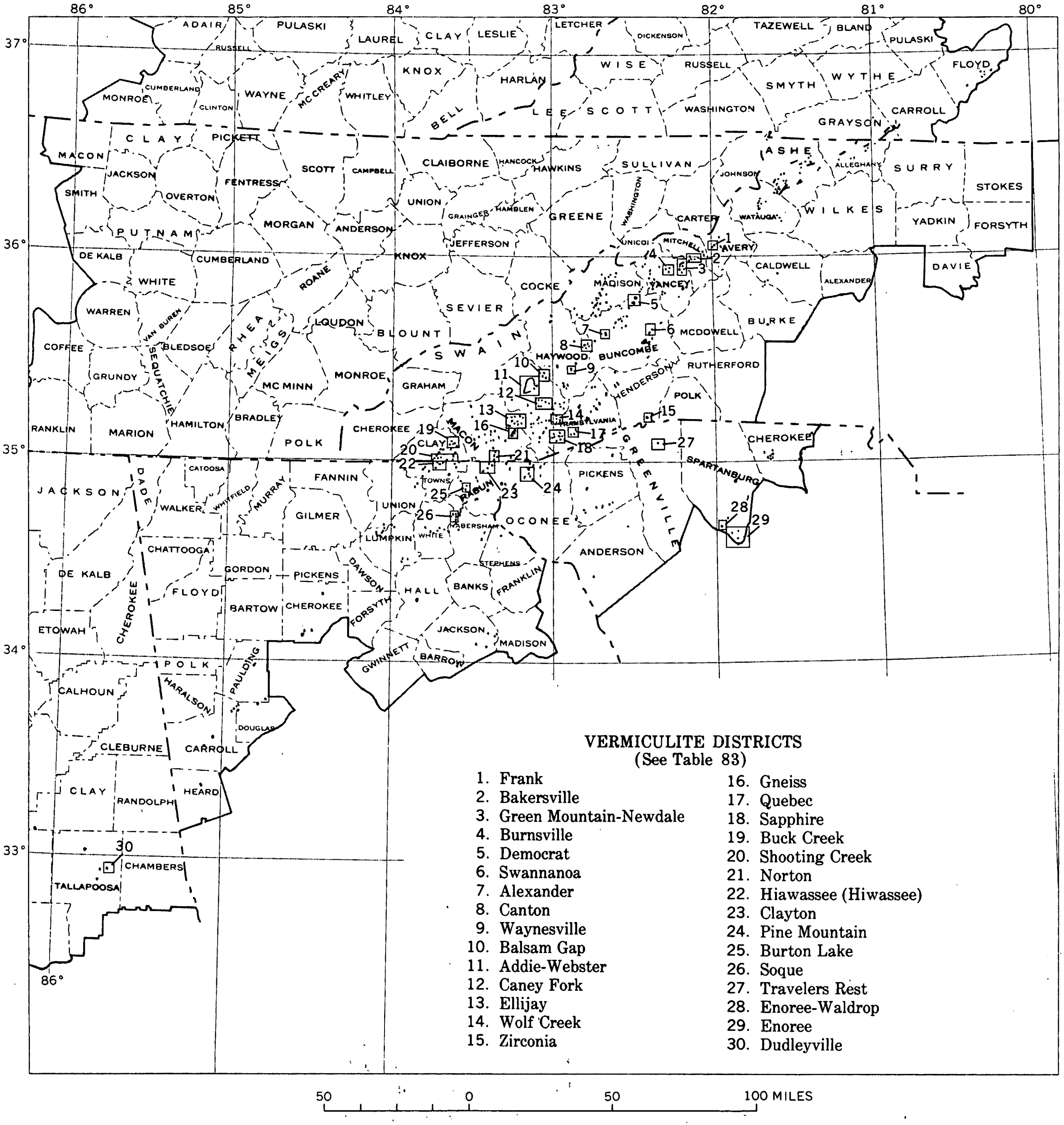

FIGURE 65.—Index map showing vermiculite districts in the Appalachian Region. Dots and irregular lines are areas of outcrop of ultramafic rocks. (Modified from Larrabee and Sweeney, this report, figure 86.)

GENERAL HABIT AND ORIGIN

Most vermiculite deposits are in ultramafic rocks that have been cut by acidic intrusive rocks—granite, syenite, or pegmatite. The older rocks have been hydrothermally altered, probably as a result of the emplacement of the younger intrusives. Commonly biotite, phlogopite, chlorite, actinolite, tremolite, and a suite of associated minerals have been formed, dependent on the composition of the host rock. The effect has been to add potassium, silica, and water. Some investigators believe that vermiculite was formed as a mineral of the hydrothermal suite (Prindle and others, 1935; Leighton, 1954), but most believe that vermiculate results from supergene alteration (weathering processes and the effects of circulating meteoric waters) of biotite, phlogopite, and chlorite that formed by hydrothermal alteration (Murdock and Hunter, 1946; Roy and Romo, 1957; Bassett, 1963). Both chemical and mineralogical studies point more and more strongly to the supergene origin, and in most cases field relations are consistent with this concept, because vermiculite is found to change downward to biotite.

The acceptance of the concept of weathering rather than a concept of hydrothermal action for the origin of the deposits markedly affects the estimation of vermiculite resources. On the basis of the habits of most known deposits, resource estimates should be restricted to material in the zone of weathering, and prospecting should be guided similarly.

GEOLOGY OF THE DEPOSITS

The association of vermiculite deposits with ultramafic rocks is obvious in figure 65, and the contrast in distribution between the deposits of the Blue Ridge and the Inner Piedmont is apparent. Individual deposits are listed by district in table 83, together with references to pertinent descriptions of the geology. Of the many published reports on the deposits in the Blue Ridge province, only a few describe the geology and mineralogy in detail (Murdock and Hunter, 1946; Kulp and Brobst, 1954). Hunter (1950, p. 125–126) has published one of the few descriptions of the important deposits of the inner Piedmont in South Carolina. Several representative districts or deposits are described in the present report.

In deposits of the Blue Ridge province, vermiculite is found in the zone of weathering, in veins and lenses along the commonly serpentinized contact of dunite and pyroxenite bodies with the enclosing rocks and with crosscutting pegmatites, and along fractures (both minor faults and joints) within the bodies. The largest and most continuous veins and lenses are at the contacts, but the highest grade vermiculite is along the internal fractures. Most dunite and pyroxenite bodies form dikes or irregular lenticular masses. Where the country rock is mafic—as hornblende gneiss or biotite schist—vermiculite may be found on both sides of the contact, but generally it is found only in the ultramafic rocks.

Hunter (1950, p. 122) described the typical zoning across one of the internal fractures where repeated alteration took place. The sequence from wall to center is (1) fresh or relatively unaltered olivine or pyroxene, (2) serpentine, (3) locally amphibole, (4) chlorite or vermiculite, and (5) in many places, a pegmatite core. At the contact of dunite with country rock, only units 1–4 are developed in the dunite. These relations are fairly representative of the deposits in the Swannanoa (Bee Tree), Ellijay, and Cowarts areas of North Carolina and the Laurel Creek and Scattaway Creek areas of northeastern Georgia (fig. 65). Prindle and others (1935), Hunter and Mattocks (1936), and Murdock and Hunter (1946) have described individual deposits in more detail, and Kulp and Brobst (1954) have published a discussion of the geochemistry. In these typical deposits of the Blue Ridge, the vermiculite-bearing veins are composed of a series of vermiculite lenses that may be as much as 4–5 feet thick and 50–60 feet long and that may extend to the base of the zone of weathering (in many places 50–60 ft). Exceptionally, the lenses may be 20 feet thick and more than 100 feet long (Hunter, 1950, p. 124).

The deposits in the inner Piedmont of South Carolina (fig. 65) are not as well known as those of the Blue Ridge, largely because exposures are poor and the rocks have been intensely and deeply weathered, but also because information obtained by the mining companies about the habit, mineralogy, size, and distribution of the vermiculite deposits is generally not available.

Hunter (1950, p. 125–126) described the inner Piedmont deposits of South Carolina, showing how they differed in lithology and structure from those in the Blue Ridge of North Carolina. The South Carolina deposits seem to have resulted from deep weathering of biotite that formed from the alteration of pyroxenite, called ultrabasic lenses, in contact with biotite gneiss and schist. Presumably the pyroxenite bodies are intrusive; if so, Hunter's description (1950, p. 126) of vermiculite masses with horizontal dimensions of 150 by 450 feet and a depth to unaltered biotite of 80 feet or so suggests pluglike bodies rather than dikes or irregular lenticular masses like the North Carolina deposits. Granite and pegmatite are present, and the formation of biotite from pyroxenite is attributed to solutions related to the acidic rocks. Although mineral zoning has not been specifically identified, Buie and Stewart's description (1954) of deposits at Tigerville suggests that zoning is generally similar to that in North Carolina. Pervasive alteration to biotite and equally pervasive weathering to vermiculite have resulted in much larger deposits than those of the dunite belt in North Carolina, Georgia, and Alabama. Since 1955, vermiculite production in the southeast has come solely from the South Carolina deposits.

TABLE 83.—*Vermiculite deposits in the Appalachian Region*

No. (fig. 65)	District; deposit(s)	County	Production	References
	North Carolina			
1	Frank; Frank (or Guy), Senia	Avery	×	Hunter (1941, p. 43–48); Murdock and Hunter (1946, p. 16–17).
2	Bakersville; Pipkins, Pitman, White Oak mine.	Mitchell	×	Murdock and Hunter (1946, p. 37); U.S. Geol. Survey, unpub. data.
3	Green Mountain-Newdale; Pleasant Grove Church, Hall, Harris Clay, Edwards.	Yancey	×	Hunter and Mattocks (1936, p. 9–10); Hunter (1941, p. 53–56).
4	Burnsville; Day Book	do	×	Hunter (1941, p. 48–53); Kulp and Brobst (1954).
5	Democrat; Holcombe Branch, Democrat.	Madison, Buncombe.		Hunter (1941, p. 58–63); Murdock and Hunter (1946, p. 36).
6	Swannanoa; Bee Tree, H. A. Coggins, Lake Eden.	Buncombe	×	Hunter and Mattocks (1936, p. 6); Murdock and Hunter (1946, p. 17–20).
7	Alexander; Juno	do		Hunter (1941, p. 63–64).
8	Canton; Newfound Gap, Hominy Grove.	Buncombe, Haywood.		Hunter (1941, p. 65–67); Murdock and Hunter (1946, p. 17, 21).
9	Waynesville; Retreat	Haywood		Murdock and Hunter (1946, p. 21).
10	Balsam Gap; Balsam Gap, Dark Ridge.	Jackson		Hunter (1941, p. 67–80).
11	Addie-Webster; Fisher, Ocher Creek, Cane Creek, Webster.	do		Hunter (1941, p. 80–97); Murdock and Hunter (1946, p. 22–24, 27).
12	Caney Fork; Cowarts, John Lovedohol, Cowards.	do		Hunter and Mattocks (1936, p. 7, 9); Murdock and Hunter (1946, p. 24–27).
13	Ellijay; Angel, Ammons (Moore's Knob), Jake Henry, McGuire, Bud Mincey (John Henry), Ellijay Creek, Charles Mincey, No. Nine, Vance Jennings, Adams Place, Higdon Mountain, Hickory Knob.	Macon	×	Hunter and Mattocks (1936, p. 6–9); Hunter (1941, p. 98–102). Murdock and Hunter (1946, p. 28–36); U.S. Geol. Survey, unpub. data.
14	Wolf Creek; Phillips, Upper Wolf Creek.	Jackson, Transylvania.		Hunter and Mattocks (1936, p. 9); Murdock and Hunter (1946, p. 37–39).
15	Zirconia; Lake Summit	Henderson		Murdock and Hunter (1946, p. 21–22).
16	Gneiss; Corundum Hill, Salem School, Pine Grove School.	Macon	×	Hunter (1941, p. 103–106); Murdock and Hunter (1946, p. 31, 34, 35).
17	Quebec; John Robinson	Transylvania		Hunter and Mattocks (1936, p. 9).
18	Sapphire; Bad Creek-Socrates Mine, Whitewater Mine, Burnt Rock Mine.	Jackson, Transylvania.	×	Murdock and Hunter (1946, p. 37–39).
19	Buck Creek; Buck Creek Peridotite.	Clay	?	Hunter and Mattocks (1936, p. 10); Hunter (1941, p. 107–112).
20	Shooting Creek; Nelson Rogers, Mark Rogers, Thumping Creek, Barnett Anderson.	do		Hunter and Mattocks (1936, p. 9); Murdock and Hunter (1946, p. 21).
21	Norton; Norton Property	Macon		Hunter and Mattocks (1936, p. 8).
	Georgia			
22	Hiawassee (Hiwassee); Jethro Burrell, Lemons Gap.	Towns		Smith (1934), Prindle (1935, p. 44–45); Hunter and Mattocks (1936, p. 8).
23	Clayton; Betty Creek	Rabun		Prindle (1935, p. 46).
24	Pine Mountain; Laurel Creek	do		Hunter and Mattocks (1936, p. 9), Hunter (1941, p. 113–117).
25	Burton Lake; Burton Lake	do		Hunter (1941, p. 112–113).
26	Soque; Mack Mountain	Habersham		Furcron (1948).

TABLE 83.—*Vermiculite deposits in the Appalachian Region*—Continued

No. (fig. 65)	District; deposit(s)	County	Production	References
		South Carolina		
27	Travelers Rest; Tigerville	Greenville	X	Hunter (1950, p. 126); Buie and Stewart (1954).
28	Enoree; Waldrop Pit	Spartanburg	X	Hunter (1950, p. 126); U.S. Geol. Survey, unpub. data.
29	Enoree; many deposits	do	X	Hunter (1950, p 126); Shirley and Johnson (1962, p. 948-949, 955).
		Alabama		
30	Dudleyville; unnamed	Tallapoosa		Hunter (1950, p. 124).

The contrast in production between Montana and South Carolina reflects the difference between the massive, large-tonnage, lower extraction-cost deposit at Libby, Mont., and the smaller, higher cost, scattered deposits of southeastern Appalachia. Most vermiculite from Appalachia is shipped as crude ore to the major marketing centers of the east coast and the Mississippi Valley. A small amount is exfoliated at plants near the mines and is sold in local markets. Transportation costs for crude ore are a significant part of the cost of exfoliated material and effectively limit both the marketing areas and the share of the market. Thus, lower transportation costs compensate in part for higher mining costs and allow some Appalachian deposits to remain active.

RESOURCE POTENTIAL

The resources of vermiculite in Appalachia can be estimated in only the most general terms, for most customary guides are lacking. The few detailed studies of individual deposits have emphasized habit and origin rather than quantity, grade, or economic potential. Production statistics, a significant clue to deposit potential, are scanty or not available.

Murdock and Hunter (1946, p. 4) estimated that the Blue Ridge-type deposits in North Carolina contained about 440,000 tons "probable" and "possible" reserves of vermiculite. The most promising districts are the Democrat, Swannanoa, and Canton of Buncombe County (and adjoining areas), the Addie-Webster and Caney Fork of Jackson County, and the Ellijay of Macon County. Production between 1946 and 1955 (the date of last production in North Carolina) was only a few thousand tons annually; total production is estimated to be about 25,000 tons. The Murdock and Hunter estimate for North Carolina indicates that resources in other Blue Ridge deposits in Alabama, Georgia, and Virginia, may be about 100,000 tons. The total potential resources for Blue Ridge-type deposits may then be slightly more than half a million tons.

Potential resources of the inner Piedmont deposits are believed to be greater than those of the Blue Ridge. Myers (1960) has stated that there are about 100 deposits of unspecified size in the Enoree district, Spartanburg and Laurens Counties, S.C., presently the only productive district in southeastern United States. Only a few of these deposits have been worked. No information is available about production or reserves.

PERLITE

Perlite is a silicic volcanic glass whose water content (generally 3–5 percent) causes abrupt and explosive expansion on rapid heating to the range 1,400°–2,100°F. It is not found in Appalachia, or anywhere east of the Mississippi for that matter, but it is included here to give additional perspective to the vermiculite industry, with which perlite is in most direct competition.

The ore comes mainly from New Mexico, but also from Arizona, California, Colorado, Hawaii, Nevada, Oregon, Texas, and Utah. Total crude ore mined in 1964 was 427,000 tons; of this, 350,000 tons (more than half again as much as vermiculite), worth about $3 million (May, 1965b, p. 825), was sold and used. Expanded perlite totalled 320,000 tons (nearly twice as much as vermiculite), worth about $15 million (May, 1965b, p. 825). Mining is generally a large-tonnage, low-unit-cost, stripping operation. Transportation costs are a very significant share of total cost, particularly of products used in northern and eastern markets. It is in these areas where competition with vermiculite is keenest. There are only two processors of perlite in Appalachia, but 11 others are in the nearby marketing centers; several of these process both vermiculite and perlite.

LIME

By George E. Ericksen, U.S. Geological Survey, and Robert D. Thomson, U.S. Bureau of Mines

Lime is principally calcium oxide (CaO), or a mixture of CaO and magnesium oxide (MgO), prepared by calcining limestone or dolomite, and is a basic industrial chemical that is manufactured at several localities in Appalachia (fig. 66). The lime-producing centers in Appalachia are (1) Birmingham, Ala., (2) central and western Pennsylvania, (3) Knoxville, Tenn., (4) southwestern Virginia and southeastern West Virginia, and (5) the Eastern Panhandle of West Virginia. In 1964, 31 lime plants were operating in these areas (fig. 66). Most of the lime is used as flux and refractory material by the steel industry, as a chemical in the manufacture of paper and for purification of water, as lime mortar by the construction industry, and as agricultural lime (aglime).

Three types of lime are marketed, quicklime, hydrated lime, and dead-burned dolomite. Quicklime is produced by calcining a high-calcium limestone at a temperature of about 2,000°F to make a product consisting almost entirely of CaO. Hydrated lime is made by treating quicklime with a controlled amount of water to transform the CaO to $Ca(OH)_2$. Dead-burned dolomite, used mainly as a refractory by the steel industry, is prepared by calcining high-purity dolomite, at high temperature (above 2,800°F). Dead-burned dolomite is relatively inert to action of atmospheric moisture and carbon dioxide, whereas the high-calcium lime is very reactive. The only dead-burned dolomite produced in Appalachia comes from the eastern panhandle of West Virginia.

The production of lime in Appalachia in 1964 totaled 2,273,257 short tons valued at $28,812,504 million. To make this lime, the companies used about 4.3 million tons of limestone and dolomite. Quicklime (including a relatively small amount of dead-burned dolomite) constituted most of the production—2,007,213 short tons valued at $25,047,610. Production of hydrated lime was 266,044 short tons valued at $3,764,894. These figures indicate that in 1964 the average value of quicklime in Appalachia was $12.48 per ton and of hydrated lime $14.15 per ton.

The high-calcium limestone and high purity dolomite described in the following section on limestone and dolomite are all potential sources of lime. High-quality aglime can be made from a magnesian limestone or calcitic dolomite as well as from pure limestone or dolomite.

Table 84 shows the geologic formations that were the sources of limestone and dolomite used for the manufacture of lime in Appalachia in 1964. By far the greatest part of high-calcium lime was produced from stone of the Vanport Limestone in western Pennsylvania, the Valentine Member (of Field, 1919) of the Curtin Formation (of Kay, 1943) in Centre County, Pa., the Mosheim Member of the Lenoir Limestone, and limestone beds in the Tomstown Dolomite in the Eastern Panhandle of West Virginia, the Holston Formation in Tennessee, and the Newala Limestone in Alabama. Dead-burned dolomite was produced only from Tomstown Dolomite of West Virginia.

Table 84.—*Limestones and dolomites used for production of lime in the Appalachian Region, 1964*

State	*County*	*Geologic formation*
Alabama	Shelby	Newala Limestone.
Pennsylvania	Armstrong	Vanport Limestone.
	Bedford	Curtin Limestone of Kay (1943).
	Butler	Vanport Limestone.
	Centre	Valentine Member of Field (1919) of the Curtin Limestone.
	Juniata	Keyser and Tonoloway Limestones.
	Mifflin	Nealmont (?) Formation of Kay (1943). Keyser and Tonoloway Limestones.
	Northumberland	Do.
	Snyder	Do.
	Westmoreland	Limestone of Pennsylvanian age.
Tennessee	Knox	Holston Formation.
Virginia	Giles	Lower Middle Ordovician limestone.
	Smyth	Do.
	Tazewell	Do.
West Virginia	Berkeley	Mosheim Member of Lenoir Limestone.
	Jefferson	Tomstown Dolomite (mined for high-calcium limestone and high-purity dolomite).
	Pendleton	Greenbrier (?) Limestone.

High-calcium limestone, suitable for the manufacture of high quality lime for industrial and metallurgical use, and construction is moderately abundant in many parts of Appalachia and should supply most present and future needs. Rock suitable for making agricultural lime is abundant and widespread.

High-purity dolomite for refractory lime is less widespread in Appalachia than high-calcium limestone. Only the Tomstown Dolomite of the Eastern Panhandle of West Virginia and the Ketona Dolomite of Alabama (now used as a fluxing stone but not used in the manufacture of lime) are major sources of high-purity dolomite. Reserves of the Ketona Dolomite are sufficiently large to supply the needs of the present or future Birmingham steel industry. Reserves of the high-purity Tomstown Dolomite are probably also large enough to supply the present market area in the future. The Honaker Dolomite of eastern Ten-

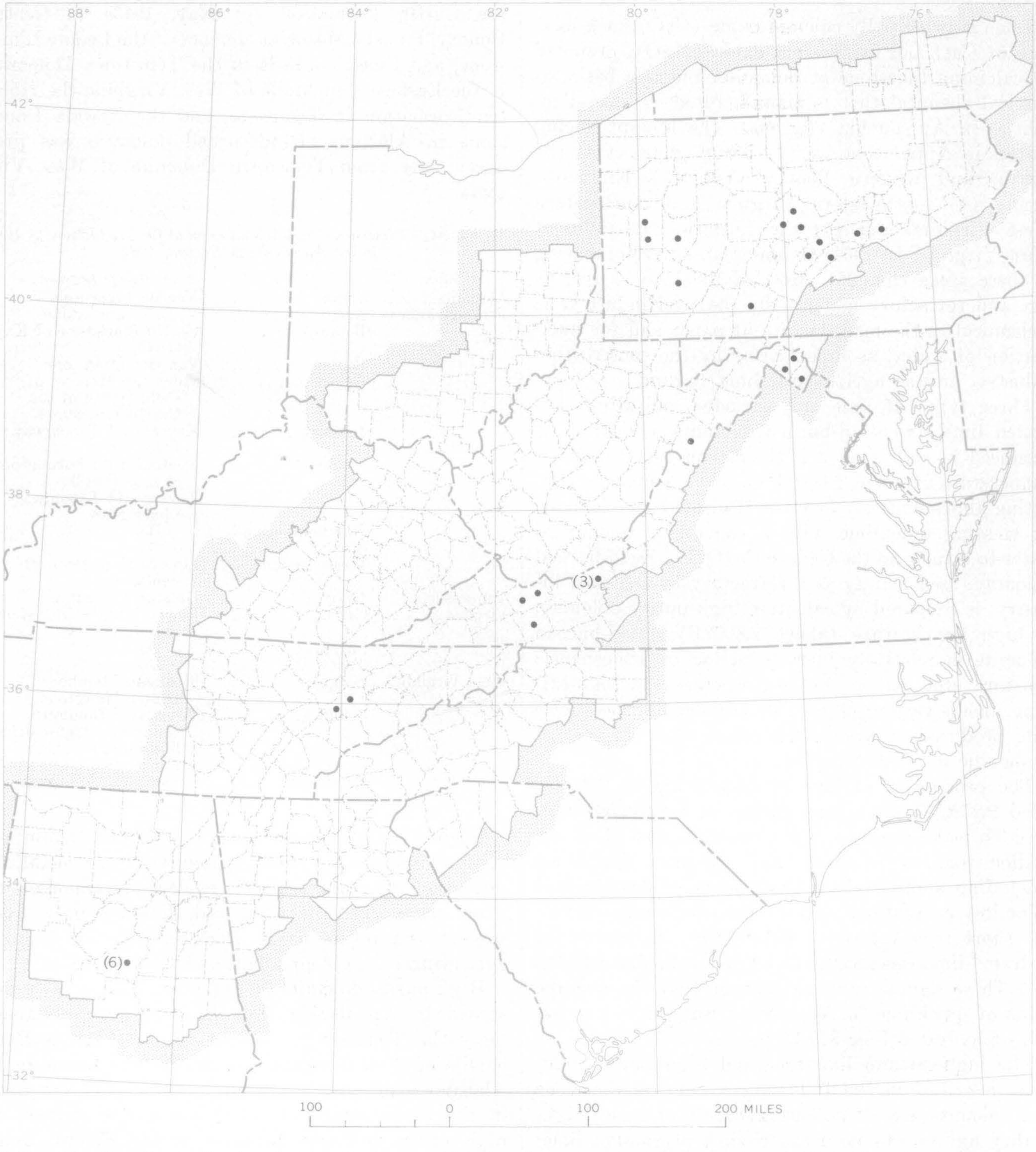

FIGURE 66.—Counties in the Appalachian Region in which lime is produced. Dots or numbers indicate lime plants in county.

nessee contains considerable amounts of high-purity dolomite suitable for refractory lime (Robert A. Laurence, written commun., 1966), particularly in Green and Carter Counties.

LIMESTONE AND DOLOMITE

By GEORGE E. ERICKSEN and DENNIS P. COX, U.S. Geological Survey

INTRODUCTION

Limestone and dolomite are among the most widely used mineral commodities in the United States and are essential to modern industry. They are classified for statistical or marketing purposes as either crushed stone, regardless of final use, or dimension stone. In this report, limestone and dolomite are discussed in several sections. This section chiefly describes their geology, chemical composition, and distribution. Other sections that describe special uses and production are those on "Cement," "Crushed Stone," "Dimension Stone," and "Lime."

Limestone and dolomite are abundant and widespread in Appalachia and constitute one of the principal mineral commodities of the region, being exceeded in total value of production only by coal and by petroleum and natural gas. During 1964, they were exploited for crushed stone at about 300 sites, mostly open pits or quarries, but at a few places in underground mines. Figure 67 shows the counties in Appalachia that had one or more active mines in 1964. Table 62 shows the production of crushed limestone and dolomite in Appalachia and its value since 1945. Production in 1964 was nearly 76 million tons having a value of about $110 million (1958 constant dollars). In addition, production of crushed marble in 1964 was 1.5 million tons valued at about $13 million (table 65).

Limestone and dolomite are carbonate rocks composed principally of the carbonate minerals calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Commonly, they are referred to as limestone but, strictly speaking, limestone is a rock composed chiefly of calcite, whereas dolomite consists chiefly of the mineral dolomite (containing 54.35 percent $CaCO_3$, and 45.65 percent $MgCO_3$).

For the purpose of this report, limestone and dolomite are considered to be rocks containing more than 50 percent of the carbonates calcite and dolomite. In limestone, calcite makes up 80 percent or more of the carbonate fraction whereas in dolomite, the mineral dolomite makes up 80 percent or more of this fraction. Rocks of more intermediate composition are called magnesian or dolomitic limestone or calcitic dolomite. Impurities in limestone and dolomite are aluminous materials such as clay and shale and siliceous material such as sand and chert. Marble is a crystalline rock, generally formed by metamorphism of limestone or dolomite.

High-calcium limestone and high-purity (or high-magnesian) dolomite are widely used in the chemical and metallurgical industries and because they are comparatively rare, have a higher value than impure carbonate rocks. Published specifications of chemical composition of these types vary. In this report, high-calcium limestone is considered to consist of 95 percent or more $CaCO_3$ even though some authors cite a minimum of 97 percent. High-purity dolomite has a comparable content of total carbonate of which not less than 40 percent is $MgCO_3$.

USES OF CRUSHED LIMESTONE AND DOLOMITE

The many uses of crushed limestone and dolomite are dependent upon either physical properties such as strength, resistance to abrasion, degree of porosity, grain size and crystallinity, and color, or upon chemical composition, wherein contained impurities are limited to specific quantities. Although specifications differ according to use, most limestone and dolomite are suitable for general-purpose crushed stone. Requirements for chemical and metallurgical stone vary according to use and availability of certain stone to a given industry. Table 85 from O'Neill (1965, p. 2) shows some examples of specifications of limestone and dolomite used by industry in Pennsylvania.

The tonnage and value of crushed limestone and dolomite, by use, produced in Appalachia in 1963 and 1964 are shown in table 86. By far the greatest use was for concrete aggregate and roadstone, but large amounts were also used in the manufacture of cement and lime and for flux and agricultural limestone. Table 87, which shows production and value of crushed marble for the same years, indicates a principal use as roadstone but also important use as terrazzo chips. Large amounts of pulverized marble (included in other uses in the table) are used in paint, putty, and other manufactured products.

The main uses or types of crushed limestone and dolomite are briefly summarized below (taken mainly from Bowles, 1956, p. 11–16).

Concrete aggregate and roadstone (also called road metal) constitute nearly two-thirds of the crushed stone produced in Appalachia; they are marketed in various sizes and used mainly by the building industry and in highway construction. The stone must be clean, hard, strong, and free of soft or friable material; it should break into irregular, more or less equidimensional fragments rather than into thin platy or

FIGURE 67.—Counties in the Appalachian Region with one or more mines producing crushed limestone or dolomite in 1964. ●, General-purpose crushed stone; most is used for concrete aggregate and roadstone; ▲, crushed stone for lime, cement, and (or) chemical and metallurgical uses. Some general-purpose crushed stone.

TABLE 85. *Chemical requirements for uses of limestone and dolomite*

[This table indicates chemical requirements as standardized by the various consuming industries. After O'Neill, 1965, p. 2]

Use	*Chemical requirements*
Limestone for portland cement.	Magnesium carbonate ($MgCO_3$) not more than 6.3 percent. Minimum calcium carbonate ($CaCO_3$) content varies from plant to plant depending on the availability of other raw materials.
Limestone for high-calcium lime.	Calcium carbonate ($CaCO_3$) content not less than 97 percent, preferably 98 percent or more.
Magnesium carbonate for high-magnesium lime.	Magesium carbonate content should be between the limits of 21 and 31.5 percent.
Limestone and magnesian limestone for steel flux (blast furnaces).	Silica (SiO_2) less than 5 percent. Alumina (Al_2O_3) less than 2 percent. Magnesium carbonate less than 8 percent to less than 31 percent. Phosphorus content should not exceed 0.01 percent.
Limestone for steel flux (open hearth).	Calcium carbonate ($CaCO_3$) content should exceed 98 percent but some limestone as low as 97 percent $CaCO_3$ is sometimes accepted.
Dolomite for refractories	Magnesium carbonate ($MgCO_3$) not less than 37.5 percent. Silica (SiO_2), ferric oxide (Fe_2O_3) and alumina (Al_2O_3) not to exceed 1 percent each.
Limestone for general chemical use.	Calcium carbonate ($CaCO_3$) content should exceed 98 percent but limestone as low as 97 percent $CaCO_3$ is sometimes used.
Agricultural limestone	Minimum of 85 percent $CaCO_3$.
Agricultural dolomite	Calcium-magnesium carbonate content should total at least 85 percent.
Limestone and dolomite for glass.	Ferric oxide (Fe_2O_3) not more than 0.05 percent. Calcium carbonate ($CaCO_3$) content should exceed 98 percent in limestone or 98 percent calcium-magnesium carbonate in dolomite.
Limestone for paint and filler.	The calcium carbonate content should exceed 96 percent but the magnesium carbonate ($MgCO_3$) should be no greater than 1 percent. Other maxima are: Fe_2O_3, 0.25 percent; SiO_2, 2.0 percent; and SO_3, 0.1 percent.

TABLE 86.—*Limestone and dolomite (crushed and broken stone) sold or used by producers in the Appalachian Region*

[Source: U.S. Bur. Mines]

Use	1963		1964	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
Concrete aggregate and roadstone	44,573	61,061	47,302	65,460
Cement	10,631	13,963	11,315	13,147
Lime	3,497	6,007	4,323	8,360
Flux	4,131	7,548	4,904	8,019
Agriculture	3,687	6,014	3,515	6,255
Railroad ballast	1,146	1,416	1,316	1,578
Riprap	509	760	173	228
Refractory (dolomite)	112	178	33	52
Other uses	2,830	6,996	2,953	6,923
Total	71,116	103,943	75,834	110,022

TABLE 87.—*Marble (crushed and broken stone) sold or used by producers in the Appalachian Region*

[Source: U.S. Bur. Mines]

Use	1963		1964	
	Short tons (thousands)	Value, in 1958 constant dollars (thousands)	Short tons (thousands)	Value, in 1958 constant dollars (thousands)
Roadstone	(1)	(1)	449	1,694
Terrazzo	240	2,369	278	2,802
Other uses	1,110	7,145	779	8,755
Total	1,350	9,514	1,506	13,251

[1] Included in other uses.

elongate fragments. Roadstone also should be resistant to abrasion and have a low porosity so that it does not break up during freezing and thawing. Concrete aggregate should be low in reactive materials such as alkalies, soluble sulfides, and certain types of silica, particularly chert, which weaken concrete or cause it to disintegrate.

Cement limestone is a limestone low in magnesium that, when mixed with the proper proportions of clay and silica, can be burned in a kiln to make portland cement. Portland cement should contain not more than 5 percent MgO. Cement limestone may be argillaceous and siliceous. One which contains about the proper proportions of $CaCO_3$, clay, and silica required for the manufacture of cement is called a cement rock.

Lime is made by calcining and pulverizing high-calcium limestone (or dolomite) to make a product used in a wide variety of chemical and metallurgical industries as well as in construction and agriculture, as described in the preceding section on "Lime."

Fluxing stone is high-calcium limestone or high-purity dolomite used as a flux in iron and steel furnaces. The most desirable sizes are 4–6 inches in diameter; generally material less than 2 inches in diameter is not used.

Agricultural limestone (agstone) is finely ground limestone or dolomite used as fertilizer, soil conditioner, and as a neutralizer of excess acids in the soil. The relative amounts of calcium and magnesium are generally of no importance although the CO_2 content should be high; therefore, a relatively pure carbonate rock is best for this purpose.

Railroad ballast, used for the construction and maintenance of railroad beds, consists of crushed limestone of the size range ¾ to 2½ inches. The specifications are similar to those for roadstone.

Riprap consists of large irregular blocks used in construction along rivers, such as shore protection, bridge piers, and docks.

Refractory stone is high-purity dolomite which is used in construction and repair of metallurgical furnaces, as bricks made of calcined dolomite, or as pulverized dolomite used in patching linings of hot furnaces.

Asphalt filler, a limestone dust of which about 80 percent will pass a 200-mesh screen, is produced as a byproduct of crushed-stone operations. It is mixed with asphalt and tar used in road construction and in the manufacture of roofing shingles and asphalt siding. Asphalt containing limestone filler is more durable as road-surfacing material and is more resistant to melting in hot weather than is asphalt without filler.

Limestone sand is washed and graded material of sand size that is used as a substitute for silica sand in mortar, wall plaster, and concrete.

Coal-mine dust is pulverized, relatively high purity limestone that is spread in coal mines to check or prevent coal-dust explosions. Such dust should contain less than 5 percent silica and should be of such a size that 100 percent will pass a 20-mesh screen and 70 percent a 200-mesh screen.

Sewage filter beds are constructed of crushed and screened limestone or dolomite that may be somewhat siliceous, but should be free of other impurities such as iron sulfide and clay. The stone should be free of fines, should be strong and compact, and should consist of fragments having rough surfaces to provide anchorage for the bacteria and a uniform porosity when laid as a bed.

Poultry grit can be made of sized finely crushed limestone.

Crushed marble has many of the same uses as crushed limestone. Marble chips are also used as a concrete aggregate in making terrazzo, a type of flooring that can be smoothed and polished after setting. Pulverized marble is used in the manufacture of paint and putty and as a filler in products such as rubber, paper, and linoleum.

OCCURRENCES IN APPALACHIA

Limestone and dolomite are abundant and widespread in the Valley and Ridge province and along the west side of Appalachia, mainly in the Interior Low Plateaus but are relatively scarce in the Appalachian Plateaus, Piedmont, and Blue Ridge provinces (Fig. 68). Limestone and dolomite formations in the Valley and Ridge province range from Cambrian to Mississippian in age and have been so intensively folded and faulted that they commonly dip steeply and crop out in parallel belts in which the same rock sequence may be repeated several times. Such repetition is well shown in eastern Tennessee where the many belts of dolomite shown in figure 68 belong to the Knox Group of Cambrian and Ordovician age. In contrast, most limestone formations in the western part of Appalachia are flat-lying rocks of Mississippian age. The flat-lying Pennsylvanian and Permian rocks underlying most of the Appalachian Plateaus (pl. 2) province have many layers of thin limestone in Ohio, Pennsylvania, and northern West Virginia. The limestone layers decrease in number to the south. Only the Vanport Limestone of western Pennsylvania and Ohio has been exploited on a large scale. Scattered lenses and bands of marble, limestone, and dolomite are found in the Piedmont and Blue Ridge provinces.

Limestone and dolomite formations in Appalachia that have been exploited most extensively and their distribution are listed in table 88. All contain excellent stone for concrete aggregate and roadstone, as well as for other uses that primarily require a hard durable stone. Most can be utilized for agricultural lime but are too impure or too variable in composition to be used as a chemical or metallurgical stone. Several of the formations contain cement limestone, and a few contain high-calcium limestone for which they are extensively exploited. High-purity dolomite is relatively rare in Appalachia, being found locally in only a few formations.

For convenience of discussion, the limestone and dolomite units of each of the three main structural belts or provinces of Appalachia—the metamorphic belt (Piedmont and Blue Ridge provinces), the folded belt (Valley and Ridge province), and the belt of relatively undeformed rocks (Appalachian Plateaus, Interior Low Plateaus, and Central Lowland)—are described separately. The carbonate rocks show distinct geologic features in each of these belts that affect their availability and utilization.

PIEDMONT AND BLUE RIDGE PROVINCES

The Piedmont and Blue Ridge provinces, which are underlain almost entirely by metamorphic and igneous rocks, contain a few carbonate rocks, mainly marble, that crop out in elongate belts and lenses trending northeastward. The marble is described in the section on "Dimension Stone" (p. 191). The Murphy marble belt is best known and has been the source of the

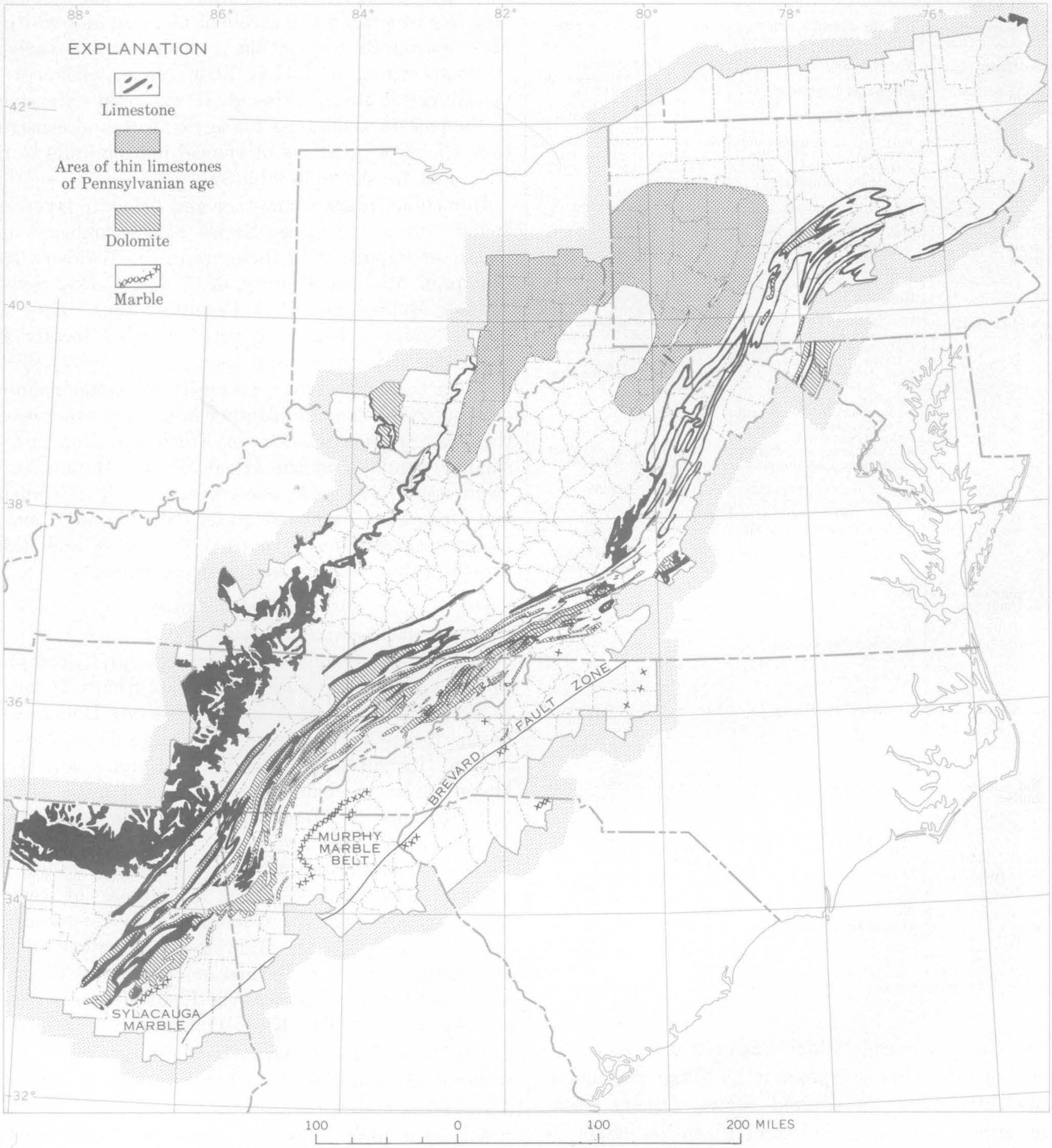

FIGURE 68.—Principal areas of limestone and dolomite in the Appalachian Region.

TABLE 88.—*Principal limestone and dolomite units in the Appalachian Region*

Geologic age	Stratigraphic unit	Region of main outcrops
Pennsylvanian	Vanport Limestone	Western Pennsylvania, eastern and southern Ohio
Mississippian	Greenbrier Limestone	Eastern West Virginia, southwestern Virginia.
	Newman Limestone	Eastern Tennessee, southwestern Virginia.
	Fort Payne Formation and Warsaw, St. Louis, Ste. Genevieve, Girkin (Gasper), and Monteagle Limestones.	Northern Alabama, northwestern Georgia, central Tennessee, and eastern Kentucky.
	Bangor Limestone	Northern Alabama and northwestern Georgia.
	Maxville Limestone	Eastern Ohio.
Devonian (?) and Silurian.	Keyser and Tonoloway Limestones.	Central Pennsylvania, eastern West Virginia.
	Cedarville and Peebles (of Foerste, 1929) Dolomites.	Southern Ohio.
	Brassfield Limestone	Eastern Kentucky, southwestern Ohio.
Late Middle Ordovician.	Chickamauga Limestone, Lenoir Limestone and Mosheim Member, and Holston Limestone.	Northeastern Alabama, northwestern Georgia, eastern Tennessee.
	New Market, Whistle Creek (of Cooper and Cooper, 1946) Rockdell, Five Oaks (of Cooper and Prouty, 1943), Lincolnshire Limestones.	Western and southwestern Virginia.
	St. Paul Group (old Stones River Group of this area).	Eastern Panhandle of West Virginia and Western Maryland.
	Several units of which the Valentine Member (of Field, 1919) of the Curtin Limestone (of Kay, 1943) is most important.	Central Pennsylvania.
	Several formations of which the Carters Limestone is most important.	Westernmost Appalachia in Tennessee and Kentucky.
Early Ordovician and Late Cambrain.	Knox Group	Northeastern Alabama, northwestern Georgia, eastern Tennessee, and southwestern Virginia.
Early Ordovician	Beekmantown Group	Central Pennsylvania, western Maryland, Eastern Panhandle of West Virginia and western Virginia.
Late Cambrian	Conococheague Group	Central Pennsylvania, western Maryland, Eastern Panhandle of West Virginia, and western Virginia.
	Ketona Dolomite	Northern Alabama.
Late and Middle Cambrian.	Elbrook Formation	Western Maryland, eastern Panhandle of West Virginia, and western Virginia.
	Conasauga Formation or Group.	Northern Alabama, northwestern Georgia, and eastern Tennessee.
Early Cambrian	Shady Dolomite	Northeastern Alabama, northwestern Georgia, eastern Tennessee, and southwestern Virginia.
	Tomstown Dolomite	Western Maryland, eastern Panhandle of West Virginia, and western Virginia.

famed Georgia marble which has been used so extensively for more than 100 years in buildings and monuments throughout the United States. Others which have either been quarried for dimension stone or crushed stone are the Sylacauga Marble Member of the Talladega Slate of Alabama, the marble along the Brevard fault zone in northeast Georgia, westernmost South Carolina, and southwestern North Carolina, the Gaffney Marble in Cherokee County, S.C., and lenses and discontinuous layers of marble in McDowell County, N.C., and in Bibb, Shelby, and Calhoun Counties, Ala. The marble makes excellent crushed stone for construction, and many units that are white and free of silica make excellent terrazzo and whiting. Most marble in Appalachia is dolomitic and variable in composition, so it has little use as chemical or metallurgical stone, although it was used extensively in the past to make lime for agriculture and construction. Chemical analyses of typical marble units in the Piedmont are shown in table 89.

Unmetamorphosed limestone and dolomite layers are found within the Ocoee Series of Precambrian age. The most important of these are in the Walden Creek Group in Madison County, N.C. and Cocke, Sevier, Blount, Monroe and Polk Counties, Tenn. They are usually impure but have been quarried locally for roadstone and agricultural lime.

Other carbonate rocks, generally unmetamorphosed, are exposed in the Grandfather Mountain window and the Hot Springs window in North Carolina and in smaller windows in the Great Smoky Mountains of Tennessee. These rocks are correlated with Cambrian and Ordovician carbonate rocks (Shady and Honaker Dolomites, and Knox Group) in the Valley and Ridge province, discussed in the following pages.

VALLEY AND RIDGE PROVINCE

Cambrian limestone and dolomites

Cambrian limestones and dolomites (pl. 3) comprise three major sequences as follows: (1) Shady Dolomite in southern Appalachia and Tomstown Dolomite in northern Appalachia; (2) Conasauga Formation or Group (including the Brierfield, Ketona, and Bibb Dolomites in Alabama) in the south, more or less equivalent to the Honaker Dolomite of northeastern Tennessee and southwestern Virginia, the Elbrook Formation of western Virginia to Maryland, and the Pleasant Hill and Warrior Limestones of central Pennsylvania; and (3) Conococheague Limestone of western Virginia and Maryland, equivalent to the Gatesburg and Mines Formations of central Pennsylvania and the lower part of the Knox Group in southern Appalachia. The Knox Group, which is Upper Cambrian and Lower Ordovician in age, is the most widespread sequence of carbonate rocks in southern Appalachia and is described separately.

All these formations have been mined for crushed stone. The Tomstown and Ketona Dolomities are the only sources of high-purity dolomite in Appalachia. The Conasauga Formation is mined extensively for limestone used to manufacture cement and lime in Alabama. The Conococheague is mined for cement limestone at Security, Md. Chemical analyses of these rocks are shown in tables 90 and 91.

TABLE 89.—*Chemical analyses of Precambrian marbles*

Location (State, county)	Lithologic unit	$CaCO_3$	$MgCO_3$	SiO_2 and (or) insoluble	Al_2O_3+Fe_2O_3	Source of information
Georgia:						
Pickens	Murphy Marble	59.32	35.8	3.2	1.0	Hunter and Gildersleeve (1946, p. 25).
		63.40	30.8	11.6	.9	Do.
		99.24	3.1	1.0	.2	Do.
		55.23	38.8	6.7	.9	Do.
		61.37	39.0	1.0	.5	Do.
North Carolina:						
Cherokee	Murphy Marble	94.5	4.0	2.9	.8	Conrad (1960, p. 51).
Swain	do	58.5	39.6	.1	1.1	Do.
Transylvania	Marble of Brevard fault zone.	56.9	36.6	3.0	1.8	Conrad (1960, p. 52).
Henderson	do	51.4	37.0	3.4	1.4	Do.
Buncombe	do	56.7	39.5	.8	.6	Do.
Mitchell	Bandana Marble of Conrad	56.0	44.8	.2	.3	Conrad (1960, p. 53).
South Carolina:						
Oconee	Marble of Inner Piedmont belt.	71.1	1.6	22.4	3.9	Overstreet and Bell (1965, p. 62).
	Marble of Brevard fault zone.	49.1	25.2	18.4	4.5	Do.
Cherokee	Marble of Kings Mountain belt.	71.4	17.3	10.3	1.1	Do.

The Shady Dolomite to the south and the Tomstown Dolomite, its stratigraphic equivalent, to the north of Roanoke, Va., crop out discontinuously along the boundary between the Valley and Ridge province and Blue Ridge province from Alabama to Pennsylvania. They are rather poorly exposed, being covered by older rocks of the Blue Ridge that have been thrust westward, by slope debris from the Blue Ridge, and by residual weathering products.

The Shady and Tomstown Dolomites are about 1,000 feet thick at most places and consist of gray to light-gray medium- to thick-bedded crystalline dolomite of variable composition, locally containing limestone and shale. Butts (1933, p. 3–4) gives a maximum thickness of 1,800 feet for the Lower Cambrian calcareous sequence of southwestern Virginia (Wythe County). These strata are now included in the Shady Dolomite and the overlying Ivanhoe Limestone Member of the Rome Formation. Edmundson (1958, p. 84) reported the Shady in Botetourt County, Va., to be 731 feet thick and to consist of high-purity dolomite. Hershey and Maher (1963, p. 38–40 and 52) described the Shady of eastern Tennessee as being about 1,200 feet thick and consisting of relatively pure dolomite, locally having layers of limestone in the upper and lower part of the sequence and sandy layers near the base. These authors stated that the Shady Dolomite of Tennessee generally contains 94 percent or more total carbonate and that it averages 52 percent $CaCO_3$ and 42 percent $MgCO_3$.

The Tomstown Dolomite in the Eastern Panhandle of West Virginia consists of high-purity dolomite (table 90) that is mined extensively for use as flux in the steel industry, for the manufacture of dead-burned dolomite, and for other purposes. McCue, Lucke, and Woodward (1939, p. 7–8) described the Tomstown of this region as follows:

> The Tomstown Dolomite, approximately 1,000 feet thick, is mainly a light blue-gray to white tough fine-grained splintery dolomite that is medium-bedded and weathers to a dark-brown color; some true limestone members and some shaly zones also occur in the formation * * *. Exposed only in Jefferson County, it contains an important belt of low-silica dolomite, the composition of which approaches the correct proportions of calcium and magnesium in a theoretically pure dolomite. This rock is well suited for certain types of furnace lining, and has been worked from several large quarries.

The Tomstown Dolomite of Maryland and Pennsylvania is generally more impure than it is to the south. Mathews and Grasty (1910, p. 400) described the Tomstown Dolomite in Washington County, Md., as a massive drab-to-white magnesian limestone of which some upper beds contain chert. Analyses of the formation here (table 90) show it to be variable in composition. The Tomstown in Pennsylvania contains considerable amounts of shale and shaly limestone (O'Neill, 1964, p. 3).

The Conasauga Formation (Middle and Upper Cambrian) in southern Appalachia and equivalent formations in the north are the next younger sequence of rocks containing abundant expoitable carbonates. These rocks are separated from the Shady and Tomstown Dolomites by a dominantly shaly sequence, the Rome Formation in southern Appalachia, and the Waynesboro Formation in the north (pl. 3). In eastern Tennessee, the Conasauga Formation or shale changes from a sequence of shale and calcareous shale beds near

TABLE 90.—*Chemical analyses of Lower and Middle Cambrian limestones and dolomites*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	CaCO$_3$[1]	MgCO$_3$[2]	SiO$_2$ and (or) insoluble	R$_2$O$_3$ (Fe$_2$O$_3$+ Al$_2$O$_3$)	Source of information
Alabama:							
Jefferson	Conasauga Formation	------	89. 0	8. 0	1. 2	0. 5	Burchard and Butts (1910, p. 198).
		------	82. 3	4. 0	7. 9	4. 1	Burchard (1940, p. 25).
		------	90. 9	4. 5	3. 9	1. 6	Burchard (1940, p. 23).
Georgia:							
Catoosa	Conasauga Formation	100	91. 5	4. 2	6. 00	1. 7	Butts and Gildersleeve (1948, p. 132).
Gordon	do	80	92. 8	5. 8	. 1	. 7	Butts and Gildersleeve (1948, p. 133).
Maryland:							
Washington	Tomstown Dolomite	55	90. 4	10. 1	1. 2	. 5	Mathews and Grasty (1910, p. 410).
		125	56. 7	40. 8	1. 8	1. 2	Mathews and Grasty (1910, p. 411).
	Elbrook Limestone	------	93. 3	4. 9	1. 2	1. 5	Mathews and Grasty (1910, p. 412).
		------	97. 4	1. 8	1. 1	. 7	Do.
		100	80. 9	9. 8	8. 7	2. 2	Mathews and Grasty (1910, p. 418).
North Carolina:							
Madison	Shady Dolomite	------	52. 1	38. 0	2. 6	. 2	Hunter and Gildersleeve (1946, p. 26).
		------	55. 2	41. 1	. 7	. 2	Do.
Pennsylvania:							
Berks (outside Appalachia.)	Tomstown Dolomite	80	54. 3	42. 6	2. 5	. 7	O'Neill (1964, p. 15).
Tennessee:							
Johnson	Shady Dolomite	100	52. 9	40. 2	5. 5	1. 4	Hershey and Maher (1963, p. 188).
Hancock	Rutledge Limestone (Conasauga Group).	80	80. 0	11. 4	6. 8	1. 7	Hershey and Maher (1963, p. 229).
Grainger	Maryville Limestone (Conasauga Group).	80	89. 2	8. 5	1. 7	. 5	Do.
Virginia:							
Botetourt	Shady Dolomite (lower unit)	395	54. 8	40. 0	4. 5	. 6	Edmundson (1958, p. 84).
	Shady Dolomite (upper unit)	336	54. 6	41. 1	3. 5	. 8	Do.
	Shady Dolomite	155	52. 0	39. 8	7. 5	. 8	Edmundson (1958, p. 82).
Washington	do	------	82. 0	9. 7	4. 1	4. 7	Mathews and Grasty (1910, p. 438).
		------	56. 7	40. 8	1. 8	1. 2	Do.
		------	90. 9	. 7	. 7	7. 0	Do.
		------	83. 0	. 9	12. 0	4. 4	Do.
West Virginia:							
Jefferson	Tomstown Dolomite	------	55. 0	45. 0	. 4	. 4	Weitz (1942, p. 18).
		------	53. 8	41. 8	1. 6	2. 7	Do.
		------	53. 9	44. 6	. 6	1. 1	Do.
		------	54. 3	44. 6	. 4	. 4	Do.
		------	58. 5	37. 3	2. 4	2. 1	McCue, Lucke, and Woodward (1939, p. 379).

[1] Recalculated from CaO for some analyses.
[2] Recalculated from MgO for some analyses.

the eastern border of the Cumberland Plateau to one consisting principally of carbonate rocks in the northeasternmost part of the State (Hershey and Maher, 1963, p. 40). Here, the Conasauga is represented by the Honaker Dolomite and an overlying sequence equivalent to the Nolichucky Shale and Maynardville Limestone. To the northeast in Virginia, carbonate rocks of equivalent age have been named the Elbrook Formation or Limestone which in turn extends northeastward through Washington County, Md., into Pennsylvania. In central Pennsylvania the Elbrook is separated into the Pleasant Hill and Warrior Limestones.

The Conasauga Formation or Group in northern Alabama, northwestern Georgia, and southeastern Tennessee consists of a sequence of interbedded shale and limestone 1,000 to 2,000 feet thick (pl. 3). In the Birmingham area, Jefferson County, Ala., it is extensively mined for cement limestone (table 53). The Ketona Dolomite, equivalent to part of the Conasauga, is mined for fluxing stone near Birmingham. Elsewhere, the Conasauga Formation has been exploited only to a limited extent. Near Birmingham the Conasauga is about 1,900 feet thick and consists of thin-bedded, dark-gray, relatively pure limestone with interbedded shale layers (Butts, 1927, p. 3).

TABLE 91.—*Chemical analyses of Upper Cambrian and Lower Ordovician limestones and dolomites*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	$CaCO_3$[1]	$MgCO_3$[2]	SiO_2 and (or) insoluble	R_2O_3 (Fe_2O_3+ Al_2O_3)	Source of information
Alabama:							
Jefferson	Ketona Dolomite	------	55.4	43.0	1.3	0.7	Gillson and others (1960, p. 159).
		------	55.4	42.2	1.1	1.0	Weitz (1942, p. 20).
		------	54.0	43.0	1.2	--------	Do.
Shelby	Ketona Dolomite	------	54.5	43.7	.6	1.3	Do.
Georgia:							
Catoosa	Knox Group	------	55.6	32.5	6.0	1.1	Butts and Gildersleeve (1948, p. 133).
Bartow	do	30	55.0	43.3	.7	.8	Do.
Walker	Newala Limestone	25	90.9	6.8	1.6	.9	Butts and Gildersleeve (1948, p. 134).
Maryland:							
Washington	Conococheague Limestone	132	87.3	3.7	7.5	3.5	Mathews and Grasty (1910, p. 413).
		132	76.6	4.2	14.3	6.5	Do.
		175	93.3	3.2	4.3	1.8	Do.
	Beekmantown Group	350	84.8	5.7	4.5	3.1	Do.
		------	83.5	10.7	4.2	1.9	Mathews and Grasty (1910, p. 416).
Pennsylvania:							
Blair	Pleasant Hill Limestone	40	85.5	5.7	2.6	3.1	O'Neill (1964, p. 17).
	Gatesburg and Mines Formations.	128	55.8	43.6	2.2	1.4	O'Neill (1964, p. 16).
Bedford	Beekmantown Group	------	52.0	40.0	6.4	1.3	O'Neill (1964, p. 11).
Fulton	do	------	77.0	19.3	2.8	.8	O'Neill (1964, p. 23).
Blair	Beekmantown Group: Stonehenge, Larke, and Nittany Dolomites.	------	54.3	44.3	2.8	.8	O'Neill (1964, p. 17).
Centre	Axemann and Bellefonte Formations.	------	44.7	38.1	21.6	4.1	O'Neill (1964, p. 18).
Blair	do	------	94.9	3.9	.9	.3	O'Neill (1964, p. 16).
Tennessee:							
Hamblen	Knox Group	50	67.4	22.7	8.7	1.3	Hershey and Maher (1963, p. 229).
Sevier	do	60	74.1	12.7	11.7	1.5	Hershey and Maher (1963, p. 230).
Washington	do	50	84.7	7.0	7.3	1.0	Do.
Anderson	Maynardville Limestone and Copper Ridge Dolomite.	100	85.1	11.7	2.6	.6	Hershey and Maher (1963, p. 188).
	Knox Group:						
Sullivan	Chepultepec Dolomite	150	74.6	17.6	6.7	1.1	Hershey and Maher (1963, p. 189).
Greene	Mascot Dolomite	50	63.8	22.3	12.1	1.8	Hershey and Maher (1963, p. 229).
Hawkins	Newala Dolomite	60	58.3	32.9	7.4	1.2	Hershey and Maher (1963, p. 188).
Virginia:							
Botetourt	Beekmantown Dolomite	307	53.5	35.9	7.3	3.3	Edmundson (1958, p. 32).
Giles	do	------	50.9	40.9	5.9	1.1	McCue, Lucke, and Woodward (1939, p. 380).
Scott	Chepultepec and Copper Ridge Dolomites.	85	52.4	40.8	6.2	.7	B. N. Cooper (1945, p. 250), R. A. Laurence (written commun., 1966).
West Virginia:							
Jefferson	Conococheague Limestone	------	82.1	8.8	7.3	1.9	McCue, Lucke, and Woodward (1939, p. 379).
Berkeley	do	------	88.7	2.7	6.4	1.8	Do.
Jefferson	Stonehenge (Chepultepec) Limestone.	------	94.7	1.4	4.0	.5	Do.
Mercer	Beekmantown Group	------	56.5	35.0	6.2	1.8	McCue, Lucke, and Woodward (1939, p. 380).
Jefferson	do	------	97.8	.7	1.1	.3	Do.
Berkeley	do	------	90.7	2.1	4.6	1.2	Do.

[1] Recalculated from CaO for some analyses.
[2] Recalculated from MgO for some analyses.

The Honaker Dolomite in northeastern Tennessee is about 2,000 feet thick (pl. 3), and consists of thin-bedded to massive dolomite and magnesian limestone and some interbedded limestone and shale. The lower part of the formation contains abundant chert (Rogers, 1953, p. 52). Magnesian limestone beds of variable composition are most abundant; they generally contain 90 percent carbonate, of which the $MgCO_3$ content ranges from 7 to 38 percent and averages slightly more than 10 percent (Hershey and Maher, 1963, p. 43).

The Elbrook Dolomite or Formation in southwestern Virginia ranges from thick-bedded medium- to coarse-grained, rather pure dolomite to thinly laminated finely crystalline shaly dolomite (Butts, 1933, p. 6). Limestone beds are present in the upper part of the formation. In Wythe County, Va., the Elbrook Dolomite is 1,800 feet thick; to the north, in Botetourt County, Va., it consists largely of dolomite as much as 2,200 feet thick (Edmundson, 1958, p. 18–19). In the Eastern Panhandle of West Virginia, the Elbrook is at least 1,250 feet thick and consists of siliceous limestone and calcareous shale (McCue, Lucke, and Woodward, 1939, p. 8–9).

In central Pennsylvania, the Elbrook Limestone grades laterally into the Pleasant Hill Limestone, consisting of about 600 feet of dark-gray thick-bedded limestone and thin-bedded shaly limestone, and the overlying Warrior Limestone, about 250 feet of medium-gray fine-grained dolomite with shale partings (O'Neill, 1964, p. 3). The Pleasant Hill Limestone in the southeast corner of Blair County, Pa., is reported to be a potential source of cement limestone; further, all three formations in Pennsylvania are reported to be potential sources of aggregate stone.

In the Valley and Ridge province of northern Appalachia, the Upper Cambrian is represented by the Conococheague Limestone which extends into the Gatesburg Formation and the overlying Mines Dolomite in central Pennsylvania (O'Neill, 1964, p. 3–4). In southern Appalachia the Upper Cambrian is represented by the Copper Ridge Dolomite of the Knox Group. The Conococheague consists mainly of dolomite and lesser amounts of interbedded limestone which is generally somewhat siliceous.

Thompson (1961, p. 18) suggested that some dolomite beds in the Gatesburg Formation at Birmingham, Pa., might be a source of metallurgical flux stone or of lime if a high magnesium content is desired. In general, however, Upper Cambrian rocks in central Pennsylvania are too impure or too variable in composition to be used for chemical or metallurgical stone and are mainly utilized for construction stone.

Edmundson (1958, p. 19) described the Conococheague Limestone of western Virginia (including Botetourt County) as follows:

> The Conococheague limestone is exposed on the flanks of the Natural Bridge syncline; west of the Pulaski-Staunton fault north of Lexington; and, in the central and western parts of Fincastle Valley. Three different facies were noted in the James River district: impure limestone with minor amounts of dolomite east of the Pulaski-Staunton fault north of Buchanan; interbedded limestone and dolomite in the northwestern belts; and largely dolomite with minor quantities of limestone in the area between Compton and Eagle Rock. The formation is marked by two distinctive features: thin laminae, containing siliceous material, which stand out as crinkly ribs on weathered surfaces of limestone, and beds of coarse-grained, friable sandstone. The siliceous banded limestones are generally more abundant near the top of the formation. Sampled units of the limestone contain from 71 to 89 percent calcium carbonate; those of dolomite from 33 to 38 percent magnesium carbonate. Silica varies from about 7 to 17 percent. The thickness of the Conococheague southeast of Natural Bridge is approximately 2,100 feet.

Mathews and Grasty (1910, p. 403–404) described the Conococheague of Maryland as consisting of about 1,500 feet of siliceous and argillaceous limestone which in part is suitable for the manufacture of cement. These authors further stated that the Conococheague had been quarried at several places and that the largest quarry furnished limestone for a cement plant near Hagerstown.

O'Neill (1964, p. 3–4) described the Gatesburg and Mines Formations in central Pennsylvania, as follows:

> The Gatesburg Formation is equivalent to the lower portion of the Conococheague Group and consists of thick-bedded, steel-blue, coarsely crystalline dolomite interbedded with many quartzites, some of which are up to 10 feet thick. The total amount of quartzite, however, makes up a relatively small proportion of the entire thickness of the formation which measures 800 feet in Centre County and 1,750 feet in Blair and Huntingdon Counties.
>
> Locally at least, up to 100 feet of highly fossiliferous, thin-bedded limestone occurs in the middle of the Gatesburg Formation.
>
> The Mines Formation is equivalent to the upper part of the Conococheague Group and consists of about 150 to 250 feet of medium-gray crystalline dolomite with an abundance of scoriaceous chert, much of which is oolitic. Unlike the underlying Gatesburg Formation, it does not include any quartzite beds.

These formations would probably make a good quality general-purpose crushed stone but are not suitable for chemical or metallurgical use.

Knox Group (Upper Cambrian and Lower Ordovician)

The Knox Group (pl. 2), is the most widespread carbonate rock sequence in southern Appalachia. Subdivisions of the Knox Group in common usage are shown in plate 3. The sequences consist mainly of dolomite, and nearly all dolomite shown in figure 68 from Tennessee southward belongs to the Knox. Limestone beds are present locally. The Knox contains hard durable stone that makes excellent roadstone and concrete aggregate. Table 91 shows chemical analyses of parts of the Knox Group in Tennessee and Georgia.

Hershey and Maher (1963, p. 43–45) described the Knox Group of Tennessee as follows:

> The Knox can be divided into two phases on the basis of rock type or lithology. One of these phases includes all of the Knox east of a line passing roughly through Kingsport and Sevierville. Here the Knox is composed of many successive beds of bluish-gray limestone with subordinate dolomite layers interspersed. The beds range in thickness from a few inches to several feet. In places shaly seams, generally less than an inch thick, are present. Elsewhere, sandy beds and lenses occur, but these commonly are less than a few feet thick. On the whole limestone and dolomite strata are slightly impure, containing variable amounts of silica, clay, and sandy materials, and to this type of rock the names Conococheague and Jonesboro apply.
>
> Elsewhere in East Tennessee the Knox is largely dolomite with subordinate limestone layers, and the formation names applied to the rock are followed by the term dolomite. The dolomite beds are as much as several feet in thickness, are usually some shade of gray or brown, and as a rule are impure. In addition to being largely dolomite this phase of the Knox is characterized by high silica content, as evidenced by the abundance of chert found in Knox soils and in bedrock exposures. The silica content increases markedly toward the west.
>
> In most areas the Knox is distinguished readily from other formations by the presence of chert in outcrops and in the overlying soils. The chert is fragmental and irregular in shape, whereas that of other formations generally is less abundant and is blocky to rounded in outline.
>
> The Knox is notably nonuniform from bed to bed and from quarry to quarry. Individual beds approach high-calcium limestone or high-purity dolomite but generally are too thin to be quarried profitably. Analyses from 22 quarries show that calcium carbonate ranges from 51.5 to 85.7 percent; magnesium carbonate ranges from 5.7 to 42.5 percent; and silica from 2.1 to 13.4 percent. The average of 22 quarries is calcium carbonate 70.0 percent; magnesium carbonate 21.3 percent, and silica 8.1 percent.
>
> The Knox Group is the most important rock unit in East Tennessee as far as economic products are concerned. It is an excellent source of hard durable dolomite and limestone for road metal, railroad ballast, riprap, filler and base course. The upper one-third of the Mascot Formation, which locally contains faintly mottled green and red beds, has been prospected for building stone. Locally, it is used for agricultural limestone, stucco dash, concrete-block facings, and refractories. Residual cherts from the Knox have been used as road metal and for some building purposes.
>
> In addition to present usage of the Knox, the high-magnesium zones are a potential source of metallic magnesium and high-magnesium lime.

The Knox Group crops out extensively in northwestern Georgia and northeastern Alabama. Limestones and dolomites are quarried in Alabama, particularly in Shelby County for both chemical and metallurgical stone. In northwestern Georgia the lower part of the Knox is poorly exposed and has been quarried at only one or two places. The uppermost part of the Knox, the Newala Limestone (pl. 3), crops out in Polk and Bartow Counties of northwest Georgia as a thick-bedded relatively pure limestone and has been quarried for the manufacture of portland cement near Rockmart, Polk County (Butts and Gildersleeve, 1948, p. 22).

Ordovician limestones and dolomites

Ordovician carbonate rocks above the Knox Group are widespread in Appalachia. They are of Middle Ordovician age in southern Appalachia and of Early and Middle Ordovician age in northern Appalachia. The Upper Ordovician strata are predominantly shale and sandstone within the Appalachian Region.

Lower Ordovician limestones and dolomites of northern Appalachia

Lower Ordovician limestones and dolomites of northern Appalachia comprise the Beekmantown Formation, Dolomite, Limestone, or Group and equivalent formations cropping out in the Valley and Ridge province from western Virginia to Pennsylvania (pl. 3). The rocks are mainly impure dolomite suitable for general-purpose crushed stone but have little or no value as chemical or metallurgical stone. Analyses of samples of these limestone and dolomite units are shown in table 91.

Edmundson (1958, p. 19–20) described the Lower Ordovician Chepultepec Limestone and overlying Beekmantown Dolomite of the central western part of Virginia as follows:

> The Chepultepec Limestone is one of the best horizons for mapping purposes throughout most of the Valley of Virginia. In this region, it is composed largely of bluish-gray, slightly laminated, fine-grained limestone and minor amounts of thin intercalations of dolomite and magnesian limestone. The maximum thickness of the formation is estimated at 500 feet. Sampled units commonly contain from about 85 to 90 percent calcium carbonate, around 6 percent magnesium carbonate, and from 4 to 6 percent silica. The Chelpultepec, for the most part, crops out in narrow valleys bordered by low hills underlain by the more resistant impure rocks of the Conococheague and Beekmantown Formations.
>
> The Beekmantown formation, with an estimated thickness of about 1,500 feet, is composed largely of gray, fine- to medium-grained dolomite. In the eastern belts, limestone perhaps comprises from 10 to 15 percent of the total thickness, whereas only an occasional thin limestone layer was noted in the western portion of the valley. The layers of dolomite are commonly characterized by distinct intersecting furrows on weathered surfaces. Sampled units of dolomite contain from 34 to 39 percent magnesium carbonate and from 5 to 10 percent silica. Chert, although generally not abundant, occurs locally as scattered irregular masses and as distinct beds at several horizons in the formation. The Beekmantown is admirably

suited for construction purposes, but does not meet the specifications for high-magnesium dolomite as defined in this bulletin.

The Beekmantown Limestone of western Maryland and the Eastern Panhandle of West Virginia is equivalent to the Chepultepec and Beekmantown of western Virginia (pl. 3). It is about 1,200 feet thick in this area and consists mainly of siliceous dolomite with relatively pure limestone near its base (Mathews and Grasty, 1910, p. 405; McCue, Lucke, and Woodward, 1939, p. 11).

In central Pennsylvania the Beekmantown Group is divided into several formations made up of a sequence of dolomite and lesser amounts of limestone, about 3,000 feet thick (pl. 3). O'Neill (1964, p. 5) described these formations as containing relatively impure limestone and dolomite suitable only for aggregate stone and roadstone. He pointed out that some of the stone (Larke Dolomite) is suitable for agricultural dolomite and that locally some beds of the Axeman Limestone are suitable for cement manufacture; other beds contained high magnesium limestone.

Middle Ordovician limestones

Middle Ordovician rocks are predominantly limestone in the Valley and Ridge province (pl. 3, columns 4, 8, 11, 13, 15) but grade into clastic rocks in eastern Tennessee and northwest Georgia (pl. 3, columns 14, 16, 18). They range in thickness from a few hundred to 2,000 feet in most of the region but exceed 5,000 feet where clastic rocks predominate. The sequence comprises many formations, which have been given local names, only some of which are shown on plate 3. The sequence includes some of the most important high-calcium and cement limestones of eastern United States such as: (1) Valentine Member (of Field, 1919) of the Curtin Formation (of Kay, 1943) in central Pennsylvania; (2) Annville and Jacksonburg Limestones in southeastern Pennsylvania (outside Appalachia); (3) New Market Limestone and Mosheim Member of the Lenoir Limestone of western Virginia and the Eastern Panhandle of West Virginia; and (4) Holston Limestone or Formation of eastern Tennessee. Analyses of Middle Ordovician limestones in Appalachia are given in table 92.

Because deposition of Middle Ordovician rocks of the Valley and Ridge province of eastern Tennessee was affected by mountain building to the east, the thick sequence of clastic beds (Athens Shale, Ottosee Shale, and Bays Formation) in the east interfingers with limestone beds (Chickamauga Limestone) in the west. Although facies changes are present in the stratified rocks in many other systems and areas in the Valley and Ridge province, the Middle Ordovician rocks are affected to a much greater degree by lateral variations. Rodgers (1953, p. 64) made the following statement about problems of Middle Ordovician stratigraphy:

> Probably more controversy has raged over the stratigraphy of the Chickamauga Limestone and equivalent rocks in the southern Appalachians than over that of any other major unit here discussed, except the Ocoee series, and this despite the generally good outcrops, the ready accessibility of the outcrop area, the well-characterized and differentiated lithologic units, the several usable key beds, and the abundant fossils. The controversy has concerned both subdivision and correlation.

The Holston Formation of eastern Tennessee (equivalent to part of Chickamauga) is the source of the famous Tennessee Marble and is a high-calcium limestone suitable for chemical and metallurgical use. Hershey and Maher (1963, p. 47–48) described the Holston as follows:

> The Holston Formation, as represented on the geologic map of East Tennessee (Rodgers, 1953), consists of two units: a lower crystalline limestone (marble) and an upper limy quartz sandstone (Tellico or Chapman Ridge Sandstone).
>
> The marble type is characteristically a pink to cedar-red, crystalline limestone of high purity (more than 97 percent $CaCO_3$). The marble weathers deeply and produces a dark-red clay soil, which locally contains fragments of red iron ore or black manganese ores. Beneath the soil mantle a highly irregular bedrock surface is developed. The interface between soil and bedrock is a complex maze of pinnacles and valleys with 15 to 20 feet of relief, resembling "badlands" topography.
>
> The upper limy sandstone unit is a slabby, dark-gray quartz sandstone, with occasional beds of sandy shale. This unit forms knobby ridges generally covered by pines. Weathering of the sandstone produces a sandy, dark-red clay containing shale chips, spongy sandstone fragments, and locally fragments of red iron ore.
>
> The Holston Formation is about 400 feet thick near Knoxville and thins to about 200 feet near Cleveland, Bradley County. The portion of Holston Formation generally quarried is a crystalline limestone. The lighter colored stone has a higher carbonate content than the darker colored units. Quarryable thicknesses of the Holston may contain 97.5 percent or more $CaCO_3$, and the $MgCO_3$ ranges from 0.0 to slightly more than 2 percent. The Holston contains substantial reserves of high-calcium limestone.
>
> Only one analysis of the Chapman Ridge phase is available. This analysis, as would be expected, shows a high content of silica, 49.4 percent; carbonates comprise approximately 46.5 percent, and the remainder is iron and alumina.
>
> The limestone phase of the Holston meets commercial requirements for marble and is extensively quarried for this purpose. In addition, the high purity, relatively uniform chemical composition of the Holston marble results in the use of this stone for making cement and agricultural limestone. It also is crushed for aggregate, road metal, and similar uses. Generally, sites for such operations are selected on the basis of proximity to markets and in areas where shattering renders the stone unsuitable for dimension purposes.

TABLE 92.—*Chemical analyses of Middle Ordovician limestones*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	$CaCO_3$[1]	$MgCO_3$[2]	SiO_2 and (or) insoluble	R_2O_3 (Al_2O_3+ Fe_2O_3)	Source of information
Alabama:							
Jefferson	Chickamauga Limestone	------	91.2	------	5.7	1.9	Burchard and Butts (1910, p. 194).
Tuscaloosa	do	------	94.9	1.2	3.5	------	Burchard and Butts (1910, p. 110).
Jefferson	Chickamauga (Mosheim and Lenoir) Limestone and Knox (Newala) Group.	------	87.7	3.6	6.1	2.3	Burchard (1940, p. 20).
St. Clair	Little Oak Limestone.	------	------	------	------	------	
Georgia:							
Walker	Lenoir Limestone	50	89.9	5.1	2.8	1.8	Butts and Gildersleeve (1948, p. 135).
Maryland:							
Washington	St. Paul (Stones River) Group	------	80.8	11.8	5.4	1.6	Mathews and Grasty (1910, p. 416).
			1.2	96.6	4.3	.8	Mathews and Grasty (1910, p.414)
Pennsylvania:							
Centre	Middle Ordovician limestones	------	94.2	2.8	2.1	.9	O'Neill (1964, p. 18).
Mifflin	do	------	55.9	34.7	6.2	2.0	O'Neill (1964, p. 32).
Fulton	do	------	87.5	4.8	7.1	.6	O'Neill (1964, p. 24).
Centre	Valentine Member (of field 1918), Curtin Limestone (of Kay 1943).	------	98.5	.2	.5	.6	O'Neill (1964, p. 18).
Centre	do	------	97.5	1.2	.8	.4	Do.
Clinton	do	------	96.8	.6	1.0	.8	O'Neill (1964, p. 20).
Tennessee:							
Claiborne	Chickamauga (lower unit)	50	87.2	3.6	7.7	1.5	Hershey and Maher (1963, p. 188).
Anderson	Chickamauga (units 3, 4)	60–80	86.5	5.8	6.5	1.2	Hershey and Maher (1963, p. 229).
Blount	Lenoir Limestone	50–60	62.7	8.1	25.3	3.8	Do.
Knox	Holston Limestone	40–50	97.9	1.0	.6	.4	Hershey and Maher (1963, p. 188).
		60	93.8	2.4	2.5	1.3	Do.
Monroe	Bays Formation	25	49.2	4.6	40.8	5.5	Hershey and Maher (1963, p. 230).
Union	Moccasin Formation	80	80.6	4.6	11.8	3.0	Do.
Smith	Carters Limestone	100	82.7	7.6	8.4	1.3	Hershey and Maher (1963, p. 149).
DeKalb	Bigby-Cannon Limestone	80	93.1	4.0	2.5	.5	Hershey and Maher (1963, p. 229).
Macon	Catheys and Leipers Limestones.	40	83.8	4.8	10.0	1.4	Hershey and Maher (1963. p. 148).
Virginia:							
Botetourt	New Market Limestone	92	96.7	1.3	0.7	0.8	Edmundson (1958, p. 31).
		85	96.1	1.4	1.0	.7	Edmundson (1958, p. 34).
Giles	Mosheim Member, Lenoir Limestone.	------	95.3	1.2	1.0	.5	McCue, Lucke, and Woodward (1939, p. 381).
	Lenoir Limestone	------	92.3	1.8	2.8	1.5	McCue, Lucke, and Woodward (1939, p. 382).
Botetourt	Lincolnshire Limestone	144	97.8	1.0	.3	.8	Edmundson (1958, p. 31).
Giles	Five Oaks Limestone of Cooper and Prouty, 1943.	96	97.1	1.5	.3	.7	B. N. Cooper (1944b, p. 40).
Russell	Rockdell Limestone	146	95.7	1.8	1.4	.5	B. N. Cooper (1945, p. 14).
West Virginia:							
Monroe	Murfreesboro Limestone (Lower part, Stones River Group).	------	92.5	3.0	5.0	.9	McCue, Lucke, and Woodward (1939, p. 380).
		------	68.3	13.8	19.9	2.7	Do.
	Mosheim Member, Lenoir Limestone.	------	96.1	1.2	.9	.5	McCue, Lucke, and Woodward (1939, p. 381).
Mercer	do	------	94.8	1.6	2.0	1.2	Do.
Pendleton	do	------	97.8	.8	.5	.1	McCue, Lucke, and Woodward (1939, p. 381).
Jefferson	do	------	96.4	2.2	1.1	.2	Do.
Berkeley	do	------	99.4	1.1	.3	.1	Do.
Mercer	Lenoir Limestone	------	93.8	1.8	2.5	.5	McCue, Lucke, and Woodward (1939, p. 382).
Jefferson	do	------	90.7	3.0	4.3	1.2	McCue, Lucke, and Woodward (1939, p. 383).
Berkeley	do	------	87.5	1.6	9.0	1.5	Do.
Pendleton	Lowville Limestone	------	94.6	1.0	2.9	.6	Do.
Jefferson	Chambersburg Limestone	------	90.9	2.8	5.7	.6	Do.

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[1] Recalculated from CaO for some analyses.
[2] Recalculated from MgO for some analyses.

Limestones in other Middle Ordovician formations (Chickamauga Limestone, Lenoir Limestone including the basal Mosheim Member, Athens Shale, Bays Formation, and Moccasin Formation) have been exploited at a few places in eastern Tennessee (Hershey and Maher, 1963, p. 45–50). They do not make a good quality crushed stone and are too impure or too variable in composition to be used as chemical and metallurgical stone or as cement limestone. The purest stone is found in the Mosheim Member of the Lenoir Limestone, which Hershey and Maher (1963, p. 47) described together with the Lenoir of eastern Tennessee as follows:

> The Lenoir Limestone is a shaly, nodular-weathering limestone which locally contains a more pure, dense, fine-grained basal member, the Mosheim Limestone. In some places the uppermost Lenoir contains sparse rough, spongy, yellowish cherts; locally the lower beds contain fragments of chert and dolomite reworked from the underlying Knox dolomite.
>
> The Lenoir is as thick as 500 feet but thins to less than 200 feet in some areas.
>
> The Lenoir weathers to a fairly rich yellow clay soil which is rapidly eroded so that the outcrop belt is marked by ledges of bedrock. The formation normally underlies valleys.
>
> Only one quarry examined in this investigation was developed entirely in the Lenoir Limestone. The analysis showed 62.7 percent $CaCO_3$ and 8.1 percent $MgCO_3$; SiO_2 was 25.3 percent. Four analyses by TVA (B. C. Moneymaker, personal communication) average 83.8 percent $CaCO_3$, 7.7 percent $MgCO_3$, and 6.9 SiO_2. These tests were made on the nodular, gray Lenoir phase.
>
> Although the Mosheim member commonly is described as "High-calcium" limestone, available analyses show this description is incorrect: the $CaCO_3$ content ranges from 91.2 to 96.7 percent, $MgCO_3$ from 3.2 to 6.3 percent, and noncarbonates from 1.4 to 3.1 percent in selected samples (B. C. Moneymaker, personal communication).
>
> The Lenoir Limestone is of minor economic importance. It crumbles rapidly when exposed to weathering and is not chemically uniform enough for a cement stone, although it is of the proper type (i.e., a shaly limestone). The Mosheim member is not of quarryable thickness in many places, and it contains too many shale partings and too much silt generally incorporated in the limestone.

In northwestern Georgia, the lower part of the Chickamauga sequence described by Butts and Gildersleeve (1948, p. 22–23, 128–130) is made up of the Murfreesboro, Lenoir (and Mosheim Member), Lebanon, and Holston Limestones which together have an aggregate thickness of about 650 feet. The Murfreesboro Limestone is fine-grained to crystalline fossiliferous limestone which in places contains much black chert. The overlying Mosheim Member is a very thin but persistent layer of very pure limestone. The Lenoir is a dark-gray medium coarse-crystalline limestone, locally containing much chert. The Holston, exposed only in Whitfield County, is a coarse-grained, fragmental limestone.

In the Valley and Ridge province of northeastern Alabama (east of Birmingham, Jefferson County), the Middle Ordovician limestone units, from oldest to youngest, are: Mosheim Member, Lenoir Limestone, and Little Oak Limestone (Adams, Butts, Stephenson, and Cooke, 1926, p. 101–114). The Mosheim is thick-bedded fine-grained limestone, having a thickness of not more than 50 feet. The Lenoir proper is a dark finely crystalline medium thick-bedded limestone about 500 feet thick. The Little Oak is a dark thick-bedded coarsely crystalline limestone that locally contains considerable chert. It has a maximum thickness of about 500 feet. The Little Oak Limestone is used for cement manufacture in Alabama (table 53).

In western Virginia (in the vicinity of Botetourt and Alleghany counties), Middle Ordovician limestones have been divided into the New Market Limestone (overlying the Beekmantown Formation), Whistle Creek Limestone,* Lincolnshire Limestone,* Edinburg Formation,* and Collierstown Limestone* (Edmundson, 1958, p. 20–23). The Whistle Creek, Edinburg, and Collierstown Limestones consist of relatively impure limestone and shale and have little economic value. The New Market and Lincolnshire Limestones have important resources of high-calcium limestone. They were described by Edmundson (1958, p. 21–22) as follows:

> The name New Market limestone (Cooper and Cooper, 1946, p. 71–74) was proposed for the succession of predominantly dense, fine-grained limestone above the Beekmantown and below the dark-gray, medium-grained, commonly cherty Lincolnshire limestone, or locally as in the Lexington area the Whistle Creek limestone. The New Market limestone is essentially the same as the formation identified by Butts as Mosheim in northern Virginia. At other localities, mainly along the belts northwest of Lexington and Newport, it includes also Butts' Murfreesboro, which is composed of impure limestone and angular fragments of chert and locally intervenes between the Beekmantown and Mosheim. The New Market limestone is composed largely of thick-bedded, compact to a glassy, bluish-gray to dove-gray limestone. Among distinguishing characteristics are specks of transparent calcite scattered through many of the layers and thin films of chalk-like material on weathered surfaces. The thickness ranges from a few feet in the belts northwest of Lexington to a possible maximum of more than 200 feet in the Highbridge Church-Indian Rock belt. However, the occurrence of chert and other impurities in the lower part of the abnormally thick sections indicates that the full thickness does not meet the specifications of high-calcium limestone. Field studies indicate that this formation, the chief "quarry rock" of the Appalachian Valley, contains at least 100 feet of high-grade limestone at several localities in Warm Springs valley. Sampled units, except where containing chert nodules, generally average about 97 percent calcium carbonate.
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* Of Cooper and Cooper (1946).

The Lincolnshire limestone (Cooper and Cooper, 1946, p. 75–78) includes those beds above the New Market (Mosheim of Butts) limestone or locally the Whistle Creek and below either the brownish-weathering beds of the Botetourt (Whitesburg of Butts) limestone or below younger beds of the Edinburg formation. The Lincolnshire varies from dark-gray, cherty limestone with minor intercalations of light-gray, coarsely granular limestone to thick units composed chiefly of the coarse-grained, high-calcium limestone. It is essentially the same as Butts' Lenoir limestone in northern Virginia and the Lenoir and overlying Holston limestones recognized by him in the Lexington area. The Holston limestone has subsequently been described as representing not a time-stratigraphic unit, but only a characteristic facies of clastic reefy high-calcium limestone within the Lincolnshire formation.

The maximum thickness of the Lincolnshire or its equivalent Lenoir and Holston limestones is about 200 feet in the vicinity of Murat southwest of Lexington. Sampled units of this coarsely granular limestone, or *Murat limestone facies* of the Lincolnshire, along the belt between Lexington and Murat contain from 97 to 98 percent calcium carbonate and represent some of the largest limestone reserves in the James River district.

The Middle Ordovician Mosheim Member of the Lenoir Limestone in the Eastern Panhandle of West Virginia, is one of the most extensively mined high-calcium limestones in Appalachia. McCue, Lucke, and Woodward (1939, p. 13) described the Mosheim and Lenoir of this area as follows (These rocks were assigned to the Stones River Group of central Tennessee on the basis of stratigraphic studies by Stose (1906). Later studies have shown this correlation to be incorrect, and Neuman (1951) proposed the name St. Paul Group to substitute for Stones River Group in Virginia, West Virginia, and Maryland.):

> Stones River Limestones form an important stratigraphic and economic section of the Ordovician in Berkeley and Jefferson Counties of northeastern West Virginia, where they crop out in the main Appalachian Valley west of the Blue Ridge. Both middle (Mosheim Limestone) and upper (Lenoir Limestone) Stones River can be readily recognized. The former is the most valuable limestone formation of the State, and is a dove-gray to light-blue fine-grained extremely pure limestone of the type known as vaughanite. Its thickness varies from less than 100 feet to about 200 feet, and it has been opened in a large number of active quarries in the vicinity of Martinsburg. * * * There is a complete absence of cherty, magnesian, or siliceous beds of any kind in the Mosheim, so that from some localities it has been possible continuously to ship rock in which the silica content is less than 1.5 percent. The overlying Lenoir, of Upper Stones River age, is 20 to 40 feet thick and consists of dark impure shelly limestones of little or no economic importance.

The Middle Ordovician limestones of central Pennsylvania comprise six formations named by Kay (1943) of which his Loysburg, Benner, Curtin and Nealmont Formations have rock suitable for crushed stone, in part high-calcium limestone. O'Neill described these formations (1964, p. 6–7) as follows:

> The Middle Ordovician of central Pennsylvania includes sections of high-calcium limestone in several formations. The most important of these is the Valentine Member of the Curtin Formation which has a sufficient thickness in places for large-scale mining. The Clover Limestone in the Loysburg Formation and the Snyder Limestone in the Benner Formation also contain high-calcium stone but in more limited quantities.
>
> * * * * * * *
>
> The Loysburg Formation lies above the Beekmantown Group in central Pennsylvania. It consists of interbedded limestone and laminated dolomites with an occasional intraformational conglomerate in the lower portion. The upper portion, the Clover Member, varies from about 40 to 80 feet in thickness and is composed of relatively pure, dense, sublithographic limestone. The maximum total thickness reported for the Loysburg is 480 feet.
>
> * * * * * * *
>
> * * * Kay (1943, p. 188–189) reported the Clover Member of the Loysburg as a potential source for chemical lime and has been used in the past for blast-furnace flux. The possibility of stone from the Loysburg Formation being acceptable for aggregate and roadstone also appears to be good.
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> * * * * * * *
>
> The Benner Formation, which overlies the Hatter Formation, is composed of two members—the Snyder and Stover Limestones. The Snyder is the basal member, consisting of light-colored, thin-bedded, detrital limestone with characteristic limestone-pebble conglomerates and dense, relatively pure, sublithographic limestone. The upper member, the Stover, consists of dark, dense, thick-bedded limestone, commonly separated by silty partings. The Benner Formation reaches a maximum thickness of about 140 feet in the northwest and thins by the loss of the upper or Stover beds to the southeast.
>
> * * * * * * *
>
> The Curtin Formation is stratigraphically above the Benner Formation and has been separated into two members. The lowermost member, the Valley View, consists of light- to dark-gray, generally fine- to medium-textured, relatively thick-bedded, impure limestones with argillaceous partings and some thin metabentonite beds. At its type section, the Valley View is 52 feet thick. The upper member, the Valentine, is an exceptionally pure limestone, especially above the basal 15 to 25 feet of its 90-foot thickness. The Valentine is made up of very-light-gray, dense, thin- to thick-bedded limestone.
>
> * * * * * * *
>
> The Curtin Formation is exposed only in portions of Centre, Clinton and Lycoming Counties. It is thickest along the northwest side of the Nittany Valley where it measures about 150 feet but thins to extinction to the southeast.
>
> The Valentine Member of the Curtin Formation is an important economic horizon which is presently being extracted at 5 locations in Centre County * * * to supply stone for flux, cement, lime, agricultural purposes, the manufacture of glass, filler, whiting, aggregate, and roadstone materials.
>
> Kay (1943, p. 200–203) reported that the Valentine reaches a maximum thickness of 75 to 90 feet on the northwest side of the Nittany Valley in a belt extending from about 4 miles west of Bellefonte to the vicinity of Jacksonville, a distance of about 15 miles. Farther northeast and southeast of this belt, the Valentine thins to extinction. Kay (1943, p. 200–203) believes this regional thinning was caused by an unconformity

which followed deposition, whereas Rones (1955, p. 177) believes it is best explained by a facies change.

Figures reported by Kay (1943, p. 200) show the Valentine to be 80 feet thick at Jacksonville, 10 feet thick at Salona, 52 feet thick at Pleasant Gap, 40 feet thick at Tylersville in Sugar Valley, and 80 feet thick at Spring Bank in Brushy Valley. It is absent at the following places: Antes Gap in the Nippenose Valley, south of Lemont in Brushy Valley, east of Loganton in Sugar Valley, and at Millheim in East Penn's Valley.

* * * * * * *

The Valley View Member of the Curtin Formation is not as pure as the Valentine Limestone but has been used for blast-furnace flux in the past. Kay (1943, p. 197) reports that it is remarkably constant in character and thickness in the Nippenose Valley and the western end of the Bellefonte district. The Valley View Member is found within all areas of the mapped Curtin Formation. Near its limits of distribution it is bevelled by an unconformity which followed deposition.

* * * * * * *

The Nealmont Formation is the lateral equivalent of the Curtin Formation and lies disconformably above the Stover Limestone. The Nealmont Formation is separated into three members—Oak Hall, Centre Hall, and Rodman, listed in order from the oldest to youngest. The Oak Hall Member consists of about 60 feet of medium-dark-gray, medium- to coarse-grained, thick-bedded limestone with some layers containing dolomite streaks. It contains a thin metabentonite bed about 18 feet below its top. The Centre Hall consists of thin-bedded, fossiliferous, shaly limestone which reaches a maximum of about 44 feet in thickness. It is separated from the underlying Oak Hall Member by a thin metabentonite bed. The Rodman is composed of dark, medium- to coarse-grained, highly fossiliferous impure limestone with some interbeds of thin, dense limestone. Black chert nodules occur in places in the lower part. Its thickness is of the order of 30 feet.

The Nealmont Formation reaches a maximum thickness of 125 to 150 feet in a northeast-southwest trending belt which averages about 8 to 10 miles in width and passes through the center of Blair County, continuing northeastward into Centre and Clinton Counties to the southwest corner of Lycoming County. It thins both to the northwest and southeast from this belt.

The Oak Hall and Centre Hall Members of the Nealmont Formation have been quarried for flux stone whereas the Rodman Member has not. The available chemical analyses for these three members substantiate their general level of acceptance as flux-stone material. * * *

A potential as use for cement limestone and agricultural limestone is also indicated by all of the chemical analyses for the Nealmont Formation. * * *

Silurian and Devonian limestones

The rocks of Silurian and Devonian age are mainly shales and sandstones in the Valley and Ridge province; limestone units are restricted in extent and thickness, being found in Appalachia only from Tennessee northward. The limestone is generally rather impure, so it is not satisfactory for chemical or metallurgical use and tends to be too variable in composition to be used as cement limestone. Table 93 shows analyses of Silurian and Devonian limestones from Appalachia. The following limestone units are recognized: Hancock Limestone (Silurian and Devonian) of northeastern Tennessee and southwesternmost Virginia; Tonoloway Limestone (Upper Silurian) extending from southeastern West Virginia northward into Pennsylvania; the Keyser Limestone (Silurian and Devonian); and the Helderberg Group of Early Devonian age, comprising the Coeymans, New Scotland, and Becraft Limestones, also extending from southeastern West Virginia northward into Pennsylvania. (See pl. 3, columns 4, 5, 7, 11, 13.)

The Hancock Limestone of northeastern Tennessee (Hershey and Maher, 1963, p. 50) is a sequence of thick-bedded limestone and dolomite containing some cherty layers. It has a maximum thickness of 300 feet. In Lee and Scott Counties, Va., the Hancock is only 105 feet thick and consists of medium-dark-gray limestone and shaly limestone containing some interbedded finely crystalline dolomite (Harris and Miller, 1963).

The Tonoloway Limestone of eastern West Virginia and southwestern Virginia is stratigraphically equivalent to the Hancock. It consists of thin-bedded argillaceous limestone and calcareous shale having a total thickness of 350–600 feet (McCue, Lucke, and Woodward, 1939, p. 18–19). In addition to its use as an aggregate, the Tonoloway is used for agricultural limestone in Grant, Pendleton, and Hardy Counties, W. Va.

The Keyser Limestone and Helderberg Group of eastern West Virginia were described by McCue, Lucke, and Woodward (1939, p. 22–25) as follows. The Keyser Limestone is best exposed in Mineral County in the northeastern part of the State. It ranges from 150 to 350 feet in thickness and is typically a blue- to dark-gray limestone that is massive and nodular in the lower part and somewhat more thin-bedded and shaly in the upper part. The overlying Coeymans Limestone, cropping out in Pendleton County and northward, is a hard crystalline limestone having an average thickness of about 20 feet. The New Scotland Limestone, the next youngest, is a shaly cherty limestone and calcareous shale generally 18–40 feet thick. The Becraft Limestone, the youngest formation of the group here, crops out only locally in Berkeley, Pocahontas, and Greenbrier Counties, W. Va. It is an arenaceous to cherty limestone as much as 120 feet thick. Limestone of the Keyser and Helderberg is used extensively for aggregate and roadstone in eastern West Virginia.

TABLE 93.—*Chemical analyses of Silurian and Devonian limestones and dolomites*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	CaCO$_3$ [1]	MgCO$_3$ [2]	SiO$_2$ and (or) insoluble	R$_2$O$_3$ (Al$_2$O$_3$+Fe$_2$O$_3$)	Source of information
Maryland:							
Allegany	Wills Creek Shale	------	62. 9	3. 3	20. 3	10. 0	McCue, Lucke, and Woodward (1939, p. 384).
Washington	Tonoloway Limestone	------	79. 8	3. 5	14. 1	2. 5	Mathews and Grasty (1910, p. 431).
		50	90. 1	1. 6	5. 6	3. 2	Mathews and Grasty) 1910, p. 435).
	Tonoloway Limestone (cement rock).	12	68. 8	4. 3	20. 2	7. 7	Mathews and Grasty (1910, p. 436).
Allegany	do	15	63. 2	10. 0	17. 6	8. 7	Mathews and Grasty (1910, p. 455).
Washington	Helderberg Limestone (includes upper 24 ft of Tonoloway; cement rock).	198	65. 8	4. 4	21. 7	7. 7	Mathews and Grasty (1910, p. 437).
Allegany	Helderberg Limestone (includes upper 40 ft of Tonoloway).	150	80. 5	2. 9	13. 5	2. 9	Mathews and Grasty (1910, p. 452).
Ohio:							
Adams	Brassfield Limestone	------	89. 4	2. 6	3. 4	1. 3	Stout (1941, p. 50).
	West Union Formation of Orton (1871).	72	52. 0	40. 5	3. 5	2. 2	Stout (1941, p. 52).
Highland	Bisher Limestone	16	48. 8	39. 7	6. 6	2. 6	Stout (1941, p. 80).
	West Union Formation of Foerste, 1929 (Lilley Member of Foerste, 1917).	17	48. 5	39. 5	7. 3	2. 5	Do.
	Cedarville and Peebles (of Foerste, 1929) Dolomites.	23	53. 6	44. 6	. 3	. 6	Stout (1941, p. 92).
Adams	do	34	52. 7	44. 2	. 9	1. 1	Stout (1941, p. 60).
Ross	Cedarville Dolomite	45	53. 7	45. 0	. 4	. 4	Stout (1941, p. 68).
Highland	Greenfield Dolomite of Orton (1871).	55	52. 9	43. 8	1. 6	. 6	Stout (1941, p. 66).
Adams	do	15	53. 8	45. 0	. 4	. 3	
Pennsylvania:							
Lycoming	Tonoloway and Keyser Limestone.	------	91. 4	3. 5	4. 6	1. 6	O'Neill (1964, p. 31).
Juniata	do	------	93. 3	2. 0	2. 1	1. 1	O'Neill (1964, p. 25).
Blair	do	------	96. 1	3. 1	2. 1	1. 0	O'Neill (1964, p. 16).
Bedford	do	40	81. 7	8. 6	7. 0	2. 6	O'Neill (1964, p. 12).
Virginia:							
Bath	Keyser Limestone (lower member).	50	91. 6	2. 5	4. 6	1. 3	Edmundson (1958, p. 75).
Alleghany	Keyser Limestone (upper member).	34	91. 1	3. 7	3. 6	1. 3	Edmundson (1958, p. 67).
	Coeymans Limestone	18	95. 7	2. 1	. 7	. 9	Do.
		45	96. 4	1. 0	1. 0	1. 1	Edmundson (1958, p. 70).
	Licking Creek Limestone of Swartz (1939).	60	92. 3	1. 2	5. 0	. 9	Edmundson (1958, p. 69).
Bath	do	55	92. 7	. 9	5. 0	. 9	Edmundson (1958, p. 74).
West Virginia:							
Pocahontas	McKenzie Formation	------	78. 2	4. 2	15. 5	1. 7	McCue, Lucke, and Woodward (1939, p. 384).
Hardy	Wills Creek Shale	------	93. 4	2. 8	2. 4	1. 2	Do.
Mineral	do	------	83. 3	5. 2	7. 7	2. 8	Do.
Greenbrier	Tonoloway Limestone	------	93. 4	2. 6	2. 6	1. 6	Do.
Pocahontas	do	------	81. 9	2. 3	10. 5	3. 8	Do.
Pendleton	do	------	89. 2	3. 4	5. 8	1. 6	McCue, Lucke, and Woodward (1939, p. 385).
Hardy	do	------	92. 9	3. 4	2. 2	. 8	Do.
Berkeley	do	------	90. 3	3. 0	5. 1	1. 7	McCue, Lucke, and Woodward (1939, p. 387).
Greenbrier	Keyser Limestone	------	75. 5	13. 2	7. 3	2. 1	McCue, Lucke, and Woodward (1939, p. 389).
Pendleton	do	------	94. 2	2. 0	3. 0	1. 1	Do.
Berkeley	do	------	90. 6	2. 3	5. 3	1. 9	McCue, Lucke, and Woodward (1939, p. 391).
Pendleton	Coeymans Limestone	------	97. 4	. 7	1. 2	1. 1	McCue, Lucke, and Woodward (1939, p. 394).
Mineral	do	------	89. 7	1. 5	8. 1	. 7	Do.
Berkeley	New Scotland Limestone	------	72. 5	. 7	25. 0	. 6	McCue, Lucke, and Woodward (1939, p. 395).
Pendleton	do	------	93. 8	1. 2	4. 2	. 6	Do.
Mercer	Becraft(?) Limestone	------	91. 9	. 2	6. 6	. 2	Do.
Morgan	do	------	88. 8	2. 0	5. 9	2. 5	Do.

[1] Recalculated from CaO for some analyses.

[2] Recalculated from MgO for some analyses.

The limestones of Silurian and Devonian age in Pennsylvania were described by O'Neill (1964, p. 7) as follows:

> The more important limestones of Silurian and Devonian Age belong to the Tonoloway, Keyser, and Helderberg Formations which have supplied raw materials for use as agricultural lime, building lime, flux, road metal and concrete. In some places, high-grade limestones from the Keyser have been quarried for chemical lime.
>
> These limestones occur in the Appalachian Mountain section of the Valley and Ridge physiographic province in Pennsylvania and are in part responsible for the floors of some narrow, steep-sided valleys that are prominent features in the central part of the State.
>
> * * * * * * *
>
> The Tonoloway Formation of Silurian age is dominantly gray and platy. In most places it consists of finely laminated, fine-grained limestone, argillaceous limestone, and calcareous shale. The maximum observed thickness of the Tonoloway in Pennsylvania is 325 feet. It is correlated with the Bossardville Limestone and Poxono Island beds in the eastern part of the State.
>
> The Keyser Formation generally has been accepted as the highest formation in the Silurian System although new data indicate that the Silurian-Devonian boundary falls within the unit. Stratigraphically it lies above the Tonoloway Formation and typically consists of light- to dark-gray, thin- to thick-bedded, highly fossiliferous limestone. The lower portion of the formation is usually characterized by many nodular limestone beds. The upper portion has been described as relatively argillaceous in places and some chert has been noted in the section. The thickness of the Keyser as measured varies between 88 and 202 feet. * * *
>
> Stone from the Keyser and Tonoloway Formations or their correlatives has been found to be satisfactory for a variety of uses. * * * At the present time, stone from these formations is being produced for aggregate and roadstone materials, agricultural limestone, lime, asphalt filler and, in one case, for cement limestone. In addition, a section of pure massive limestone which occurs near the base of the Keyser Formation in Blair County has furnished a supply of stone for chemical lime and flux stone. * * *
>
> * * * * * * *
>
> The Helderberg Formation is Lower Devonian in age and is composed of three members. The basal member, the Coeymans, consists of coarse, thick-bedded, crinoidal limestone, locally shaly in its lower portion. In the eastern part of the State, the Coeymans becomes sandy. Chert is usually present. Its maximum thickness is about 10 feet.
>
> The middle member of the Helderberg Formation is the New Scotland. It consists of dark-gray, thin-bedded crystalline limestone varying from 6 to 13 feet thick at the base, above which lies shales, interbedded with impure limestones and chert. The maximum total thickness of the New Scotland Member is about 44 feet.
>
> The upper member of the Helderberg Formation is the Mandata, equivalent to the Port Ewen Shale and Becraft Limestone in the eastern part of the State. The Mandata is in general a dark-gray, calcareous, thin-bedded shale. * * *
>
> The economic potential for the Helderberg Formation cannot be rated good because of the abundance of shale and the relatively thin units of interbedded limestone. * * *

APPALACHIAN PLATEAUS, INTERIOR LOW PLATEAUS, AND CENTRAL LOWLAND

The Appalachian Plateaus, Interior Low Plateaus, and Central Lowland provinces are characterized by flat-lying rocks of which those of Mississippian, Pennsylvanian, and Permian age crop out most extensively. At places along the border of the region older rocks are exposed. Each of the systems have limestone units that are quarried for use as crushed stone. Limestone of Pennsylvanian age, mainly the Vanport Limestone, is an important source of high-calcium limestone for chemical and metallurgical use and of cement limestone. Limestone units of Mississippian age, mainly the Ste. Genevieve, Monteagle, and Girkin (Gasper of former usage) Limestones, have important resources of high-calcium stone.

Ordovician limestones and dolomites

Several Ordovician carbonate rock units are exposed in the westernmost counties of the Appalachian Region in Tennessee (pl. 2) and were described by Hershey and Maher (1963, p. 66–75).

The oldest rocks exposed in the Appalachian Plateaus belong to the Knox Group and crop out in the Sequatchie Valley of Tennessee and Alabama. In Jackson County, Tenn., the Knox is overlain by the Wells Creek Dolomite which is about 130 feet thick and is similar in lithology to the dolomite of the Knox. The Ridley Limestone, younger than the Wells Creek, crops out in a limited area in Smith County, Tenn., and in counties west of Appalachia. It is about 93 feet thick and consists of light gray to gray thick-bedded dense fine-grained limestone and interbeds of sugary-textured magnesian limestone. Overlying the Ridley is the Lebanon Limestone which averages about 90 feet thick and consists of thin-bedded limestone similar in lithology to the Ridley. The Carters Limestone, the next youngest formation of the region, is exposed in Smith and DeKalb Counties, Tenn. It consists of an upper thin-bedded unit averaging about 10 feet thick and a lower thick-bedded unit about 50 feet thick separated by a thin metabentonite layer. The two units are similar lithologically, but the lower unit has interbeds of magnesian limestone. The only other Ordovician limestone unit exposed in the region is the Leipers Limestone which crops out in southwestern Franklin County, Tenn. It averages about 75 feet thick and consists of bluish-gray fine- to medium-grained limestone and argillaceous limestone.

The Chickamauga Limestone crops out along Elk River, Limestone County, northernmost Alabama. According to Adams, Butts, Stephenson, and Cooke (1926, p. 122), the Chickamauga consists of a thin unit of rather thick-bedded limestone overlain by

50–75 feet of thin-bedded cobbly highly fossiliferous limestone with clay partings.

Other Middle Ordovician limestone units are exposed along the Kentucky River on the west border of Appalachia in central Kentucky. They include the Tyrone, Oregon, and Camp Nelson Limestones which are quarried for roadstone, concrete aggregate, and agricultural limestone.

Several hundred feet of Upper Ordovician thin limestone and interbedded calcareous shale are exposed in Adams, Brown, Highland, and Clermont Counties of southern Ohio and nearby counties in Kentucky (Stout, 1941, p. 46–108). Because of their high shale content, they have been quarried only locally for small amounts of crushed stone.

Silurian and Devonian limestones and dolomites

Silurian limestone and dolomite are found in Ohio and Kentucky (pl. 3, columns 10, 12) and Devonian limestone in the northern part of Otsego County, N.Y. Elsewhere in the Appalachian Plateaus, Interior Low Plateaus, and Central Lowland, Silurian and Devonian rocks consist mainly of shale. The well-known Columbus Limestone (Devonian) that is mined extensively in central Ohio extends into Appalachia in the subsurface and in some areas could be mined underground as it is in Summit County, Ohio, north of Appalachia.

The Silurian System of southern Ohio includes the Brassfield Limestone, West Union Formation of Orton (1871), Cedarville Dolomite, Peebles Dolomite of Foerste (1929), and Greenfield Dolomite of Orton (1871) described by Stout (1941, p. 47–49, 51–110). The Brassfield consists of thin- to medium-bedded hard dense crystalline limestone and interbedded shale having a maximum thickness of about 70 feet. It makes a good construction stone and roadstone and is in part a high-calcium limestone. It is used as a cement limestone in southern Ohio, west of Appalachia. The West Union Dolomite or Formation is a medium- to thick-bedded coarsely crystalline, somewhat siliceous dolomite as much as 72 feet thick. The overlying Cedarville and Peebles Dolomites range from 40 to 120 feet in thickness and consist of massive porous to cavernous, crystalline relatively pure dolomite. They are mined for metallurgical use in Adams County. The Greenfield Dolomite is as much as 100 feet thick and consists of massive porous coarsely crystalline, relatively pure dolomite.

Limestone of Devonian age is mined in Otsego and Tompkins Counties, N.Y., mainly for concrete aggregate and roadstone, but some stone produced in Tompkins County is used as blast-furnace flux. The Onondaga Limestone is exploited in Otsego County and the Tully Limestone in Tompkins County. In central and western New York, north of the Appalachian counties, Devonian limestone is extensively quarried.

Mississippian limestones

Mississippian limestone units crop out extensively along the western border of Appalachia in Alabama, Tennessee, and Kentucky and to a lesser extent along the boundary between the Appalachian Plateaus and the Valley and Ridge provinces. They crop out locally in western Pennsylvania and eastern Ohio. Limestone units in the eastern part of the Appalachian Plateaus and nearby Valley and Ridge include the following formations: Loyalhanna Limestone in southwestern Pennsylvania, Greenbrier Limestone, which extends from Pennsylvania through eastern West Virginia into southwesternmost Virginia, and Newman Limestone in eastern Tennessee (pl. 3, columns 4, 7, 13, 15). Typical analyses of limestone in these formations are given in table 94.

In western Pennsylvania the Loyalhanna and Greenbrier Limestones and one or two other thin limestone units of Mississippian age have been mined on a small scale as sources of lime, roadstone, railroad ballast, and paving blocks (B. L. Miller, 1934, p. 130–131). The Loyalhanna Limestone, exposed only in southwestern Pennsylvania, is generally 40–60 feet thick, but at places is absent and at others is as much as 80 feet thick. The typical rock is a hard fine-grained calcareous sandstone in which quartz sand grains are cemented by $CaCO_3$. It has been burned to make a natural mortar that does not need addition of sand. The Greenbrier Limestone in Fayette County is stratigraphically 40–50 feet about the Loyalhanna. It ranges from less than 10 to about 40 feet in thickness and consists of a dark thick-bedded relatively pure limestone that has been quarried to make furnace flux and high-quality white lime.

The Greenbrier Limestone attains its greatest thickness and is an important source of crushed stone in southeastern West Virginia and southwesternmost Virginia. In Lee and Scott Counties, Va., the Greenbrier consists of about 450 feet of dark- to olive-gray fine-grained to oolitic and granular limestone (Harris and Miller, 1958). In southeastern West Virginia, the formation consists of limestone and interbedded shale as much as 1,000 feet thick (McCue, Lucke, and Woodward, 1939, p. 28–29). The Greenbrier of this region contains some high-calcium limestone.

Hershey and Maher (1963, p. 51) gave the following information about the Newman Limestone of eastern Tennessee: The formation is about 1,200 feet thick in Blount County and consists of shaly lime-

TABLE 94.—*Chemical analyses of Mississippian limestones*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	$CaCO_3$ [1]	$MgCO_3$ [2]	SiO_2 and (or) insoluble	R_2O_3 (Al_2O_3 + Fe_2O_3)	Source of information
Alabama:							
Blount	Bangor Limestone	100	96.7	0.7	1.0	0.8	Burchard and Butts (1910, p. 190).
		150	89.6	8.2	2.0	.8	Burchard and Butts (1910, p. 191).
Georgia:							
Catoosa	Fort Payne Limestone	20	96.3	1.7	.6	.8	Butts and Gildersleeve (1948, p. 135).
Dade	Bangor Limestone	50	99.1	1.0	.7	.8	Do.
Kentucky:							
Carter	Ste. Genevieve and Girkin Limestones.	21	98.0	.3	1.4	.3	Stokley (1949, p. 31).
Morgan	do	20	98.2	1.0	.6	.2	Stokley (1949, p. 32).
Powell	do	28	98.4	.5	.7	.4	Do.
Lee	do	38 (?)	96.4	.7	2.5	.4	Stokley (1949, p. 33).
Pulaski	do	35	96.2	------	2.5	.5	Stokley (1949, p. 35).
Wayne	do	20	96.9	.8	1.3	.3	Stokley (1949, p. 36).
Harlan	Ste. Genevieve Limestone	23	95.0	2.4	1.3	.2	Stokley (1949, p. 43).
Estill	"Paint Creek" Limestone	28	96.2	------	--------	.3	Stokley and McFarlan (1952, p. 52).
Pulaski	do	33	97.4	------	--------	--------	Stokley and Walker (1953, p. 51).
	"Glen Dean" Limestone	10	80.6	4.2	7.8	2.9	Stokley and Walker (1953, p. 49).
Maryland:							
Allegany	Greenbrier Limestone	8	95.3	.2	2.9	1.8	Mathews and Grasty (1910, p. 460).
		8	77.1	3.1	13.9	6.2	Do.
Ohio:							
Lawrence	Maxville Limestone	40	81.2	5.6	8.8	2.2	Lamborn (1951, p. 175).
Perry	do	------	90.9	3.5	2.4	1.8	Lamborn (1951, p. 298).
Muskingum	do	18	96.2	.8	1.6	.7	Lamborn (1951, p. 242).
Tennessee:							
Franklin	"Ste. Genevieve-Gasper" Formation.	40	86.6	4.3	8.5	0.5	Hershey and Maher (1963, p. 229).
Putnam	do	80	95.4	2.7	1.5	.4	Hershey and Maher (1963, p. 230).
Cumberland	do	50	97.5	1.5	.7	.3	Hershey and Maher (1963, p. 147).
	"Glen Dean" Limestone	------	82.8	6.9	8.8	1.5	Do.
Sequatchie	do	70	95.9	2.2	1.6	.4	Hershey and Maher (1963, p. 149).
Marion	"Ste. Genevieve-Gasper" and "Glen Dean" Fms.	140	88.9	4.4	5.3	1.3	Hershey and Maher (1963, p. 148).
		140	91.4	6.1	2.1	.5	Do.
West Virginia:							
Mercer	Greenbrier Limestone	8	91.2	2.3	3.6	.7	McCue, Lucke, and Woodward (1939, p. 397).
Mercer	do	42	88.6	3.1	7.2	.7	Do.
Greenbrier	do	20	85.4	1.8	12.6	.6	McCue, Lucke, and Woodward (1939, p. 399).
		32	93.5	1.6	3.3	.9	McCue, Lucke, and Woodward (1939, p. 400).
Monroe	do	15	89.7	2.3	7.7	.6	McCue, Lucke, and Woodward (1939, p. 399).
Pocahontas	do	61	94.6	2.4	2.6	.5	McCue, Lucke, and Woodward (1939, p. 402).
Randolph	do	20	84.7	2.6	11.5	.7	McCue, Lucke, and Woodward (1939, p. 403).
Tucker	do	60	91.1	2.2	6.2	.6	McCue, Lucke, and Woodward (1939, p. 405).
Monongalia	do	100	89.1	2.1	6.1	.4	Do.

[1] Recalculated from CaO for some analyses.
[2] Recalculated from MgO for some analyses.

stone and limy shale. In Hawkins County, to the northeast, it thickens to 2,800 feet. The lower part of the formation is shaly and dolomitic, the middle part is more limy, and the upper part is shaly and has several beds of sandstone. In Bradley and Hamilton Counties to the southwest, it consists of shaly limestone in the lower part and contains beds of pure limestone in its upper part. Several limestone units consist of more than 95 percent $CaCO_3$; these units and the Holston Limestone contain the purest limestone of eastern Tennessee.

The widespread Upper Mississippian rocks along the western border of Appalachia (pl. 2) include several limestone units that have been extensively mined for crushed stone. The limestone is characteristically low in magnesia, and although the amount of other impurities varies greatly, at least two formations, the Ste. Genevieve and Girkin Limestones contain abundant high-calcium limestone. The most widespread Mississippian limestone units cropping out in Kentucky, Tennessee, and Alabama, are from oldest to youngest: Warsaw Limestone, St. Louis Limestone, Ste. Genevieve Limestone, Girkin (Gasper) Limestone (locally the Monteagle, Renault, and Paint Creek Limestones in Kentucky), and Glen Dean Limestone. In southern Appalachia, the sequence is underlain by the Fort Payne Formation which locally contains limestone beds. In Alabama it is overlain by the Bangor Limestone. In Ohio, the Maxville Limestone is the only limestone of Mississippian age. Chemical analyses of the limestone in some of these formations are given in table 94.

The following data about these Mississippian limestone formations have been summarized from several reports, including Adams and others (1926), Alabama; Hershey and Maher (1963), Tennessee; McFarlan (1943) and McGrain (1956, 1958), Kentucky; and Morse (1910) and Lamborn (1951), Ohio.

The Warsaw Formation is 80–100 feet thick in the southwestern Appalachian counties of Kentucky and in Tennessee; it thickens to a maximum of about 200 feet in northwest Alabama. It consists of variable amounts of interbedded limestone, shale, and sandstone. In Kentucky, the limestone is locally siliceous or argillaceous, whereas in Alabama it is somewhat purer and has been used for flux.

The St. Louis Limestone crops out extensively in the region extending from northern Kentucky to northwestern Alabama and along the Pine Mountain fault in eastern Kentucky. In Kentucky the formation ranges from 30 to 117 feet thick, in Tennessee from about 180 to 200 feet thick, and in Alabama from 150 to 175 feet thick. The formation consists mainly of siliceous and cherty limestone in Kentucky. In Tennessee and Alabama the limestone is interbedded with dolomitic layers, but the rock is somewhat higher in total carbonate than in Kentucky, at places averaging as much as 95 percent. The St. Louis Limestone is quarried extensively for crushed stone, mainly roadstone and concrete aggregate.

The Ste. Genevieve and Girkin (Gasper) Limestones crop out in the same region as the St. Louis Limestone. The Ste. Genevieve is as much as 60 feet thick in northeastern Kentucky, about 80 feet thick in southern Kentucky, where it is the lower member of the Monteagle Limestone (Lewis and Thaden, 1965), and 75–100 feet thick in northern Alabama. It is partly a high-calcium limestone. Hershey and Maher (1963, p. 80–83) described the Ste. Genevieve and Gasper of Tennessee as attaining a maximum exposed thickness of 300 feet and consisting of two rock types, a thick-bedded oolitic fragmental coarse-grained very pure limestone and a nonoolitic fine-grained to crystalline less pure limestone. Beds of oolitic limestone are as much as 30 feet thick and some average more than 97 percent $CaCO_3$. The Ste. Genevieve has been extensively mined for general-purpose crushed stone throughout its area of outcrop in Appalachia and as cement limestone in eastern Tennessee.

The Girkin or Gasper Limestone in northern Alabama is mainly thick-bedded oolitic limestone and interbedded fine-grained limestone about 100 feet thick. Like the Ste. Genevieve, it grades into a shale facies towards the west and south in Alabama.

The upper member of the Monteagle Limestone of Tennessee and southern Kentucky is equivalent to the Girkin (Gasper) and to the Renault and Paint Creek Limestones of western Kentucky (Lewis and Thaden, 1965). Locally it is more than 200 feet thick in Wayne County, Ky., but thins to the north and is 20 feet thick in Carter County. The upper member is similar in lithology to the Ste. Genevieve Member, in part consisting of massive oolitic high-calcium limestone.

The Glen Dean Limestone, the next youngest Mississippian limestone formation, crops out in Kentucky and Tennessee. It is 15–180 feet thick in Kentucky and averages 150 feet in thickness in Tennessee, although in Marion County, southern Tennessee, it attains a maximum thickness of 250 feet. In Kentucky the Glen Dean locally is the equivalent of the Bangor Limestone and consists chiefly of thick-bedded impure limestone and some interbedded pure limestone layers. At places it contains much interbedded shale.

The Glen Dean of Tennessee is a medium- to thick-bedded fine- to medium-grained limestone and interbedded oolitic limestone and shale. The formation is mined for aggregate and roadstone.

The Bangor Limestone of Alabama is variable in thickness, ranging from about 100 feet to nearly 700 feet. It is thick-bedded, crystalline and oolitic, very pure, and is quarried as a source of high-calcium limestone, used mainly for flux.

The Maxville Limestone, the uppermost formation of the Mississippian System of Ohio, occurs in isolated outcrops in a belt extending from Muskingum County in the north to Scioto County in the south. Its spotty distribution results from erosion of the formation before deposition of overlying rocks of Pennsylvanian age (Lamborn, 1951, p. 20). Maximum thickness is about 200 feet. In Muskingum County, where it is extensively mined for use as crushed stone as well as for cement limestone and chemical and metallurgical limestone, it is about 35 feet thick (Lamborn, 1951, p. 241–242). Morse (1910, p. 100) stated that in Muskingum and Perry Counties the formation could be divided into two units, a lower of massive clayey limestone and an upper of thin- to medium-bedded limestone with shale partings. The maximum thickness of the upper unit is 22 feet and that of the lower unit is slightly more than 25 feet in this area.

Pennsylvanian and Permian limestones

Several thin limestone layers occur in the thick coal-bearing sequence of Pennsylvanian and Permian age in Pennsylvania, Ohio, and West Virginia (fig. 68). Of these, the Vanport Limestone is extensively quarried as a source of flux stone and cement limestone as well as for aggregate stone and roadstone. The other limestone layers are generally either thinner or more impure than the Vanport and have been mined only locally as a source of roadstone, aggregate stone, and agricultural limestone. Selected chemical analyses of Pennsylvanian limestones are shown in table 95.

The following data pertaining to the limestone unit of the Pennsylvanian System have been taken from four reports: B. L. Miller (1934) and O'Neill (1964), Pennsylvania; Lamborn (1951), Ohio; and McCue, Lucke, and Woodward (1939), West Virginia. Limestone beds occur in each of the major rock series of the Pennsylvanian System, Pottsville Group, Allegheny Group, Conemaugh Formation, and Monongahela Group. Their aggregate thickness, however, is small in comparison with the clastic rocks and coals.

TABLE 95.—*Chemical analyses of Pennsylvanian limestones*

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	$CaCO_3$[1]	$MgCO_3$[2]	SiO_2 and (or) insoluble	R_2O_3 ($Al_2O_3+Fe_2O_3$)	Source of information
Ohio:							
Lawrence	Allegheny Formation:						
	Vanport Limestone Member (bottom layer).	5.7	96.4	0.8	0.7	0.9	Lamborn (1951, p. 179).
	Vanport Limestone Member (top layer).	1.3	95.3	.7	1.4	1.2	Do.
	Vanport Limestone Member	5.5	94.8	1.2	.7	1.6	Lamborn (1951, p. 177).
Muskingum	do	6	50.7	.9	42.0	4.4	Lamborn (1951, p. 257).
	Hamden Limestone Member of Stout (1918).	2	95.8	1.6	1.9	1.3	Lamborn (1951, p. 259).
Lawrence	Conemaugh Formation:						
	Cambridge Limestone Member.	8	59.8	1.6	32.6	3.6	Lamborn (1951, p. 188).
Muskingum	do	8	56.4	1.6	33.8	6.2	Lamborn (1951, p. 261).
	Bloomfield Limestone Member of Stout (1918).	2.5	92.5	.8	3.7	1.2	Lamborn (1951, p. 263).
	Ames Limestone Member	1.7	82.6	3.0	4.8	8.2	Lamborn (1951, p. 264).
Jefferson	do	6.7	88.0	1.9	5.1	2.8	Lamborn (1951, p. 166).
Noble	Lower Pittsburgh (Summerfield) Limestone Member.	6.5	84.6	7.3	4.8	1.6	Lamborn (1951, p. 275).
Muskingum	Monongahela Formation:						
	Fishpot Limestone Member	5.2	81.6	8.5	5.9	2.2	Lamborn (1951, p. 267).
Holmes	Allegheny Formation:						
	Putnam Hill Limestone Member.	5.5	92.4	2.0	2.6	1.7	Lamborn (1951, p. 150).
Monroe	Monongahela Formation:						
	Redstone Member	6.5	81.1	3.0	9.6	3.1	Lamborn (1951, p. 214).
Belmont	Conemaugh Formation:						
	Upper Pittsburgh Member	3.9	70.3	15.9	5.8	4.5	Lamborn (1951, p. 57).
	Washington Formation:						
	Elm Grove Limestone Member.	1.7	87.8	1.2	5.9	2.0	Lamborn (1951, p. 69).

See footnotes at end of table.

TABLE 95.—*Chemical analyses of Pennsylvanian limestones*—Continued

Location (State, county)	Stratigraphic unit	Thickness sampled (feet)	$CaCO_3$ [1]	$MgCO_3$ [2]	SiO_2 and (or) insoluble	R_2O_3 (Al_2O_3+ Fe_2O_3)	Source of information
Pennsylvania:							
Elk	Vanport Limestone	10	86.9	6.7	2.4	2.2	Miller (1934, p. 361).
Indiana	do	4	92.9	1.6	2.1	2.0	Miller (1934, p. 427).
Lawrence	Vanport Limestone (avg grade quarry rock).	------	94.3	1.3	2.0	2.2	Miller (1934, p. 486).
	Vanport Limestone	22	87.5	1.5	6.3	3.3	O'Neill (1964, p. 28).
Butler	do	21	94.8	Trace	2.6	3.3	Do.
		------	94.5	.5	3.1	1.0	O'Neill (1964, p. 17).
		------	85.6	1.8	7.4	5.6	Do.
Armstrong	do	------	94.5	------	2.6	2.9	O'Neill (1964, p. 10).
	Johnstown Limestone	------	53.8	10	23.8	7.7	Miller (1934, p. 180).
Indiana	do	7	82.3	8.0	5.5	2.6	Miller (1934, p. 428).
Somerset	do	------	52.9	16.1	17.8	^{3}8.4	Miller (1934, p. 640).
Elk	Freeport Formation:						
	Lower part	------	81.9	7.2	6.5	2.8	Miller (1934, p. 363).
Armstrong	Upper part	4	86.4	2.7	7.4	2.2	Miller (1934, p. 186).
Clarion	do	------	93.8	2.3	1.8	.8	Miller (1934, p. 312).
Westmoreland	do	------	92.0	1.7	4.1	1.5	Miller (1934, p. 682).
Indiana	do	------	84.4	2.8	9.2	2.1	Miller (1934, p. 431).
Somerset	Barton Limestone of Swartz, Price, and Bassler (1919).	------	55.6	14.2	19.8	^{3}7.6	Miller (1934, p. 643).
	Conemaugh Formation:						
	Lower Pittsburgh Limestone Member.	------	64.7	2.2	20.7	^{3}4.7	Do.
Fayette	Upper Pittsburgh Limestone Member.	------	87.9	1.7	7.4	^{3}1.4	Miller (1934, p. 373).
	Pittsburgh Formation:						
	Redstone Limestone Member	------	66.5	17.7	9.5	^{3}4.4	Do.
Somerset	do	------	86.6	6.2	4.0	1.8	Miller (1934, p. 644).
	Fishpot Member	------	74.8	6.7	11.5	^{3}4.1	Do.
Fayette	do	------	80.6	2.2	10.8	1.5	Miller (1934, p. 374).
Indiana	Sewickley Member	------	79.8	3.6	12.2	3.0	Miller (1934, p. 433).
Washington	Benwood Limestone Bed, Sewickley Member.	------	48.8	20.6	22.5	^{3}6.0	Miller (1934, p. 666).
Greene	do	------	84.9	6.5	4.5	2.2	Miller (1934, p. 401).
Greene	Waynesburg Formation	------	66.8	13.0	11.4	6.2	Miller (1934, p. 402).
Somerset	Uniontown Formation	------	72.6	12.6	9.2	^{3}2.5	Miller (1934, p. 644).
West Virginia:							
Harrison	Conemaugh Formation:						
	Ewing Limestone Member	------	92.2	1.1	2.1	1.4	McCue, Lucke, Woodward (1939, p. 408).
Barbour	Elk Lick Limestone Member	------	87.1	3.1	5.4	2.7	Do.
Taylor	Clarksburg Limestone Member	------	67.8	3.3	17.9	8.1	Do.
Monongalia	do	------	80.3	2.3	11.2	5.3	McCue, Lucke, Woodward (1939, p. 409).
	Upper Pittsburgh Limestone Member.	------	77.6	2.1	14.5	3.6	Do.
	Monongahela Formation:						
Harrison	Redstone Limestone Member	------	76.6	6.8	8.5	4.7	Do.
		------	59.6	20.2	11.5	6.1	Do.
Monongalia	Sewickley Limestone Member	------	50.1	17.3	23.2	7.4	Do.
		------	82.6	3.8	8.6	4.8	McCue, Lucke, Woodward (1939, p. 410).
Ohio	Benwood Limestone Member	------	56.8	12.0	22.2	7.8	McCue, Lucke, Woodward (1939, p. 412).
		------	72.7	14.0	9.8	3.0	Do.
Doddridge	Uniontown Limestone Member.	------	82.8	1.6	9.5	4.4	McCue, Lucke, Woodward (1939, p. 413).
		------	90.2	1.4	5.8	1.5	McCue, Lucke, Woodward (1939, p. 412).

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[1] Recalculated from CaO for some analyses.
[2] Recalculated from MgO for some analyses.
[3] Reported as Al_2O_3 and $FeCO_3$.

Limestone units of the Mercer Formation of the Pottsville Group have been quarried in Ohio and western Pennsylvania. They are generally 2–4 feet thick but locally are as much as 10 feet thick and consist of hard dark-gray to black fossiliferous limestone. The upper Mercer limestone is 15–40 feet stratigraphically above the lower Mercer limestone. The limestone has been quarried on a small scale as a source of agricultural limestone, flux stone, stone for lime, roadstone, and ornamental stone.

Limestone units of the Allegheny Group or Formation that have been mined are: Putnam Hill Limestone Member (Ohio), Vanport Limestone (Ohio, Pennsylvania), Johnstown Limestone (Pennsylvania), lower part Freeport Formation (Ohio, Pennsylvania), and upper part Freeport Formation (Pennsylvania). The Putnam Hill Limestone Member ranges from a few inches to about 13 feet in thickness and averages about 3 feet. It is a gray to bluish-gray hard dense, locally cherty limestone, which is quarried at a few places in eastern Ohio as a source of agricultural limestone.

The Vanport Limestone crops out in western Pennsylvania and eastern Ohio. In Pennsylvania it has been mined extensively as a source of cement limestone, stone for lime, flux, agricultural limestone, and roadstone. It consists of dense massive- to thin-bedded gray fossiliferous somewhat agrillaceous limestone generally less than 30 feet thick. It is low in $MgCO_3$ and averages 90–95 percent $CaCO_3$. The Vanport is of more limited extent in eastern Ohio, where it is generally 4–6 feet thick, having a maximum thickness of about 10 feet. It is gray to light brown, fine grained, and fossiliferous. The upper part is commonly cherty.

The Johnstown Limestone attains its greatest thickness, 8½ feet, in Cambria County, Pa., where it has been mined in the past as a source of natural cement rock and stone for manufacture of lime. It is an argillaceous, ferruginous, and locally dolomitic limestone.

The lower and upper limestones of the Freeport Formation of eastern Ohio and western Pennsylvania are each 2–8 feet thick but locally attain a thickness of 15–20 feet. The two units are similar lithologically, consisting of light-gray to bluish-gray dense argillaceous and ferruginous limestone. They have been quarried locally as a source of agricultural limestone and roadstone. Formerly they were burned to make lime.

Limestones of the Conemaugh Formation that have been exploited for crushed stone, mainly roadstone, are as follows: Brush Creek Limestone Member (Ohio), Cambridge Limestone Member (Ohio), Ames Limestone Member (Ohio, Pennsylvania), Coleman Limestone of Platt and Platt (1877) and Wellersburg Limestone of Swartz (1922) (Pennsylvania), Clarksburg Limestone Member (Pennsylvania), Upper Pittsburgh Limestone Members (Ohio), Ewing Limestone Member (Ohio) and Lower Pittsburgh Limestone Member (Ohio).

The Brush Creek Limestone Member of southeastern Ohio consists of two layers of blue-gray hard cherty ferruginous limestone separated by a few feet of shale; the sequence is as much as 25–30 feet thick. The limestone has been quarried in Gallia and Lawrence Counties for roadstone.

The Cambridge Limestone Member, which crops out at many places in eastern Ohio, is recognized also in western Maryland, northern West Virginia, and western Pennsylvania. It varies greatly in chemical and physical character from place to place and only locally contains limestone suitable for roadstone. The member is thickest in Guernsey and Muskingum Counties, Ohio, where it is a siliceous limestone having a maximum thickness of about 12 feet. In Gallia County, Ohio, the Cambridge is 1–4 feet thick and consists of a relatively high purity limestone that has been quarried as a source of agricultural limestone and roadstone.

The Ames Limestone Member is the most widespread limestone formation of the Conemaugh Group in eastern Ohio, where it has been quarried at many places as a source of roadstone and to a lesser extent for agricultural limestone and fluxing stone. It generally is 1–4 feet thick but locally is as much as 15 feet thick and consists of gray, pink, or greenish hard crystalline fossiliferous limestone. In Pennsylvania, the Ames is thinner and less widespread. It has been mined on a small scale in only a few places as a source of lime.

B. L. Miller (1934, p. 640–642) described several limestone members of the Conemaugh that had been exploited for crushed stone in Somerset County, Pa. These include the Coleman Limestone Members of Platt and Platt (1877), Ames (Berlin) Limestone, Elk Lick (Wellersburg or Barton or others) Limestone, Clarksburg Limestone, and Upper Pittsburgh Limestone Members. The limestones are in layers ranging from 3 to 10 feet in thickness in a sequence of clastic rocks and coals having an aggregate thickness of 200–300 feet. The Berlin and Wellersburg contain relatively pure limestone; the others are somewhat argillaceous. The Upper Pittsburgh Limestone Member also has been exploited on a small scale at a few localities in Ohio as a source of agricultural limestone and roadstone.

Limestone units of the Monongahela Group or Formation that have been exploited are as follows: Redstone Member (Ohio, Pennsylvania, West Virginia), Fishpot Member (Ohio, Pennsylvania), Benwood Limestone Member (Ohio, West Virginia, and Pennsylvania), Uniontown Limestone Member (Ohio, Pennsylvania), and Waynesburg Limestone Member (Pennsylvania).

The Redstone Member has been quarried for agricultural limestone and roadstone in Ohio, for fluxing stone and burned agricultural lime in Pennsylvania, mainly in Fayette County, and for crushed stone in West Virginia. In Ohio, the Redstone varies considerably in thickness, being as much as 40 feet thick and consisting of several layers of gray to dark-bluish-gray dense limestone separated by thin layers of clay or calcareous shale. In Fayette County, Pa., the member consists of as much as 10–20 feet of gray relatively pure limestone. In northern West Virginia, the Redstone generally is 6–9 feet thick and consists of light- to dark-gray fine-grained nodular to massive ferruginous limestone.

The Fishpot Member has been mined in Ohio as a source of roadstone and agricultural limestone and in Pennsylvania, mainly in Fayette and Westmoreland Counties, as a source of fluxing stone and burned lime. Where best developed in Ohio, the Fishpot is as much as 35 feet thick and consists of a thin- to medium-bedded light-brown to dark-gray hard dense limestone and interbedded shale. Some rock is dolomitic. The Fishpot of Fayette County, Pa., also is as much as 35 feet thick and ranges from very impure ferruginous limestone to relatively pure limestone that is well suited for lime and fluxing stone.

The Benwood Limestone Member is one of the most persistent and thickest limestone units of Pennsylvanian age in Ohio, Pennsylvania, and West Virginia. It has been exploited as a source of lime, roadstone, and agricultural limestone. The member is 52–65 feet thick in Ohio and consists of dark hard thin- to thick-bedded limestone with partings of calcareous shale. It reaches a maximum thickness of 160 feet in Allegheny County, Pa., where it consists of several beds of limestone separated by thick layers of shale.

The Uniontown Limestone Member has been quarried in Ohio and Pennsylvania, as a source of flux stone, lime, agricultural limestone, and roadstone. It is generally 10–30 feet thick and is similar to the Benwood in consisting of thin- to thick-bedded limestone and abundant interbedded shale. The limestone is locally dolomitic and argillaceous.

The Waynesburg Limestone Member has been mined on a small scale at several places in western Pennsylvania where it is as much as 35 feet thick. It consists of interbedded limestone and shale similar to the Uniontown.

Limestone of the Dunkard Group of latest Pennsylvanian and Permian age that have been exploited include the Lower, Middle, and Upper Washington Limestone Members, the Blacksville Limestone Member of White (1891), and the Jollytown Limestone Member, all of the Washington Formation. They crop out in western Pennsylvania where they have been exploited for aggregate stone, roadstone, and agricultural limestone. They occur as layers a few feet to about 30 feet thick interstratified with sandstone and shale in a sequence ranging from 150 to 220 feet thick. The layers consist of light-gray to black hard argillaceous to relatively pure limestone.

Limestone units of the Greene Formation of Permian age which overlies the Washington Formation within the Dunkard Group, have been exploited for roadstone and lime in western Pennsylvania, mainly in Washington and Greene Counties. They range from 6 to 12 feet in maximum thickness and consist of gray to black argillaceous to relatively pure limestone.

RESOURCE POTENTIAL

Resources of limestone and dolomite in Appalachia are widely distributed and so abundant as to be virtually inexhaustable. Most are suitable for crushed or broken stone for construction, road building, and related uses, and can also be used for agricultural limestone. Because of their wide distribution, these products are within comparatively short haulage distances of major markets and constitute a vital resource in the expanding economy of Appalachia. Cement limestone, of more restricted distribution, is very abundant in some regions and is the basis for the large cement industry of Appalachia.

High-calcium limestone and high-purity dolomite suitable for chemical and metallurgical uses are the most valuable types of carbonate rocks. They occur in minable quantities only locally and in only a few of the formations in Appalachia. According to Gillson and others (1960, p. 150–159) high-calcium limestone for chemical and metallurgical use is produced mainly from the following formations and members: (1) Valentine Member (of Field, 1919) of the Curtin Formation (of Kay, 1943) in central Pennsylvania; (2) Vanport Limestone in western Pennsylvania; (3) Mosheim Member of the Lenoir Limestone in the Eastern Panhandle of West Virginia; (4) New Market Limestone (equivalent to the Mosheim) in western Virginia; (5) Greenbrier Limestone in southwestern Virginia; (6) Holston Limestone in eastern Tennessee; (7) Conasauga, Longview, Newala, and Bangor Limestones in northern Alabama; (8) upper member of the Monteagle Limestone and its equivalents (Paint

Creek and Girkin "Gaspar" Limestones) in eastern Kentucky. High-purity dolomite for metallurgical use is produced only from the Tomstown Dolomite in the Eastern Panhandle of West Virginia, the Ketona Dolomite in northern Alabama and the Peebles Dolomite of Foerste (1929) in Adams County, Ohio.

The formations are potential sources of high-calcium limestone in areas other than where they are being mined. Probably Mississippian limestone, the Greenbrier of southwestern Virginia and eastern West Virginia, the Ste. Genevieve and upper members of the Monteagle Limestone, and the Girkin (Gasper) Limestones along the west side of Appalachia warrant development for chemical use. The best potential sources of high-purity dolomite, other than the Tomstown, Ketona, and Peebles Dolomites now mined, are the Shady Dolomite found along the eastern side of the Valley and Ridge province from northern Alabama to southwestern Virginia, dolomite in the Knox Group in eastern Tennessee, and the Cedarville Dolomite in southern Ohio.

ROOFING GRANULES

By D. M. LARRABEE, U.S. Geological Survey

The mining, milling, and artificial coloring of rock for roofing granules in this county yielded a product valued at an estimated $46 million in 1965. Large quantities of at least one suitable rock are present in Appalachia, but the problems of distribution and marketing are such that all plants making granules, and the roofing manufacturers using the granules, are outside this area.

MANUFACTURING SPECIFICATIONS

Roofing granules are stone particles that have been crushed and screened commonly to specific sizes between 10 and 35 mesh (Tyler standard screens); the sized particles are carefully blended to give maximum coverage of the asphalt that binds them to asphalt-impregnated "felt" (J. A. Brown, 1960). This kind of roofing is often referred to as "mineral-surfaced" roofing and is applied in either strip shingle or roll form. The chief purposes of the granules are to prevent ultraviolet light from breaking down the asphalt with resultant failure of the roofing material and to fireproof the exposed roof surface. Theoretically any rock that meets rather rigid requirements, regardless of color, might be used.

In contrast to granules, and often confused with them, are roofing "gravels" or roofing "chips." These are naturally colored, coarsely crushed (¼ inch and larger) gravel or stone that is rolled or pressed into the top dressing of hot asphalt on built-up roofing commonly used on flat or exceptionally low-pitched roofs. The purpose of "gravel" primarily is the same as that of granules—to protect and fireproof the asphalt that provides a waterproof roof. White is the predominant color used, for reasons of light reflection. Marble, dolomite, limestone, chert, quartzite, gravel, slag, and some varieties of coquina are used for "gravel." Natural white, buff, brown, red, and green "gravels" are marketed locally, especially in parts of California where a variety of such colored rock is available.

In order to brighten the appearance of roofs, certain naturally colored rocks were used in the early days of the industry; these rocks were chiefly red, green, and purple slates, greenstone, purple aporhyolite, and buff chert. Black slate granules also were used because of the prevalence of black slate shingles on many buildings since the 1800's. Colored slag and crushed brick have been used; granules also were made from "common" clay or fire clay baked in multiple hearth (vertical) furnaces. Slate was preferred by many roofing manufacturers, not only for its natural color but also for the flat particles resulting from its cleavage; this shape was believed to provide better coverage for the asphalt. This rock was preferred also because of the long association of the term "slate" with roofs in the minds of homeowners, and many roofers continue to refer to all granules as "slate," regardless of their true nature. The fact that a ton of flat slate granules covered more square feet of roofing than a ton of equidimensional granules, at a consequent lower weight and lower cost per square (100 square feet of roof surface), was not overlooked by the manufacturers of the finished roofing product.

Slate is no longer used in quantity as a granule on the exposed part of roofing, partly because of the accentuated tendency to form "rights and lefts" or "shading" (especially in natural black slate) where strip shingles are not properly applied on the roof. Most slate particles, having a strong tendency toward flatness, are rolled onto the asphalt base facing slightly in a single direction; when the shingles are cut, the granules on different shingles may face in opposite directions. Improper application results in a "patchwork" roof, some sharply defined areas appearing to be of a shade of color different from the rest of the roof when in fact they are the same. A second reason that fewer slate granules are used now is that under some conditions they are less firmly imbedded in the asphalt than are more angular or equidimensional granules, resulting in more shedding, that is, a higher proportion of "drop-outs," after which the asphalt is exposed directly to the sun.

More recently, brighter colors have been demanded, with the result that artificially colored granules are manufactured and marketed widely; today most granules sold are of this type. In recent years the preference changed from roofing of a single or "solid" artificial dark color to that having blends of pastel colors, and finally, today, to white for light—and therefore heat—reflection, and other single colors. Solid green, gray, black, red, brown, buff, and a few darker blends are made. Blue is now used only in blends. White is of special importance where modern roofs are of low pitch, and the attic spaces beneath roofs are therefore smaller and become heated in a shorter time. Today, although most roofing granules are artificially colored, some natural granules are used in color blends and beneath the overlay (headlap) of some shingles to reduce the cost.

To be suitable for artificially colored granules, rock should be hard and tough but preferably not excessively abrasive to manufacturing equipment. It should be of uniform color, of fine to medium grain, preferably opaque or nearly so, nonporous and nondisintegrating under weathering conditions, and chemically compatible with the coloring process. The mineral content and texture of individual granules should be physically compatible with the temperature used in the coloring process, and on crushing the rock should yield roughly equidimensional rather than flat particles. Large quantities of any rock selected must be present in a single deposit, and the chemical and physical properties of all rock quarried should be as uniform as possible. A light color usually is preferred over dark because less pigment normally is required to produce the popular white granules from the former. Other factors being equal, a low free-silica content is desirable to reduce the silicosis hazard to workers.

Among the best rocks for roofing granules are fine-grained volcanic rocks, such as some felsite and the lighter colored greenstone; coarser but entirely acceptable rocks include porphyritic volcanic rocks, diabase, and some nepheline syenite. A few dark rocks, such as basalt, have been used. Fine-grained light-gray or impure quartzite has been proven acceptable when properly pigmented, in spite of a strong trade prejudice against certain types of coarse-grained pure quartzite, based upon the reported transmission of ultraviolet light through pigmented granules. Of the above rocks, rhyolite, diabase, and quartzite are usually abrasive. Massive, nonschistose rocks other than those listed above can be used, but the granules may be inferior, or high-quality granules may be produced only at an increased cost. However, under certain conditions of location preference, less satisfactory base rock can be used successfully with an overall economy to the producer.

Deposits of rock meeting the above requirements, in addition to several necessary favorable operating conditions, are not common within a reasonable transportation distance of most market areas. Few areas that furnish a choice of such deposits contain locations available for quarry and mill sites that include the large areas necessary for disposal of the overburden, waste rock necessarily quarried, and fines produced during milling; this last item alone may be as much as 50 percent of the rock milled, and for most of this waste material no market has been found. Because such rock deposits are not common and reserves are governed by manmade boundaries such as railroads, highways, and property lines as well as by geology and topography, the search for and testing of additional suitable rock is a continuing extensive and expensive requirement.

The table below summarizes the most recent published data available on the production of granules.

Roofing granules sold or used in the United States, 1959–63

[Manufactured from stone, slate, slag, broken ceramics, sand, gravel, diatomite, and pumice; probably includes some roofing "gravel." Source: Key (1966, p. 34)]

Year	Natural		Artificially colored [1]		Total	
	Short tons (thousands)	Value (thousands of dollars)	Short tons (thousands)	Value (thousands of dollars)	Short tons (thousands)	Value (thousands of dollars)
1959	446	4, 264	1, 447	34, 372	1, 893	38, 636
1960	649	5, 454	1, 443	33, 767	2, 092	39, 221
1961	663	5, 544	1, 534	35, 654	2, 197	41, 198
1962	647	5, 384	1, 786	42, 247	2, 433	47, 631
1963	696	5, 856	1, 667	38, 352	2, 363	44, 208

[1] A small quantity of brick granules is included.

The value of domestic production for 1965 is estimated by the writer to exceed $46 million. Production by States is not given, in order to protect confidential information of the producing companies.

ROOFING GRANULES IN APPALACHIA

Probably the sources of best rock for granules within the area of Appalachia are certain units in the Mount Rogers Volcanic Group, which also includes some nonusable metamorphosed sedimentary rocks. Most of the volcanic units are somewhat slaty, schistose, or phyllitic, and therefore are less desirable than more massive rock. The Mount Rogers Volcanic Group described by Hamilton (in King and Ferguson, 1960) is present in the common corner of Virginia, North Carolina, and Tennessee. In Virginia, the group crops out in Grayson, Smyth, and Washington Counties. In North Carolina it is present in Ashe County, and in Tennessee in Johnson County. Its general area of outcrop is indicated on the geologic map of the Appalachian Region (pl. 2).

Volcanic rocks of this group are on the high parts of Whitetop Mountain and Mount Rogers in Virginia and on Pond Mountain in North Carolina. They occur also on the outlying masses of Fodderstack Mountain and Stark Ridge in Tennessee. However, metasedimentary rock units of the group underlie most of the lower ground, for example, along much of the route followed by the Norfolk and Western Railway. Rhyolite of varying degrees of schistosity, but of possible use, occurs along the railroad in the vicinity of the North Carolina-Virginia State line (D. W. Rankin, oral commun., Jan. 25, 1966). The volcanic rocks generally include massive lava flows and tuffs, according to Hamilton, and at various places range from reddish maroon or purplish to bluish gray; most are very fine grained. For additional details the reader is referred to the report by King and Ferguson (1960).

Other usable raw materials may be available in the wide variety of rocks present in various parts of Appalachia. The possible distribution of suitable hard and tough rocks within each major market area can be determined from the many geologic maps and reports now available. Sources of quartzite, if desired, can be found by reference to the section on "Silica," (p. 337). However, the purest quartzite recommended as a source of silica would be inferior to an impure quartzite for granules because of the high translucency of pure quartzite.

The writer knows of no production of artificially colored granules from within the area of Appalachia. In general, sources of suitable rock outside this area are closer to the roofing manufacturing plants and the largest markets. Demands for such roofing granules within Appalachia currently are met chiefly by manufacturing plants at Little Rock, Ark., Annapolis, Mo., Augusta, Ga., and Charmian and Delta, Pa. Because a competitive modern colored-granule plant requires an investment of approximately $5 million, the raw materials, markets, and related economic factors require detailed evaluation.

SAND AND GRAVEL

By Charles H. Maxwell, U.S. Geological Survey, Donald J. Frendzel, and Robert G. Stansfield, U.S. Bureau of Mines

THE NATIONAL INDUSTRY

Sand and gravel are so common that most people rarely consider them as mineral commodities, yet they constitute the largest volume of mineral raw materials produced from the earth (Carter, 1965, p. 353). In 1964, 868.8 million short tons of sand and gravel was produced in the United States (table 96), representing the largest production volume of any mineral commodity in the Nation. The 1964 value of $894 million in current dollars amounted to only 2 percent of the total value of United States mineral production, but the individual values of only five commodities exceeded that of sand and gravel—crude petroleum, natural gas, bituminous coal, portland cement, and stone (D'Amico, 1965, p. 108).

Sand is usually defined as granual material 2 mm or less in diameter (>0.0625 mm) which passes through a No. 5 sieve but is predominantly retained by the No. 200 (74 micron) sieve. Gravel generally includes fragments that are larger than 2 mm in diameter (4–64 mm); however, boulder and cobble gravel have sizes of +256 and 64–256 mm, respectively (Wentworth, 1922, p. 377–392; Carter, 1965, p. 354).

Sand and gravel are produced in every State, and deposits exist in nearly every county. In 1964, 5,685 commercial sand and gravel plants reported production (Barton and Cotter, 1965). California led in national production with 113 million short tons, followed by Michigan (51.9 million tons), New York (39.3 million tons), Ohio (37.8 million tons), Minnesota (35.8 million tons), Illinois (34.9 million tons), Wisconsin (34.3 million tons), and Washington (31.9 million tons). The sand and gravel produced in these eight States represented 44 percent of U.S. production and 14 percent of the value of national output in current dollars.

Of total 1964 United States sand and gravel output, 96 percent was sold or used by producers for construction purposes, 3 percent as industrial sand, and 1 percent as miscellaneous gravel (table 97). Sand and gravel for construction purposes are used mainly as aggregate for cement and asphalt, concrete, mortar, and plaster; in highway construction for sub-base, base, and surface courses; and for fill. Additional details can be found in Barton and Cotter (1965) and Cotter (in U.S. Bur. Mines, 1965a, p. 779–788).

TABLE 96.—*Production and value of sand and gravel in the United States and the Appalachian Region, 1945–64*

[Includes sand and gravel sold or used by producers (commercial and noncommercial) in the U.S. and Appalachia; excludes such production from possessions and other areas administered by the United States. Source: U.S. Bur. Mines]

Year	United States		Appalachian Region		
	Short tons (thousands)	Value in thousands of current dollars	Short tons (thousands)	Value, in thousands of—	
				Current dollars	1958 constant dollars
1945	195, 524	128, 837	11, 754	13, 537	17, 835
1946	254, 131	171, 386	24, 798	19, 130	24, 909
1947	287, 659	216, 869	18, 127	23, 067	27, 893
1948	319, 266	252, 498	19, 343	26, 006	30, 134
1949	319, 104	248, 443	15, 908	23, 279	26, 820
1950	370, 455	295, 040	19, 603	27, 310	31, 106
1951	400, 634	333, 714	23, 320	33, 750	35, 830
1952	435, 622	353, 527	22, 327	31, 657	33, 183
1953	440, 399	374, 795	21, 775	31, 805	33, 726
1954	556, 537	504, 127	23, 902	33, 778	36, 358
1955	592, 153	536, 236	23, 636	35, 319	38, 431
1956	626, 495	596, 195	27, 077	33, 653	35, 460
1957	632, 255	599, 750	24, 674	34, 682	35, 247
1958	684, 498	652, 789	25, 776	41, 125	41, 125
1959	730, 205	728, 712	27, 680	44, 717	44, 100
1960	709, 792	720, 432	27, 939	42, 911	42, 529
1961	751, 784	751, 301	26, 880	42, 131	41, 878
1962	776, 701	794, 725	29, 481	46, 521	46, 195
1963	821, 850	847, 272	29, 624	47, 640	47, 449
1964	868, 779	894, 092	31, 053	49, 858	49, 609
Total	10, 773, 843	10, 000, 740	474, 677	681, 876	719, 817

TABLE 97.—*Sand and gravel sold or used by producers in the United States and the Appalachian Region, by uses, in 1964*

[See headnote, table 96. Source: U.S. Bur. Mines]

Use	United States		Appalachian Region		
	Short tons (thousands)	Value in thousands of current dollars	Short tons (thousands)	Value, in thousands of—	
				Current dollars	1958 constant dollars
Construction sand	303, 358	283, 794	13, 714	18, 041	17, 949
Industrial sand	23, 283	74, 335	3, 455	13, 883	13, 813
Construction gravel	536, 308	529, 237	13, 640	17, 469	17, 382
Miscellaneous gravel	5, 830	6, 726	244	465	463
Total	868, 779	894, 092	31, 053	49, 858	49, 607

Few other producers of mineral commodities are faced with the numerous and complex technical and economic problems inherent to the sand and gravel industry (Cotter, in U.S. Bur. Mines, 1965a, p. 779). Among the dominant economic factors which bear on output of sand and gravel are: low unit value, high transportation cost, changes in specifications and market areas, restrictive zoning legislation, seasonality of operation and day-to-day weather changes, competition with alternate building materials, and adequate supplies of water with the accompanying problem of waste-water disposal.

At the point of production, sand and gravel have a low value per ton. For example, construction sand and gravel, which made up 88 percent of total Appalachia sand and gravel output in 1964, had an average value of $1.30 per ton in current dollars. Industrial sand, which represented 11 percent of Appalachian production in 1964, had an average value of $4.02 per ton in current dollars. Transportation costs (at places more than two-thirds of the selling price) are therefore an important economic factor in the industry. Inasmuch as the unit value is low, overall costs of production must be kept low and transportation costs must be held to a minimum. The ingenuity of manufacturers of excavating, processing, and transportation equipment has helped to maintain the low overall production costs in the industry (Cotter, in U.S. Bur. Mines, 1965a, p. 779); increased utilization of portable plants, shortening the distance to market, and unitized train systems have also been steps toward reducing transportation costs.

Because of the many uses of sand and gravel and the many jurisdictions in which they are used, the number and variety of specifications increase and change continually. Changes in specifications have economic impact on mining, processing, and marketing. Specifications now require tests for soundness, freedom from deleterious particles, resistance to freezing and thawing, adhesion of bitumens, size gradation, and many others. Specifications are written by users of foundry sand, by manufacturers of abrasives, glass, chemicals, and ceramics, by building associations, by governmental agencies, by highway engineers, and by the American Society for Testing and Materials.

Sand and gravel operations are affected in many ways by zoning ordinances. Restrictive zoning legislation has curtailed operations or removed from production many deposits in suburbia. More attention should be directed toward multiple land use in which sand and gravel deposits are removed prior to building of schools, housing developments, and shopping centers.

Competition for markets by alternate materials is sharp. Crushed stone, blast furnace slag, and fly ash are used to supplement or replace sand and gravel in some types of construction (Cotter, in U.S. Bur. Mines, 1965a, p. 782–783). Such alternate products may be sold at prices near those received for sand and gravel, and their transportation costs may be lower.

THE INDUSTRY IN APPALACHIA

The early history of sand and gravel production in Appalachia as well as in the United States is not detailed in the literature, for there was little activity that could be called an organized industry until 1902, the first year national sand and gravel statistics were published. Even these statistics were not a true measure of the extent of the industry because much of the production was obtained by the consumers themselves from local deposits and was not reported. As consumer requirements became more and more exacting and as demand became too large to be supplied from local sources, a progressively larger part of the production was by organized sand and gravel companies that had equipment to size and wash the products to conform with consumers specification (Bowles, 1947, p. 312). As the industry grew, more complete statistics gradually became available.

In 1964, 31 million short tons of sand and gravel was produced in Appalachia, valued at $49.9 million in current dollars (table 96). Of these totals, 17 million tons was sand, valued at $32 million, and 14 million tons was gravel, valued at $17.9 million.

Table 96, which compares production of sand and gravel in the United States and Appalachia from 1945 to 1964, shows that, compared with national output in 1964, Appalachia sand and gravel amounted to 4 percent of production and 6 percent of value; corresponding figures for 1945 were 6 percent and 11 percent, respectively. During the 1945–64 period, Appalachia sand and gravel totaled 4 percent and 7 percent of national production and value, respectively.

In 1964, 30 million tons of sand and gravel was produced by commercial operations and 1 million tons by noncommercial operations (Government-and-contractor operations; table 98). Of the total quantity produced, 29.7 million tons was prepared (cleaned and sorted) and had a value of $48.9 million; 1.4 million tons was unprepared and valued at $1 million.

Table 99 compares production of sand and gravel in the Appalachian parts of 12 States with the total production in each State for 1945 and 1964. In 1964, Pennsylvania was by far the largest producer in Appalachia, followed by West Virginia, Ohio, New York, North Carolina, Tennessee, and Alabama, all of which produced moderate amounts of sand and gravel. The Appalachian parts of other States produced very little sand and gravel. Production in Appalachia showed nearly a threefold increase from 1945 to 1964, whereas total production for the Appalachian States showed nearly a fourfold increase.

Firms in the sand and gravel industry range from one-man operations to large corporations with 20 or more producing plants. "Individual plants comprise small portable units, many of which produce less than 25,000 tons per year, and the multiunit operations of large corporations often associated with crushed stone plants, ready-mixed concrete plants, and slag processing that individually produced in excess of one million tons annually" (Cotter, in U.S. Bur. Mines, 1965a, p. 799). In 1945, there were 206 individual operations functioning in the Appalachian sand and gravel industry (not including dredges). By 1964, the total operations (not including dredges) had increased to 320, consisting of 216 stationary, 59 portable, and 45 combination.

TABLE 98.—*Sand and gravel sold or used by producers in the United States and the Appalachian Region, by classes of operation and degrees of preparation, in 1964*

[See headnote, table 96. Source: U.S. Bur. Mines]

	United States		Appalachian Region	
	Short tons (thousands)	Value, in thousands of current dollars	Short tons (thousands)	Value, in thousands of current dollars
Commercial:				
Prepared	560, 391	663, 737	29, 094	48, 480
Unprepared	61, 001	36, 314	958	790
Total	621, 392	700, 051	30, 052	49, 270
Government-and-contractor operations:				
Prepared	180, 974	158, 537	573	428
Unprepared	66, 413	35, 504	428	160
Total	247, 387	194, 041	1, 001	588
Grand total	868, 779	894, 092	31, 053	49, 858

TABLE 99.—*Sand and gravel sold or used by producers in the Appalachian Region, by States, in 1964 and 1945*

[See headnote, table 96. In thousands of short tons and thousands of current dollars. Source: U.S. Bur. Mines]

	1964				1945			
	Appalachia		State total, including Appalachia		Appalachia [1]		State total, including Appalachia	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Pennsylvania	10, 649	18, 092	16, 199	26, 414	4, 724	5, 654	6, 769	7, 248
West Virginia	5, 472	11, 555	5, 472	11, 555	2, 502	3, 323	2, 502	3, 323
Ohio	4, 584	7, 169	37, 771	45, 567	1, 854	2, 132	9, 420	7, 985
New York	3, 577	4, 433	39, 282	38, 583	926	798	7, 478	5, 050
North Carolina	2, 733	2, 615	11, 150	10, 404	205	186	2, 394	1, 517
Tennessee	1, 682	2, 656	7, 972	10, 245	692	732	3, 098	2, 578
Alabama	1, 679	1, 968	5, 840	6, 191	698	551	2, 542	1, 581
Maryland	295	790	15, 041	18, 071	66	99	2, 899	2, 695
Virginia	208	366	10, 588	13, 722	0	0	2, 965	2, 721
South Carolina	169	208	4, 622	5, 262	1	(2)	320	202
Kentucky	4	4	6, 560	6, 297	31	22	1, 175	1, 033
Georgia	1	2	4, 159	4, 311	55	40	605	350
Total	31, 053	49, 858	164, 656	196, 622	11, 754	13, 537	42, 167	36, 283

[1] Data shown for total quantity and value vary from table 97 due to rounding.
[2] Less than $100.00.

In 1964, 20.5 million tons of sand and gravel was transported by trucks, 3.7 million tons by railroad, and 6.4 million tons by watercraft within and outside the Appalachian Region. Such shipments total 30.6 million tons compared with a total Appalachian production of 31 million tons (table 96); the remaining half million tons of production represents output from some noncommercial (Government-and-contractor) operations for which mode of transportation is not available. The bulk of shipment remained within the region; most sand and gravel is used within 25–35 miles of the point of production, and the majority of such consumers received deliveries by truck. Railroads are used primarily to ship the higher priced industrial sand; such shipments may move hundreds of miles outside the Appalachian Region. Waterborne shipments generally do not move great distances from the point of production.

DEPOSITS IN APPALACHIA

The gross distribution of sand and gravel in Appalachia is shown on figure 69. This map shows seven areas grouped into three general categories according to relative abundance. Most of the sand and gravel deposits in Appalachia are classified as fluvial, glacial, or residual.

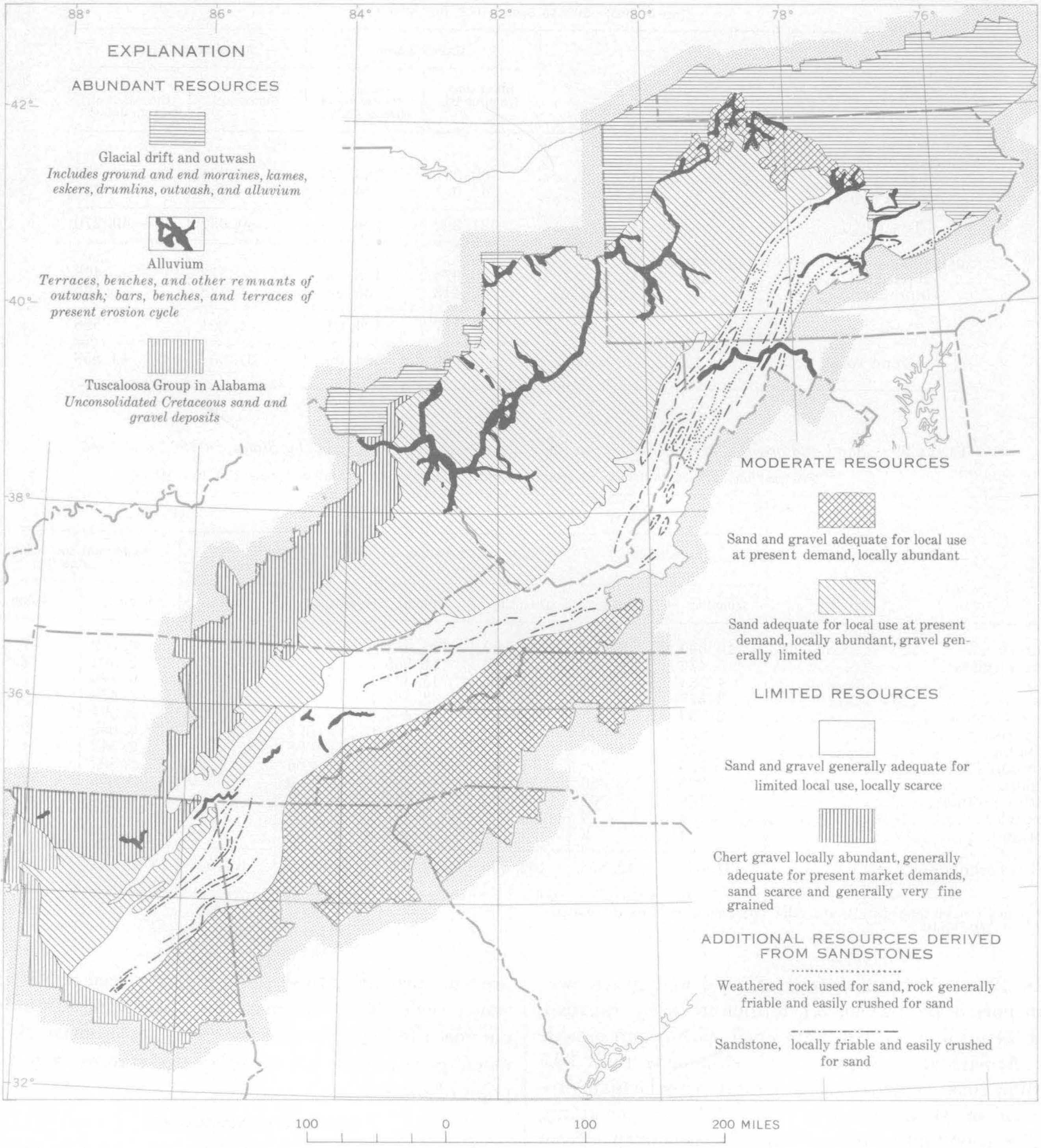

FIGURE 69.—Sand and gravel resources in the Appalachian Region.

FLUVIAL DEPOSITS

Fluvial deposits are the most extensively exploited source of sand and gravel in Appalachia. They include deposits in or near present rivers and perched benches, terraces, and remnants of glacial outwash associated with former rivers. Fluvial deposits occur in nearly all rivers and streams in Appalachia and are the principal sources of sand and gravel in most of the region. The major rivers with abundant resources which are extensively exploited (fig. 69) are the Susquehanna, Monongahela, Allegheny, Ohio, and Potomac Rivers and major tributaries in northern Appalachia, and parts of the Tennessee River and tributaries in the south.

High-level terraces in the Susquehanna and Ohio River systems range from about 10 to 130 feet thick and 40 to 2,000 feet wide, although most are about 30–50 feet thick and 100–300 feet wide. They vary from a few tens of feet to several tens of miles in length. Detailed information about these deposits is available in many reports, including Woolsey (1906), Shaw (1910), Phalen and Martin (1911), Leverett (1934), Richardson (1936), and Peltier (1949).

One of the principal sources of commercial sand and gravel in Tennessee and northern Alabama is the Tennessee River system, in sections of the rivers between the dams and reservoirs, and to some extent from the reservoirs. The sand in the Tennessee River is clear angular quartz, and gravel is composed of sandstone fragments, chert, and quartzite (Gildersleeve, 1946c, 1946d, 1946e).

Many other rivers and streams have appreciable sand and gravel deposits of less commercial potential. Deposits of this type are the main source of sand and gravel in the regions shown in figure 69 as having moderate to limited resources.

In the Piedmont and Blue Ridge provinces (fig. 69), sand and gravel deposits are numerous but vary greatly in size and are confined largely to flood plains and stream channels along the major drainage systems. Although resources are limited in some localities to small deposits of a few hundred tons, they generally range from river deposits of several thousand tons to broad flood-plain deposits containing 500,000 tons or more. In general, the deposits are erratic in areal distribution and size, and large deposits are uncommon. The deposits are poorly sorted and consist of rock boulders and fragments, and granular particles of quartz, feldspar, mica, and lesser amounts of other minerals. Most deposits are suitable for use as concrete aggregate (E. A. Smith and McCalley, 1904; Teas, 1921; Jones, 1926; Broadhurst, 1955).

Within the Appalachian Plateaus province (fig. 69), large amounts of sand and limited amounts of gravel occur in deposits which are largely confined to small flood plains and river channels along the major drainage systems. This area corresponds in general to the outcrop pattern of rocks of Pennsylvanian (Pottsville Group, Allegheny Group, Conemaugh Formation, and Monongahela Group) and Permian age. The rocks are relatively flat lying, deeply dissected, and contain numerous sandstone beds. Most of the sandstone is fine to medium grained and weathers to form sand deposits, but a few beds, especially conglomerates of the Pottsville Group, are coarse enough to yield gravel deposits. Gravel is generally composed of sandstone and chert fragments mixed with smaller amounts of other rocks and quartz fragments. Sand deposits consist mainly of angular to rounded quartz grains and quartzite fragments. Coal fragments are common in many of the river sands and often constitute a problem in their economic development.

The part of Appalachia which lies west of the Pennsylvanian outcrops is deficient in sand resources (fig. 69). The area is underlain by flat-lying Ordovician to Mississippian rocks, predominantly limestone, cherty limestone, dolomite, siltstone, and minor amounts of shale, which are poor source rocks for sand and gravel. Sand and gravel deposits are small and are generally limited to existing stream channels. Sand deposits are scarce and the sand is fine grained. Chert gravel is present in most drainage systems in deposits ranging from a few tons to several hundred thousand tons. The chert gravel is generally unsuitable for aggregate, but it is usable for most other purposes.

The area containing the least amount of sand and gravel is in the region on figure 69 which more or less corresponds to the Valley and Ridge province. The area is underlain by complexly folded and faulted rocks, Cambrian through Pennsylvanian in age, predominantly shale and carbonates with subordinate sandstone beds. Most sand and gravel deposits are small, generally limited to stream channels. The sand is predominantly fine grained. Locally gravel deposits are predominantly chert.

GLACIAL DEPOSITS

Many large deposits of sand and gravel in the glaciated region of the northern part of Appalachia, in New York, Pennsylvania, and Ohio, are suitable for commercial exploitation. These large deposits, along with the many large fluvial deposits, and innumerable small deposits, form large resources of sand and gravel.

Pleistocene glaciers and melt water transported and deposited tremendous quanties of clay, sand, gravel, and boulders. The resulting deposits are either moraines that consist of unstratified and poorly sorted rock debris mixed with sand and clay, called glacial drift, laid down directly from glacial ice, or sorted stratified deposits, called glaciofluvial deposits, laid down by melt water in contact with or in front of the ice. Glaciofluvial deposits yield nearly all of the readily usable sand and gravel and form the deposits known as kames, eskers, outwash plains, and valley train terraces.

The glacial deposits are of two recognized ages, corresponding to the older Illinoian and the younger Wisconsin Glaciations (fig. 69).

RESIDUAL DEPOSITS AND FRIABLE SANDSTONES

Unconsolidated residual or colluvial deposits of sand derived from the weathering of sandstone, and friable sandstone beds are an important source of good quality sand in Appalachia, especially in those areas deficient in other sand and gravel resources. These deposits have been widely used in parts of Pennsylvania and West Virginia and in northern Alabama and Tennessee, but not to any large extent elsewhere in Appalachia. The major potential sources occur mostly in the Valley and Ridge province (fig. 69). The Oriskany Sandstone of Early Devonian age and sandstone of the Pocono Formation, Mississippian age, are most widely exploited. However, sand has been recovered from many other formations including the Upper Cambrian Gatesburg Formation, the Lower Cambrian Erwin Quartzite, the Silurian Tuscarora Quartzite, and sandstones of Pennsylvanian age (Pennsylvania Bur. Statistics and Reformation, 1944). These, and other sandstone formations, are potential sources of sand, and in some places gravel, in many localities other than those shown in figure 69.

The unconsolidated to poorly consolidated Upper Cretaceous Tuscaloosa Group is a major source of sand and gravel in northern Alabama. The Tuscaloosa consists predominantly of sand, but with some clay and gravel in lenticular and interfingering beds. Thickness of the group ranges from about 200 feet near the western border of Alabama to a maximum of about 700 feet in Tuscaloosa County to the east. The basal 25–75 feet is crossbedded gravelly micaceous sand, locally interbedded with, or largely replaced by, clay. The gravel is largely quartz and quartzite and is mostly in the basal part. The middle part of the group is largely quartz sand, with some glauconitic sand and clay; locally it contains lenses of coarse sand and gravel (Drennen, 1953). Most of the group in northwestern Alabama, and the upper part of the group elsewhere, is composed of lenticular beds of chert gravel, sand, silt, and clay; the gravel contains progressively increased amounts of quartz to the east. The chert gravel is most abundant at the base of the upper unit of the group, gradually decreasing upward (Conant and others, 1945).

RESOURCE POTENTIAL

Appalachia has widespread large resources of sand and gravel, generally adequate for the foreseeable future. However, there is need for systematic evaluation of these resources, not only in order to establish available reserves and grades of material, but also to aid in exploitation of the more valuable deposits before urbanization. The areas which are deficient in sand and gravel will probably continue to be dependent on substitute materials, such as crushed stone, slag, expanded shale aggregate, and imported sand and gravel.

Despite the many technical and economic problems, the sand and gravel industry has fared well generally. Major construction programs will continue to be primarily dependent upon large supplies of low-priced raw materials such as sand and gravel. Both Federal and State highway programs may be expected to expand. Large amounts of sand are used as separation media in coal preparation plants, and the amount should increase as demand for prepared coal increases. The demand for the higher priced specialty sands may be expected to increase. "No new uses are foreseen for the great volume of sand and gravel used in construction, but new applications for chemical products derived from silica, and expansion of use in paints, silicone rubber, plastics, paper, pharmaceuticals, and as dehydrating agents, will increase markets for high-grade silica" (Cotter, in U.S. Bur. Mines, 1965a, p. 788). Forecasts of increases in national income, population, and demand for various types of housing indicate that national production of sand and gravel may reach 1.8 billion tons in 1980 compared with about 869 million tons in 1964 (Cotter, in U.S. Bur. Mines, 1965a, p. 787).

To assist the industry in meeting market demands, a variety of organizations are conducting research on methods for prospecting for sand and gravel deposits, processing, development of new uses, and improvement of specifications; manufacturers of mining and processing equipment are conducting research to develop more efficient machinery. All such efforts are designed to alleviate the technical-economic problems of the industry.

NONMETALS

ABRASIVES

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INTRODUCTION

Abrasives are substances that are used to grind, polish, abrade, scour, clean, or otherwise remove solid material by rubbing and impact (Ladoo, 1960, p. 1). They may be natural or manufactured: Natural abrasives include all minerals and rocks which are used for abrasive purposes without chemical or physical change other than crushing, shaping, or bonding into suitable forms. Manufactured or artificial abrasives are made either by heat or chemical change from metals or mineral raw materials.

Natural abrasives should possess certain properties, among which are hardness and toughness, proper grain or particle size and shape, suitable fracture or cleavage, and a high degree of uniformity and purity. For some uses it is desirable that they be chemically inert and stable at high temperatures.

Abrasives are classified into three groups according to hardness (Ladoo, 1960, p. 2), those of superior hardness (7–10 on the Mohs' scale), intermediate hardness (5.5–7), and inferior hardness (less than 5.5). Among the materials of superior hardness are diamonds with a hardness of 10 followed in decreasing order by corundum, emery, and garnet. In the intermediate hardness range are such minerals and rocks as flint, quartz, quartzite, sandstone, silica sand, feldspar, perlite, and pumice. Natural materials of inferior hardness include chalk, clay, diatomite, iron oxides, limestone, rottenstone, talc, and tripoli.

Abrasives, both natural and artificial, are used in various forms, such as powders, loose grains, bonded grains in various shapes, coated grains, and as massive material. Each has a special use depending on the type of abrasive material. Loose grains and powders are used for surfacing and polishing stone and glass, sawing stone, sand blasting, grinding lenses, polishing gem stones, manufacture of grinding and buffing wheels, and in scouring compounds, soaps, and toothpowders. Bonded abrasives consist of grains bonded or molded and pressed into articles such as grinding wheels, bricks, blocks and stones for sharpening and polishing. Coated abrasives are materials such as sand paper and emery cloth. Massive materials are cut and shaped and used as grindstones, millstones, and tube-mill liners (Stuckey, 1965, p. 346).

Artificial abrasives have replaced natural abrasives to a large extent for grinding metal because their properties can be varied and accurately controlled to suit different needs. Modern high-speed industrial machining requires a high degree of accuracy and uniformity in specialized tools that cannot be achieved with natural abrasives. Artificial abrasives include electric-furnace products, chemical precipitates, and miscellaneous manufactured products. Abrasive grains are produced from a wide variety of materials and may be used as precisely sized loose grains or combined with other materials for making bonded shapes, coated abrasives, abrasive tools, cleaners, polishes, and grinding paste. Artificial abrasives include materials such as the oxides of cerium, chromium, aluminum, iron, tin, and zirconium; silicon, titanium, boron and tungsten carbides; zirconium silicate and hard burned clay; and metallic abrasives such as steel balls and shot, angular steel grit, and steel, brass, and copper wool.

Natural abrasives are interchangeable with artificial abrasives and are preferable for many general purposes because they are less costly. Some natural abrasives have become specialized for certain uses, like almandite garnet for which no satisfactory substitute has been found. Mined in New York State, it is processed and used extensively for coating abrasive papers and cloth and for grinding glass and lenses. Hard natural abrasive materials such as silica sand, corundum, garnet, flint, and chert, used for sand blasting, compete with artificial abrasives such as fused alumina, silicon carbide, and steel shot. Use of any particular abrasive for this purpose largely depends on cost factors and the hardness of the object being scoured by sand blasting.

Both natural and artificial abrasive grains are bonded by various substances such as resins, rubber, shellac, or vitrified ceramic mixes to produce grinding wheels and blocks, bricks and sticks which are further shaped by cutting for marketing as oilstones, synthetic stones, and razor and cylinder hones. Such artificial stone has replaced to a large extent the natural stone which is quarried and sawed to various shapes.

Most abrasive materials are prepared for a specific industrial use and sold at prices that vary widely depending on specifications. Domestic garnet marketed to specification has a variable value depending upon particle size. New York abrasive garnet grains range in price from 12¾ cents per pound for coarser sizes in carload lots to 53 cents per pound for micron-sized powder in retail lots (Ambrose, in U.S. Bur. Mines, 1965a, p. 355–359). According to Metal and Mineral Markets (1965), the market value of ground and sized amorphous silica ranges from $27 a 50-pound bag, 90–98 percent silica ground to −325 mesh, to $85 a 50-pound bag, 90 percent silica ground to −10 microns. Rose and cream-colored tripoli, ground to −40 mesh (single grinding), or double ground to −110 mesh is valued at 2¾ cents per pound, and air floated to −200 mesh, 3 cents per pound.

In 1964, the total reported value of natural and artificial abrasives sold or used in the United States was $155.2 million, of which $65.7 million was produced domestically and $89.5 million was imported. Domestically produced natural abrasives include tripoli, garnet, emery, and special products such as grinding pebbles, tube mill liners, and natural silica abrasive for oilstones and other sharpening stones. Not included are silica sand, quartz, ground and calcined clays, lime, talc, ground feldspar, river silt, slate flour, and others for which detailed production data are not available. In the 20-year period 1944–64, the value of artificial abrasives sold or used in the United States has more than doubled from $24.8 million in 1944 to $63.4 million in 1964.

Although there has been a general decline in use of natural abrasives (table 100), natural silicate abrasive grains and powder produced from garnet, silica sand and quartz, pumice, tripoli, and rottenstone continue to find preference for certain special uses as do the soft nonsiliceous abrasives such as feldspar, chalk, and china clay. It is primarily in the field of hard abrasives that artificial abrasives dominate.

Continued industrial expansion in the United States will no doubt create additional demand for various types of abrasive materials. A careful study of natural abrasive resources and extensive research in their physical properties and potential uses may be needed to rejuvenate the industry. Stone abrasive products formerly produced in Appalachia, such as solid natural-stone wheels, hones, whetstones, oilstones, and polishing stones, are still in demand, but are imported.

DEPOSITS IN APPALACHIA

Many types of natural abrasive materials are found in Appalachia and all have been used at some time. Among these are corundum, emery, garnet, various forms of silica and sand, feldspar, rottenstone, and tripoli. At present, output is confined to grindstones from Washington County, Ohio, rottenstone from Lycoming County, Pa., and silica from alaskite in Mitchell County, N.C., and Campbell and Franklin Counties, Tenn. From 1922 through 1945, Appalachia produced a variety of special abrasive sandstone products, including grindstones and pulpstones from Ohio and West Virginia and oilstones, whetstones, and scythestones from Ohio. By 1946, only grindstones continued to find favor in competition with bonded or coated abrasives. Grindstones and pulpstones were produced from sandstone quarried mainly in Coshocton, Holmes, Jefferson, Morgan, and Washington Counties, Ohio, and in Jefferson and Monongalia Counties, W. Va. Quarries in Scioto County, Ohio, furnished natural abrasive stone products, oilstones, whetstones, and scythestones as late as 1940. Tripoli was mined in Bradley County, Tenn., from 1924 through 1933. Garnet was recovered as a byproduct of kyanite milling in Yancey County, N.C., during the period 1936–43.

Artificial abrasives, aluminum oxides and carbides of considerable value were manufactured in Calhoun County, Ala., from 1925 through 1952.

Table 100 shows the annual values of abrasives produced in Appalachia during the period 1922–64.

TABLE 100.—*Total value of abrasive materials produced in the Appalachian Region for 1922–64*

[Source: U.S. Bur. of Mines]

Year	Value, in 1958 constant dollars (thousands)	Year	Value, in 1958 constant dollars (thousands)
1922	1,076	1943	1,142
1923	1,697	1944	852
1924	1,866	1945	854
1925	2,629	1946	869
1926	2,709	1947	1,259
1927	2,835	1948	705
1928	3,278	1949	655
1929	2,823	1950	404
1930	1,781	1951	700
1931	924	1952	264
1932	796	1953	176
1933	1,262	1954	222
1934	1,512	1955	191
1935	1,598	1956	274
1936	1,374	1957	190
1937	1,522	1958	102
1938	812	1959	144
1939	1,076	1960	78
1940	1,230	1961	181
1941	1,555	1962	178
1942	1,266	1963	177
		1964	136
Total			45,374

CORUNDUM

Corundum or aluminum oxide (Al_2O_3) is, with the exception of diamond, the hardest mineral known. It has a theoretical composition of 52.9 percent aluminum and 47.1 percent oxygen (Eardley-Wilmot, 1927a, p. 1). Corundum has a hardness of 9 on Mohs' scale and a specific gravity ranging from 3.95 to 4.10. It crystallizes in the hexagonal system and generally occurs as long, tapered six-sided prisms or massive material of dull opaque gray, brown, pink, and white color.

The mineral generally is classified as common corundum, gem corundum, and emery. Three types of common corundum are: (a) block, a massive form showing little or no development of parting and having a high degree of purity; (b) crystal, consisting of more or less well-developed crystals or crystal aggregates of various sizes; and (c) sand, a mixture of minute crystals and small irregular grains. Gem corundum includes all the transparent varieties suitable for cutting. Among these are ruby and sapphire. Gem corundum is discussed in the section on "Gem-stone, Mineral, and Fossil Collecting" (p. 288). Emery is a mixture of corundum and magnetite or spinel. Corundum is used as abrasive powder, abrasive paper and cloth, and in the manufacture of bonded grinding wheels and sharpening stones.

Corundum has a wide geological distribution and has been found in at least 20 rock types (Metcalf, 1944, p. 2). It generally is disseminated in crystalline limestone and dolomite, gneiss, mica and chlorite schist, nepheline syenite, granite, peridotite, and pegmatite. It is also found as pebbles, grains, and weathered crystals in placers (Ladoo and Myers, 1951, p. 167). It is commonly associated with magnetite, mica, chlorite, garnet, pyrite, olivine, spinel, amphibole, pyroxene, and chromite.

Corundum in Appalachia occurs in both igneous and metamorphic rocks, but nearly all the deposits of economic significance are associated with ultramafic igneous rocks. The Corundum Hill deposit, Macon County, N.C. (fig. 70, No. 5), a typical deposit, is peripheral to a large mass of dunite roughly 1,200 feet long and 500 feet wide, composed of partly serpentinized granular olivine. Most surrounding rock is biotite schist, but in the southeast, a hornblende gneiss is close to the dunite contact.

A zone 3–40 feet wide consisting of chlorite, talc, and vermiculite, is generally present along the margins of the dunite. Within this zone, on the southeastern side, is a discontinuous vein as much as 10 feet wide of chlorite and corundum. A similar, but narrower, vein extends for about 200 feet on the northeast side. The veins contain block, crystal, and sand corundum. The southeastern vein was mined for a distance of 1,300 feet and the northeastern vein 900 feet in surface and underground workings.

Mining began as early as 1871 (table 101) at the Corundum Hill deposit and from then until 1905 most corundum produced in the United States came from North Carolina and Georgia. After 1905, abrasive corundum was produced only during World War I, from 1917 to 1919. During World War II, from 1943 through 1944, the U.S. Bureau of Mines extensively examined and explored the Buck Creek and Corundum Hill deposits, as well as deposits in Georgia. A few experimental shipments were made but corundum could not be successfully produced (Stuckey, 1965, p. 348–349). More recently some old corundum workings were reopened as commercial collecting grounds for gem stones and minerals. Large reserves of highly variable grade are known to exist at both Corundum Hill and Buck Creek (table 101). Developments in modern milling techniques might make it possible to concentrate material that previously could not compete with imported corundum.

EMERY

Emery is a mixture of corundum and magnetite (true emery) or corundum and spinel (spinel emery). It resembles a fine-grained iron ore, is dark gray to black, and has a dull to metallic luster. Its hardness ranges from 7 to 9, depending on the percentage of corundum. Most emery is formed by contact metamorphism and occurs as irregularly shaped bodies in crystalline limestone, peridotite, and amphibole schist.

Emery is used in several forms. Loose grains and powder are used with abrasive saws and grinding disks for cutting and polishing of minerals, rocks, and metal, and for grinding fine lenses. Coated abrasives such as emery cloth and paper are used for fine finishing work. Emery is bonded into blocks and grinding wheels for coarse grinding of cast iron. Lump emery is used to grind talc, paint, barite, and graphite. A newer and growing use is in nonskid concrete in floors and stair treads (Ladoo and Myers, 1951, p. 171; Johnstone and Johnstone, 1961, p. 171–172).

The major commercial emery deposits of the United States are at Peekskill, Westchester County, N.Y., and near Whittles, Pittsylvania County, Va., both outside Appalachia. A few small deposits occur in Alabama and North Carolina as shown in figure 70. Very minor production has been recorded from one or two of these deposits, the greatest being about 100 tons of emery in 1898 from the Fairview mine near Franklin, Macon County, N.C. The last production recorded was in 1918 from deposits on Mine Fork in Yancey County, N.C. (Stuckey, 1965, p. 351).

The emery deposits of Appalachia are small and low grade and cannot be mined in competition with those at Peekskill, N.Y.

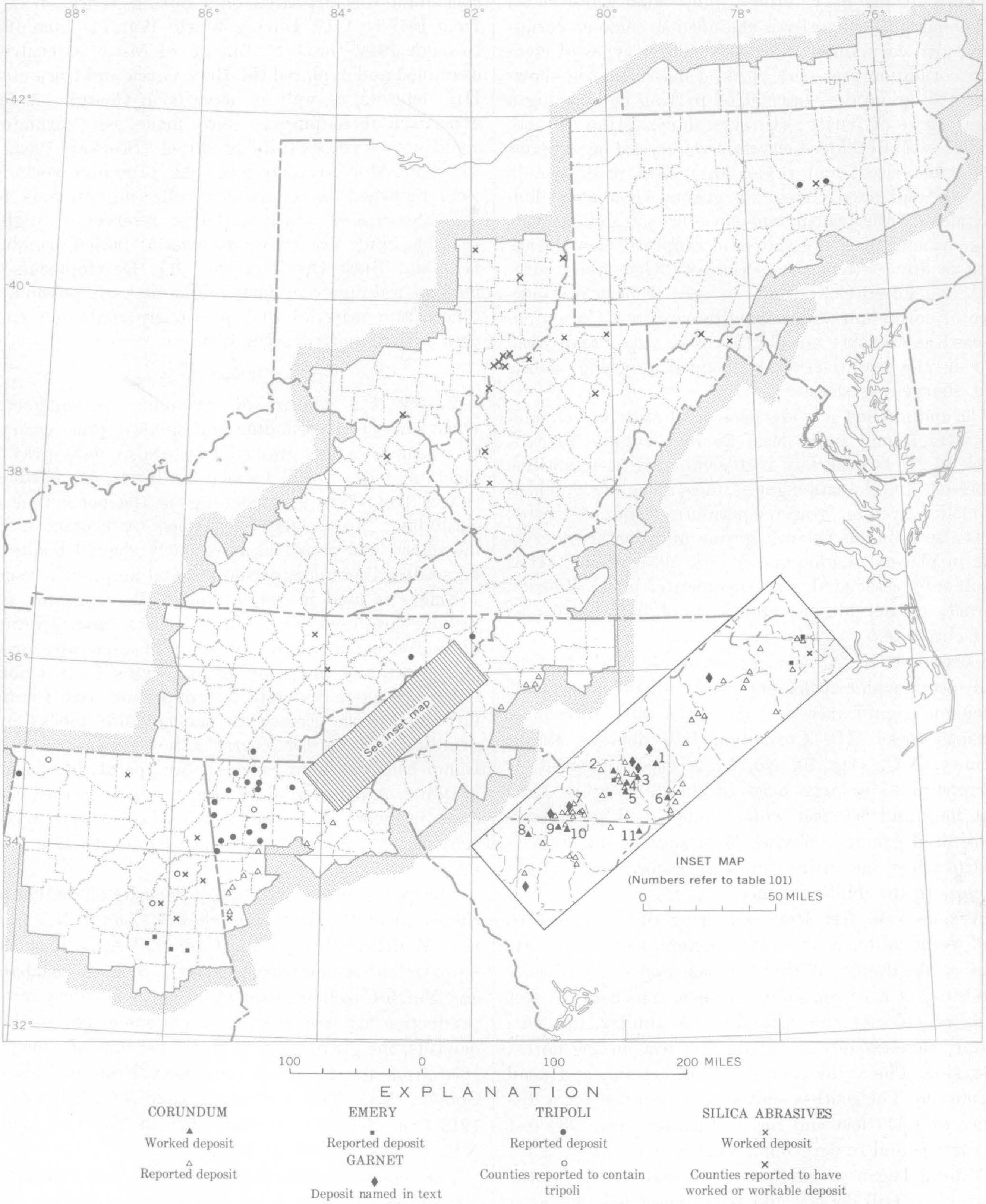


FIGURE 70.—Deposits of abrasive materials in the Appalachian Region. Numbers refer to Table 101.

TABLE 101.—*Major corundum deposits in the Appalachian Region*

No. (fig. 70)	Mine, location	History	Material produced	Geology	Workings	Production	Resources	References
	North Carolina							
5	Corundum Hill mine, Macon County.	Began 1871, major periods of activity 1878–1900, 1914–19.	Block, crystal, and sand corundum.	An oval peridotite body, 1,200 by 500 ft, enclosed in gneiss, contains a vein of chlorite and corundum as much as 10 ft wide yielding 7.5–50 percent corundum.	The "Big Vein" has 900 ft of surface cuts as much as 55 ft deep, 3 shafts and several drifts. "Zeb Jones" or "Small Vein" has a surface cut and a 93-foot shaft with 2 drift levels.	200–300 tons annually 1878–1900; 1200 tons 1914–19. Total 6,700 tons.	500 tons of ore yielding about 150 tons cleaned corundum.	Ballard (1947a); Stuckey (1965 p. 349).
7	Big Shaft, Big Shaft Extension, and Herbert or Buck Creek mines, Buck Creek area, Clay County.	Prospected 1875, mining began 1892, active 1892–96, 1906.	Block and crystal corundum.	Veins of corundum, chlorite, and feldspar in a peridotite mass and crystals disseminated in amphibolite. Corundum content as much as 50 percent.	Big Shaft and Big Shaft Extension mine from veins as much as 3 ft with a maximum corundum content of 40 percent. Herbert mine in a blanket deposit near surface, pinching out at 40 ft. Numerous veins worked from surface cuts.	Total about 230 tons.	100 tons coarse abrasive 10–40 percent. 2,700 tons optical grade 2.5–8 percent.	Ballard (1947b); Hadley (1949).
1	McChastain mine, Jackson County.	Began prior to 1900, active 1901, 1935.	Rounded masses of corundum with a hull of mica.	Veins 4–8 ft in mica schist along contact of hornblende gneiss and quartz-mica gneiss. Corundum content 20–25 percent.	Tunnels and opencuts along 600 ft of contact.	20+ tons	No large reserves discovered.	W. A. White ([1943?], p. 10–11).
4	Mincey mine, Macon County.	Began 1891, active 1891–94, reopened 1917–18 with no production.	Crystals as much as 1 inch in diameter.	A 2-ft-wide vein of corundum in a 6–8-ft chlorite vein in dunite.	Opencut 200 ft long, 30 ft deep, 2 drifts at 50 ft and 100 ft below cut, vertical shaft 130 ft.	150 tons	150 tons	W. A. White ([1943?], p. 11–13).
3	Goodensville mine, Jackson County.	Began during World War I, active until 1918.	Crystal and sand (buckwheat) corundum.	A 3–4-foot vein	Two short adits with an aggregate length of 50–60 ft.	Several tons	Some left, but no estimate on amount.	W. A. White ([1943?], p. 13–14).
2	Sheffield mine, Macon County.	Active in late 1800's.	Crystal corundum.	Crystals found in saprolite of hornblende gneiss, 3–5 percent corundum.	Opencuts 60–70 ft deep.	?	None, worked out.	W. A. White ([1943?], p. 14).
6	Bad Creek mine, Sapphire area, Jackson County.	do	?	From a 9-ft vein with a 15–20 percent corundum content.	Many shallow trenches and opencuts.	?	Some available	W. A. White ([1943?], p. 15).
	Georgia							
11	Laurel Creek mine, Rabun County.	Began 1880, active 1880–93.	Block and crystal corundum.	From a 2- to 15-foot vein, 300 ft long, in an oval peridotite body 800 by 1,600 ft. Average corundum content 10 percent.	Five shafts, tunnels, stopes, 3 opencuts.	3,000 tons (est.)	468 tons (est.)	W. C. Hudson (unpub. data, 1943).
8	Track Rock mine, Union County.	Began around 1893.	Crystals wrapped in margerite.	From 15-ft thick saprolite of schist.	A 198-foot tunnel, trenches, and test pits.	Several tons	None	Ballard (1948).
10	Hog Creek mine, Towns County.	Prospected 1890	Crystal corundum.	From a 4-ft vein of chlorite schist in peridotite.	A 190-ft trench, 2 shallow shafts, test pits.	?	None	Ballard (1946).
9	Bell Creek mine, Towns County.	Prospected prior to 1893.	Crystal corundum.	From a 10-ft vein of chlorite schist in hornblende gneiss.	A 100-ft cut, 3 pits, all filled.	?	?	W. C. Hudson (unpub. data, 1943).

GARNET

Garnet minerals comprise at least seven different species, all of which are silicates containing varying amounts of iron, calcium, aluminum, magnesium, manganese, and chromium. All possess similar physical properties including a hardness of 6.5–7.5 and a specific gravity of 3.4–4.3. Garnet ranges in color from almost black, through dark red, pink, brown, green, yellow to white.

The chief use of garnet is as an abrasive, although the clear transparent crystals, particularly the deep red ones, have long been used as semiprecious gems. More than 90 percent is fabricated into garnet-coated paper and cloth, the remainder is used as loose grains (Johnstone and Johnstone, 1961, p. 210). Most garnet-coated paper and cloth is used in woodworking, but some is used to smooth leather, rubber, and metal. Most abrasive garnet used in the United States comes from the Barton mine, Warren County, N.Y., well outside Appalachia.

Garnet as isolated grains is a common constituent of gneiss and schist, some igneous rocks, and of some contact metasomatic calcareous rocks. It occurs in many rocks in Appalachia but is present in minable quantity and quality only in North Carolina. The largest deposits are in Clay and Jackson Counties; smaller ones are in Macon, Madison, and Burke Counties.

Two large garnet deposits are in Clay County, N.C. One at Penland Bald on Buck Creek is a very large deposit of garnetiferous hornblende gneiss in which crystals of almandite garnet (an iron-aluminum garnet), as much as 2.5 inches in diameter, make up 3–25 percent of the total rock mass. A similar large deposit on Shooting Creek has very large reserves of high grade abrasive garnet. The rugged character of the surrounding country hinders their development (Ladoo, 1922, p. 4).

Three garnet deposits were worked in Jackson County. A large deposit of rhodolite garnet on Sugar Loaf and Doubletop Mountains, 2.5 miles south of Willets, consists of garnet crystals, as much as 3/4 inch in diameter, in a quartz biotite gneiss. The garnets constitute 25–50 percent of the total rock mass. Mining began around 1900 and continued intermittently until 1926. The Rhodolite Co. erected a mill near the quarry in 1925 but the operation closed down in 1926 because of the limited market for its product. Nevertheless, large reserves of high quality, readily accessible abrasive garnet remain. The two other deposits, the Savannah at the head of Betty Creek and the Presley near Speedwell, were worked intermittently for a number of years around 1900. No information is available as to reserves in these two deposits.

Deposits elsewhere in North Carolina are small. Southwest of Marshall near Little Pine Creek, Madison County, garnet crystals 1–2 inches in diameter were mined from a zone 8–10 feet thick in a chlorite schist. This mining was about 1900 or 1905, and total production was very small. In 1944, garnets were produced as a byproduct of the kyanite concentrating mill of the Celo Mines Co. in Yancey County (Stuckey, 1965, p. 351–352).

Garnet abrasives are still widely used in industry and it is possible that at some future date the high grade deposits in North Carolina may again produce.

TRIPOLI AND ROTTENSTONE

Tripoli is a type of micro- or cryptocrystalline silica derived from the decomposition of chert or highly siliceous limestone. (Tripoli should not be confused with tripolite, a type of diatomaceous earth.) It is commonly known as soft silica or amorphous silica. Rottenstone, considered to be a type of tripoli, has a lower silica content. Most tripoli is used as a mild abrasive in buffing and polishing compounds and in washing powders; rottenstone is used as a fine-ground abrasive and as a filler in paint.

The abrasives industry divides tripoli into two principal types based on physical properties and named for the major producing regions (Ladoo and Myers, 1951, p. 561–562). The first, the Missouri-Oaklahoma type, is porous, lightweight, soft, and easily crumbled and ranges from cream colored to yellow, brown, rose, and red. When dry it is very absorbent. Individual grains are hard enough to scratch steel. It occurs as layers in compact bedded deposits. The second, the Illinois-Tennessee type, ranges from a powdery noncoherent material in Tennessee to hard compact and dense material in Illinois. It is usually pure white and is much less absorbent than the Missouri type. It occurs in extensive thick beds mixed with unaltered chert.

Tripoli has been reported in weathered Knox Dolomite in Bradley, Greene, Johnson, and Sullivan Counties, Tenn. The Black Fox mine near Cleveland, Bradley County, produced small amounts of tripoli in the past. Similar deposits near Greeneville, Greene County, and near Butler, Johnson County, also have been worked. All have large resources, as yet unused.

Deposits of tripoli also have been found in Alabama and Georgia. In Alabama, tripoli has been reported in weathered Knox Dolomite in Calhoun and Talladega Counties and in the Fort Payne Formation in Lauderdale and Colbert Counties. According to Schrader, Stone, and Sanford (1917, p. 15), some tripoli has been mined and shipped from the deposit in Talladega County. Most tripoli deposits of northwestern Georgia occur in weathered Knox Dolomite. Several have been worked at various times, but none is presently active (Crickmay, 1937, p. 4–7). The sections on "Clay" and "Silica" give information about the geology of the Georgia deposits. (See p. 181, 346.)

Rottenstone, found in Lycoming County, Pa., has been mined continuously for many years. It is lower in silica content and heavier in unit weight than tripoli and occurs as the weathered residue of the Trenton Limestone. Production is small, and resources are adequate to sustain this level of production for many years.

QUARTZ ABRASIVES

Quartz, or silica (SiO_2), is an abundant and widespread mineral that has many uses as a natural abrasive. Large amounts of massive relatively pure quartz are found in veins and in layered deposits of sand, sandstone, and quartzite. Massive vein quartz is little used as abrasive, but sand and sandstone are extensively used. Quartz generally is a white-to-clear mineral having a hardness of 7; it lacks distinct cleavage and breaks into irregular fragments with sharp edges and corners.

Quartz is an ideal abrasive material for many purposes. Annual production approaches 2 million short tons; it exceeds total production of all other natural and artificial abrasives in the United States. Quartz abrasives are used as fine grains and powders for sand blasting, sand paper, and sawing of dimension stone; as pebbles and nodules in ball mills; and as large, shaped pieces for tube-mill linings, grindstones, whetstones, and pulpstones. The unit value of these products is low.

Abrasive quartz has been produced on a small scale throughout Appalachia. The more important worked deposits are shown in figure 70, and some characteristic features of these deposits are listed in table 102. Additional information about quartz is given in the section on "Silica."

TABLE 102.—*Quartz abrasives in the Appalachian Region*

State, county	Abrasive	Producing formation	References
Pennsylvania:			
Lycoming	Sand	Oriskany Group (sandstone)	Carter, "Silica" section, this report (p. 337).
Maryland:			
Allegany	Sand	Tuscarora Quartzite	Carter, "Silica" section, this report. Murphy (1960a, b).
Ohio:			
Harrison, Holmes, Jefferson, Scioto, Washington.	Grindstones Blasting sand	Berea Sandstone Dunkard Group (sandstone)	Santmyers (1931a–c); Schrader, Stone, and Sanford (1917).
West Virginia:			
Boone, Jackson, Kanawha, Monongalia, Morgan, Pleasants, Upshur, Wetzel, Wood.	Grindstones Pulpstones	Marietta Sandstone Dunkard Group (sandstone)	Santmyers (1931a–c); Schrader, Stone, and Sanford (1917); Cross and Schemel (1956, p. 59–60).
Kentucky:			
Carter	Sand	Lee Formation (sandstone)	McGrain (1956, p. 31).
Tennessee:			
Campbell, Franklin	Sand	Sewanee Conglomerate (sandstone).	
Knox	Sand	Bed of Tennessee River	Murphy (1960a, b).
Alabama:			
Calhoun, Cherokee, Clay, Cleburne, Talladega.	Grinding mill liners	Quartzite	Metcalf (1940, p. 4).
Madison	Millstones		Schrader, Stone, and Sanford (1917).

Artificial abrasives have largely replaced natural abrasives in most forms, but a demand still exists for low-cost natural silica abrasives, particularly blasting sand. Undoubtedly the sand and sandstone deposits of Appalachia could be used for this purpose much more extensively than they are now if demand and prices made it economical to develop these resources.

Hard-turned grindstones, once a necessity on most farms for sharpening knives, axes, and other cutting tools, have been largely replaced or augmented by bench-mounted high-speed grinding wheels. Pulpstones, formerly cut and shaped from natural stone, have been replaced by more efficient bonded and shaped artificial abrasives that are less costly. Flat millstones (which revolved parallel to each other horizontally to grind grain, gypsum or talc), and chaser stones (stone wheels which role on a circular track paved with hard stone, once used for grinding nonmetallic minerals such as feldspar, quartz, and barite) have been outmoded and replaced by other grinding media (Newland and Hartnagel, 1932, p. 53–54). Ohio and West Virginia still produce natural grindstones.

ARTIFICIAL ABRASIVES

The market for artificial abrasives is large and continually expanding. Domestic production is great, but considerable material is imported, chiefly from Canada. The raw materials necessary to manufacture artificial abrasives (mainly silica, coal or coke, clay, bauxite, and salt) are abundant and widespread in Appalachia (O'Neill, 1941, p. 7). Given sufficient demand and a favorable price, Appalachia could undoubtedly compete with other areas of the United States in production of artificial abrasives.

Artificial abrasives are not presently being produced in Appalachia, but aluminum oxide (alundum) was produced in Anniston, Calhoun County, Ala., until 1952. In 1956, the Norton Co., one of the largest domestic producers of artificial abrasives, opened a refractory plant in Huntsville, Madison County, Ala., which might be expanded at a later date to include the production of alundum and carborundum (silicon carbide) (American Metal Market, 1955).

ARSENIC

By ROBERT A. LAURENCE, U.S. Geological Survey

Arsenic is marketed principally in the form of its trioxide (As_2O_3), known as white arsenic, used for the manufacture of insecticides, and to a lesser extent for wood preservatives, weed killers, and glass manufacture. Small amounts of metallic arsenic are added to lead for manufacture of lead shot and lead-base-bearing alloys and to copper for automobile radiators and other purposes. Most arsenic produced in the United States is recovered as white arsenic in flue dust from base-metal smelters. The United States is the world's largest consumer and second largest producer. Resources are adequate for domestic needs. Additional information about use, production, and technology of arsenic is given by A. M. Lansche (in U.S. Bur. Mines, 1965a, p. 75–80).

In Appalachia, arsenic occurs in the mineral arsenopyrite (FeAsS), a widespread but minor constituent of gold ores of the Piedmont province (Pardee and Park, 1948, p. 37). Gold-quartz veins in Randolph and Clay Counties near Cragford, Ala., contain abundant arsenopyrite (Ross, 1935, p. 107) which might be recoverable as a byproduct of gold mining.

Between 1903 and 1919, nearly 100 tons of white arsenic was produced at Rewald, Floyd County, Va., from arsenopyrite mined nearby. The arsenopyrite occurs chiefly in lenticular or podlike veins and in lesser amounts in the country rock, a quartz sericite schist. Further exploration seems warranted when there is sufficient demand for arsenic (Dietrich, 1959, p. 123).

ASBESTOS

By ALICE E. FRENCH, U.S. Geological Survey, and
ROBERT G. STANSFIELD, U.S. Bureau of Mines

Asbestos is a name applied to a group of minerals that can be separated into flexible fibers. Important physical properties of asbestos are: tough and flexible fibers, incombustibility, high resistance to acid, and slow heat conduction. Asbestos minerals fall into two groups—serpentine and amphibole. The chief variety of serpentine asbestos is chrysotile which represents about 95 percent of world production. The minerals anthophyllite, actinolite, tremolite, amosite, and crocidolite of the amphibole group account for the remaining 5 percent of world production.

Most commercial deposits of chrysotile occur as crosscutting discontinuous veins in massive serpentine bodies. Chrysotile fibers are fine, silky, and strong; they range from a fraction of an inch to more than 6 inches long. They are easily spun, as much as 32,000 feet of thread being produced from a pound of the best quality chrysotile. The world's major deposits of chrysotile are found in Quebec, Canada; other important sources are in the U.S.S.R., Rhodesia, Swaziland, and South Africa. The deposits in the United States are relatively small and occur in California, Vermont, and Arizona. Chrysotile has been reported in North Carolina and Georgia, but only in very small amounts of no commercial importance. It is doubtful that any larger deposits exist in Appalachia (Stuckey, 1965, p. 355).

Of the varieties of amphibole asbestos, anthophyllite and tremolite are the only ones occurring in exploitable deposits in the United States. Anthophyllite is the only asbestos mineral found in Appalachia in commercial or potentially commercial amounts. It occurs in North Carolina, Georgia, and Alabama in peridotite and dunite bodies. Three types of anthophyllite are recognized on the basis of the arrangement of the fibers with respect to each other and to the wall rock of the deposit. These types are cross-fiber (where the fibers are parallel to each other and perpendicular to the walls), slip-fiber (where the fibers are parallel to the wall), and mass-fiber (where the fibers do not occur in veins, but in bundles of varying size scattered throughout the rock). The fibers have low tensile strength and are only slightly flexible; therefore they are not suited to spinning. Anthophyllite is, however, superior to all other varieties in resistance to heat and acid, and finds wide use in chemical filters, plastic insulating cement for pipes, welding rod coatings, rubber, cement and plastic insulation products, flooring, and plaster.

The United States is the world's largest consumer of asbestos. Ranking sixth among the world's producers, it imports more than 90 percent of its requirements. Canada leads the world in production with 40 percent of the total output. In 1964, U.S. production of asbestos increased 52 percent over 1963, and totaled 101,000 tons valued at $8.1 million. Asbestos was mined in four States, listed in order of their production: California, Vermont, Arizona, and North Carolina.

In recent years, chrysotile has represented about 96 percent of the asbestos consumed annually in the United States (May, 1964, p. 252). Domestic chrysotile is mined in California, Vermont, and Arizona. Tremolite has been mined in California and anthophyllite in Georgia and North Carolina. During the period 1909 through 1964, a total of 1.1 million tons of asbestos was mined in the United States.

Although substitutes have been developed for some uses of asbestos, few are economically competitive. Fiberglass, plastics, and silicone products have limited value as substitutes. Aluminum sheets are used to some extent to replace asbestos as an insulation against radiant heat. In certain applications, the substitution

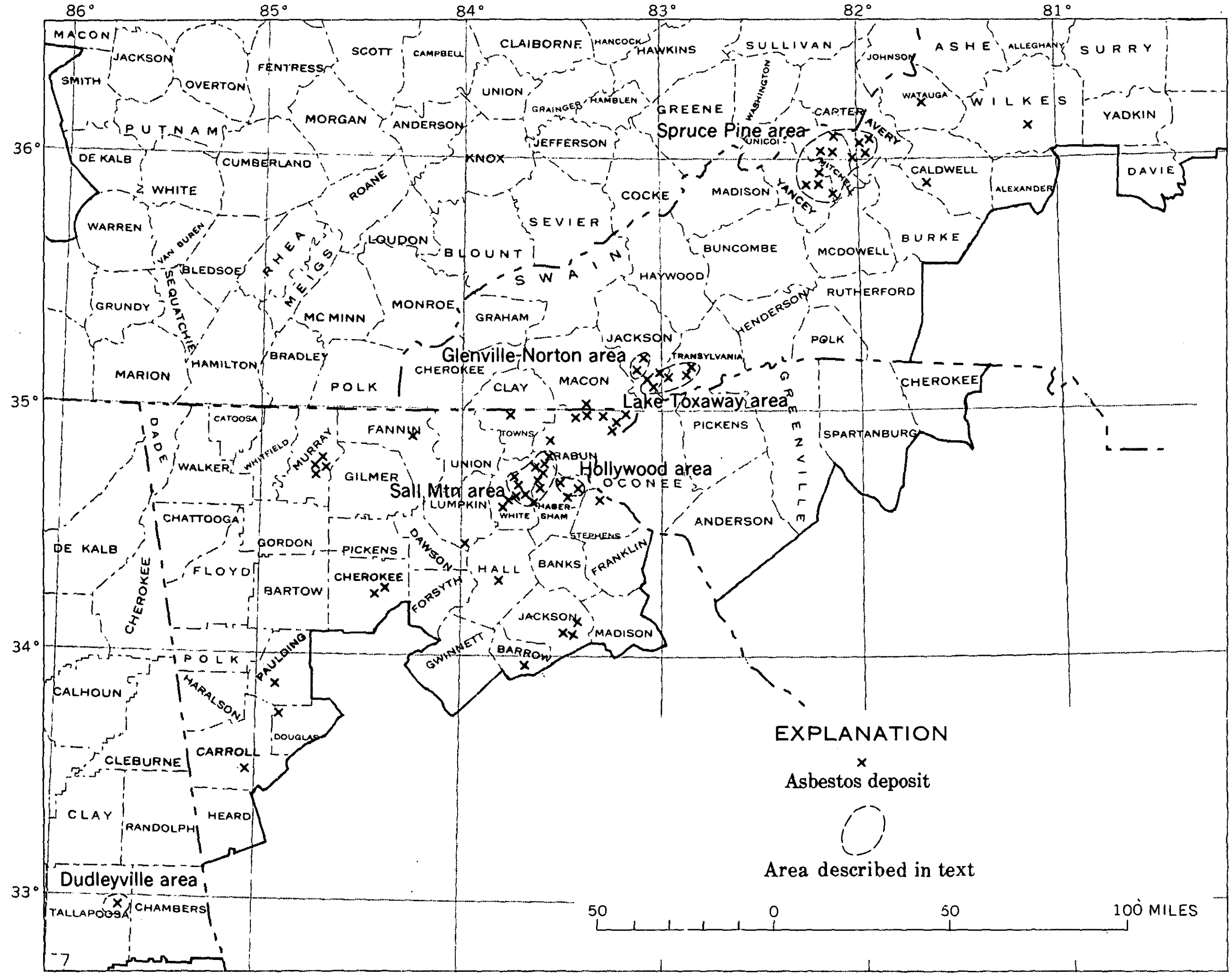


FIGURE 71.—Asbestos deposits in the southeastern part of the Appalachian Region.

of lower grade asbestos for higher grades has been made possible through research (Kennedy, 1960, p. 80).

The important commercial uses of asbestos require strong, flexible fibers. Chrysotile, therefore, is the asbestos mineral most in demand, and accounted for 96 percent of the asbestos consumed in the United States in 1964. Chrysotile from Quebec, Canada, is readily shipped to manufacturers of asbestos products in the New England States.

Because of its low strength and relative inflexibility, amphibole asbestos mined in Appalachia has been limited chiefly to making chemically resistant filters, welding rod castings, and fillers or additives in rubber, wall coatings, battery boxes, and molded insulation. Use in these products constitutes only a minor part of the total asbestos consumption in the United States.

Most of the asbestos deposits of North Carolina and Georgia lie in a zone extending from the Spruce Pine area in Avery, Mitchell, and Yancey Counties, N.C., into White, Habersham, and Rabun Counties, Ga. (fig. 71). The zone continues southwest across Georgia into Alabama, but most of the deposits of asbestos are either very small or lie outside the area of Appalachia.

There are four main areas of asbestos deposits in North Carolina: (1) Spruce Pine area in Avery, Mitchell, and Yancey Counties, (2) Lake Toxaway area in Transylvania and eastern Jackson Counties, (3) Glenville-Norton area in southern Jackson County, and (4) scattered small areas in Macon and Caldwell Counties (Stuckey, 1965, p. 360).

North Carolina has produced anthophyllite asbestos intermittently for many years (Brobst, 1962, p. 22), mainly from the Blue Rock mine in Yancey County and the Frank mine in Avery County. The State has produced an estimated 100,000 tons of high grade ore, and the present reserves are estimated to be at least

100,000 tons (Stuckey, 1965, p. 362). An anthophyllite processing mill was erected in Avery County in 1925 and was improved in 1935. In 1952, a processing plant was constructed in Mitchell County for treatment of asbestos from the Spruce Pine area. The only production in North Carolina since 1955 has been by the Powhatan Mining Co. from Yancey, Transylvania, and Jackson Counties (Conrad and others, 1963, p. 29–36). This company is also presently mining anthophyllite in the Dudleyville area of northeastern Tallapoosa County, Ala.

From 1894 until 1908, anthophyllite was the principal type of asbestos mined in the United States, and Georgia contributed a large part of the total production of that period (Hopkins, 1914, p. 113). The State's output has been chiefly from deposits within the Appalachian counties of Barrow, Habersham, Rabun, and White. The two most important producing areas in Georgia are: (1) Sall Mountain in White County, and (2) Hollywood, Habersham County (Hopkins, 1914, p. 153–170). With some interruptions, asbestos was mined in White County from 1894 through 1930, and was processed in a mill at Gainesville (Bowles, 1955, p. 57). Habersham and Barrow Counties were production centers from 1923 to 1927 (Bowles, 1937, p. 26); Barrow County produced a small tonnage of anthophyllite again in 1943. Anthophyllite was mined in Rabun County each year from 1942 through 1954, the last year that asbestos was reported mined in Georgia.

The asbestos in the Sall Mountain deposits is of the mass-fiber type, and 90–95 percent of the rock quarried was reported to be fiber. Most of the high grade material has been mined out, and present reserves are probably small. The Hollywood deposits are also of the mass-fiber type although the quality is not as high as that at Sall Mountain. The deposits are rather large and have not been extensively exploited (Bowles, 1955, p. 26). No estimate of present reserves is available. There are numerous other small asbestos deposits in nearby areas, some of which have been worked at various times, but no data on production and reserves are available.

In summary, asbestos occurs in veins in the ultramafic rocks which are very abundant and widespread in the Blue Ridge and Piedmont provinces of southern Appalachia. It is possible that resources of asbestos in these rocks are moderately large but they cannot be evaluated on the basis of present scanty knowledge. However, the potential for discovery of asbestos in ultramafic rocks is good. The known deposits are of the short-fiber type of anthoyphyllite asbestos, and any deposits found in the future probably also will be of this type.

BARITE

By Donald A. Brobst, U.S. Geological Survey, and
Robert G. Hobbs, U.S. Bureau of Mines

Barite ($BaSO_4$) is an abundant and widespread mineral used primarily as an additive because it is heavy, nonabrasive, and inert chemically. It is a soft, generally white to gray heavy crystalline mineral (specific gravity=4.5) that occurs in many geological environments in sedimentary, igneous, and metamorphic rocks. In ore deposits it occurs alone or, more commonly, in association with quartz, jasper, chert, fluorite, celestite, and various carbonate and metallic sulfide minerals.

About 90 percent of the barite consumed in the United States is ground to −325 mesh and added to the fluids used in rotary drilling for oil and gas. The resulting heavy fluid facilitates removal of cuttings in drilling and controls high oil and gas pressures at depth. The other 10 percent is used for a wide variety of purposes. Among the uses based on weight and inertness are as fillers in paint, paper, textiles, rubber goods, asbestos products and as heavy aggregate for concrete construction material. Chemicals derived from barium are used in the manufacture of glass and ceramics and in a host of industrial products. A newly developed fuel cell uses barium with oxygen or chlorine as an oxidizer; after one hour's operation, it still has about three times the energy of a silver-zinc battery (Cole, 1965).

Market specifications for barite vary according to its use; higher purity is required by the paint and chemical industries, whereas less stringent specifications are required for use in drilling fluid. Statistics from the U.S. Bureau of Mines indicate that domestic crude barite, f.o.b. mines, in 1965 averaged about $12.00 per short ton, and ground barite had an average value of about $25.00 per short ton. Additional information on the uses, specifications, prices, and many other aspects of the barite industry is summarized by Lewis (in U.S. Bur. Mines, 1965a, p. 91–99).

THE NATIONAL INDUSTRY

Barite mining in the United States began about 1845 in Virginia. In the latter half of the 19th century, many residual and vein deposits in the Appalachian States were mined on a small scale. Much of this barite was used as a adulterant to increase the weight of foods until the passage of federal laws to govern their purity. The modern barite industry in the United States began during World War I when deposits in Missouri and the Appalachian States were developed to replace the supply previously imported from Germany. In the years that followed, the domestic deposits were able to supply most of the increasing industrial demands in the United States. The use of barite in fluid for rotary drilling in petroleum exploration and development began in 1926. This single need increased the demand for barite, and domestic production and imports reached a high from 1955 to 1957, with only a slight decline since then. Barite production from 1910 to 1964 of the United States and Appalachia is shown in table 103.

TABLE 103—*Production of barite, 1910–64*

[Domestic barite sold or used by producers in the United States. W, withheld to avoid disclosing individual company data; included in total. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1910	7, 011	51	42, 975	424
1911	11, 424	92	38, 445	413
1912	8, 439	81	37, 478	489
1913	9, 247	88	45, 298	481
1914	15, 211	101	52, 747	449
1915	57, 669	349	108, 547	737
1916	148, 085	1, 365	221, 952	2, 424
1917	135, 538	1, 500	206, 888	2, 460
1918	94, 875	1, 049	155, 368	1, 897
1919	125, 221	1, 593	209, 330	2, 778
1920	118, 722	1, 424	228, 113	2, 930
1921	37, 201	393	66, 369	728
1922	84, 114	1, 092	155, 040	1, 813
1923	126, 489	1, 650	214, 183	2, 764
1924	114, 274	1, 548	196, 332	2, 660
1925	119, 924	1, 464	228, 063	2, 911
1926	103, 564	1, 314	237, 875	3, 241
1927	121, 870	1, 371	254, 265	3, 038
1928	136, 790	1, 543	269, 544	3, 179
1929	124, 676	1, 334	277, 269	3, 280
1930	69, 740	708	234, 932	2, 781
1931	53, 576	597	174, 520	2, 027
1932	26, 250	381	129, 854	1, 727
1933	41, 666	635	167, 880	2, 036
1934	54, 520	758	209, 850	2, 481
1935	52, 660	684	225, 111	2, 863
1936	86, 058	1, 081	283, 160	3, 842
1937	118, 609	1, 306	355, 888	4, 893
1938	W	W	309, 663	4, 293
1939	W	W	383, 609	5, 096
1940	W	W	409, 353	5, 585
1941	W	W	503, 156	6, 218
1942	W	W	429, 484	4, 507
1943	W	W	420, 343	4, 357
1944	W	W	518, 617	4, 976
1945	W	W	696, 062	7, 047
1946	W	W	724, 362	6, 830
1947	W	W	834, 082	7, 462
1948	W	W	799, 848	7, 755
1949	W	W	717, 313	6, 500
1950	72, 888	873	695, 414	7, 055
1951	72, 117	893	860, 669	8, 458
1952	97, 540	1, 218	941, 825	9, 222
1953	81, 846	1, 131	944, 212	10, 006
1954	75, 492	1, 143	883, 283	9, 158
1955	130, 396	1, 990	1, 108, 103	11, 761
1956	174, 139	3, 105	1, 299, 888	14, 223
1957	175, 072	3, 031	1, 145, 791	13, 107
1958	108, 511	2, 285	605, 402	7, 508
1959	89, 484	1, 784	901, 815	10, 159
1960	119, 304	2, 326	714, 276	8, 498
1961	W	W	796, 804	9, 244
1962	W	W	860, 312	9, 751
1963	W	W	823, 615	9, 408
1964	W	W	829, 741	9, 747
Total	5, 527, 986	77, 234	25, 184, 318	279, 677

Twelve States produced barite in 1964, but the major production came from Missouri, Arkansas, Nevada, Tennessee, Georgia, and South Carolina. Most midwestern and western barite was used in well drilling near the mining areas. The southeastern producers in Georgia, Tennessee, and South Carolina supplied industry on the east coast and shipped small amounts to the Gulf Coast for well drilling.

Domestic barite production is supplemented by imports chiefly from Canada, Mexico, Peru, Morocco, Ireland, and Greece. In 1964, imports were 600,000 tons of crude barite, 1,100 tons of crushed barite, and 5,400 tons of barium chemicals (Cole, 1965).

The domestic barite industry is largely dependent on the continued prosperity of the oil and gas industry. Reduced domestic barite production since 1957 is a direct result of the decline in petroleum exploration. Another factor, though small now, is the increased use of air and natural gas instead of drilling fluids as the circulating medium in rotary drilling. The use of barite in the paint, rubber, and glass industries has shown a sharp rise since 1961, but barite consumption in these industries is expected to stabilize or even decline within the next few years.

THE INDUSTRY IN APPALACHIA

Barite occurrences and deposits are widespread in and near Appalachia and the southern part of the region has supplied an important part of the Nation's requirements since 1880. Production has been recorded from Virginia, Tennessee, Kentucky, Alabama, Georgia, North Carolina, and South Carolina; but since World War II, only Georgia, Tennessee, and South Carolina have yielded substantial amounts of barite.

The Cartersville district, Bartow County, Ga., ranks first in importance in Appalachia, both in quantity and continuity of production. Since 1916, barite has been the chief product of the area, although some iron ore is produced now and some manganese ore was mined until 1963. In 1964, the district yielded 13 percent of the domestic barite production and by itself made Georgia fourth in rank of barite-mining States. Barite from this district brings the highest average price of that produced in all States.

The second- and third-rank barite districts of Appalachia are the Sweetwater district, Loudon, McMinn, and Monroe Counties, Tenn., and the Kings Creek district, Cherokee and York Counties, S.C. Production from the latter is considerably smaller than that of the Cartersville and Sweetwater districts.

The success of the major barite mining operations in the Appalachian States results from a favorable combination of economic factors. Residual deposits such as those in the Cartersville and Sweetwater districts have been valuable since the earliest days of barite mining chiefly because of their large size, ease of mining by opencut, and low-cost beneficiation to obtain a high-quality product easily transportable to major markets.

The vein barite of the Kings Creek district is also mined by opencut, but is a lower volume, higher cost mining operation when compared to mining of residual deposits. Some other residual and vein deposits in this region have ore of sufficient quality and quantity to support small to moderate mining operations, but many have not been explored or developed enough to be competitive with nearby established mines.

DEPOSITS IN APPALACHIA

Two types of barite deposits occur in Appalachia: vein and cavity fillings and residual. Vein and cavity-filling deposits are those in which barite and associated minerals occur along faults, gashes, joints, bedding and foliation planes, breccia zones, solution channels, and sinkholes. Most barite deposits in the bedrock of Appalachia are apparently associated with faults and fractures resulting from folding, although some geologists now think that many breccia zones resulted from collapse related to solution of carbonate rocks (Hoagland, Hill, and Fulweiler, 1965). Only a few vein deposits have commercial value now. These include the Kings Creek district, South Carolina, the Del Rio district, Tennessee, and the Hot Springs district, North Carolina.

Residual deposits are concentrations of barite, generally enclosed in clay, that are derived from weathering of rocks containing barite. Residual deposits are known from Pennsylvania to Alabama, chiefly in residual clays derived from Cambrian and Ordovician carbonate rocks. Many of these deposits, derived from low-grade vein and cavity-filling deposits, are now of major commercial importance, particularly in the Sweetwater district, Tennessee, and the Cartersville district, Georgia.

Individual barite districts, mines, and prospects in Appalachia are summarized in table 104. The table is numerically keyed to figure 72 which shows the distribution, relative size of reserves, and geologic type of the deposits. The parts of New York, Ohio, West Virginia, and Maryland included in Appalachia have no known deposits of barite.

Prospecting in the future might well require the coordinated study and application of methods of economic geology, geochemistry, geophysics, and geomorphology (Laurence, 1960, p. 178). Such studies should lead to the selection of favorable areas worthy of more intensive exploration by drilling, trenching, and pitting. Techniques for drilling residual deposits were described by Kesler (1949).

The valleys in the Valley and Ridge province of Appalachia, underlain chiefly by Cambrian and Ordovician carbonate rocks and their associated residual clays, are an overwhelming large but attractive target for further exploration. These rocks contain widely scattered low-grade deposits of barite overlain by residual clays containing minable deposits of barite.

Laurence (1960, p. 178) suggested that favorable places for finding new residual barite deposits in the Sweetwater district, Tennessee, should include two or more of the following features: (1) presence of weathered lower member of the Kingsport Formation; (2) a well-developed northwest-trending minor anticline crossing regional strike; (3) location on or near a divide between two, and preferably three, major tributaries of the Hiwassee and Tennessee Rivers; (4) moderate elevation above the alluvial bottoms of the Coosa (peneplain) level; and (5) dark-red soil of alluvial or colluvial origin. Similar useful criteria could be established by detailed work in many other parts of the Valley and Ridge province.

Thrust faults are the keys to locating barite deposits of the Del Rio district, Tennessee (Ferguson and Jewell, 1951), and the adjacent Hot Springs district, North Carolina (Oriel, 1950). The traces of these thrust faults should be carefully prospected and any drilling done should transect the thrust planes. In the Del Rio district, most deposits of the Mocassin Gap type are directly beneath a prominent quartzite ledge about 50 feet thick. The veins commonly containing abundant ankerite crop out as brown-stained ledges or weather to a distinctive reddish-brown soil. Locally, this type of vein is capped on the surface by silicified or jasperoid-limonite material that sticks up like a backbone (Ferguson and Jewell, 1951, p. 96).

Barite deposits in the metamorphic rocks of the Kings Creek belt, South Carolina, and elsewhere probably are amenable to prospecting by geochemical methods, as described by Brobst and Ward (1965). Disseminated barite in the Battleground Schist shows that barium-rich halos might surround the larger concentrations of barite. Geochemical prospecting in the metamorphic rocks in Grayson County, Va., and southern Cleburne County, Ala., might help to evaluate the potential of barite deposits at these areas.

RESERVES AND RESOURCE POTENTIAL

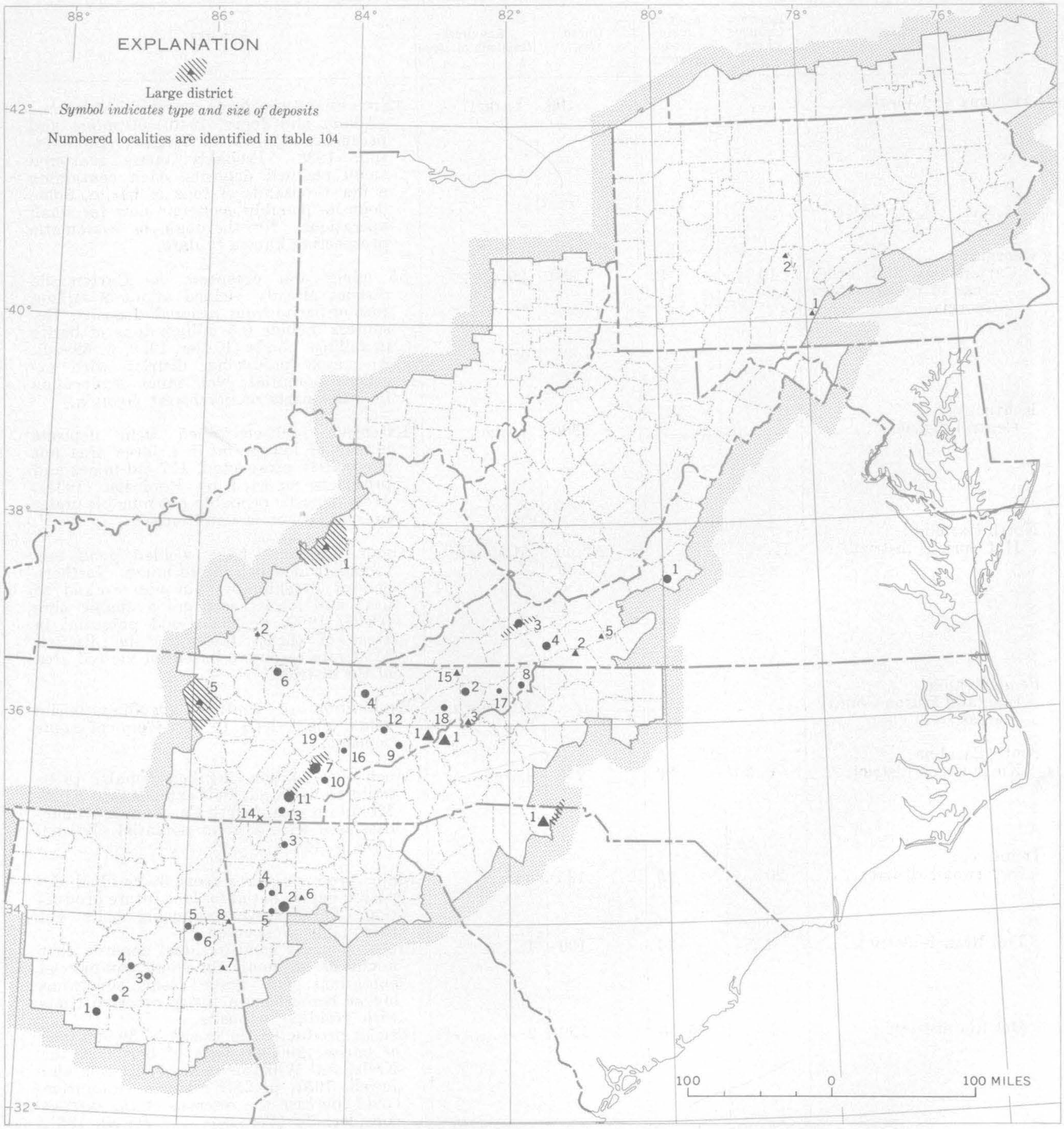
Conservative estimates of the barite reserves and resources are shown in table 105. Most of the reserves listed are in major producing districts. Where data are insufficient to attach numerical values to the reserves and resources, the remarks in the table explain the basis for the appraisal of that area. Symbols in figure 72 also indicate relative size of reserves.

TABLE 104.—*Barite districts, mines, and prospects in the Appalachian Region*

No. (fig. 72)	District, mine, or prospect	Mode of occurrence	Host rock	Remarks	Reference
			Alabama		
1	Sinks district, Bibb County	Residual	Newala Limestone of Ordovician age.	Deposits in residual clay overlying bedrock containing thin veins of barite.	Adams and Jones (1940).
2	Longview-Saginaw district, Shelby County.	do	do	do	Do.
3	Vincent-Harpersville-Wilsonville district, Shelby County.	do	do	do	Do.
4	Leeds, Jefferson County	do	do	do	Do.
5	Beaver Creek Valley, St. Clair County; Greens Valley, Etowah County.	do	do	do	Do.
6	Angel Station district, Calhoun County.	do	Knox Dolomite of Cambrian and Ordovician age.	Renewed activity in 1965	Do.
7	Southern Cleburne County	Veins	Ashland Mica Schist of Precambrian age.		Do.
8	Southeastern Cherokee County	do	Weisner Formation of Cambrian age.	One prospect	Do.
			Georgia		
1	Kingston prospects, Bartow County; Bass Ferry prospects, Floyd County.	Residual	Knox Group of Cambrian and Ordovician age.	Probably small deposits	Hull (1920).
2	Cartersville district, Bartow County.	do	Weisner Formation, and (1) Shady Dolomite and (2) dolomite of Rome Formation, all of Cambrian age.	Large commercial deposits. Different terms for same host rocks (1) Hull (1920), (2) Kesler (1950); Kesler's work is the newest detailed study of the district.	Hull (1920); Kesler (1950).
3	Eton district, Murray County; Ruralvale deposit, Whitfield, County.	do	Conasauga Formation of Cambrian age and Knox Group of Cambrian and Ordovician age.	District is 3.5 miles long, 0.5 mile wide. Small deposits.	Hull (1920).
4	Plainville area, Floyd and Gordon Counties.	do	Conasauga Formation of Cambrian age.	Small deposits of good ore	Do.
5	Stilesboro prospect, Bartow County.	do	Knox Group of Cambrian and Ordovician age.	Small accumulations	Do.
6	Waleska deposit, Cherokee County.	Veins	Quartzite in Ocoee Series of Precambrian age.	Ore, in place, is sharply defined lens or layer. Bedded deposit(?).	Do.
			Kentucky		
1	Central district, Clark, Garrard, Lincoln, and Madison Counties in Appalachia and parts or all of Andersen, Bourbon, Boyle, Fayette, Franklin, Harrison, Henry, Jessamine, Mercer, Owen, Scott, and Woodford Counties outside Appalachia.	Steeply dipping veins and fault breccia fillings with barite, fluorite, calcite, sphalerite, and galena.	Sedimentary rocks of Ordovician age.	200 veins reported; veins structurally controlled and most trend within 30° of N; many veins in zones not over 4 ft wide. Area probably not thoroughly prospected. Barite chief vein mineral, most abundant in veins in Middle Ordovician limestones. Veins at least 600 ft deep and may persist for 1,000 ft.	Robinson (1931).
2	Dove Creek prospects, Russell County.	do	Ft. Payne Formation of Mississippian age and Leipers Limestone of Ordovician age.	Similar to Central district	Taylor (1962).
			North Carolina		
1	Hot Springs district, Madison County.	Veins and lenses in breccia zones along several major faults.	Snowbird Group of Precambrian age and Max Patch Granite of Precambrian age.	Five mines yielded most of the barite, but other prospects might be valuable mining properties. Most productive mines along trace of Mine Ridge thrust fault.	Stuckey (1942); Oriel (1950).
			Pennsylvania		
1	Fort Littleton deposit, Fulton County.	Veins	Sedimentary rocks of Silurian and Devonian age.	Vein controlled by vertical fault zone 15 ft wide; traced 2,000 ft on the surface.	Socolow (1959).
2	Birmingham area, Blair County	Vein and residual	Limestone of Ordovician age	Veins with lead and zinc minerals. Probably not commercial.	Butts and others (1939).
			South Carolina		
1	Kings Creek district, Cherokee County.	Veins	Barite in a zone of sericite schist in Battleground Schist adjacent to Bessemer Granite, both of Ordovician to Mississippian age.	Reported maximum vein width is 12 ft, depth 250 ft. Major district; nearly continous production since 1885. Part of a barite belt that extends for 20 miles north into the Kings Mountain area, North Carolina.	Van Horn and others (1949); Wilson (1958); McCauley (1962).

TABLE 104.—*Barite districts, mines, and prospects in the Appalachian Region*—Continued

No. (fig. 72)	District, mine, or prospect	Mode of occurrence	Host rock	Remarks	Reference
	Tennessee				
1	Del Rio district, Cocke County	Veins	Snowbird Group of Precambrian age and Unicoi Formation of Cambrian age.	Two types of deposits structurally controlled by Brushy Mountain and other thrust faults: (1) Barite replacement of granulated gouge; the Williams-type. (2) Barite filling in more open and less intensely sheared rocks, the Mocassin Gap-type.	Ferguson and Jewell (1951).
2	Fall Branch district, Greene, Sullivan, and Washington Counties.	Residual	Knox Group of Cambrian and Ordovician age.	Small high-grade deposits	Laurence (1938); Rankin and others (1938).
3	Chandler mine, Unicoi County	Veins	Granitic rocks of Precambrian age.	Veins 1.5–5 ft wide with vuggy white barite and manganese oxides; small deposits.	R. A. Laurence (unpub. data, 1965).
4	Lost Creek district, Union County.	Residual	Murfreesboro Limestone of Ordovician age.	Deposits of white barite worked in 1938. One mine reopened in 1964.	Gildersleeve (1946a).
5	Middle Tennessee district, De Kalb, Putnam, Smith Counties in Appalachia; extending into Cannon, Davidson, Rutherford, Trousdale, Wilson, and Williamson Counties outside Appalachia.	Veins	Carters and other limestones of Ordovician age.	Veins with barite, fluorite, calcite, and sulfides of lead, zinc, copper, and iron associated with fault zones. Only Bannister mine, Davidson County, worked for barite.	Jewell (1947).
6	Pall Mall district, Fentress County.	Residual	Warsaw Limestone of Mississippian age.	Barite in all workings in one 10–30-ft bed underlain by sticky green clay. Has produced 50,000 tons of barite.	Rankin and others (1938).
7	Sweetwater district, McMinn, Monroe, and Loudon Counties.	do	Chiefly in Kingsport Formation and other units of the Knox Group of Cambrian and Ordovician age.	Deposits occur in 3 narrow belts bordered by thrust faults. Major producing district.	Gordon (1918); Laurence (1939, 1960); Rankin and others (1938).
8	Big Dry Run, Johnson County	do	Shady Dolomite of Cambrian age.	Small productiln in 1961	R. A. Laurence (unpub. data, 1965).
9	Nun's Cove prospects, Sevier County.	do	Newala Limestone of Ordovician age.	Probably no large deposits	Do.
10	Notchy Creek prospects, Monroe County.	do	Kingsport Formation of Ordovician age.		Maher (1964b).
11	Mouse Creek prospects, McMinn and Bradley Counties.	do	Upper part of Knox Group of Cambrian and Ordovician age.	In western belt of Sweetwater district. Mined ln late 1930's and early 1940's.	R. A. Laurence (unpub. data, 1965).
12	Kodak mine, Sevier County	do	Kingsport Formation of Ordovician age.	Old mine, idle, small production	Maher (1964b).
13	Cleveland mine, Bradley County	do	Kingsport Formation of Ordovician age.	Long abandoned. Large tonnages not expected because of limited outcrop of favorable host rocks.	Swingle (1959).
14	Shoffner prospect, Hamilton County.	do	Copper Ridge Dolomite of Cambrian age.	Unevaluated	J. C. Dunlap (unpub. data, 1945).
15	Click Creek deposit, Hawkins County.	Veins	Limestone of Cambrian age	Clear barite crystals sold as mineral specimens.	R. A. Laurence (unpub. data, 1965).
16	Friendsville prospect, Blount County.	Residual	Limestone of Ordovician age		Dunlap (1945).
17	Stony Creek prospect, Carter County.	do	Shady Dolomite of Cambrian age.		King and others (1944).
18	Johnson Anticline area, Greene County.	do	Knox Group of Cambrian and Ordovician age.	Similar to Fall Branch district. Old small operations at several places.	R. A. Laurence (unpub. data, 1965).
19	Chestnut Ridge occurrence, Roane County.	do	do	30-ft-wide zone exposed in road cut. Not worked.	Maher and Finlayson (1965).
	Virginia				
1	Botetourt County area	Residual	Beekmantown Limestone of Ordovician age.	Deposits not worked in many years.	Edmundson (1938).
2	Grayson County area	Residual and vein deposits in fault zones and fractures parallel to the foliation of the enclosing metamorphic rocks.	Grayson Granodiorite Gneiss of Precambrian age.	do	Do.
3	Russell-Tazewell Counties area	Residual, vein, and replacement bodies localized along bedding planes, fractures, or breccia zones.	Beekmantown Limestone of Ordovician age.	Mainly residual deposits worked commercially. The Leonard mine probably has the largest resources. Deposits not worked in many years.	Do.
4	Smyth County area	Residual, vein, and replacement deposits.	Beekmantown Limestone and Nittany Dolomite of Ordovician age.	Principal occurrences within 3 miles of Marion, the county seat. Deposits not worked in many years.	Do.
5	Austinville-Ivanhoe-Bertha area, Wythe County.	do	Shady Dolomite of Cambrian age.	Barite associated with oxidized iron, lead, and zinc ores.	Currier (1935a).



Type of deposit	SIZE CATEGORIES			
	Very large deposit or group of deposits. Production plus reserves greater than 1,000,000 tons $BaSO_4$	Large deposit or group of deposits. Production plus reserves greater than 10,000 tons $BaSO_4$	Deposit or group of deposits. Production plus reserves less than 10,000 tons $BaSO_4$	Occurence, prospect, or group of prospects. Potential unevaluated or small
Residual	●	●	•	•
Vein		▲	▲	▲
Unclassified				×

FIGURE 72.—Barite deposits in the Appalachian Region. Numbers refer to table 104.

Table 105.—*Barite reserves and resources in the Appalachian Region*

Area	Reserves (millions of tons)	Approximate grade (percent)	Depth (feet)	Resources (millions of tons)	Remarks
Alabama and Virginia	--------	--------	100	Large(?)	42 mines and prospects reported in Alabama (Adams and Jones, 1940). 50 mines and prospects reported in Virginia (Edmundson, 1938). Probably many scattered small residual deposits, each containing a few thousands of tons of barite. Some deposits possibly economic now for small operations. No thorough or systematic prospecting known to date.
Georgia:					
Cartersville and other areas in northwestern Georgia.	10	12	250	20	35 mines and prospects in Cartersville district already yielded about 2 million tons of barite from residual deposits. Resources include 0.5 million tons of barite in tailings ponds (Kesler, 1950, p. 59–60). A major producing district with excellent potential. Not much exploration in other parts of northwest Georgia.
Kentucky:					
Central district	--------	--------	600	Large	Extensive fault-controlled vein deposits mostly of low grade in a large area not adequately prospected. 177 old mines and prospects reported by Robinson (1931). Most deposits probably not minable under present economic conditions.
North Carolina:					
Hot Springs district	--------	--------	About 300	Moderate	About 10 mines have yielded good ore, some left at depth in old mines. Northern end of Stackhouse vein not worked to date and lowest cost ore available here (Oriel, 1950, p. 52). Good potential in areas of thrust faults in the district. Moderate resources based on limited area of the district.
Pennsylvania:					
Blair and Fulton County areas.	--------	--------	----------	Unknown	Exploration of faults controlling barite veins might lead to discovery of some deposits.
South Carolina:					
Kings Creek district	0. 5+	30	250	Large	Much of a 20-mile-long belt remains to be explored in detail. Belt extends into Kings Mountain area, North Carolina. A productive area with a good potential (Wilson, 1958, p. 44).
Tennessee:					
Sweetwater district	20	15	125	40	Major producing area from 39 residual deposits; has potential for long future production. Three large producing belts not thoroughly prospected.
Fall Branch district	0. 5	20	100	1	Probably many small residual deposits that might be economic for small commercial operations. Ore grade seems somewhat higher here than in many other districts with residual deposits.
Del Rio district	1	25–50	100	2	District production in excess of 50,000 tons of barite; 200,000 tons of barite in the Krebs and Williams mines (Ferguson and Jewell, 1951, p. 61). Further exploration could increase the reserves of the district considerably (Ferguson and Jewell, 1951, p. 96).
Middle Tennessee district.	--------	--------	200	Large	Large resources in veins less than 3 ft wide in fractures in Ordovician carbonate rocks. Most of known deposits are small and not economic now. Area not well prospected (Jewell, 1947).
Other areas	--------	15	100	2	Mostly small residual deposits, some with associated veins in bedrock, generally Cambrian and Ordovician carbonate rocks. Most areas not well prospected.

The barite resources of Appalachia are large and nationally significant. This region has yielded commercial barite for many years from many deposits and districts, and the outlook for future production is excellent. The Sweetwater district, Tennessee, the Cartersville district, Georgia, and the Kings Creek district, South Carolina, are now the major barite-producing areas of the eastern United States. Resources in these districts alone are probably large enough to support barite mining for many years under present economic conditions. Further exploration should lead to the discovery and development of additional minable deposits and as prices increase, deposits now considered uneconomic or marginal should become minable.

Vein and residual deposits associated chiefly with the Cambrian and Ordovician rocks in the Valley and Ridge province of Appalachia constitute a large barite resource, and there is the possibility of discovering large new deposits. Many residual deposits containing minable ore are known outside of the Cartersville and Sweetwater districts, but most of these probably will support only small operations of short duration.

The barite resources in the zone of thrust faults in the Del Rio district, Tennessee, and the adjacent Hot Springs district, North Carolina, offer good possibilities for additional production, particularly with some favorable changes in the economic conditions. Most of these deposits would have to be mined by underground methods and thus are not competitive with nearby residual deposits now mined in open pits.

The vein deposits of middle Tennessee and central Kentucky also contain large barite resources. Newly discovered veins of barite associated with fluorite and base metals, as much as 8 feet wide, have been reported recently in the Ford quadrangle, Clark County, Ky., by the U.S. Geological Survey (Douglas Black, unpub. data, 1965). The economic potential of these deposits has not yet been thoroughly established.

FELDSPAR

By F. G. Lesure, U.S. Geological Survey, and Stanley A. Feitler and Robert G. Stansfield, U.S. Bureau of Mines

Feldspar is the general name for a group of anhydrous aluminum silicate minerals that contain varying amounts of potassium, sodium, and calcium. The feldspar minerals are important rock-forming minerals and constitute nearly 60 percent of many igneous rocks. The principal potassium feldspars are orthoclase and microcline, which have the same chemical composition ($KAlSi_3O_8$) but different crystal form. The sodium-calcium feldspars, called plagioclase, form a complete series of minerals ranging from pure $NaAlSi_3O_8$ (albite) to pure $CaAl_2Si_2O_8$ (anorthite). The plagioclase minerals between albite and anorthite, in the order of decreasing sodium content and increasing calcium content, are oligoclase, andesine, labradorite, and bytownite. Natural orthoclase and microcline generally contain 10–25 percent $NaAlSi_3O_8$, and plagioclase generally contains 5–15 percent $KAlSi_3O_8$. Intergrowths of orthoclase or microcline with albite are called perthite, a common pegmatite mineral.

Producers and consumers know feldspar as a beneficiated mixture composed of feldspar minerals with less than 5 percent to more than 20 percent quartz and very small amounts of other minerals. Perthitic microcline ("potash spar"), albite ("soda spar"), and oligoclase ("soda-lime spar") are the principal types of feldspar mined in the Appalachian Region.

USE AND ECONOMIC IMPORTANCE

From 1960 to 1964 about 54 percent of the feldspar sold in the United States was used in glass, 31 percent in pottery, 4 percent in enamel, and 11 percent in soap, abrasives, mineral fillers, welding-rod coatings, and other miscellaneous uses (Wells, 1965a). Feldspar is a source of alumina, soda, and potash in glass. The alumina improves workability, retards devitrification, and increases chemical stability of the finished product. Iron oxide, a coloring agent, is the most common undesirable impurity in glass-grade feldspar. The maximum acceptable iron oxide content of feldspar for flint glass is 0.1 percent, but as much as 0.5 percent is acceptable for green or amber glass. Minerals too refractory to melt at temperatures used in glass manufacture are undesirable because unmelted fragments appear as flaws in finished glass. Specifications usually require the feldspar to be ground to −20 or −30 mesh, with not more than 10–20 percent −140 mesh. The use of feldspar in glass was begun in 1925 and became standard practice in the glass-container industry about 1935 and in the flat-glass industry by 1940. A little more than 110 pounds of feldspar is used in an average ton of glass containers, slightly less than 100 pounds in a ton of flat glass.

Feldspar is used in the ceramic industry because it fuses at lower temperatures than most other ingredients and cements crystalline phases in some types of ceramics. It also acts as a flux in physicochemical reactions of crystalline phases in whiteware. Feldspar generally imparts strength, toughness, and durability to the finished product. It therefore is used in amounts from 10 to 35 percent of the body and from 30 to 50 percent of the glaze in many types of ceramics. The ratio of potassium to sodium in the feldspar affects the firing characteristics, and, in general, high-potash material is preferred. Products are available with potassium to sodium ratios varying from 5:1 to less than 1:1. Specifications limit the silica content and stipulate maximum iron oxide content of 0.1 percent; the material also must be free of dark mineral particles. Feldspar for ceramic use is generally ground to −200 mesh. Feldspar has been used as an ingredient in ceramics in China since the Tang dynasty (A.D. 621–945) and in Europe since the 18th century (Burgess, 1949, p. 349).

Uses of feldspar other than in glass and ceramics are few, and consumption is small. The most important other use is in abrasives and in special soaps because of physical properties such as cleavage, hardness, and white color. Excellent cleavage in two directions provides sharp edges; feldspar hardness is less than that of glass, so its use in household cleansers minimizes damage by scratching. Feldspar is also used in electric welding-rod coatings as a source of potassium to improve arc characteristics and to serve as a flux. Small quantities are used as a mineral filler or extender, and some feldspar has been used in roofing granules, poultry grit, and other crushed-stone uses.

In recent years, various materials have been used in the glass and ceramic industries as substitutes for feldspar. Chief among these are nepheline syenite, aplite, talc, pyrophyllite, electric-furnace slag, and lithospar (Wells, in U.S. Bur. Mines, 1965a, p. 324). Most nepheline syenite contains too much iron oxide for use in glass, but a deposit in Ontario, Canada, is low in iron and is mined extensively. Aplite is the trade name for a feldspar mixture produced in Amherst, Nelson, and Hanover Counties, Va., from anorthosite and quartz monzonite. Talc can substitute for feldspar in dinnerware and wall tile; pyrophyllite is used in enamels and wall tile. Electric-furnace slag is used as a source of alumina in glass, and lithospar is a mixture of spodumene and feldspar used as a flux.

HISTORY AND PRODUCTION

Feldspar was first mined in the United States in 1825 from pegmatite bodies in Connecticut and shipped to England for use in ceramics (DuBois, 1940, p. 207). Although it has been said that the Indians mined and sold partly kaolinized feldspar from western North Carolina before 1744, the first recorded shipment from that State was made in 1911 when W. E. Dibbell recovered feldspar from the dump of the Flat Rock mica mine in Mitchell County and shipped it to the Golding Sons plant in East Liverpool, Ohio. Within several years, North Carolina became a major producer (table 106) and has for many years produced about half of the annual United States total. In recent years California, Connecticut, Georgia, South Carolina, and South Dakota have been the other important feldspar producers.

TABLE 106.—*Production of crude feldspar, 1911–64*

[Source: U.S. Bur. Mines]

Year	Appalachia [1]		United States	
	Long tons	Value in 1958 constant dollars (thousands)	Long tons	Value in 1958 constant dollars (thousands)
1911	956	8	25,117	297
1912	5,380	48	23,626	285
1913	10,715	93	40,582	458
1914	14,145	125	76,242	764
1915	20,635	108	65,068	417
1916	30,955	186	75,165	603
1917	42,463	276	89,320	639
1918	35,732	291	59,840	505
1919	22,495	188	41,232	355
1920	36,521	256	92,619	774
1921	40,712	355	76,126	689
1922	56,043	538	117,129	1,362
1923	57,622	599	145,004	1,757
1924	97,075	1,106	204,772	2,607
1925	76,806	849	185,706	2,249
1926	91,433	1,102	209,989	2,938
1927	100,756	1,113	202,497	2,590
1928	105,560	1,141	210,811	2,571
1929	103,273	1,062	197,699	2,263
1930	103,163	1,073	171,788	1,929
1931	86,429	1,030	147,119	1,754
1932	58,465	696	104,715	1,249
1933	85,962	1,125	150,633	1,859
1934	79,844	1,042	154,188	1,909
1935	82,499	1,105	189,550	2,300
1936	102,393	1,356	244,726	2,989
1937	94,595	1,176	268,532	3,020
1938	56,795	633	196,119	1,917
1939	76,738	864	253,466	2,419
1940	79,312	918	290,763	2,735
1941	100,016	1,096	338,860	3,015
1942	93,644	900	316,166	2,608
1943	112,144	1,022	308,180	2,564
1944	122,857	1,088	327,408	2,537
1945	148,493	1,138	373,054	2,663
1946	230,367	1,567	508,380	3,378
1947	220,997	1,308	459,910	2,915
1948	201,774	1,294	460,713	2,971
1949	160,916	1,121	369,378	2,625
1950	183,027	1,261	407,925	2,914
1951	166,361	1,306	400,439	2,989
1952	240,364	2,532	542,137	3,874
1953	268,042	3,489	578,456	4,872
1954	230,744	2,390	526,590	3,757
1955	242,724	2,377	550,861	4,927
1956	255,637	3,363	560,074	6,142
1957	233,439	2,773	498,057	5,015
1958	224,647	2,520	469,738	4,278
1959	292,114	2,894	548,390	5,299
1960	[2] 270,761	[2] 2,756	502,380	4,736
1961	[2] 251,858	[2] 2,462	496,808	5,089
1962	[2] 244,708	[2] 2,357	492,476	5,040
1963	[2] 267,654	[2] 2,810	548,954	5,503
1964	[2] 281,449	[2] 2,330	587,194	5,362
Total	6,900,209	68,616	15,482,671	143,276

[1] Mainly production in North Carolina; excludes production in South Carolina.
[2] Includes Cleveland County, N.C.

Most of the feldspar produced in North Carolina has come from Appalachia and until 1946 consisted primarily of perthite and oligoclase handcobbed from coarse-grained pegmatites. In 1936 the U.S. Bureau of Mines in cooperation with the University of Alabama and the Golding-Keene Co. of New Hampshire began an investigation of the concentration of feldspar by table agglomeration and flotation (O'Meara and others, 1939). The first commercial plant to produce feldspar by flotation began operation at Kona, Mitchell County, N.C., in 1946. Use of flotation permitted low-cost mining of finer grained pegmatite and granite, and thus greatly increased potential sources of raw material. In 1965 there were 10 active feldspar mills owned by 7 companies in Appalachia and adjacent areas (table

107). All but two use flotation, and more than 93 percent of the North Carolina feldspar production in 1964 consisted of flotation concentrates (Sweeney and Conrad, 1965). To indicate the trend, the following statistics show the relatively rapid increase in use of flotation. In 1964, about 67 percent of the feldspar used in the United States was from flotation concentrates, 17 percent was from hand sorting, and 16 percent was from feldspar-silica mixtures (Wells, 1965a). In 1957 these figures were 42, 46, and 12 percent, respectively.

TABLE 107.—*Feldspar mills operating in the Appalachian Region and adjacent areas during 1965*

[Milling process is designated wet for plants using flotation and dry for plants not using flotation]

Company (affiliation)	Town	County	Process
Appalachian Region			
North Carolina:			
International Minerals & Chemical Corp., Consolidated Feldspar Department	Kona	Mitchell	Wet.
	Spruce Pine	do	Do.
The Feldspar Corp. (Pacific Tin Corp.)	do	do	Do.
	Bowditch	Yancey	Dry.
Lawson-United Feldspar & Mineral Co	Minpro	Mitchell	Wet.
South Carolina: Spartan Minerals Corp. (Spartan Mills)	Pacolet	Spartanburg	Do.
Adjacent areas			
Georgia:			
The Georgia Marble Co., Consolidated Quarry Div	Lithonia	De Kalb	Wet.
The Feldspar Corp. (Pacific Tin Corp.), Appalachian Minerals Co. Div	Monticello	Jasper	Do.
North Carolina: Foote Mineral Co.	Kings Mountain	Cleveland	Do.
Virginia: Clinchfield Sand & Feldspar Corp. (H. T. Campbell and Sons Corp.)	Bedford	Bedford	Dry.

The only other feldspar producer in Appalachia outside North Carolina is in Spartanburg County, S.C., where a feldspar-quartz product is recovered from the screenings of a crushed granite operation. Production began in 1959 and had a significant increase in 1963 and 1964. Production figures are not included in Appalachian totals (table 106) to avoid disclosure of individual company data.

Production of feldspar in Georgia has come mostly from pegmatite and granite in De Kalb and Jasper Counties outside Appalachia.

Feldspar plants in the eastern United States, including those in Appalachia, operated at an average of 51-percent capacity in 1962, although a few plants exceeded two-thirds capacity. This low average rate of plant utilization follows the historic trend for the U.S. feldspar industry, which has averaged 50 percent or less plant utilization since 1920 (Feitler, 1967, p. 7).

Feldspar is mined by open-pit and underground methods. Most mines producing ore for beneficiation are open pits using power equipment and producing 300–800 tons per day. Selective mining is done in zoned pegmatites, usually at a rate of less than 100 tons a day. The broken rock is sorted by hand during loading or on a picking belt. Feldspar has also been produced as a byproduct of sheet mica mining which requires the broken rock to be sorted and moved by hand. The number of small producers using handcobbing methods is decreasing as labor and material costs increase. Details of the mining, beneficiation, and marketing of feldspar are given by Castle and Gillson (1960) and Wells (1965a).

The average value of crude feldspar was $9.74 per long ton in 1964 and $9.51 in 1960 (Wells, 1965a). The average value of ground feldspar was $11.82 per short ton in 1964 and $13.40 in 1960. Prices quoted for ground feldspar in Engineering and Mining Journal Metal and Mineral Markets for October 1965 were as follows: North Carolina, 40 mesh, glass, $13.50–$15.00; 200 mesh, $17.50–$21.00.

The delivered cost per unit of alumina plus alkalies is the basis for determining relative value of competing feldspar products used in the glass industry. The transportation cost is therefore an important element in marketing feldspar for glass. The ceramic industry, however, is more concerned with a particular feldspar and its effect on the delicate balance of ceramic mix, plant operation, and product quality. In general one feldspar product cannot be substituted for another in a ceramic mix without extensive tests. A ceramic feldspar sometimes is shipped past other producing plants to consumers who would rather pay more freight than change their raw materials.

GEOLOGIC OCCURRENCE

Commercial deposits of feldspar are found in pegmatite, in granite and related igneous rocks, and in beach sand and alluvium.

Pegmatite is generally a light-colored coarsely crystaline igneous rock, found as lenticular or tabular bodies in metamorphic rocks or in large granitic intrusions. Individual mineral grains and crystals range in length from an inch or less to many feet. Pegmatite bodies range from small pods and veins to large masses hundreds of feet thick and thousands of feet long. Feldspar, quartz, and mica are the most common minerals present; rare and unusual minerals are found in some deposits. In many pegmatite bodies, the minerals are more or less evenly distributed throughout, but in others they are segregated into certain layers or parts of the body called zones (fig. 83, p. 316). These zones can sometimes be selectively mined to recover the desired minerals by hand sorting and are, therefore, important economically. The mineral perthite, highly desirable in the ceramic industry, commonly is abuandant as very large crystals in the intermediate zones or cores of zoned pegmatite bodies.

Granite and related igneous rocks are composed of one or two kinds of alkalic feldspar and quartz and minor amounts of various other minerals, mainly muscovite, biotite, and hornblende. Granite bodies range from small masses measured in feet to very large masses measured in miles. Grain size ranges from less than one-fourth inch to an inch or more. Light-colored granite, such as alaskite, contains only small amounts of ferromagnesian minerals and can be mined in bulk. A mixture of potassium and sodium feldspar is recovered by milling and flotation. Feldspar-quartz mixtures are also produced as a byproduct of granite quarrying.

Beach sand and alluvial deposits formed as the result of erosion of granite rocks or pegmatite, such as those of Pacific Grove, Monterey County, Calif., may be rich enough to be worked.

FELDSPAR DEPOSITS IN APPALACHIA

Deposits of feldspar occur in all the pegmatite districts of the Blue Ridge and Piedmont provinces in Appalachia (fig. 84, p. 317), but most feldspar is now mined from the large fine-grained pegmatite or alaskite (granite) bodies in the Spruce Pine district, North Carolina (fig. 85, p. 319). The general features of the important pegmatite districts are described in the section on "Mica" (p. 311) and the feldspar occurrences are summarized in table 108.

RESOURCE POTENTIAL

Analysis of production trends of feldspar for glass and ceramics indicates an increase of 20–25 percent in feldspar production by 1970 that will be due mainly to increase in glass production (Feitler, 1967, p. 35). Since World War II there has been a trend toward establishing new glass-container manufacturing facilities in consuming areas. An anticipated continuation of this trend should result in the location of more glass plants in southern United States, out of competitive range of Canadian nepheline syenite and possibly of Virginia aplite, thereby increasing the demand for Appalachian feldspar.

Potential resources of feldspar in intrusive rocks of the Blue Ridge and Piedmont provinces of Appalachia are very large. In the Spruce Pine district alone, the reserves of feldspar, in alaskite bodies within 50 feet of the surface and recoverable by flotation, exceed 200 million tons (Brobst, 1962, p. A15). No quantitative data exists on reserves or resources of feldspar in zoned pegmatites; many deposits of high-grade potassium feldspar have been worked out. Deposits in most of the pegmatite districts other than Spruce Pine are in general too small or too far from a grinding plant to be of economic importance at the present market value of feldspar.

TABLE 108.—*Handcobbable feldspar in pegmatite districts of the Appalachian Region*

[Data modified after Parker (1950, table 4)]

District	Potassium feldspar			Sodium feldspar		
	Position within pegmatite	Actual production	Potential production	Position within pegmatite	Actual production	Potential production
North Carolina:						
Sandy Ridge	Core, intermediate zone.	Small	Small	Wall zone		Small.
Jefferson-Boone	Core	do	Moderate			
Wilkes			Small			
Spruce Pine	Core, intermediate zone.	Large	Large	Intermediate and wall zone.	Large	Large.
Woodlawn		Small	Small			
Shelby-Hickory, Oak Hill, and Hiddenite.	Intermediate zone	do	Moderate	Wall zone		
Buncombe	Core, intermediate zone.	do	Small			
Bryson City	do	Moderate	Moderate	Intermediate zones	Moderate	Moderate.
Franklin-Sylva	do	do	do			Do.
Cashiers	do	Small	do	Wall zone; disseminated.	None	Small.
Zirconia	Center	do	Small			
South Carolina districts.	Intermediate zone	Small(?)	do			
Georgia districts		Small	do			
Alabama districts	Core, intermediate zone.	None	do			

FERTILIZER RAW MATERIALS

By HELMUTH WEDOW, Jr., U.S. Geological Survey, and ROBERT G. STANSFIELD, U.S. Bureau of Mines

INTRODUCTION

Nitrogen, phosphorus, and potassium are the three most important nutritive elements that plants obtain from the soil. They are often referred to as the fertizer elements, and production of each is largely for agricultural fertilizer. Output consequently follows closely the ever-growing demand for fertilizers resulting from population growth and the increased recognition of the benefits of greater fertilizer use.

Of the three elements, a small amount of potassium, a byproduct of a cement-plant operation in Washington County, Md., is the only raw material presently extracted in Appalachia by the mineral industry. Synthetic nitrogen and its compounds are manufactured in localities within the area by private firms and also by the National Fertilizer Development Center of the Tennessee Valley Authority at Muscle Shoals, Ala.

Nitrogen is a colorless gas that makes up about 78 percent of the atmosphere. In mineral deposits it normally occurs as salts of nitric acid (HNO_3) called nitrates. Sodium nitrate ($NaNO_3$) from the extensive Chilean deposits was virtually the only commercial supply of nitrogen from the early 19th century until the 1920's. During the first half of the 19th century and especially during the War of 1812 and the Civil War, nitrates were produced from cave earth in hundreds of limestone caves in the Appalachian States (Barr, 1961, p. 54–55). Since the 1920's, the chemical industry has produced the major part of the world's supply of nitrogen by fixation from the atmosphere. Other nitrogenous substances such as anumonium (NH_4OH) and ammonium sulfate hydroxide ($(NH_4)_2SO_4$) are obtained as byproduct from coking plants; urea is synthesized from natural gas. Organic refuse was the chief source of nitrogen prior to the 19th century and continues to supply small amounts today.

The major synthetic nitrogen product is ammonia (NH_3), from which many other compounds and salts are made for use in the fertilizer, chemical, and explosive industries. This last use led the Federal Government during World War I to build synthetic nitrogen facilities at Muscle Shoals, Ala. In 1934, these facilities were turned over to TVA for fertilizer research and have been expanded.

The synthetic nitrogen industry in the United States has expanded greatly since World War II; production in 1964 amounted to 8.6 million short tons of contained nitrogen.

Most commercial phosphorus is obtained from sedimentary phosphate rock deposits. Small amounts of apatite and guano are mined at a few places as sources of phosphate. The grade of phosphate rock is usually expressed by its content of phosphorus pentoxide (P_2O_5) or the equivalent in tricalcium phosphate ($Ca_3(PO_4)_2$), also known as bone phosphate of lime (BPL).

Most phosphate rock produced domestically is used for the manufacture of superphosphate and triple superphosphate fertilizers. A fraction is used to make phosphate compounds, such as water softeners, detergents and cleaning products, plasticizers, and insecticides. Elemental phosphorus also is used by the military for incendiary bombs and smoke screens (R. W. Lewis, in U.S. Bur. Mines, 1965a, p. 703).

Production of phosphate rock is more than adequate to meet domestic needs and there is a sizable export. U.S. production has increased fourfold since 1945 (table 109); in 1964, it was 23 million long tons valued at $160 million (1958 constant dollars), coming principally from operations in Florida, Tennessee, Idaho, and Montana.

TABLE 109.—*Marketable production of phosphate rock in the United States, 1945–64*

[1945–49, shipments; 1950–64, marketable production. Source: U.S. Bur. Mines]

Year	Long tons (thousands)	Value, in 1958 constant dollars (thousands)
1945	5, 807	31, 555
1946	6, 861	40, 422
1947	9, 027	56, 396
1948	8, 669	58, 517
1949	8, 987	59, 235
1950	11, 114	72, 137
1951	10, 775	68, 750
1952	12, 065	75, 952
1953	12, 504	81, 261
1954	13, 821	93, 291
1955	12, 265	82, 020
1956	15, 747	103, 180
1957	13, 976	89, 118
1958	14, 879	93, 693
1959	15, 869	97, 395
1960	17, 516	115, 999
1961	18, 559	129, 752
1962	19, 382	133, 364
1963	19, 855	139, 263
1964	22, 960	160, 262
Total	270, 638	1, 781, 562

The phosphate rock output of Tennessee, second largest in the Nation, comes from outside Appalachia. At Muscle Shoals, Colbert County, Ala., the TVA produces fertilizers from rock shipped from Tennessee and Florida. Additional detail regarding fertilizer manufacture by TVA is given in the annual report of the Office of Agricultural and Chemical Development (Tennessee Valley Authority, 1964).

PHOSPHATE IN APPALACHIA

Phosphate minerals occur in a wide variety of deposits in Appalachia but only two basic types of deposits are of potential economic importance: (1) bedded phosphate rock containing phosphate nodules, oolites, or grains, or their reworked clastic equivalents, incorporated in Precambrian and Paleozoic sedimentary rocks, and (2) lateritic or residual accumulations in the sand, clay, or other residuum derived by the weathering of bedrock. The known deposits of Appalachia are listed in table 110.

The phosphorus content of most Appalachian deposits (fig. 73) is much too low for fertilizer raw material. Mining or significant prospecting was conducted at only four localities (table 110, Nos. 1–4). Most of the production was in the early decade of the 20th century and certainly did not exceed 10,000 tons of phosphate rock. As far as is known, all material produced was ground locally for direct agricultural use.

The Chattanooga Shale and Maury Formation of the Eastern Highland Rim of Tennessee and Kentucky contain scattered locally abundant nodules of phosphorite (B locs., table 110, fig. 73). Early in the 20th century an abortive attempt was made to mine these nodules near Boma, Smith County, Tenn. (loc. 1, table 110). Future production of phosphate from this source must await the mining of the Chattanooga Shale for one or more of its other constituents (Conant and Swanson, 1961, p. 70).

Some phosphate rock was produced from the W. L. Newman mine in Juniata County, Pa. (table 110), around the turn of the century. This deposit is but one of many occurrences of phosphate in the Oriskany Formation or stratigraphically equivalent Ridgeley Sandstone cropping out in Appalachia from Pennsylvania southward to Tennessee (C locs., table 110, fig. 73). W. D. Carter (unpub. data, 1966) summarized the knowledge of and general guides for future exploration of the "Oriskany phosphates" as follows:

1. Phosphatic material is found as oolite shales of Onondaga age and nodules at the top of the Ridgeley, also below it as secondary minerals in veinlets in weathered chert. The known material is probably too low grade or too thin to be of economic interest at the present time.
2. Most promising occurrences are in areas where the Ridgeley (Oriskany) is relatively thin, especially near the eastern margin of the basin of deposition in central Pennsylvania. Such areas might be better for exploration because the known affinity of phosphorite with sediments of shallow marine origin.
3. Geiger and scintillation-type counters are useful in locating the top of the Oriskany where the formation is thinly covered by colluvium. Where normal background is approximately 0.006 mr per hr, the Ridgeley Sandstone ranges from 0.009 to 0.012 mr per hr and the overlying shales range from 0.015 to 0.30 mr per hr.
4. Preliminary geochemical sampling of soils near the Newman phosphate prospect show 0.1 percent P_2O_5 in shales and soils distant from the deposit. Soils downslope and near the workings range from 0.2 to 0.4 percent P_2O_5 while thin soils resting on phosphatic layers contain as much as 0.7 percent P_2O_5.
5. Careful geological mapping along with soil and outcrop sampling and trenching along the "Oriskany" outcrop should reveal additional areas of phosphatic material in Juniata County, Pennsylvania. If results are favorable, a modest drilling program should be considered to determine the thickness, areal extent, and average grade of the deposits.

The Johnson County, Tenn., phosphate field (loc. 3, table 110) probably produced several thousand tons of hand-cobbed phosphate rock. Although little is known about the deposits of this district, they are believed to be small and scattered. Most deposits appear to be of lateritic or secondary origin, formed by the leaching and redisposition or residual accumulation of phosphatic material from lower grade bedrock sources, and therefore are similar in origin to the iron, manganese, and bauxite deposits of the area. Jenkins (1916, p. 83–84) reported black oolitic phosphorite with about 25 percent P_2O_5 from one locality in the district; it is not known whether this material is part of the Lower Cambrian sedimentary sequence or merely an unusual variant of the lateritic residual type of deposit. Clearly, the phosphate deposits of the district need to be studied to determine the size and grade and possibility of beneficiation.

The Middle and Upper Ordovician phosphatic limestones of northern Alabama and central Tennessee and Kentucky (A locs., table 110 and fig. 73) are too low in grade to be mined. The well-known brown phosphates of central Tennessee, just outside of Appalachia, are residual accumulations formed by the leaching of the calcium carbonate from phosphatic limestones. Similar deposits have been mined in Kentucky, just west of Appalachia. Similar residual accumulations occur but have not been prospected in the outcrop areas within Appalachia (Nelson, 1913, p. 152, 154). According to Wilson (1962) however, phosphatic limestones are less abundant on the eastern side of the Central Basin of Tennessee than on the south and west.

Although most Middle Ordovician rocks of Kentucky are outside Appalachia, the broad belt of Upper Ordovician strata extending from Lincoln and Garrard Counties northeastward contains phosphatic limestones similar to those of Tennessee. No quantitative data are available about the phosphate content of these rocks or of residual material derived from them.

Phosphate pellets, nodules, or pebbles also have been noted in the Cambrian Helenmode Formation of the Chilhowee Group in northeastern Tennessee and southwestern Virginia (H locs., table 110), in Middle Cambrian fine-grained sandstones of eastern Tennessee (loc. F, table 110), in Middle Ordovician limestones and shales in eastern Tennessee and southwestern Virginia (I locs., table 110), in the Upper Ordovician Martinsburg Shale and Oswego Sandstone of Virginia and West Virginia (E locs., table 110), and in the Lower Devonian New Scotland Formation of West Virginia (loc. D, table 110). Information is not available on their abundance.

Wavellite and crandellite, secondary aluminous phosphates, occur in small quantities at the Newman mine in Pennsylvania (loc. 4, table 110, fig. 73) and wavellite has been reported from five other localities within Appalachia (G locs., table 110, fig. 73). The amounts of these minerals are small in Appalachia, but 400 tons were produced in 1905 from residual deposits of the Tomstown Dolomite (equivalent to the Shady Dolomite) near Mount Holly Springs, Cumberland County, Pa. (Stose, 1907), a few miles outside Appalachia.

Bedded arkosic phosphorite in the Precambrian Wilhite Formation in Sevier County, Tenn. (loc. 2, table 110, fig. 73), was first noted by P. B. Stockdale in 1946 (unpub. data). Because of the generally poor exposures in the area, its extent, thickness, and grade have not yet been determined. In 1962, S. W. Maher and R. C. Milici (oral commun., 1965) found phosphorite pebbles in an intraformational conglomerate in the Wilhite Formation about 75 miles southwest of the Sevier County prospect. Information available through 1965 on the occurrence of Precambrian phosphorite in eastern Tennessee has been summarized by Wedow, Carpenter, and Lehr (1966). More recently, reconnaissance by Wedow and Carpenter has demonstrated that phosphorite occurs at many localities in the Precambrian Ocoee Series both as nodules and thin lenses in several black slate units and as pebbles in associated coarser clastic beds. These occurrences indicate the possibility of finding minable phosphate rock in the Precambrian sedimentary sequence.

The rapidly increasing worldwide demand for phosphatic rock as fertilizer raw material warrants a thorough reevaluation of the phosphate potential of the Appalachian Region. Application of new prospecting techniques (McKelvey, 1963; Sheldon, 1964) based on regional lithofacies patterns and paleoenvironments of deposition of sedimentary strata may locate deposits of marine phosphorite that have not been found by conventional prospecting.

Search for residual or lateritic deposits should be made. The Johnson County phosphate field, the wavellite occurrences in the east Tennessee manganese mines, and the abnormally high phosphorus content of the residual manganese and iron ores on the Lower Cambrian carbonate rocks (Shady, Tomstown, and Rome Formations) indicate that secondary phosphate is widespread in the Great Valley. Further search and exploration may find minable concentrations. Phosphatic material may have been overlooked, for much residual phosphorite resembles the chert and clay derived from weathering of the parent rock.

POTASSIUM

Historically, the term "potash" referred to the potassium-bearing residue obtained in iron pots by evaporation of leachings from wood ashes. Commercially, the name has come to mean either the potassium oxide (K_2O) equivalent, or the general term for potassium compounds. About 94 percent of the potassium consumed in the United States is used by agriculture (R. W. Lewis, in U.S. Bur. Mines, 1965a, p. 721). The remaining 6 percent is used by industry in the manufacture of such diverse products as detergents, ceramics, textiles, dyes, mineral water, matches, explosives, and gypsum plasterboard.

The United States leads the world in potash production. Domestic output has risen from about 1,000 tons in 1915 to 2,900,000 tons (K_2O equivalent) in 1964. Production has more than tripled since 1945 (table 111). The total 1964 domestic production was valued at $113.5 million (1958 constant dollars). More than 90 percent of this total was mined in New Mexico where the major ore is sylvinite, a mixture of sylvite (KCl) and halite (NaCl); California and Utah supply the bulk of the remainder from brines.

During World War I and for some years following, potash was in scarce supply in the United States, and every possible domestic source was investigated and utilized. Within Appalachia, minor amounts of potash were recovered as a byproduct from cement-manufacturing plants or blast furnaces in Pennsylvania, Ohio, Maryland, Tennessee, and Alabama. With the discovery and development of the large western saline deposits in the 1920's, byproduct recovery of potash in Appalachia declined. At present, the only output consists of potassium salts extratced from dust collected in the Cottrell precipitator of the Security plant of the Marquette Cement Co. near Hagerstown, Washington County, Md. (Eilertsen, 1965). Production figures are withheld to avoid disclosing company data.

TABLE 110.—*Phosphate-rock localities in the Appalachian Region*

No. or letter (fig. 73)	Locality	Description or mode of occurrence	Host rock	Remarks	References
1	Mine Lick Creek, about 1 mile south of Boma, Smith County, Tenn.	Phosphate nodules in 3-ft shale bed, chiefly in lower part of shale where they make up about 50 percent of the bed.	Mississippian Maury Formation.	Probably mined in early 1900's; production probably did not exceed several hundred tons. No assay data available, but analyses of similar material shows nodules contain 29–33 percent P_2O_5 (Conant and Swanson, 1961, p. 70).	Nelson (1913, p. 149, 150).
2	Dunn Creek, near the East Fork manganese mine, about 14 miles northeast of Sevierville, Sevier County, Tenn.	Sedimentary arkosic phosphorite bed as much as 4 ft thick and 1,200 ft long; lies at base of arkose sequence.	In lower unit of Precambrian Yellow Breeches Member of the Wilhite Formation of the Ocoee Series.	Samples contain as much as 34 percent P_2O_5, chiefly in a carbonate-fluorapatite (francolite). Deposit closely associated spatially with the manganese oxides and carbonates of the East Fork manganese mine in a complex structural environment.	B. Gildersleeve (unpub. data, T.V.A., 1945); P. B. Stockdale (written commun. to H. A. Beekner, 1945); P. B. Stockdale (unpub. data, 1946); Hamilton (1961, p. A50) Wedow and others (1966).
3	Vicinity of Mountain City, Roan Creek Valley, and Doe Creek Valley, Johnson County, Tenn.	Pockets and irregular bodies of phosphate rock concentrated in weathered or residual material from dolomite or dolomitic limestone. Source of phosphate was probably from weathering of slightly phosphatic siliceous dolomite and dolomitic shale. Black oolitic, probably marine, phosphorite is reported at one locality in the Rome Formation (Jenkins, 1916, p. 83–84).	Lower Cambrian Shady and Rome Formations, generally near the contact between the two formations.	Prospected and worked in two main periods, 1915–18 and in the 1930's; total production probably did not exceed several thousand tons and was ground for direct local fertilizer use. Hand-cobbed phosphate ore contains as much as 35 percent P_2O_5 but averages 20–30 percent P_2O_5. Phosphate minerals are chiefly carbonate-fluorapatite.	Jenkins (1916); Phalen (1917a, p. 234–236); W. J. Penhallegon (unpub. data, T.V.A., 1937); King and Ferguson (1960, p. 48).
4	Newman phosphate mine, near East Waterford, Juniata County, Pa.	Carbonate-fluorapatite in calcareous nodules in sandstone and chert; also veinlets of crandallite and wavellite, probably of lateritic origin, in fractured chert.	In upper 10–20 ft of Shriver Chert and in the Ridgeley Sandstone of the Lower Devonian Oriskany Group.	Approximately 4,000 tons mined from 1899–1902. Material produced contained as much as 12 percent P_2O_5.	Ihlseng (1896); Hovey (1904, p. 1049); Stone (1939); W. D. Carter (unpub. data, 1966).
A	Limestone County, Ala.; chiefly De Kalb, Smith, Jackson, and Macon Counties, Tenn.; and Garrard, Madison, Clark, Montgomery, Bath, and Fleming Counties, Ky.	Residual concentrations of fluorapatite from phosphatic limestone.	Middle and Upper Ordovician limestones.	Similar to brown phosphate deposits of south-central Tennessee.	Hastings (1959); Tennessee Valley Authority (1962, p. M10–M12); Smith and Whitlatch (1940); Foerste (1913); Freeman (1949, p. 134–138).
B	Central and eastern Tennessee, south-central Kentucky, northern Alabama, and northwestern Georgia.	Phosphate nodules in shale.	Devonian & Mississippian Chattanooga Shale and Mississippian Maury Formation.	Nodules generally contain 25–30 percent P_2O_5. See also item 1, this table.	Glover (1959, p. 140–141, 143–145); Conant and Swanson (1961, p. 47, 65–66, 70).
C	Valley and Ridge province in Tennessee, Virginia, West Virginia, and Pennsylvania.	Grains, nodules, and layers of carbonate-fluorapatite, and, locally, aluminum phosphate minerals, in sandstone, shale, and chert; associated with glauconite locally.	Lower Devonian sandstone, chert, and shale. (In upper beds of Oriskany Formation and lower beds of Onondaga Formation.)	Samples contain as much as 26 percent P_2O_5. See also item 4, this table.	Ihlseng (1896); Watson (1907, p. 302); Stose (1914); Woodward (1943, p. 136, 257, 259, 260, 261, 264, 271, 280, 298); Harris and Miller (1958); W. D. Carter (unpub. data, 1966).
D	Hampshire, Hardy, and Mineral Counties, W. Va.	Scattered to abundant phosphatic nodules and pebbles in shale.	Lower Devonian New Scotland Formation.	--------------------	Woodward (1943, p. 88, 207, 211, 223).
E	Virginia and West Virginia	Scattered to abundant phosphatic nodules in sandstone and shale.	Upper Ordovician Martinsburg and Oswego Formations.	--------------------	Woodward (1951, p. 355, 359, 360, 361, 368, 379, 381).
F	Watts Bar Dam area, Rhea and Meigs Counties, Tenn.	Small globular masses and pellets of phosphatic(?) material in thin-bedded dark fine-grained pyritic sandstone.	Basal Middle Cambrian sandstone.	Bed in foundation of Watts Bar Dam about 7½ ft thick; sample contains 7 percent P_2O_5.	Fox (1944, p. 164, 167).
G	Johnson, Unicoi, Greene, and Cocke Counties, Tenn.	Wavellite in minor quantities in fractures and cavities in ores and associated chert in some manganese mines.	Residual material from Lower Cambrian Shady and Rome Formations.	Minute grains of wavellite as well as other phosphate minerals scattered in the manganese and iron ores residual on the Shady Dolomite probably are the cause of the relatively high phosphorus content of these ores. Wavellite is reported from near Coal City, St. Clair County, Ala., with geologic relations unknown (Palache and others, 1951, p. 964), but general location suggests that it is probably related to the Lower Devonian Oriskany beds.	Stose and Schrader (1923, p. 88–89, 90–91); King and others (1944, p. 148, 196, 248).
H	Wythe County, Va., and Johnson County, Tenn.	Greenish phosphatic nodules and pellets and green phosphatic calcareous quartzite; also phosphatic arkosic sandstone.	Lower Cambrian Helenmode Formation.	No data available on abundance of phosphatic nodules or pellets. Occurrence of phosphatic material in this unit or in the lowermost part of the Shady Dolomite was not noted by King and Ferguson (1960, p. 41–52), R. L. Miller (1944, p. 13–27), or Currier (1935a, p. 14–35).	Stose (1942, p. 169, 172); Stose and Stose (1957, p. 105–113, 116).
I	Friendsville area, Blount County, Tenn.; Marion area, Smyth County, Va.; and Thompson Valley and Burkes Garden, Tazewell County, Va.	Phosphatic nodules and pellets in shale and argillaceous limestone.	Middle Ordovician shales and limestones.	--------------------	B. N. Cooper (oral commun., 1966); Cooper (1944a, p. 38–39).

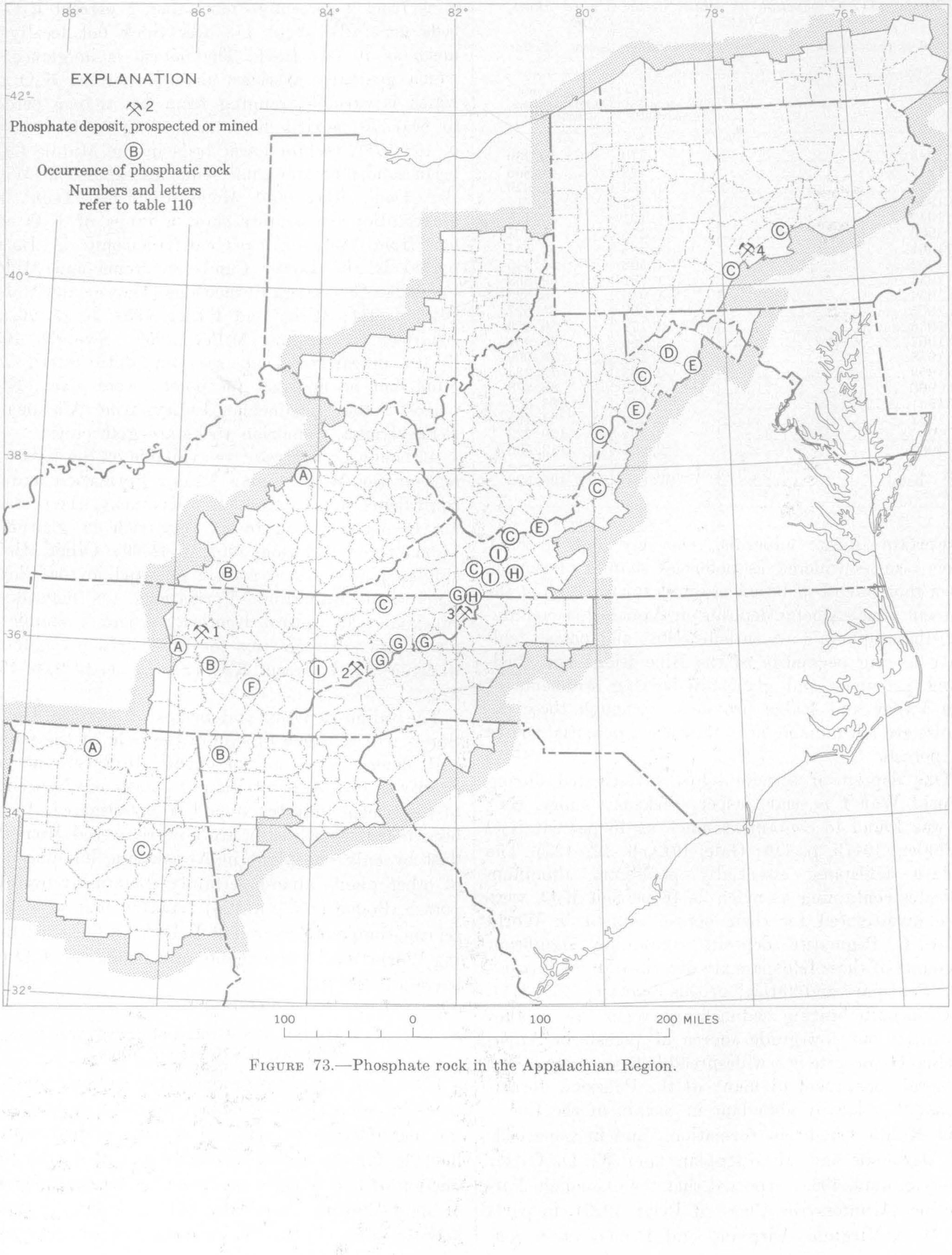


FIGURE 73.—Phosphate rock in the Appalachian Region.

TABLE 111.—*Production of potash in the United States, 1945–64*

[1945–53, producer sales; 1954–64, marketable production. Source: U.S. Bur. Mines]

Year	Short tons K_2O (thousands)	Value, in 1958 constant dollars (thousands)
1945	870	39,939
1946	928	41,896
1947	1,053	41,979
1948	1,143	41,711
1949	1,121	40,446
1950	1,276	45,303
1951	1,408	47,547
1952	1,598	56,345
1953	1,732	69,353
1954	1,949	78,523
1955	2,067	85,527
1956	2,172	86,516
1957	2,266	85,991
1958	2,147	75,000
1959	2,383	79,284
1960	2,638	88,878
1961	2,732	103,837
1962	2,452	94,195
1963	2,864	109,723
1964	2,897	113,530
Total	37,696	1,425,523

Certain silicate minerals, relatively high in K_2O, have been considered as potential sources of potash, even though cost of beneficiation is far too high at the present time. Among deposits in Appalachia containing these minerals are sericite schist and potash-feldspar-bearing pegmatite of the Blue Ridge and Piedmont provinces and glauconite-bearing sediments of the Valley and Ridge province. Although these deposits are not minable now, they are a potential source of potash.

One deposit of sericite schist investigated during World War I is near Jasper, Pickens County, Ga.; it was found to contain as much as 10 percent K_2O (Phalen, 1917b, p. 116; Gale, 1919, p. 122–123). The potash feldspars, essentially potassium aluminum silicates containing as much as 16 percent K_2O, were also investigated for their potash content in World War I. Pegmatite deposits containing significant amounts of these feldspars are described in the sections on "Feldspar" and "Mica" of this report (p. 277, 311).

Glauconite-bearing sedimentary rocks are another potential but low-grade source of potash in Appalachia. Glauconite is a widespread but generally minor mineral constituent of many of the Paleozoic formations; it is locally abundant in certain of the Lower and Middle Cambrian formations, and in some beds of Devonian and Mississippian age. W. D. Carter (unpub. data, 1965) reported that the Onondaga Formation (Huntersville Chert of Price, 1929), in parts of West Virginia, Virginia, and Pennsylvania contains from 2 percent to more than 5 percent K_2O in beds generally about 1–3 feet thick but locally as much as 10 feet thick. The potash is in glauconite which generally averages about 7 percent K_2O but which is variable, ranging from less than 5 percent to near 10 percent K_2O. According to Fox (1944, p. 166–167), certain lower beds in the Middle Cambrian sandstone and shale sequence exposed at Watts Bar Dam, Rhea and Meigs Counties, Tenn., are glauconitic; six samples show a range of K_2O content from 0.46 to 4.70 percent. Glauconite is also reported in the Lower Cambrian Rome and Middle Cambrian Conasauga Formations (Harvey and Maher, 1948, p. 284; Miller and Fuller, 1954, p. 25, 26, 30, 164–166; Harris and Miller, 1956; Swingle, 1959, p. 10) in eastern Tennessee and southwestern Virginia, but no analyses for potash were given. Elsewhere in the Appalachian Valley, from Alabama to Pennsylvania, Cambrian rocks are glauconitic.

Although no analyses are available on the K_2O content of the Mississippian Maury Formation and its equivalents in Tennessee and Kentucky, these strata are locally reported to be very rich in glauconite (Conant and Swanson, 1961, p. 62–69). Other Mississippian glauconitic rocks are reported in the Floyds Knob and Muldraugh Formations (as defined by Stockdale) in central Kentucky where a sample of glauconitic siltstone from the Floyds Knob was found to contain 4.24 percent K_2O (Stockdale, 1939, p. 191–222).

The saline deposits and brines of western United States will continue to supply the bulk of the potash both domestically and for export. However, the possibility of greater production of potash as a byproduct of the cement industry should be investigated. As has been noted, potash salts are now recovered from flue dust by only one plant in Appalachia, but flue dust of other plants almost certainly contains recoverable potash. Bogue (1955, p. 126) reported that some U.S. cement companies recovered K_2O from flue dust during World War I in amounts of 2 pounds of K_2O per barrel of cement.

FLUORSPAR

By R. E. VAN ALSTINE, U.S. Geological Survey, and JOHN W. SWEENEY, U.S. Bureau of Mines

Fluorspar, a mineral product of considerable importance in our national economy, is used mainly (1) in the manufacture of artificial cryolite and aluminum fluoride for the aluminum industry, (2) in the production of hydrofluoric acid used for the manufacture of most fluorine chemicals, (3) as a flux in steelmaking, and (4) in the manufacture of glass and enameled products. In general, substitutes for the mineral in any of these uses have not proved satisfactory, although about 900 tons of synthetic calcium fluoride made by Tennessee Valley Authority from phosphate rock mined outside of Appalachia was used as a flux in the steel industry. This calcium fluoride was made in 1951–53 at an experimental fertilizer plant producing fused tricalcium phosphate (H. W. Davis, 1954; Metcalf and Hardeman, 1955; A. H. Reed, Jr., and Hardeman, 1956).

Fluorspar is marketed in acid, ceramic, and metallurgical grades. Acid-grade fluorspar contains at least 97 percent CaF_2. Ceramic-grade material generally contains at least 93–95 percent CaF_2. Metallurgical-grade fluorspar must contain more than 60 percent effective calcium fluoride, which is determined by subtracting 2.5 percent for each percent of silica from the total percentage of CaF_2. Of the approximately 736,000 short tons of fluorspar consumed in the United States in 1963, about 58 percent was acid grade, 37 percent was metallurgical grade, and 5 percent was ceramic grade (Ambrose, 1964).

The United States is the world's leading consumer of fluorspar and was long the leading producer. Since 1952, imports have exceeded production and in 1964 amounted to about 688,000 tons, more than three times the domestic production of about 217,000 tons, which came largely from southern Illinois, western Kentucky, Montana, Nevada, and Colorado. Approximately 80 percent of imports are from Mexico, which has been the leading fluorspar producer since 1956. Spain and Italy supply nearly all other fluorspar imports. The large increase in imports in recent years was in response to the strong demands of the consuming industries and the requirements of the national stockpile, which occurred when domestic production of higher cost fluorspar fell to about half of our maximum World War II production.

Although all 12 States in Appalachia use fluorspar and together consumed one-third of the fluorspar consumed in the United States in 1963 (Ambrose, 1964), this mineral is not being mined anywhere in Appalachia. The Boatman and Alcorn mines in central Tennessee (Jewell, 1947, p. 69–74, 78–82) and the Gilley mine in Alabama (O'Neill, 1950) have yielded a total of approximately 1,500 tons of fluorspar since the early 1900's; production was recorded in the periods 1902–06, 1918, 1928, 1935–36, and 1941–43. Less than two-tenths of 1 percent of the U.S. fluorspar production recorded since 1880 can be attributed to Appalachia. Appalachian fluorspar deposits are small or low grade in comparison with those of the southern Illinois and western Kentucky district, the source of more than 80 percent of U.S. recorded production.

Thirty-eight fluorite localities in Appalachia, including some mineralogic occurrences representing types of deposits that are productive elsewhere, are shown on figure 74. The localities are arranged in three groups (table 112): (1) fluorite occurrences, (2) barite-fluorite-calcite deposits, and (3) fluorite in metalliferous deposits. Only the second group, which is regarded as the most important potential source of fluorspar, is considered below.

Barite-fluorite-calcite deposits are principally narrow steeply dipping veins that formed along faults by fracture filling and breccia replacement, with only minor replacement of the wall rock. The deposits of the central Kentucky (Currier, 1923; Robinson, 1931; Jolly and Heyl, 1964) and central Tennessee districts (Jewell, 1947), the eastern parts of which are in Appalachia (fig. 74, Nos. 11, 23), are localized within gently dipping Ordovician limestones on the Lexington and Nashville domes, respectively. The most likely future sources of fluorspar in Appalachia are these two districts. In addition some fluorspar might be recovered from the Sweetwater district (No. 25) of Tennessee, where northeast-trending belts contain barite and fluorite veinlets along cross folds and breccia zones (Laurence, 1939, 1960); from the Del Rio district (No. 28) of Tennessee (Ferguson and Jewell, 1951); and from the Hot Springs district (No. 31) of North Carolina (Oriel, 1950), where barite and fluorite have replaced granulated and mylonitized rocks along and near thrust faults.

The relative quantities of barite, fluorite, and calcite in the deposits vary widely. Fluorite rarely constitutes more than one-third of any given deposit; however, barite is so abundant that it has been mined at about half the localities shown in table 112. Fluorite forms 20 percent of some barite veins and replacement masses in Virginia (Edmundson, 1938, p. 12). Small quantities of quartz, sphalerite, galena, pyrite, and chalcopyrite are present in many deposits.

At several Tennessee localities, residual ore bodies formed by the weathering of low-grade bedrock deposits have yielded fluorspar or barite. The productive Boatman and Alcorn deposits of the central Tennessee district are residual deposits of "gravel" spar probably derived from fluorspar cavity-fillings or replacements along bedding in the limestone (Fohs, 1907, p. 35; Jewell, 1947, p. 73, 81). In the Sweetwater barite district (No. 25), fluorite is present in greater quantity in the deeper parts of the residual ore bodies, and all mines worked to bedrock exposed barite-fluorite veinlets in brecciated and dolomitized limestone (Laurence, 1960, p. 173, 175). At one of the pits currently being worked for residual barite in this district, veinlets in the bedrock were estimated to consist of one-third fluorite and two-thirds barite (A. V. Heyl, U.S. Geol. Survey, oral commun., Dec. 1965).

TABLE 112.—*Fluorite localities in the Appalachian Region*

No. (fig. 74)	Name	County, State	Country rock
	Fluorite occurrences		
1	Roaring Branch	Lycoming, Pa	Devonian sandstone and shale.
2	Bushkill	Pike, Pa	Middle Devonian limestone.
3	Bellefonte quadrangle	Centre, Pa	Cambrian and Ordovician limestone.
4	Winfield	Union, Pa	Silurian limestone.
5	Mount Union area	Mifflin, Pa	Silurian (?) limestone.
6	Cumberland area	Allegany, Md	Devonian limestone.
7	Tonoloway Creek	Washington, Md	Do.
8	Paw Paw area	Hampshire, W. Va	Devonian sandstone and shale.
9	Shepherdstown	Jefferson, W. Va	Cambrian limestone.
10	Baker	Hardy, W. Va	Silurian limestone.
12	Matthews veins	Russell, Ky	Middle Ordovician limestone.
13	East Stone Gap	Wise, Va	Silurian limestone.
14	Snowflake	Scott, Va	Cambrian Conasauga Shale.
16	Mount Rogers area (Elk Garden).	Smyth-Grayson, Va	Precambrian(?) rhyolitie volcanic rocks.
22	Independence	Grayson, Va	Precambrian granite.
24	Bowden prospect	Fentress, Tenn	Mississippian limestone.
32	Memory-Chestnut Ridge area.	Avery, N.C	Precambrian quartz monzonite gneiss.
33	Brown Mountain	Burke-Caldwell, N.C	Precambrian granite.
34	Graysville	Catoosa, Ga	Ordovician dolomite.
35	Ranger	Gordon, Ga	Cambrian Conasauga Formation.
37	Dorough deposit	Jefferson, Ala	Ordovician dolomite.
38	Sinks Proper deposit	Bibb, Ala	Do.
	Barite-fluorite-calcite deposits		
11	Central Kentucky district (east part).	Clark, Madison, Garrard, Lincoln, Ky.	Middle Ordovician limestones.
15	Counts barite mine	Russell, Va	Ordovician Beekmantown Dolomite.
17	Myers, Copenhaver, Henderlite, and Eller barite mines.	Smyth, Va	Ordovician dolomite and limestone.
21	F. Vaught barite prospect.	Grayson, Va	Precambrian pegmatitic granite gneiss.
23	Central Tennessee district (east part).	Smith, DeKalb, Putnam, Tenn.	Middle Ordovician limestone units.
25	Sweetwater district	McMinn, Monroe, Loudon, Tenn.	Ordovician limestone (Kingsport Formation).
28	Williams and Krebs barite mines, Del Rio district.	Cocke, Tenn	Precambrian and Cambrian clastic rocks.
31	Hot Springs district	Madison, N.C	Precambrian and Cambrian clastic and Precambrian crystalline rocks.
36	Gilley deposit	Cherokee, Ala	Cambrian Conasauga Limestone.
	Fluorite in metalliferous deposits		
18	Sugar Grove lead mine	Smyth, Va	Cambrian Shady Dolomite.
19	Cedar Springs zinc prospects.	Wythe, Va	Do.
20	Austinville zinc district	do	Do.
26	Eve Mills zinc area	Monroe, Tenn	Ordovician limestone (Kingsport Formation).
27	Jefferson City zinc district.	Jefferson, Tenn	Do.
29	Finney and Teagarden magnetite deposit.	Carter, Tenn	Precambrian Cranberry Gneiss.
30	Redmond lead-zinc mine.	Haywood, N.C	Precambrian granite gneiss.

When the large supply of low-cost imports is no longer available and economic conditions in the domestic fluorspar industry once again favor exploration and development, fluorspar deposits in Appalachia will merit further attention. Newer methods of exploration, mining, and beneficiation also should help make the barite-fluorite-calcite deposits in carbonate rocks more nearly economic. In particular, sink-float processes that separate fluorspar from vein calcite or carbonate wall rock have made the use of lower grade deposits profitable elsewhere in the United States. By this means, some low-grade ores can be upgraded to a metallurgical-grade material, and others become a feed for flotation plants. Methods for making commercial-grade flotation concentrates of fluorite and barite from mixed ores recently have been described by Eddy and Browning (1964), Browning, Eddy, and McVay (1963), and Bloom, McKinney, and Evans (1963).

An estimate of the fluorspar resources in Appalachia cannot be made from the scanty quantitative data available. Deposits in central Tennessee (Jewell, 1947, p. 39) and elsewhere have not been adequately prospected, although some are possibly extensive.

GEM-STONE, MINERAL, AND FOSSIL COLLECTING

by ALICE E. FRENCH, U.S. Geological Survey

The collecting of minerals, rocks, and fossils has become a hobby for an increasingly large number of people. Many "rockhound" clubs exist throughout the country, as well as numerous professional and semiprofessional societies of student and amateur collectors. Appalachia affords a wide variety of rock types, gem stones, ore minerals, uncommon and unusual minerals, and fossils for both the serious student of geology and mineralogy and the amateur collector.

This report is a generalized treatment of gem-stone and mineral collecting. Table 113 may be used as a guide in showing which minerals are available in various parts of Appalachia. Figure 75 shows the counties in Appalachia that contain collecting localities. Nearly all the collecting areas are located on private property, and permission must be obtained from owners before entering any area to collect.

The origins and geologic settings of the many minerals found in Appalachia are discussed in other sections of this report, which can be consulted for more information on those aspects. The sections on "Mica" and "Feldspar" are particularly useful, for they describe pegmatites, the sources of many unusual minerals and beautiful crystals of more common minerals. Extensive and detailed information on specific min-

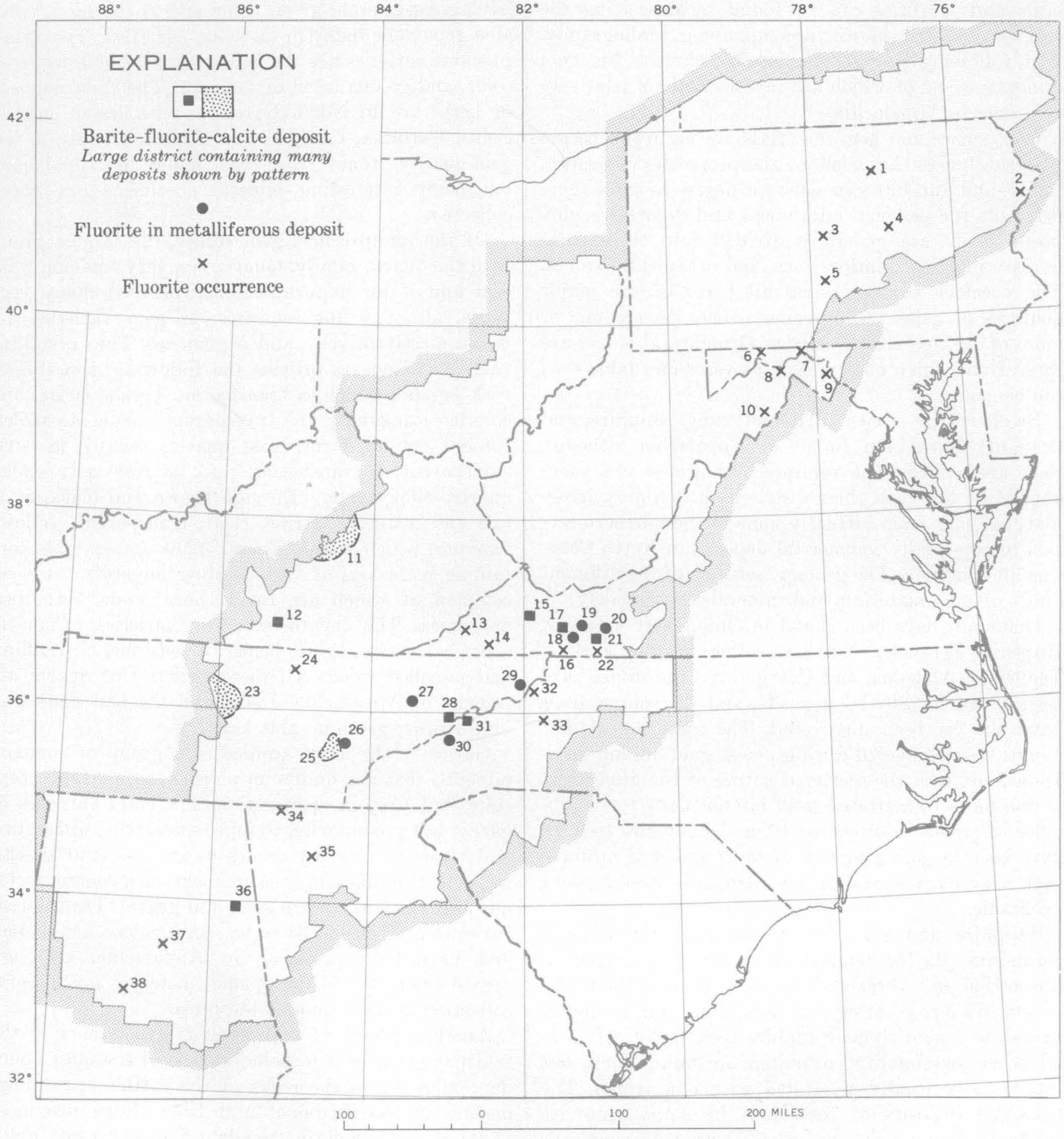


FIGURE 74.—Fluorite in the Appalachian Region. Numbers refer to table 112.

erals and localities can be found by consulting the references listed in the accompanying bibliography. The following paragraphs briefly describe the gem minerals, some of which are rare and others relatively abundant in Appalachia.

Gem stones and gem materials are naturally occurring substances that combine the properties of beauty, rarity, and durability in sufficient degree to make them desirable for personal adornment and decorative purposes. They are generally divided into three categories: precious, semiprecious, and ornamental stones. The precious stones possess all three of the major qualities of gems. Semiprecious stones possess one or more of the necessary qualities. Ornamental stones are those from which objects such as vases and table tops can be made.

Precious gem stones (diamond, ruby, sapphire, and emerald) have been found in Appalachia although they are scarce. The semiprecious stones are more abundant; however, their distribution is highly irregular, ranging from virtually none in the northern section to potentially commercial deposits in North Carolina and Georgia. The geologic settings of the different kinds of gem materials and minerals vary widely.

Diamonds have been found in Ohio, West Virginia, Virginia, Kentucky, North Carolina, South Carolina, Tennessee, Alabama, and Georgia. All the stones have been found in alluvial deposits, and the source areas have not yet been discovered. The majority of diamonds were recovered during placer gold mining operations, and thus the scattered nature of the discoveries is due more to scattered gold mining than to the absence of stones in other localities. Discoveries seem to have been largely a matter of luck, and it is unlikely that a systematic search for diamonds would prove profitable.

Sapphire and ruby are varieties of the mineral corundum, the occurrence of which is described in the section on "Abrasives" (p. 261). Ruby is the transparent deep-red variety of corundum and is highly prized as a gem stone. Sapphire technically refers to all other gem-quality corundum, including pink, but the name is usually associated with blue stones. The principal deposits of corundum in Appalachia are found in North Carolina, where both ruby and sapphire occur with common corundum. Lesser amounts occur in Georgia, Alabama, and South Carolina.

The mineral beryl generally occurs in long prismatic crystals; it is most commonly found in pegmatite dikes. Three important varieties of beryl, used as gem stones, are found in Appalachia. Emerald is a precious gem having an emerald-green color and is the most valuable gem stone today in its value per carat. Two semiprecious varieties are the aquamarine of blue to green color, and golden beryl or heliodor. The chief deposits of beryl are in North Carolina, with lesser ones in South Carolina, Georgia, and Alabama. Only a few gem-quality stones have been found in Appalachia, but many interesting mineral specimens have been collected.

Of the semiprecious gem stones, the largest group is in the quartz family. Quartz is a very common mineral and is an important constituent of many rock types, although the semiprecious gem varieties are found mostly in veins and pegmatites. The crystalline varieties of quartz provide the following gem stones: rock crystal, which is transparent, crystal clear, and colorless; amethyst, the transparent purple- to violet-colored crystal form; rose quartz, usually massive, transparent to translucent, pink to rose red; smoky quartz, smoky yellow through brown and black, crystals and massive; citrine, clear, transparent, yellow; sagenite, which is the general name for crystals containing inclusions of various other minerals, the most common of which are rutile, hornblende, actinolite, and mica. The cryptocrystalline varieties of quartz are: chalcedony, agate, jasper, bloodstone, chert, flint, and petrified wood. All these varieties of quartz are present in Appalachia. Details on the best collecting localities are given in table 113.

Garnet is the name applied to a group of common minerals that are similar in physical properties except color, but vary in composition. The chief varieties of garnet are grossularite, pyrope, spessartite, almandite, and rhodolite. Garnet occurs in gneisses and schists, in pegmatite dikes, in igneous rocks, as a contact metamorphic mineral, and in sand and gravel. Transparent varieties are considered to be semiprecious gem stones and have been produced in Appalachia, although second-class, flawed, or opaque material for mineral collection is much more widespread.

Another group of semiprecious gem stones is the feldspar group which includes some of the most abundant minerals in the rocks of the earth's crust. Pegmatites in the Piedmont and Blue Ridge provinces of Appalachia contain abundant feldspar (see "Feldspar" and "Mica" sections, p. 277, 311), and a few contain the gem varieties amazonstone, sunstone, and moonstone.

Other gem materials found in Appalachia are hiddenite, tourmaline, turquoise, rhodonite, rutile, enstatite, kyanite, epidote, and staurolite.

Many types of ornamental stone occur in Appalachia. Two especially striking ornamental stones in North Carolina are unakite, a mixture of bright red to pink feldspar and light-green epidote, and orbicular gabbro-diorite, consisting of white feldspar with circular spherules of dark-green hornblende.

Because of its special interest to collectors, gold might be mentioned as a specific mineral occurring in Appalachia. Gold has been found in many parts of the region, and deposits are described in the "Gold" section (p. 385). Many alluvial deposits, including those of present streams as well as terrace deposits of former streams, and residual deposits contain small amounts of gold that can be recovered by panning. In some areas interesting specimens of gold-quartz ore have been found.

Fossils, another favorite geological material for collectors, are abundant in many of the sedimentary formations in Appalachia. The coal-bearing strata of Pennsylvanian age have particularly beautiful specimens of plant remains. Many varieties of marine shells are found in formations ranging from Cambrian through Permian age. Most State geological surveys have published lists of fossils and of collecting localities; some of these reports are cited in the accompanying bibliography.

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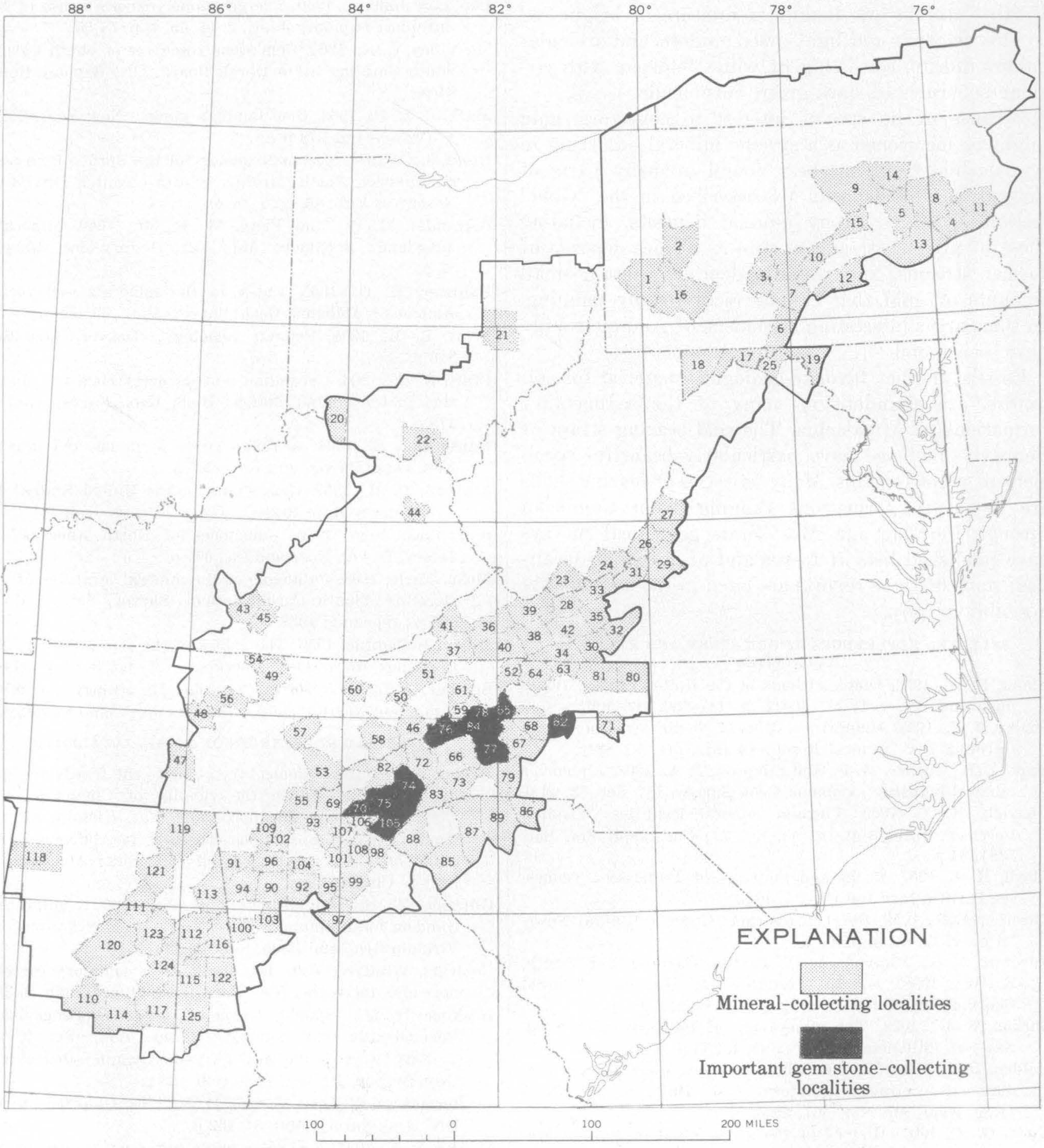

FIGURE 75.—Counties in the Appalachian Region reported to have mineral-collecting localities. Numbers refer to table 113.

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	Pennsylvania		
1	Allegheny: Glassmere Wittmer	Barite, calcite, chalcopyrite, marcasite, pyrite, wurtzite.	Barite and calcite concretions in carbonaceous clay-shale lenses above a limestone. Other minerals are found along fractures or cracks in the concretions.
2	Armstrong: North Vandergrift	Barite, calcite, galena, sphalerite	Barite nodules with galena and sphalerite in limy shale at base of Upper Freeport coal bed.
3	Blair:		
	Culp	Anglesite, barite, calcite, cerussite, dolomite, galena, pyrite, smithsonite.	Minerals fill fractures or are replacements in limestone folded into the Sinking Valley anticline.
	Bells Mills	Celestite	
4	Carbon:		
	Mount Pisgah	Allophane, andersonite, calcite, carnotite, chlorite, gypsum, liebigite, quartz, schroeckingerite, tyuyamunite.	Minerals in Pennsylvanian red sandstone and conglomerate in lenses containing carbonaceous material.
	Mauch Chunk Ridge	Autunite, carnotite, jasper, malachite, mica, uranophane.	Same geology as above, except in rocks of Devonian age.
	Penn Haven Junction	Carnotite, chlorite, hematite, ilmenite, kasolite, leucoxene.	Do.
	Hauto	Quartz crystals	
5	Columbia: Berwick	Calcite; see also No. 14.	See No. 14.
6	Fulton: Fort Littleton	Barite, calcite, chalcopyrite, pyrite, quartz.	Minerals in limestone fractures and vugs. Barite, calcite, and quartz are massive; chalcopyrite and pyrite occur as small crystals.
7	Huntingdon: Birmingham	Amethyst	
8	Luzerne:		
	Hazleton, West Pittston	Pyrite	Pyrite in thin sheets in narrow crevices in slate and anthracite. The anthracite suitably resistant and able to take a high polish is found in small deposits.
	Glen Summit	Anthracite (coal)	
9	Lycoming	See No. 14	See No. 14.
10	Mifflin: Mount Union	Strontianite	
11	Monroe: Kunkletown	Quartz, azurite	Quartz crystals in fractures and vugs in a sandstone. Quartz crystals are found loose in weathered sand. Azurite crystals are found on the quartz.
12	Perry: Millerstown	Malachite	
13	Schuylkill: Mahonoy City	Pyrite	Same geology as in Luzerne County (No. 8).
14	Sullivan: Sonestown, Lairdsville (Lycoming County), and Central (Columbia County).	Azurite, barite, bornite, chalcocite, chalcopyrite, chrysocolla, covellite, galena, malachite, marcasite, metatorbernite, uranophane, uranospinite.	Copper-uranium minerals found as discontinuous gray-green lenses in reddish-brown sandstone and shale. Lenses usually contain black fossil-plant remains.
15	Union: Winfield	Aragonite, calcite, dolomite, fluorite, galena, quartz.	Minerals in Silurian and Devonia n(?) Keyser Limestone. Aragonite, calcite, and dolomite in vugs and solution channels. Other minerals along lower bedding plane contact of Keyser and Tonoloway Limestones.
16	Westmoreland:		
	Ligonier	Quartz crystals	
	Greensburg	Petrified wood	

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	Maryland		
17	Allegany:		
	Cumberland	Aragonite, celestite, fluorite	Aragonite in stalactite formations in caves. Celestite and fluorite in limestone.
	Frostburg	Barite.	
18	Garrett:		
	Youghiogheny River	Barite, flint	Nodules and concretions in streambed.
	Savage River	Gold, silver	Gold and silver are associated with small amounts of lead, zinc, iron, and copper sulphides in veins in Devonian shales and sandstones.
19	Washington:		
	Boonsboro	Aragonite	Aragonite in stalagmite and stalactite formations in the Crystal Grottoes caverns.
	Burkittsville	Quartz crystals	Quartz crystals in sandstone.
	Weverton	Smoky, milky, and blue quartz	
	Keedysville	Quartz crystals inclosing limonite	
	Martin's Mountain	Fluorite	Fluorite in limestone.
	Harpers Ferry	Apatite, epidote, garnet, orthoclase, plagioclase, quartz, thuringite, manganite.	
	Clear Spring	Calcite	Beautiful twinned crystals of nailhead spar calcite in clay-filled fissures in limestone.
	Conococheague Creek	Quartz, dolomite	Doubly terminated quartz crystals and saddle-shaped dolomite crystals in limestone.
	Hancock	Quartz, barite, galena	Milky quartz crystals in pockets in the Oriskany Sandstone.
	Utica	Petrified wood	
	Ohio		
20	Clermont: Milford	Diamond	Only locality in Ohio ever to produce a diamond; from alluvial glacial material, with small amounts of gold.
21	Muskingum: Flint Ridge	Chert, quartz	Colorful chert in beds 5–6 ft thick in Pennsylvanian Vanport Limestone. Cavities in chert lined with smoky quartz crystals, amethyst, and clear quartz crystals; agate, jasper, and carnelian in seams.
22	Scioto	Catlinite (pipestone)	Catlinite is a hard siliceous red clay formerly used by Indians who carved their peace pipes from it.
	West Virginia		
23	Mercer:		
	Willowton	Onyx	Greenish-white translucent calcite, similar to Mexican onyx, was quarried here.
	East River Mountain	Barite	
24	Monroe: Peterstown	Diamond	The only diamond ever found in West Virginia is the famous "Punch Jones" stone of more than 34 carats, found in alluvial material.
25	Morgan: Berkeley Springs	Quartz	Quartz crystals are found in a sandstone quarried for glass sand.

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
		Virginia	
26	Alleghany: Clifton Forge	Hydrozincite, crandallite, apatite, hemimorphite.	These minerals are in cave deposits.
27	Bath: McClung	Pyrite, calcite	Crystals along joint planes in Devonian black shale.
28	Bland: Bland	Agate, quartz	
	Tazewell: Bluefield	Wavellite	Wavellite occurs in spherical aggregates with radial fibrous structure in association with manganese oxides.
29	Botetourt: Fincastle	Barite	
30	Carroll:		
	Dugspur, Hillsville	Copper	Native copper in quartz veins in hornblende gneiss.
	Southwestern area	Graphite	Graphite occurs locally in quartzite of Saddle Gneiss.
	Hillsville	Pyrrhotite, pyrite, arsenopyrite, coquimbite, cuprite, actinolite, spessartite.	Pyrrhotite is one of the chief minerals in a southwest-trending mineralized zone, the "Gossan Lead." The other minerals are associated with the main ore at many places.
	Woodlawn	Ilmenite, kyanite, rutile	Minerals in a southwest-trending belt of garnet-staurolite schist.
	Catrons Mill	Sillimanite	Sillimanite locally in Saddle Gneiss; as xenoliths in Striped Rock Granite.
	Galax (area extends into Grayson County).	Staurolite	Large crystals occur in Lynchburg Gneiss; cruciform penetration twins with a twinning angle of 60° are abundant. Clear yellow prisms occur in a glassy quartz at Hampton mine.
	Laurel Fork	Quartz	Many crystals clear, smoky, milky, or opaque, as much as 6 pounds, found in unconsolidated overburden.
31	Craig: Newcastle	Hematite	Hematite is present in Clinton ore beds.
32	Floyd:		
	Pilot-Terry's Fork road	Gold, silver	Small flakes are present in alluvium in old Brush Creek gold field.
	Indian Valley	Schreibersite	Mineral is present in a meteorite.
	Floyd Court House	Chalcocite, steatite	
	Floyd	Pyrrhotite, pyrite, malachite, conichalcite.	Pyrrhotite is the main ore mineral associated with copper minerals and other iron sulfides. The best collecting is at Toncrae, 6 miles southwest of Floyd.
	Terry's Fork	Arsenopyrite, apatite, wulfenite	
	Willis, Floyd, Alum Ridge, Indian Valley.	Rutile	Large crystals found at several localities; some twinned, some with quartz.
	Along country road 617	Gypsum-selenite, melanterite, pickeringite.	Small crystals of selenite occur as surficial coatings on the Alum Phyllite of Dietrich (1959).
	Laurel Fork, Willis	Quartz	Clear, smoky, and blue quartz crystals, some weighing more than 100 pounds, occur in the Little River Gneiss of Dietrich (1959). Some have chlorite and rutile inclusions.
	Pizarro	Anthophyllite, clinozoisite	Asbestiform anthophyllite with fibers as long as 90 cm; radial groups also occur in the area.
	Burks Ford, Floyd	Garnet, Staurolite	Garnets found in mica schist and gneiss of the Lynchburg. Small staurolite crystals, twinned and untwinned, also in Lynchburg Gneiss.
33	Giles:		
	Newport	Quartz	Crystals are colorless to smoky, and are of special interest because they are distorted. Some contain cavities partially fluid filled.
	Various locations	Agate, onyx	Minerals in veins and fracture fillings.

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	Virginia—Continued		
34	Grayson:		
	Elk Creek Village	Gold, pyrite	Gold and pyrite are in a quartz vein.
	Speedwell, Hampton, Independence, Fox Creek, Elk Creek.	Barite	
	Various locations	Chalcedony, quartz, penite	Minerals occur together in some flows of Mount Rogers Volcanic Group.
	do	Jasper	In agglomerate and tuff of Flat Ridge Formation.
	Edmonds	Talc, chrysotile	Talc and chrysotile fibers present in serpentinite.
	Independence	Hedenbergite, rhodonite	Coarsely crystalline hedenbergite found in veins with magnetite and spessartite.
	Galax, Hickory Knob, Rich Mountain.	Tourmaline	Black crystals in quartz veins in mica schists.
	Grant, Edmonds	Tremolite	Tremolite in marble near Grant and as long-bladed prisms in serpentinite near Edmonds.
	Bennington Mill, Flat Branch, Longs Gap.	Hornblende	Large crystals of hornblende in pegmatites of the Carsonville Granite.
	Peach Bottom Church	Hastingsite, epidote	Hastingsite in syenite facies of Striped Rock Granite, with massive epidote.
	Galax, Independence	Spessartite	Spessartite-bearing veins occur in Gossan Lead and several belts trending northeast near Galax in schist and gneiss formations.
	Catrons Mill (Carroll County).	Sillimanite	See Carroll County.
	Hampton Ford	Staurolite	See Galax, Carroll County.
	Grant	Sphene, unakite, tremolite	Sphene and tremolite occur in marble and unakite in granite.
	Iron Mountain	Barite, fluorite	
35	Pulaski: Delton	Smithsonite, hemimorphite	
36	Russell:		
	Maiden Spring Fork	Galena	
	Castlewood	Smithsonite	
	Spring City	Barite	Barite in northeast-trending belt extending into Tazewell County.
37	Scott: Nickelsville	Chalcedony	
38	Smyth:		
	Rye Valley	Galena, sphalerite, rhodonite	
	Saltville	Halite, phosphorite, gypsum, anhydrite.	
	Marion	Barite, kaolinite, halloysite, fluorite.	Colloform masses of kaolinite and halloysite in fractures in brecciated sandstone.
	Plasterco (Washington County).	Satin spar (gypsum)	
	Rich Valley	Quartz	Well-formed single and multiple-twinned crystals and some distorted crystals are found in the alluvium.
39	Tazewell: Pounding Mill	Diamond	One diamond crystal was found in alluvium.
40	Washington:		
	White Top-Mount Rogers road.	Fluorite	Fluorite occurs in a rhyolite.
	Plasterco	Anhydrite, gypsum-selenite satin spar, halite.	
41	Wise: East Stone Gap	Calcite, celestite, strontianite	
42	Wythe:		
	Austinville	Fluorite, smithsonite, barite	
	Ivanhoe	Gypsum-selenite	
	Painters Branch	Asbestos	

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	Kentucky		
43	Adair: Montpelier	Diamond	A diamond crystal was reported from a stream in the area.
44	Elliott: Ison's Creek	Enstatite, garnet, phenacite	Minerals occur in a peridotite.
45	Russell	Diamond	This stone may be the same as that reported in Adair County.
	Tennessee		
46	Cocke: Del Rio	Unakite, barite, fluorite	Unakite occurs in granite.
47	Coffee: Beechgrove	Chalcedony	Mineral in nodules and fragments.
48	DeKalb	Barite, fluorite	
49	Fentress:		
	Pall Mall	Barite	
	Buffalo Cove	Celestite	
50	Hamblen: Russellville	Quartz	
51	Hawkins: Click Creek	Barite, calcite	Barite occurs as light green transparent crystals; calcite is the dogtooth spar variety.
52	Johnson: Mountain City	Phosphorite	
53	Monroe:		
	Coker Creek district	Gold	Gold chiefly in placer deposits.
	Toqua	Quartz	Quartz crystals are found loose in red clay.
54	Pickett: Various locations	Barite	
55	Polk: Ducktown-Copperhill district.	Copper ore, gold, staurolite, azurite, malachite.	Minerals in limestone bodies in highly deformed mica schist.
56	Putnam: Cookeville	Agate, jasper	Agate and jasper nodules in stream gravels.
	Buffalo Valley	Fluorite	
57	Roane: Clinch River	Diamond	A 3-carat diamond was found near an Indian mound on the Clinch River. This stone may be the same as that reported in Union County.
58	Sevier:		
	Douglas Dam	Quartz	
	English Mountain	Barite	
59	Unicoi	Unakite	Unakite is found in granite.
60	Union: Luttrell	Diamond	A diamond crystal of 1.8 carats was found in Flat Creek. This stone may be the same as that found in Roane County.
61	Washington: Fall Branch district.	Barite	The barite area extends into Greene and Sullivan Counties.
	North Carolina		
62	Alexander: Hiddenite	Emerald, hiddenite, quartz, rutile, tourmaline, aquamarine, garnet, pyrite, feldspar.	Minerals in veins in Precambrian gneiss or pockets in pegmatites.
	Taylorsville, Liberty Church	Rutile, rutilated quartz	Do.
	Stony Point	Rutile, xenotime, monazite, rutilated quartz.	Found in pegmatites and as water-worn crystals in streams.
63	Alleghany: Sparta	Garnet, rhodonite	Rhodonite occurs with vein manganese.
64	Ashe:		
	West Jefferson	Beryl, mica, aquamarine	Good beryl crystals obtained from mica mines.
	Crumpler	Staurolite	Well-formed staurolite crystals occur in mica gneiss.
	Phoenix Mountain	Quartz	Large clear quartz crystals occur in pockets in granite.
65	Avery: See No. 78.		
66	Buncombe:		
	Black Mtn. Station	Beryl, kyanite, corundum	
	Balsam Gap to Ridgecrest	Beryl, corundum, kyanite	
	Democrat	Moonstone, chalcedony, garnet, olivine.	
	Asheville	Aquamarine, chrysoprase	

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	North Carolina—Continued		
67	Burke:		
	Ramsey	Beryl, garnet, corundum, kyanite, tourmaline, sillimanite.	Minerals in pegmatites.
	Burke Chapel, Morganton	Tourmaline, quartz, garnet, aquamarine, beryl.	Do.
	Brindletown	Gold, monazite, quartz, beryl, tourmaline, garnet, diamond, rutilated quartz, zircon, kyanite, amethyst.	Minerals in stream sands.
	Bridgewater	Itacolumite (flexible sandstone)	Itacolumite occurs as boulders weathered from the Erwin Quartzite.
68	Caldwell:		
	Collettsville	Pyrite, epidote	Massive epidote and pyrite crystals suitable for lapidary work occur in mica schist.
	Dudley Shoals	Sillimanite	Sillimanite, ranging from a few fine needles to almost pure nodules, occurs in mica schist.
69	Cherokee:		
	Marble	Ottrelite mica, staurolite, garnet, sillimanite.	Minerals in metamorphic rocks.
	Murphy	Talc, tremolite, sillimanite tourmaline.	Do.
	Beaverdam Creek	Smoky quartz	Smoky quartz in creek gravels.
70	Clay:		
	Buck Creek	Corundum (ruby), smaragdite, garnet.	Minerals occur in schist. The amphibolite, smaragdite, is emerald green, with ruby-red corundum nodules.
	Shooting Creek	Corundum, rutile, smaragdite	Corundum occurs in mica schist. Rutile found as water-worn crystals in the creek and also in saprolite.
	Brasstown	Garnet, staurolite	Minerals occur in a mica schist and are frequently found weathered out in the soil.
71	Davie:		
	Farmington	Columbite, autunite	Minerals occur in pegmatites.
	Oaks Ferry	Orbicular gabbro-diorite	Rock is interesting for ornamental items; composed of white feldspar and perfectly circular spherules of dark-green hornblende; found in boulders along the Yadkin River.
72	Haywood:		
	Sunburst	Quartz	Rose quartz in quartz boulders at Shining Rock.
	Retreat	Corundum, kyanite, garnet	Minerals in small pegmatites.
	Canton	Corundum	Corundum occurs in pegmatites.
73	Henderson:		
	Tuxedo	Rare-earth minerals—anatase, sphene, zircon, auerlite, monazite, apatite, epidote, garnet.	Minerals occur in pegmatites.
	Lake Summit	Agate	
	Bat Cave	Epidote	Epidote veins occur in gneisses and in a pink granite.
74	Jackson:		
	Webster	Enstatite, chalcedony, talc, magnesite, quartz, serpentine, genthite, chromite, chrysotile, olivine, diopside, tremolite, anthophyllite, actinolite, phenacite.	Minerals occur in an ultramafic ring dike, on which the town of Webster is built.
	Balsam	Enstatite, chromite, talc, olivine, phenacite.	Minerals in peridotite. Olivine crystals exceptionally large, some more than 5 inches in diameter.
	Horsepasture River	Corundum	Corundum occurs in peridotite.
	Willets	Garnet	Garnet in mica schist.
	Sapphire Lake	Beryl, garnet, tourmaline, samarskite, ruby.	Minerals occur in a pegmatite.
	Sheepcliff Mountain	Beryl, quartz, garnet, mica, samarskite.	Do.
	Whitewater River	Sapphire	
	Whiteside Mountain	Beryl	Large crystals found in pegmatites.

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	North Carolina—Continued		
75	Macon:		
	Cowee Creek, near Franklin	Ruby, garnet, sillimanite, staurolite, iolite, pyrite, rutile, enstatite, hornblende, zircon, kyanite, sapphire, quartz, spinel, chromite, tremolite.	Minerals found in a gravel deposit, covered by top soil averaging 2 ft in depth. The gravel fills the valley floor of Cowee Creek and Calder Fork.
	Corundum Hill	Ruby, sapphire, amethyst, spinel	Corundum and other minerals in lenses and rounded masses of crystals in dunite.
	Burningtown	Corundum	Well-crystallized pink and purple corundum is found.
	Ellijay	do	Gem-quality corundum is found here, particularly a bronze variety which frequently shows asterism.
	Highlands	Corundum, rutile, asbestos, vermiculite, garnet, amethyst, golden beryl, tourmaline.	Beryl and tourmaline in pegmatites; the other minerals in veins.
	Whiteside Mountain	Garnet	
	Dry Falls	Beryl	
	Tessentee Creek	Amethyst, aquamarine, beryl	Excellent amethyst crystals disseminated in kaolinite weathered from a pegmatite.
	Mason's Mountain	Garnet, moonstone	
	Tremont Mountain	Chrysoprase	
76	Madison:		
	Lemon Gap	Allanite	This radioactive mineral occurs in pegmatites and granites.
	Redmon	Allanite, garnet	Do.
	Bluff	Barite, unakite	Barite crystals and crystalline masses in veins.
	Roaring Fork Creek	Unakite	Unakite occurs as seams and veins in granite, and is used as an ornamental stone because of the unusual colors of its contained green epidote and pink feldspar.
	Petersburg	Monazite	Massive and crystalline monazite occurs in pegmatites.
	Mars Hill	Corundum, serpentine, olivine, chromite, spinel.	
	Hot Springs	Jasper, calcite	Minerals occur in limestone and dolomite.
	Bear Creek	Staurolite	
	Reeds Creek	Aquamarine, jasper	
77	McDowell:		
	Dysartville	Diamond, gold, zircon, corundum	Minerals in stream gravels. Three diamonds were recovered during placer gold mining operations.
	Woodlawn	Calcite, quartz	Calcite and quartz crystals occur in Shady Dolomite.
	Nebo	Quartz	
	Western McDowell County	Graphite, kyanite	Minerals in mica schist in parallel bands trending northeast.
	Graybeard Mountain	Beryl, garnet, samarskite, columbite.	Minerals in a pegmatite.
78	Mitchell, Avery, Yancey: Spruce Pine district (Spruce Pine, Bakersville, Bandana, and Burnsville areas).	Actinolite, albite, allanite, amazonite, apatite, aquamarine, autunite, beryl, bornite, chalcopyrite, columbite, corundum, covellite, cyrtolite, emerald, epidote, essonite, fluorite, garnet, gummite, kyanite, malachite, mica, monazite, moonstone, oligoclase, opal, orthoclase, pyrite, quartz, rutile, samarskite, sphalerite, sunstone, talc, thulite, torbernite, tourmaline, tremolite, unakite, uraninite, zircon, zoisite.	The Spruce Pine district is one of the chief mica and feldspar producing areas in the United States. It covers an area of 250 square miles and contains hundreds of pegmatites. Not all the minerals listed are found in any one deposit, but they are present within the district. For a more detailed description of the geology of the area, see the sections on "Mica" and "Feldspar" (p. 277, 311).

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	North Carolina—Continued		
79	Rutherford:		
	Thermal City	Garnet	Massive and crystalline garnet occurs.
	Marlin's Knob	do	Garnet occurs in gneiss.
	Ellenboro	Garnet, beryl, rose quartz	
	Duncans Creek	Golden beryl, asteriated quartz	
	Rutherfordton	Quartz, mica, corundum	Quartz in float and stream gravel of Hollands Creek; other minerals in pegmatite.
	Sunshine	Milky quartz, gold	
	Gilkey	Mica, corundum	Minerals occur in mica schist with lenses of pink corundum.
	Cane Creek	Diamond, gold	A diamond was found during gold mining.
80	Stokes:		
	Orchard Gap, Hanging Rock Mountain, Danbury.	Itacolumite (flexible sandstone)	Itacolumite occurs in a quartzite.
	Dan River	Rose quartz	
	Martin's Quarry	Hematite, chalcedony, opal, jasper, amethyst.	
	Coffee Gap	Lazulite	Massive lazulite is found with quartz.
81	Surry: Elkin, White Plains	Quartz	
82	Swain:		
	Bryson City	Feldspar, quartz, mica, garnet, pyrite, allanite, samarskite, magnetite, thulite, beryl.	Minerals occur in pegmatites striking northeast.
	Deep Creek camp site	Kyanite, staurolite	Minerals occur in graphite schist.
83	Transylvania:		
	Looking Glass Rock off U.S. Highway 276.	Quartz, garnet	Smoky quartz in veins.
	Rosman, Balsam Grove	Quartz	
	Fairfield Valley	Gold	Placer gold in streams.
	Oakland	Corundum, enstatite	Minerals are found in a dunite.
	Blue Ridge	Pyrite, garnet	Minerals in float.
	Henry Mountain	Calcite	Dogtooth calcite crystals occur.
84	Yancey:		
	Sampson Mountain	Corundum	Well-formed crystals of white to blue corundum are found in a mine.
	South Carolina		
85	Anderson:		
	Anderson	Amethyst, sapphire, garnet, aquamarine, beryl, zircon, corundum, mica, quartz, tourmaline, topaz.	Minerals in pegmatite dikes and weathered outcrops of mica slate.
	Iva	Beryl, mica	
	Moffettsville	Amethyst	Clear crystals of good color occur in narrow pockets in mica slate.
	Pelzer	Aquamarine, beryl, tourmaline	Beryl and tourmaline crystals in quartz veins, gneiss, and mica schist.
	Cooks	Corundum, zircon, garnet	Crystals in streams and weathered slate outcrops.
	Easley	Gold	Gold in quartz veins in slate.
86	Cherokee:		
	Bowen River	Amethyst, zircon, sapphire, monazite, corundum, topaz.	These minerals are found in small veins and in stream gravels.
	Blacksburg	Sapphire, beryl, emerald, amethyst, zircon.	Minerals occur in a schist and in pegmatites cutting the schist.
	Gaffney	Sapphire	
	Kings Creek Station	Gold, pyrite	Minerals in quartz veins cutting mica schist.
87	Greenville:		
	Montague	Quartz, tourmaline, mica	Mica, tourmaline, rock crystal, and smoky quartz occur in a pegmatite.
	Piedmont	Beryl	Beryl in a pegmatite.
	Pelzer (Anderson County)	Beryl, aquamarine, tourmaline, mica, sillimanite.	Good beryl and tourmaline specimens in quartz veins, gneiss, and mica schist.
	Greer	Gold, sillimanite	Gold occurs in quartz veins cutting mica schist.
	Tigerville	Zircon	Large crystals found in old vermiculite mines and in stream gravel.

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	South Carolina—Continued		
88	Oconee:		
	Adams Crossing	Gold	Gold is found both in placer deposits and disseminated in quartz veins cutting the mica schist.
	Walhalla	Gold, pyrite, galena	
	Soapstone Hill	Talc, mica, corundum, tremolite	
89	Spartanburg:		
	Spartanburg	Asbestos	
	Fingerville	Corundum	
	Georgia		
90	Bartow:		
	Kingston	Agate, jasper	Red and brown agate and jasper occur along streams.
	Cartersville	Barite	Barite occurs in the Shady Dolomite.
91	Chattooga:		
	Summerville	Agate	
	Graysville	Fluorite	
92	Cherokee:		
	Ball Ground	Rutilated quartz, staurolite, garnet, beryl, mica, gold.	Minerals in veins in mica schist.
	Holly Springs	Apatite, talc	Minerals are found in serpentine.
	Sharp Mountain Creek, Bluff Creek.	Staurolite	Crystals in stream gravels.
93	Fannin:		
	Blue Ridge, Morgantown	Staurolite	Well-formed staurolite crystals showing several types of twinning found in creek sand.
	Mineral Bluff	do	Large crystals, generally containing garnet, found in soil.
	Cole's Crossing	do	Unusually well-formed generally twinned crystals in sericite phyllite.
94	Floyd: Rome	Quartz	
95	Forsyth: Cumming	Amethyst	
96	Gordon: Ranger	Fluorite	
97	Gwinnett:		
	Buford	Agate, moonstone	
	Norcross	Moonstone	Moonstone is found in a pegmatite.
98	Habersham: Clarkesville	Agate, ruby, kyanite	
99	Hall: Gainesville, Glade Creek	Diamond	Some small diamond crystals were found during gold-mining operations.
100	Haralson: Bremen	Quartz	
101	Lumpkin:		
	Ward Gap	Topaz, mica	
	Dahlonega	Gold	Both lode and placer gold occur.
102	Murray: Fincher Bluff	Quartz	Silicified oolite occurs in the lower parts of the Knox Dolomite.
103	Paulding: Dallas	Garnet	Garnet found on surface near a copper mine.
104	Pickens: Tate	Golden beryl, aquamarine	Minerals in a pegmatite.
105	Rabun:		
	Clayton	Amethyst, quartz, beryl, corundum, aquamarine, mica.	Minerals can be found on mine dumps in the area. They occur in veins associated with mica.
	Laurel Creek	Ruby, sapphire	
106	Towns:		
	Charlie Creek	Amethyst	
	Hiawassee	Corundum, sapphire, smaragdite	Corundum in veins with smaragdite and in beach deposits near Elf.
107	Union:		
	Hightower Bald	Amethyst, quartz	
	Blairsville	Ruby	
108	White:		
	Nacoochee	Apatite, gold	Both lode and placer gold occur.
	Racoochee	Diamond	Two small crystals found during gold-mining operations.
	Sall Mountain	Asbestos	
109	Whitfield: Dalton	Jasper, quartz	

TABLE 113.—*Mineral-collecting localities in the Appalachian Region*—Continued

No. (fig. 75)	County: key geographic feature	Minerals	Remarks
	Alabama		
110	Bibb:		
	Centerville	Chert, barite, galena, fluorite.	
	Woodstock	Vivianite	
111	Blount: Blountsville	Agate, chert	Minerals in pits along Highway 128.
112	Calhoun: Wellington	Barite	
113	Cherokee:		
	Center	Tektites	Dark-green and dark-blue tektites have been found associated with iron meteorites.
	Spring Garden	Fluorite	Fluorite occurs in veins cutting limestone.
114	Chilton: Clanton	Kyanite, mica, vanadium	Minerals in a graphitic schist.
115	Clay:		
	Erin, Idaho	Turquoise	Light-green to yellowish-green vein turquoise found in schist.
	Lineville	Beryl, quartz, mica	Minerals in veins in schist and gneiss.
	Pyriton	Pyrite	
116	Cleburne:		
	Turkey Heaven	Kyanite	Kyanite in veins in schist and gneiss.
	Arbacoochee district	Gold	Placer gold in stream gravels.
117	Coosa:		
	Rockford	Cassiterite, quartz, mica, beryl, aquamarine, metastrengite, bermanite, rockbridgeite.	Minerals occur in pegmatites and veins in schist and gneiss.
	Hissop	Golden beryl, quartz, aquamarine	Minerals in veins in schist.
	Bradford	Corundum, sapphire	Dark-brown corundum showing asterism is found.
	Nexburg	Kyanite	
118	Franklin: Phil Campbell	Carnelian	Carnelian found in gravel pits north of town.
119	Jackson: Gurley	Chert	Colorful compact chert occurs in the area.
120	Jefferson:		
	Pleasant Grove Church	Turquoise	Turquoise in thin veins in schist.
	Birmingham	Diamond	A 4-carat diamond crystal of faint yellow color was found in alluvium.
121	Marshall: Guntersville	Quartz	Quartz crystals occur.
122	Randolph: Pinetucky	Beryl, mica, gold, aquamarine	Minerals occur in pegmatites.
123	St. Clair: Prescott Siding	Diamond	A 2-carat greenish crystal was found in alluvium.
124	Talladega: Winterboro	Talc	
125	Tallapoosa:		
	Zana	Smoky quartz, beryl	
	Dudleyville	Asbestos, corundum, chromite	Minerals occur in dikes.
	Dadeville	Corundum, chromite, damourite, talc.	Minerals occur in dikes in mica gneiss.
	Hog Mountain	Gold	Gold is found in quartz veins in quartz diorite.

GRAPHITE

By Paul L. Weis, U.S. Geological Survey and Stanley A. Feitler, U.S. Bureau of Mines

Graphite is a naturally occurring form of pure crystalline carbon. It is marketed in three categories termed "flake" ("or crystalline flake"), "amorphous lump and chip" (or "lump and chip"), and "amorphous." The terms reflect the distinctive appearance and physical characteristics of the natural graphite. Because of these differences, each type lends itself ideally to certain products and uses. The origin and geologic occurrence of the three types are distinctive.

Flake graphite occurs as flat flakelike grains more or less evenly disseminated in metamorphosed sedimentary rocks, where it formed through the alteration of carbonaceous material that was part of an original sediment. Lump and chip graphite occurs as the major constituent of veins that may be found cutting rocks of all kinds. Amorphous graphite is extremely fine grained, earthy-looking graphite that may make up either a minor or major part of a slightly metamorphosed sedimentary rock, but the highest quality, and the type most widely used, is formed through the graphitization of coal beds.

All graphite exhibits a combination of physical and chemical characteristics not possessed by other substances. It is extremely soft but has a very high melting point and is highly resistant to chemical change. It is also an excellent conductor of heat and electricity. These qualities, singly or in combination, make it particularly useful for the manufacture of crucibles and related refractory ware to smelt metals, especially brass; the manufacture of carbon brushes for electric motors; and as heavy-duty or high-temperature lubricants. Graphite also is used for foundry facings, the manufacture of pencils, dry-cell batteries, corrosion-resistant paints, inert fillers in rubber and insecticides, gunpowder coatings, and many other purposes.

UNITED STATES PRODUCTION AND CONSUMPTION

Although graphite is a widely used mineral, the total quantity used in any one year is small (table 114). Even less flake graphite, the only type occurring in significant quantities in Appalachia (Alabama), is consumed (table 115). Currently the only U.S. production of graphite is flake by one mine in Texas which supplies only a fraction of domestic needs.

U.S. graphite production was greatest in 1917 and 1918, when it reached more than 12,500 tons per year, and was nearly as large again in 1943 and 1948, when it reached about 10,000 tons. In few other years since 1910 has production been more than 5,000 tons, and there was no production in some years. Figure 76 shows U.S. consumption and production for the period 1910–64.

Table 114.—*United States consumption of graphite, all types, 1952–64*

[Source: U.S. Bur. Mines, Minerals Yearbooks, 1959–64]

Year	Consumption (short tons)	Value (thousands of dollars)
1952–56 (avg)	36, 096	5, 085
1957	41, 029	5, 568
1958	28, 823	3, 972
1959	40, 239	5, 395
1960	37, 289	4, 773
1961	35, 652	4, 651
1962	44, 383	5, 648
1963	47, 006	6, 111
1964	54, 043	7, 026

Table 115.—*United States consumption of crystalline flake graphite by use, 1959–64*

[In short tons. Source: U.S. Bur. Mines, Minerals Yearbooks, 1959–64]

Use	1959	1960	1961	1962	1963	1964
Batteries	26	22	71	103	67	(1)
Brake linings	442	424	375	361	465	485
Carbon brushes	155	72	121	156	152	155
Crucibles, retorts, stoppers, nozzles	3, 483	2, 987	[2] 3, 141	[2] 3, 412	[2] 3, 487	[2] 3, 901
Foundry facings	410	434	350	184	1, 321	1, 886
Lubricants	2, 083	1, 344	2, 004	1, 505	1, 426	1, 636
Packings	234	196	167	279	267	236
Pencils	323	493	622	645	583	862
All other uses	283	[2] 546	483	829	1, 217	1, 032
Total	7, 439	6, 518	7, 344	7, 474	8, 985	10, 193
Value	$1, 638, 122	$1, 449, 181	$1, 550, 362	$1, 666, 445	$1, 917, 890	$2, 160, 344

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[1] Withheld to avoid disclosing individual company data; included with "All other uses."

[2] Includes some amorphous graphite.

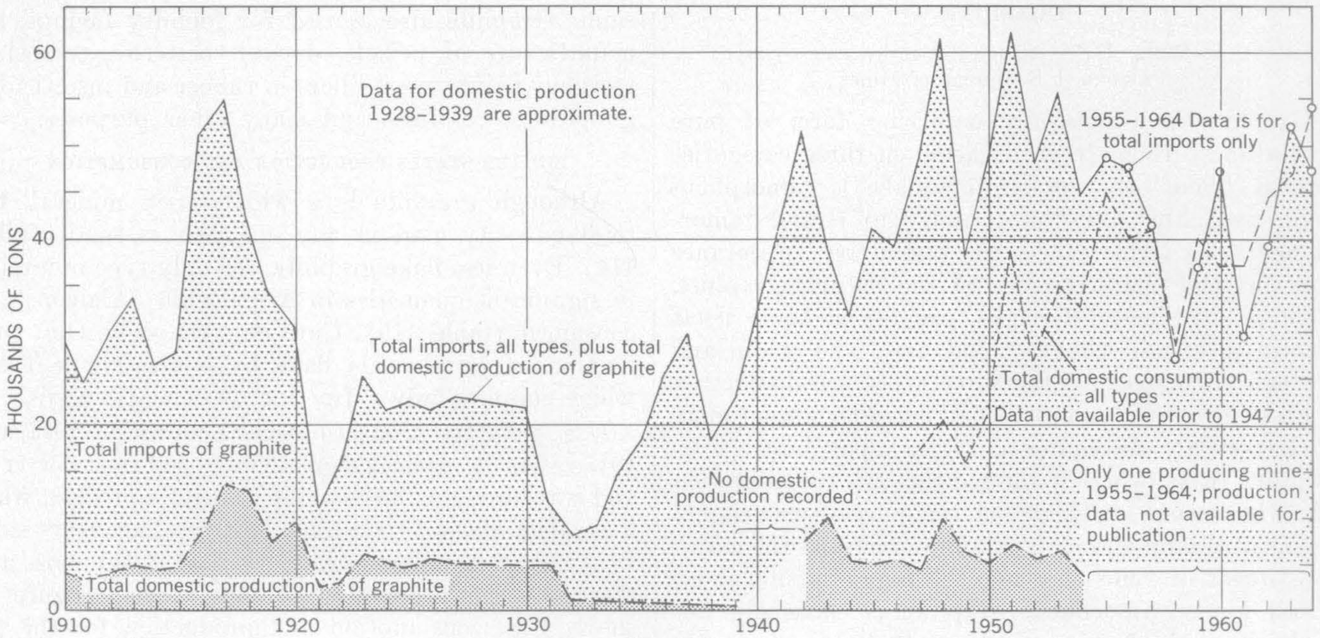


FIGURE 76.—Consumption and production of graphite in the United States for the period 1910–64.

In the years of peak production, during World Wars I and II, most graphite mined in the United States came from Alabama. During 1918, 42 graphite deposits were being worked in that State. Important amounts of crystalline flake graphite have also been mined in New York, Pennsylvania, and Texas. Most production from New York and Pennsylvania was before 1915, although a small amount was mined in Pennsylvania during World War II and intermittently since then. Graphite has been mined intermittently in Texas from about 1913 to the present (J. W. Cole, in U.S. Bur. Mines, 1965a, p. 399–409).

The experience and habits of the consuming industry are important to potential domestic producers. Consumers have geared their industrial processes to raw materials from a particular source and are understandably reluctant to change. This factor is especially important because demand is small (table 115). Domestic producers need to develop more stable markets, perhaps through a sales, service, and research organization. Even if they are able to capture a significant proportion of the market, however, gross income would not be large, and net profits may well be too small to pay for the combined costs of production and marketing.

The future of the domestic graphite industry also may be affected by the increasing production of "artificial" graphite. Synthetic graphite has been made in electric furnaces for years, but generally for special-purpose very high purity products, such as graphite bricks for atomic-power reactors. Synthetic graphite is not now greatly different in value from natural graphite, but most is finer grained and lacks some of the physical properties of natural flake graphite. Further technologic development may lead to the production of usable synthetic flake graphite.

The outlook for domestic production may be more optimistic than in the past. Since World War II, only one domestic mine (in Texas) has had almost continuous production, and consumers have found domestic graphite suitable for some uses. The general increase in industrial production in response to growing population has raised the average annual needs, so the existence of large well-known deposits, of demonstrated quality and productivity, represents a potential resource for a small industry capable of expanded production.

DEPOSITS IN APPALACHIA

Graphite occurs as a minor constituent in many of the rocks in Appalachia, but the principal deposits are those of Alabama. Mining has been attempted in many places, but most such efforts were short lived and unsuccessful.

Low-grade amorphous graphite was mined from the Brevard Schist of Cambrian age at Graphiteville, McDowell County, N.C. (Keith, 1905, p. 8). Graphite content is said to reach 25 percent in places (Pratt, 1905, p. 1159). Attempts to produce a refined product in 1911 apparently met with little success.

Both crystalline flake and amorphous graphite occur in Georgia. Limited production of flake is reported from Madison County in 1928 and 1941, and from Habersham County in 1938. Amorphous graphite near Emerson, Bartow County, was mined in 1907 and 1911, and refined amorphous graphite was produced in Bartow County in 1909, 1910, and 1912, and in Habersham County in 1931.

None of the North Carolina and Georgia deposits are believed to be of sufficiently high quality and tenor to be of commercial value at present.

Synthetic graphite is produced in Burke County, N.C., and Elk County, Pa.; most of it is not now marketed in direct competition with natural graphite. The trend, however, is toward increasing use of synthetic graphite for uses which were formerly the exclusive domain of natural graphite.

Most graphite production in Alabama has been during major wars, when imports were restricted or cut off entirely. When foreign sources of supply again became available, consumers bought imported graphite and Alabama mines shut down. The graphite industry of Alabama has difficulty competing with the foreign deposits which are larger and contain substantially coarser, higher grade flake. Some of the foreign deposits are easily mined, and in many of them, simple and inexpensive concentration methods produce a considerable range of products that are cheaper, generally higher in quality, and more uniform in grade.

Flake graphite deposits in Clay, Coosa, and Chilton Counties, Ala., are in two northeast-trending belts in the Ashland Mica Schist of Precambrian age (fig. 77). From 1 to 5 percent of flake graphite is disseminated in lenses or layers in the coarse siliceous mica schist. Brown (1925) identified 13 such layers, called leads by the graphite miners. Some have been traced for at least 4,000 feet, and several have been mined for 500 feet along strike without exposing their ends. Total length of some deposits may be measurable in miles, although not all is necessarily of ore grade. Thickness of recognizable deposits ranges from a few feet to more than 100 feet.

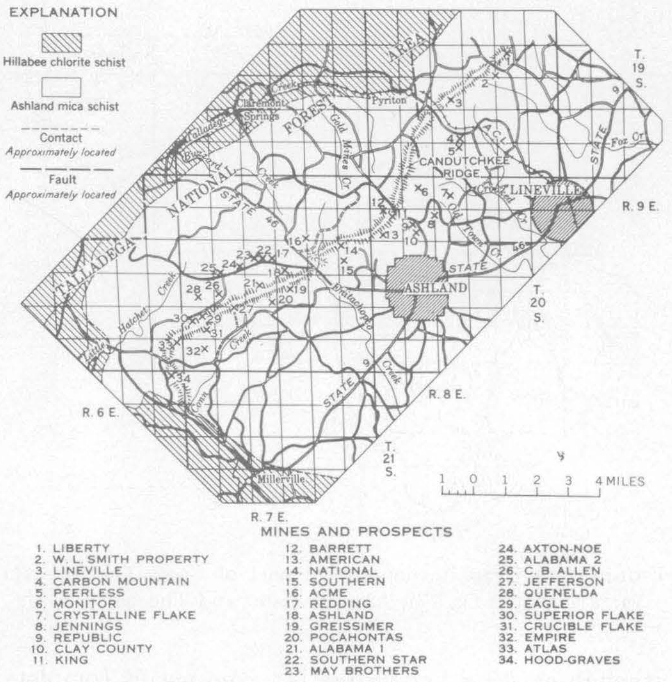


FIGURE 78.—Graphite mines and prospects in part of Clay County, Ala. (Area shown in fig. 77). After Pallister and Thoenen (1948).

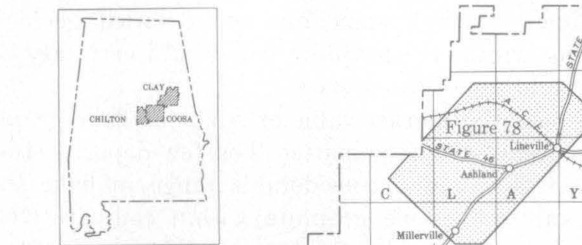


FIGURE 77.—Areas of graphite deposits in Clay, Coosa, and Chilton Counties, Ala. After Pallister and Thoenen (1948).

Most Alabama graphite deposits are tabular, relatively uniform in dip, and have few structural complications as, for example, ore bodies at the Pocahontas, Redding, C. B. Allen, and Southern Star mines (fig. 78). Others are complexly folded and faulted. The Crucible Flake mine shows intricate isoclinal folding in part of the southeast lead and its enclosing rocks, which are also offset by faults in places. Deposits at the Alabama 1 and Superior Flake mines also are faulted.

The largest number of mines is in the northeastern belt (fig. 78), and consequently the geology of that belt and the characteristics of the deposits are better known than those of the southwestern belt (figs. 79 and 80). Work by the U.S. Geological Survey (Cameron and Weis, 1960) and by the U.S. Bureau of Mines (Pallister and Thoenen, 1948) has shown that,

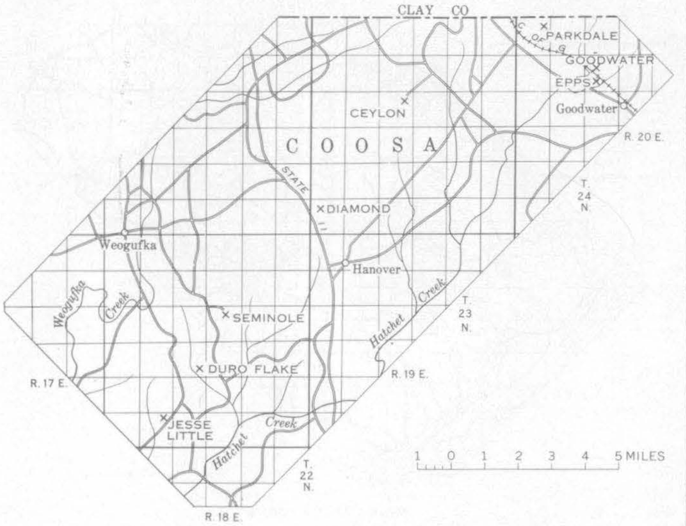


FIGURE 79.—Graphite deposits in part of Coosa County, Ala. (area shown in fig. 77). After Pallister and Thoenen (1948).

although existing knowledge is by no means complete, enough is known to give a reasonably complete picture of the nature and possible extent of the graphite resources of the area. In much of the area in both belts, intense weathering extends to depths of 50–100 feet. As a result, many of the mines were largely or entirely in material that was easily excavated and which required little crushing before beneficiation. Extensive reserves remain in weathered rock. However, a few mines produced graphite from slightly weathered or unweathered ore and demonstrated that a satisfactory product can also be recovered from fresh rock.

The locations of known graphite mines are shown in figures 78–80. Reserves remaining in these deposits are large, but almost certainly represent only a part of the total graphite resources of Alabama. Additional exploration, particularly trenching across the strike in areas near and between known deposits, would likely expose much additional graphitic rock. The nearest domestic deposits of flake graphite that might be considered competitive are those in New York, Pennsylvania, and Texas. Since about 1954, domestic production of graphite has been largely or entirely from a single mine in Texas. Production figures for that mine cannot be published, but they constitute only a small percentage of the graphite consumed in the United States.

RESOURCE POTENTIAL

Pallister and Thoenen (1948) reported that the combined reserves in known graphite deposits of Alabama amount to some 25 million tons. The amount of graphite recoverable from this ore is not precisely known, but potential resources are large. So many deposits are already known, at least in part, that additional exploration does not appear worthwhile at this time, although trenching and detailed geologic mapping within the graphite belt would certainly result in additional discoveries.

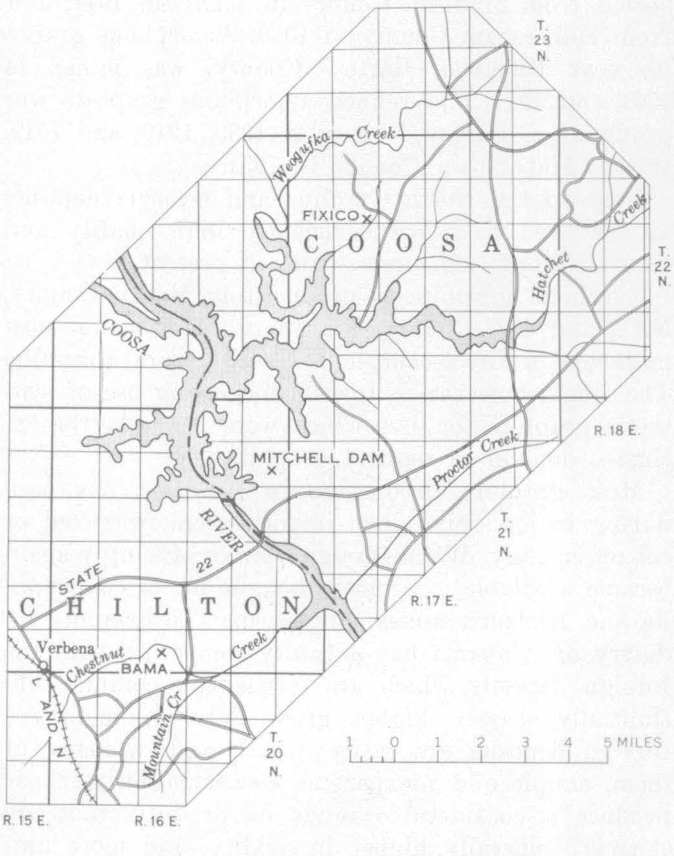


FIGURE 80.—Graphite deposits in parts of Chilton and Coosa Counties, Ala. (area shown in fig. 77). After Pallister and Thoenen (1948).

The potential market value of Alabama flake graphite resources is another matter. The few deposits studied in detail show a considerable range in flake size and total recoverable graphite within comparatively short distances, but the geologic factors that control those variations have not been recognized. Consequently, accurate prediction of the type and amount of graphite in any one deposit cannot be made. More important, little information concerning the quality of the graphite is available. Flake size is only one factor controlling the value of the product. Other properties such as density, toughness, and performance in various uses are not well known, and the degree to which Alabama graphite can substitute for graphite from other sources now being utilized has never been adequately determined. Further, the ability of Alabama producers to furnish a uniform product or range of products for industry has never been fully tested.

Adequate testing of the graphite to determine the full range of potential products would be expensive and time consuming.

It is concluded that the resource potential is large, but the future outlook is limited at best because of the small size of the potential market, the relatively low grade of most deposits, and the difficulties that beset the domestic producer in trying to gain a market already supplied from competitive sources.

KYANITE GROUP OF MINERALS

By Gilbert H. Espenshade, U.S. Geological Survey, and Nils A. Eilertsen, U.S. Bureau of Mines

USES AND PRODUCTION

The kyanite or sillimanite group of minerals consists of kyanite, sillimanite, and andalusite—all with the same chemical composition ($Al_2O_3 \cdot SiO_2$)—and topaz and dumortierite, which also are aluminum silicate minerals. When heated to high temperatures, these minerals all convert to the compound mullite ($3Al_2O_3 \cdot 2SiO_2$) and silica glass; refractories made from these materials are commonly known as mullite refractories. Owing to their high-alumina content, mullite refractories will withstand high temperatures, abrupt temperature change, and corrosive action, such as occur in metallurgical and glass furnaces and certain types of kilns and boilers.

Mullite can also be made from various mixtures of aluminous and siliceous materials such as bauxite, Bayer process alumina, clay and silica sand; this type of mullite is called synthetic mullite. The coarse fraction in refractory brick and other shapes is made from synthetic mullite and imported lump kyanite. Some fine-grained domestic kyanite concentrate is blended with this coarse material, but the bulk of domestic kyanite concentrates is used for refractory cements, mortars, and ramming mixtures. Domestic kyanite concentrate can also be used as an additive to increase the alumina content of fire clay in order to make higher heat duty refractories.

Kyanite was once produced by mines within Appalachia in the Burnsville-Swannanoa area, North Carolina, and the Clarkesville district, Georgia, but the mines closed between 1944 and 1949. The entire U.S. production now comes from four mines in Virginia, South Carolina, and Georgia, all of which are east of Appalachia. The supply pattern of the kyanite industry has changed markedly since 1945, as can be seen in table 116. Imports exceeded domestic production for many years, and synthetic mullite production was small. Now U.S. consumption, which has increased considerably, is dominantly supplied by domestic kyanite and synthetic mullite, and exports exceed imports in amount. The domestic consumption of gyanite and synthetic mullite in 1964 was estimated to exceed 100,000 tons; imports were 2,386 tons in 1964, and exports 6,080 tons (J. D. Cooper, 1965b).

Table 116.—*Kyanite and synthetic mullite production, imports, and exports*

	1945	1951–55 (yearly average)	1960	1963
Kyanite production (estimated)[1] short tons	12,300	22,000	33,600	44,800
Synthetic mullite production [2] do	?	17,000	21,497	29,588
Kyanite imports [2] do	14,554	9,531	6,052	2,624
Kyanite exports [2] do	307	1,203	3,255	5,050
Price, domestic kyanite, per ton [3]	\$24–\$35	\$26–\$40	\$42–\$55	\$42–\$55

[1] Varley (1965, p. 104). Varley's estimates are given here to indicate the order of magnitude; accurate production figures are withheld to avoid disclosing individual company information.

[2] Klinefelter and Cooper (1961, p. 32–33) and U.S. Bur. Mines Minerals Yearbooks.

[3] First figure is for 35-mesh concentrates, second figure is for 200-mesh.

Although the domestic demand for kyanite and mullite has increased steadily and these products are highly important for specialized uses, the industry is small. J. D. Cooper (in U.S. Bur. Mines, 1965a, p. 481) reported that about 135 people were employed in mining and milling kyanite in 1963, and probably not more than 500 people in the manufacture of synthetic mullite and mullite refractories.

Normally, domestic kyanite operations lose 10–15 percent of the total kyanite in desliming and thickening, and an additional 5–10 percent is lost as unfloated kyanite. These losses, when combined with magnetic separation losses of about 15 percent, lower the overall recovery of kyanite to 60–70 percent. A research program of the Bureau of Mines is currently underway at the Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala., to improve the grade of kyanite concentrates while increasing recovery and reducing processing costs. Other objectives are to develop methods for producing low-iron titanium-free kyanite for use in porcelain and glass manufacture.

DEPOSITS IN APPALACHIA

Kyanite, sillimanite, and andalusite are relatively common minerals that are widespread in certain types of metamorphic rocks in many parts of the world; topaz and dumortierite are much less common. In the southeastern States, members of the kyanite group occur in several types of deposits: quartzose rock, micaceous schist and gneiss, quartz veins and pegmatites, and stream and beach placers (Espenshade and Potter, 1960; Espenshade, 1962). The kyanite group minerals are most abundant in quartzose deposits and in some micaceous schist and gneiss. All except dumortierite occur in quartzose deposits east of Appalachia in a belt that extends from central Virginia to eastern Georgia. Kyanite and sillimanite are the only members of the group that are known to occur in abundance within Appalachia, principally as deposits in micaceous schist and gneiss. The deposits lie in several belts in the area of metamorphic rocks that borders the southeastern part of Appalachia (fig. 81); minor occurrences in schist, quartz veins, pegmatites, and placers are not shown on this map.

Kyanite-bearing schist and gneiss are known at various places in the mountains of the western Carolinas and northern Georgia, the major deposits being those of the Burnsville-Swannanoa area in Buncombe, Yancey, and Mitchell Counties, N.C., and in the Clarkesville district, Habersham and Rabun Counties, Ga., and Oconee County, S.C. In the Burnsville-Swannanoa area, kyanite schist and gneiss occur in a belt several miles wide and about 30 miles long (Espenshade and Potter, 1960, p. 60–62; Brobst, 1962, p. 23–24). Kyanite was mined here by the Yancey Cyanite Co. from 1934 to 1944 from surface and underground workings in kyanite-garnet-mica gneiss on the slopes of Bowlens Pyramid and Celo Knob in the northern part of the belt. Kyanite content of ore mined was 10–11 percent in the early days of operation, and 7.0–7.5 percent in July 1943. Brobst (1962, p. 23–24) concluded that large amounts of gneiss in the area have about 15 percent kyanite, and as much as 40 percent locally. In the Clarkesville district, kyanite occurs in graphitic mica schist in circular belts surrounding a large dome (Prindle and others, 1935, p. 7–19; Teague and Furcron, 1948; Espenshade and Potter, 1960, p. 99–102). Kyanite was mined at several localities between 1932 and 1949 from residual soil and weathered schist near Clarkesville and from a placer deposit on Raper Creek. Kyanite content of the schist in the Clarkesville district ranges from 1 to 15 percent and averages about 6–8 percent. Other kyanite schist deposits, which seem to be smaller than the ones just described, occur in Swain County, N.C. (Hadley and Goldsmith, 1963, p. 99–104; Hadley, oral commun., 1966), and Fannin and Union Counties, Ga. (Prindle and others, 1935, p. 19–23).

The principal deposits of sillimanite lie to the east of the kyanite deposits; they consist of sillimanite-biotite-quartz schist in broad belts that extend from central North Carolina (Cliffside-Elkin belt) through

FIGURE 81.—Principal kyanite and sillimanite deposits in the southeastern part of the Appalachian Region.

South Carolina to eastern Georgia. The boundaries of these belts are generalized on fig. 81; there are extensive areas within the belts where sillimanite is scarce or absent. Sillimanite schist also occurs in the Warne-Sylva belt in southwestern North Carolina and Towns County, Ga., near the westernmost kyanite deposits; kyanite and sillimanite have been found together at several places in the Warne-Sylva belt.

Investigation of the sillimanite deposits of the southeastern United States was stimulated during World War II and afterward by difficulties in maintaining adequate supplies of kyanite from domestic production and imports. Considerable information has been gathered about the distribution and characteristics of the deposits (Furcron and Teague, 1945; L. L. Smith, 1945; Hudson, 1946; Teague, 1950; Hash and Van Horn, 1951; Overstreet and Griffitts, 1955; Espenshade and Potter, 1960; Overstreet and Bell, 1965). Samples of sillimanite schist were taken from many localities and tested to see if concentrates of sillimanite could be made. In many samples, satisfactory separation of sillimanite was found to be difficult because of one or more of the following characteristics: very fine grain size of much of the sillimanite, intimate intergrowths of sillimanite with mica, sericitic alteration of sillimanite, and coatings of iron oxide on sillimanite. The most promising results were obtained from samples from Dudley Shoals, Caldwell County, N.C., and Wards Creek, Cleveland County, N.C., (just east of Appalachia) according to Hash and Van Horn (1951, p. 6, 12–16), from the Pelzer deposit, Greenville County, S.C. (Hudson, 1946, p. 5–6), and from Elbert and Hart Counties, Ga. (just east of the Appalachia boundary), according to Furcron and Teague (1945, p. 11–19), Hudson (1946, p. 6–8), and Teague (1950). The Warne-Sylva belt was thought by Hash and Van Horn (1951, p. 18–20) to be about a mile wide, but recent work by F. G. Lesure (oral commun., 1966) indicates that sillimanite occurs intermittently across the strike for about 10 miles near Franklin, Macon County, N.C. Sillimanite content was found to vary widely in the different belts. Although in many places it was 10 percent or less, a content of 17 percent sillimanite was found in two large samples, one of 7,500 pounds from the Pelzer area, S.C., and one of 8,700 pounds from Hart County, Ga. (Hudson, 1946, p. 9–11).

RESOURCE POTENTIAL

The productive kyanite mines of the Piedmont province east of Appalachia are all in quartzose deposits that contain as much as 25–30 percent kyanite. Reserves of these rich quartzose ores are on the order of 100 million tons (Espenshade and Potter, 1960, p. 34), sufficient to last for many years at present production rates. Within Appalachia, the amount of metamorphic rock containing kyanite or sillimanite is probably much larger, but the content of kyanite or sillimanite is only about half that of the productive quartzose ores.

The resources of kyanite and sillimanite in the Appalachian Region are enormous, and although at present they do not compete with deposits near to, but outside, the region, they constitute a potential resource for the future.

LITHIUM AND BERYLLIUM MINERALS

By WALLACE R. GRIFFITTS, U.S. Geological Survey, and JOHN W. SWEENEY, U.S. Bureau of Mines

Lithium and beryllium minerals, used for the manufacture of the respective metals and for many chemical uses, are found in the southern Piedmont (fig. 82) in pegmatites of the tin-spodumene belt. Very little of the lithium- and beryllium-bearing part of this belt extends into Appalachia. During 1964, spodumene (lithium mineral) was produced from pegmatites outside but near the border of Appalachia. Beryl, the beryllium mineral present in small amounts, was not recovered.

Lithium is soft, silver-white, and the lightest of all metals. It is used in various forms in the production of greases, batteries, welding and brazing fluxes, ceramics, air-conditioning refrigerants, bleaches, and for the generation of hydrogen. Lithium-magnesium alloys have been developed which show promise for use in aerospace and industrial structural components. Additional detail regarding uses of lithium is given by Eilertsen (in U.S. Bur. Mines, 1965a, p. 531–536).

Most lithium used in the United States is obtained (1) from the minerals spodumene, amblygonite, petalite, and lepidolite, which are mined from pegmatite deposits, or (2) from the brines of Searles Lake, Calif. The United States has substantial reserves of lithium and produces about two-thirds of its requirements. The other third is obtained mainly from South Africa and Canada.

The tin-spodumene belt, which extends from near Lincolnton, N.C., to Gaffney, S.C., contains one of the largest resources of lithium minerals in the world (for a geological description, see the section on "Tin," p. 435). The lithium of this belt is all contained in the mineral spodumene ($LiAlSi_2O_6$), which is rather evenly distributed through masses of spodumene-microcline-albite-quartz pegmatite that may exceed 200 feet in width or 2,000 feet in length. Nearly all the lithium deposits of this belt are in North Carolina, outside Appalachia. The Foote Mineral Co. and

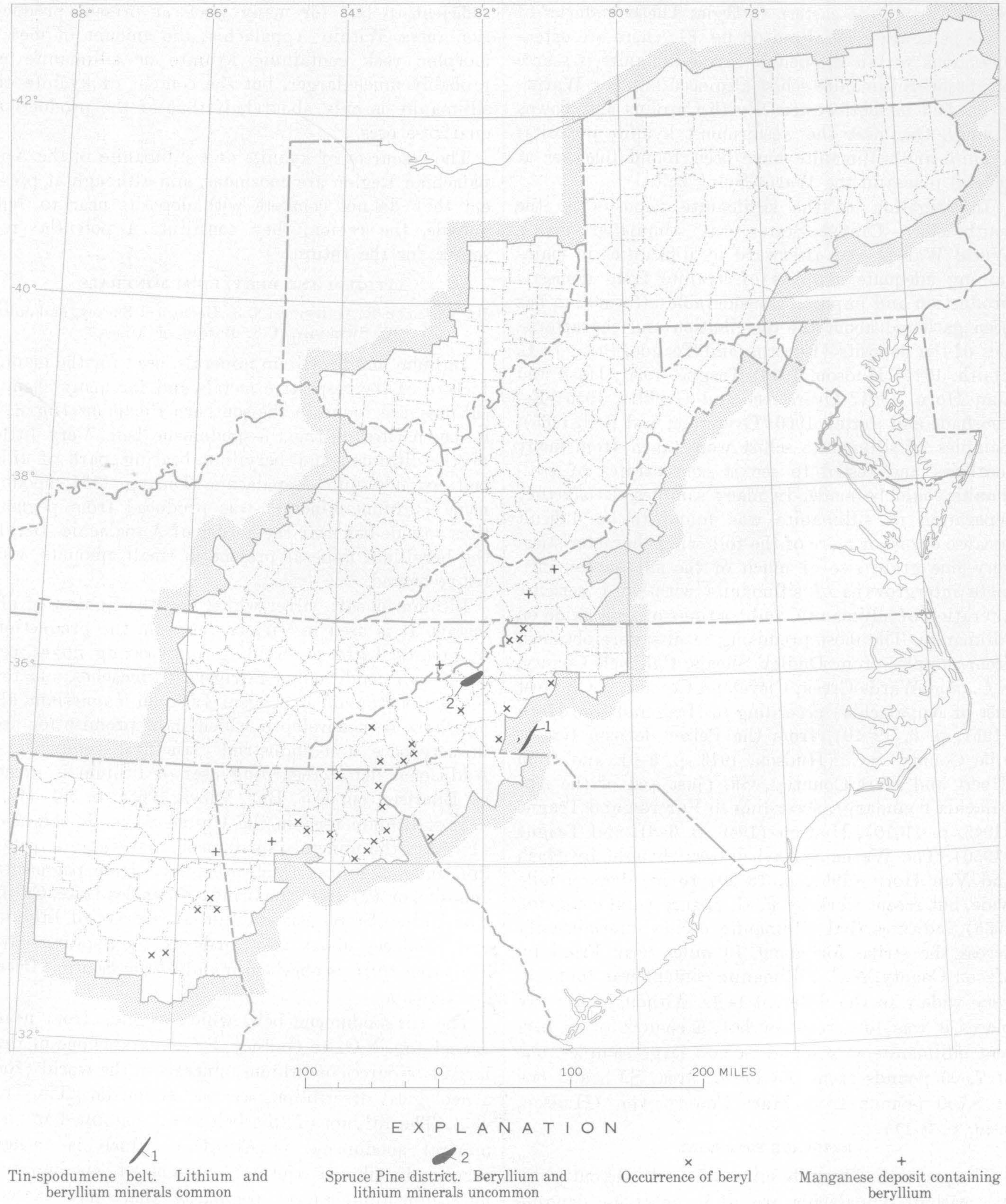


FIGURE 82.—Lithium and beryllium occurrences in the Appalachian Region.

the Lithium Corp. of America have built large plants in North Carolina just outside Appalachia, to exploit these deposits. Concentrates of spodumene produced by the Foote Mineral Co. are processed at Sunbright, Scott County, Va., to produce lithium hydroxide. The lithium-rich pegmatites barely extend into Cherokee County (within Appalachia), and the deposits there are small and of little or no economic importance.

Specimens of the lithium mica, lepidolite, have been found in Appalachia in Yancey County, N.C., but not in economically important amounts. Lithiophorite, a lithium-bearing manganese mineral in some Appalachian manganese deposits, is of little or no economic importance. Hiddenite, the gem variety of spodumene, was formerly mined in a pegmatite near Hiddenite, Alexander County, N.C.

Both the Foote Mineral Co. and the Lithium Corp. are developing deposits of lithium-bearing brines in the Western United States. Production from these western deposits will inhibit an early expansion of the North Carolina operations, but will also delay the exhaustion of the spodumene deposits and thus the life of the mining operations. Brines containing more than 200 ppm in lithium are found in the Onondaga Limestone and Oriskany Sandstone of Devonian age in gas wells at a depth of 7,500 feet in Westmoreland County, Pa.; however, no brines are presently being treated for lithium in Appalachia.

Beryllium is the seventh lightest metal and is used in alloying some softer and ductile metals, in aerospace applications, as a moderator and reflector material in nuclear reactors, and in oxide form for ceramic applications. The largest use is in beryllium-copper alloy which is frequently used in the manufacture of antisparking tools, and in springs, bellows, diaphragms, and engine parts. Additional detail regarding uses of beryllium is given by Eilertsen (in U.S. Bur. Mines, 1965a, p. 101–109).

Beryllium is consumed in much smaller amounts than many other metals; the consumption of ore by the United States increased from 1,013 tons in 1946 to an all-time high of only 9,692 tons in 1960. Adequate and increasing supplies of beryllium ore have been maintained by imports, mainly from pegmatite deposits in South Africa, Brazil, Argentina, India, and Australia. Since 1960, less than 4 percent of the total supply has been from domestic deposits.

The most common beryllium mineral and the only one that is an ore mineral is beryl ($Be_3Al_2Si_6O_{18}$). Other beryllium minerals that have been found in the southeastern United States are bertrandite ($Be_4Si_2O_7(OH)_2$), phenakite (Be_2SiO_4), and helvite ($Mn_4Be_3Si_3O_{12}{\bullet}S$), but none of these has been found within Appalachia.

Beryllium minerals are found in pegmatites and in a variety of mineral deposits of other types, but only pegmatite deposits have been found in Appalachia. The only nonpegmatitic deposits in the Southeastern United States are the high-temperature tin-bearing veins at Irish Creek, Va., east of Appalachia. Beryllium has been found in concentrations of 0.01 percent or more in several manganese deposits in Appalachia, but no beryllium mineral has been identified in any of these. The occurrence is of academic but not of economic interest.

The pegmatite deposits in Appalachia generally contain less beryl than those in Northeastern United States or in South Dakota. Only in the tin-spodumene belt that extends about from Lincolnton, N.C., to Gaffney, S.C., do most individual bodies of pegmatite contain beryl. (See section on "Tin," p. 435). The amount of beryl in this belt is immense—several hundred thousand tons at least—but the mineral is in tiny particles that are difficult to recover, and the grade is low, about ½ percent in the rock. Only the southern tip of the beryl-rich part of the belt, containing few deposits, is in Appalachia. In other parts of Appalachia, beryl crystals are found here and there in pegmatites that are mined for feldspar or mica. More crystals have probably been found in Mitchell, Avery, and Yancey Counties, N.C., than in other areas. However, few of these occurrences are of economic interest.

Within 10 years the pegmatite deposits may encounter very severe competition from beryllium deposits of other types, particularly from those in Utah, which have large reserves of ore averaging almost 10 times more beryllium per ton of rock than ores of the tin-spodumene belt. There is little likelihood that an industry based upon local beryllium deposits can be developed in the southeastern United States. In the foreseeable future, the annual income from byproduct beryl in this region probably will not exceed a few thousand dollars.

MICA

By F. G. Lesure, U.S. Geological Survey, and L. E. Shirley, U.S. Bureau of Mines

Mica is the general name for several complex hydrous aluminum silicate minerals. The principal mica minerals are muscovite (white mica), biotite (black mica), and phlogopite (amber mica). All have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. The micas are common minerals. Muscovite is the most important commercially in the United States, but some biotite has been mined. Commercial phlogopite comes from Canada and the Malagasy Republic.

TYPES OF MICA, USES, AND PRICES

Two types of mica are sold: sheet mica which must be relatively flat, free from most defects, and large enough that it can be cut in pieces 1 square inch or larger; and scrap mica which includes all mica that does no meet sheet mica specifications and is generally ground to a powder. Small sheets of untrimmed mica of poorer quality that can be punched or trimmed into disks 1 inch or larger in diameter are classified as punch mica and are included in the general term "sheet mica." Built-up mica made from very thin sheets ("splittings") and reconstituted mica made from delaminated scrap can be substituted for larger sheet mica for some uses.

Sheet mica

Sheet-quality muscovite is obtained from large crystals, generally called books, scattered throughout unzoned pegmatites or concentrated in certain units of zoned pegmatites. Sheet mica is an important dielectric and insulating material used in the manufacture of electronic and electrical equipment such as electronic vacuum tubes for radio and television, capacitors, motors, transformers, generators, and electrical household appliances. No other electrical insulating material, either natural or synthetic, possesses all the physical and electrical properties that have made mica important (Mantague, 1960, p. 552). Nonelectronic uses include shields for high-temperature steam-gage glasses, regulator diaphrams, and, in years gone by, stove windows and lamp chimneys. The value of sheet mica depends on the color, size, structure, and quality of the natural crystals. The manner in which the crystals are obtained by mining and the care and skill of preparation are also important factors affecting the value. Quality of sheet mica varies widely within and between mica districts and even within a single deposit or mica-rich shoot. A detailed discussion of the quality and classification of mica from the Appalachian Region has been written by Jahns and Lancaster (1950), and only a brief summary is given here.

Muscovite in sheets as thin as paper is generally colorless but thicker sheets may range in color from red- or yellow-brown to greenish brown or green. Reddish brown or ruby mica brings a higher price than green mica.

The best sheet mica is clear, flat, and free of mineral inclusions and structural defects. Mica that contains primary or secondary inclusions or impurities is called stained mica. The primary impurities include air bubbles, mottling, and mineral intergrowths and inclusions; the secondary impurities are air creep, clay, iron oxide and manganese oxide inclusions, and organic or vegetable stain (Jahns and Lancaster, 1950, p. 12). Specks, spots, and streaks of magnetite, hematite, and pyrite occur sparsely or in dense concentrations between sheets of stained mica in unweathered deposits. Films of clay, limonite, or manganese oxides coat the sheets of mica in some weathered deposits. Some mica books are difficult to split because they contain crystals of biotite, quartz, feldspar, garnet, apatite, tourmaline, or other minerals that are interlayered with the mica sheets or penetrate several sheets. Such books are generally said to be "tied."

Structural defects of the mica crystals are also of primary and secondary origin. The most common primary defects are reeves and wedge structure. Reeves are lines, striations, or shallow corrugations that lie in the plane of the cleavage. Where two sets of reeves intersect at an angle of nearly 60°, the resulting mica is said to have "A" structure. Wedge structure is caused by interlayering of sheets of unequal size. Some muscovite books have discontinuous sheets, partial intergrowth of sheets, or internal distortions and do not split freely. These books, termed "locky," or "tangled," are of value only for scrap. Secondary structural defects include bending, cracking, twisting, and ruling, all caused by deformation of the mica after crystallization. Bending ranges from slight waves to right-angle or S-shaped bends. Ruling is a secondary cleavage that cuts the basal cleavage at an angle of about 67°.

Crude books of mica must be at least 2 inches across to yield trimmed sheet mica. The average commercial book is about 5 inches across and about one-fifth to one-half as thick as wide. In some deposits, books measuring 8–12 inches are common. A few larger books that weigh 50–300 pounds are found. Probably the largest book of muscovite reported from the Appalachian Region was a book of "A" mica weighing 4,320 pounds and measuring 36 by 42 inches across and 32 inches thick from the Fannie Gouge mine in Yancey County, N.C. (Urban, 1932, p. 4).

Scrap mica.

Many mica deposits contain only scrap-quality mica, and a large amount of scrap is produced during the mining, trimming, and fabricating of sheet mica. Most scrap mica, however, is produced from weathered alaskite bodies and as a byproduct from the mining of feldspar and clay. Some scrap is also produced from mica schist. Scrap mica obtained from clay or feldspar deposits or from mica schist is generally finely divided and is often called flake mica. Most scrap mica is ground to a powdery material by either a wet or dry process.

Dry-ground mica is used chiefly in the manufacture of rolled roofing or asphalt shingles, wallboard, cement, oil-well drilling mud, paints, rubber goods, plastic, and welding rods. Wet-ground mica is used chiefly in the manufacture of wall paper, rubber goods, and paint. The value of scrap mica depends on the color and the freedom from impurities. There are few rigid requirements. Mica that is very pale appears white when ground and is more desirable than colored varieties. Scrap mica produced during the preparation of sheet mica is high quality because of its relative freedom from quartz and feldspar. In general, scrap mica should be free of mud and clay, have a minimum of stain, and contain little or no grit. Biotite content is generally kept below 2 percent.

Prices

The selling price of mica can range from only a few cents per pound for punch or scrap to many dollars a pound for large sheets of the best quality. In 1958 the price schedule under the U.S. Government purchase program for sheet mica of superior quality (termed "good stained or better") ranged from $17.50 per pound for the smallest sizes to $70 per pound for the large sizes. Prices in 1958 for India mica of similar quality ranged from $2.50 to $37 per pound (Montague, 1960, table 8). In 1965 prices for sheet mica as quoted in "Metal and Mineral Markets" (published by Engineering and Mining Journal) ranged from 70¢ a pound for sheets 1½ inches across to $8.00 a pound for sheets 8 inches or more across. Punch mica brought 7–12¢ a pound. Scrap mica generally brought $30–40 per short ton. Ground mica prices ranged from 3¢–4¢ per pound dry-ground to 6.5¢–8.75¢ per pound wet-ground.

MINING AND PREPARATION

Sheet-mica mining methods are simple and sometimes primitive. Most of the mines are small and generally shallow. Only a minimum of equipment, including compressor, jack hammer, hoist, and pump, is generally used. Open-pit methods are used where possible, but most deposits are mined to some extent in underground workings that are generally irregular and follow the mica in rich shoots or from one rich pocket to another. Drilling and blasting must be done carefully to avoid damage to the mica. After a blast, crystals of mica are handpicked from broken rock. Large rocks are broken with sledges, and all material is hoisted to the surface. Because of the hand work involved, mining costs are high in relation to the average amount of sheet mica found in most deposits.

Processing of sheet mica requires extensive hand labor in cobbing or removing dirt or rock from the books, in rifting or splitting the books into thin sheets, and in trimming broken edges and imperfections from the sheets. Complete quantitative data are not available, but estimates of recovery of good trimmed mica from crude mica range from 2 to 8 percent for the average mine and are as much as 19 percent from good quality crude mica in a few mines (Urban, 1932; Amos, 1959, p. 33, table 1).

Details of the preparation and classification of mica and trade practices of the industry are too elaborate to discuss here. The best published reference is by Chand Mull Rajgarhia (1951), whose knowledge of the subject was based on a lifetime of experience in the sheet mica business in India, which supplies most of the world's mica. Excellent references written in the United States are by Wierum and others (1938), Jahns and Lancaster (1950), Montague (1960), and Skow (1962).

Most economic deposits of scrap mica are so deeply weathered that they can be mined in bulk with power equipment and the ore washed and screened to recover the mica. The content of recoverable mica ranges from 3 to 20 percent. In simple washing plant operations, mica smaller than 8 mesh is not recovered readily, but by the use of spiral concentrators, better recovery is possible (Broadhurst and Hash, 1953, p. 6; Skow, 1962, p. 86). Flake mica is recovered by spiral concentrators in the processing of clay and feldspar.

Recent studies by the U.S. Bureau of Mines have shown the practicality of flotation methods to recover finer size fractions in weathered mica pegmatite ore (Browning and others, 1965) and mica schist ore (Browning and Bennett, 1965). Six plants, located in California, Alabama, and North Carolina, either are, or soon will be using these new methods. These plants will produce about half the annual U.S. total of scrap mica. In North Carolina alone, more than 50 deposits of mica schist have been evaluated in recent years by the North Carolina Division of Mineral Resources and the State Mineral Research Laboratory.

Scrap mica from sheet operations, from scrap mining, and from clay and feldspar mining may be blended before grinding. Wet-ground mica is produced in chaser mills using wooden grinding surfaces. The finished product is usually white, has a greasy unguent feel, and has a pronounced sheen (Broadhurst and Hash, 1953, p. 9). Individual particles are highly polished and have smooth edges. Particle size generally ranges from 80 to 350 mesh. Dry-ground mica is produced in rod mills, hammer mills, cage disintegrators and various types of attrition mills (Skow, 1962, p. 89). The product is a flat white powder having little luster; individual particles have rough edges and little polish. Particle size ranges from 20 to 250 mesh. Some special micronized mica has particle sizes of 1,000–3,000 mesh or 5–20 microns.

HISTORY AND PRODUCTION

Mica was mined in North Carolina, Virginia, and Alabama by the Indians more than a thousand years before the coming of the white man (Prufer, 1964, p. 90), but modern mining began in New Hampshire in 1803 and in North Carolina in 1867. The grinding of scrap mica began in a small way in North Carolina about 1870 (Broadhurst and Hash, 1953, p. 13) and grew rapidly after 1890. In Appalachia, mica has been produced in a region extending from western North Carolina through northern South Carolina and northern Georgia to central Alabama.

North Carolina is the principal mica-producing State in Appalachia and the Nation, and has produced more than 99 percent of the total sheet mica and 78 percent of the total scrap mica in Appalachia. Although sheet mica has been produced in 20 counties and scrap mica in 18, the principal sheet mica-producing counties have been Mitchell, Avery, Yancey, and Macon, listed in order of output; the principal scrap-producing counties have been Yancey, Mitchell, Avery, and Macon.

Mica mining began in South Carolina about 1900, and there has been only sporadic mining activity since that time. Most of the sheet and scrap mica production in the Appalachian area has come from Greenville and Anderson Counties. Cherokee, Oconee, Pickens, and Spartanburg Counties have produced small quantities of sheet mica. The principal flake-mica production comes from Lancaster County, outside Appalachia. The recorded sheet-mica production in the Appalachian counties of South Carolina, in the period 1925–65, was 12,000 pounds valued at $54,000 (1958 constant dollars); total scrap-mica production was 133 tons valued at $2,000 (1958 constant dollars).

Most mica mined in the early years in Georgia came from counties within Appalachia. Early records show that mica was mined in Rabun County in 1882, in Cherokee and Pickens Counties in 1889, and in Lumpkin and Union Counties in 1898 (Furcron and Teague, 1943, p. 13–14). Production of sheet and (or) scrap mica also has been recorded from Bartow, Franklin, Habersham, and Hall Counties. These nine counties in 1925–64 produced 30,000 pounds of sheet mica valued at $132,000 (1958 constant dollars) and scrap mica totaling 148,000 short tons valued at $3.0 million (1958 constant dollars).

Commercial mica mining in Alabama began about 1870 in Randolph County and 1874 in Chilton County. Most mining activity has been in Randolph, Clay, and Cleburne Counties, although mica has also been produced in Chambers, Coosa, Elmore, and Tallapoosa Counties. Total recorded production in Alabama for 1925–64 was 52,000 pounds of sheet mica valued at $118,000 (1958 constant dollars) and 97,000 short tons of scrap mica valued at $3.6 million (1958 constant dollars).

Scrap mica was recovered from Recent silt deposits in Davy Crockett Lake, Greene County, Tenn., from 1956 to 1960.

In Pennsylvania, ground mica is produced from sericite schist in Cumberland and Adams Counties, just east of the Appalachian Region.

The United States produces only a small amount of its domestic needs for sheet mica and relies on imports from India and Brazil for its principal requirements. Production outside the Appalachian Region has come mostly from New Hampshire, Maine, Connecticut, Georgia, Virginia, South Dakota, and New Mexico. The total production of sheet mica in the United States in 1964 was 243,000 pounds valued at $48,000 (1958 constant dollars); most of this mica probably came from North Carolina, and much of it probably from counties in Appalachia. The total production of scrap mica in the United States in 1964 totaled 115,000 short tons valued at $3.3 million (1958 constant dollars). From 1925 through 1964, 43.2 million pounds of sheet mica and nearly 2 million tons of scrap mica were produced in the United States. During the same period the Appalachian Region has a recorded production of nearly 10 million pounds of sheet mica and 1.2 million tons of scrap mica. Because production records in mica mining are generally poor, the actual sheet-mica production in Appalachia was probably greater than the recorded total. Yearly production and value of sheet and scrap mica in Appalachia and the United States are shown in table 117.

GEOLOGY

Deposits of sheet and scrap mica in the Appalachian Region are restricted to areas of metamorphic and igneous rock in the Blue Ridge and Piedmont provinces in North Carolina, South Carolina, Georgia, and Alabama. Sheet mica deposits occur only in pegmatites; scrap mica deposits are found in pegmatites, granite, and mica-rich metamorphic rocks.

Pegmatites are generally light-colored, coarsely crystalline igneous rocks, commonly found as dikes

TABLE 117.—*Production of mica, 1925–64*

[Source: U.S. Bur. Mines]

Year	Sheet				Scrap			
	Appalachia		United States		Appalachia		United States	
	Pounds	Value, in 1958 constant dollars (thousands)	Pounds	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1925	82, 022	40	1, 793, 865	550	2, 359	58	9, 695	297
1926	186, 319	89	2, 172, 159	731	432	16	7, 043	250
1927	403, 580	146	1, 512, 492	385	2, 138	68	6, 280	200
1928	454, 378	162	1, 681, 777	418	3, 540	102	7, 760	239
1929	469, 046	143	2, 035, 128	507	2, 608	81	6, 253	209
1930	353, 763	108	1, 465, 485	320	3, 940	121	6, 732	197
1931	138, 273	38	962, 953	228	3, 616	115	6, 621	202
1932	28, 158	13	338, 997	106	2, 667	82	7, 040	194
1933	43, 718	23	364, 540	126	2, 719	87	8, 751	234
1934	99, 210	41	583, 528	201	1, 843	63	7, 719	224
1935	144, 049	49	936, 633	368	9, 651	327	18, 852	558
1936	153, 182	87	1, 319, 233	468	10, 079	352	20, 955	599
1937	231, 039	124	1, 694, 538	622	12, 830	464	25, 196	775
1938	96, 727	22	939, 507	298	11, 298	344	20, 257	548
1939	143, 805	82	813, 708	302	7, 693	264	24, 672	678
1940	327, 442	175	1, 625, 437	628	5, 680	192	22, 386	677
1941	373, 297	232	2, 666, 453	1, 125	8, 100	213	32, 500	879
1942	651, 103	371	2, 761, 844	1, 223	10, 658	327	43, 262	1, 132
1943	583, 359	1, 119	3, 448, 199	5, 029	21, 182	632	46, 138	1, 150
1944	719, 307	1, 913	1, 523, 313	4, 564	12, 302	374	51, 727	1, 523
1945	194, 900	1, 601	1, 298, 587	971	18, 211	483	41, 060	1, 070
1946	138, 534	77	1, 078, 867	284	22, 232	614	53, 602	1, 355
1947	67, 781	95	415, 589	140	28, 857	682	49, 797	1, 325
1948	235, 474	50	270, 042	53	42, 965	1, 097	52, 157	1, 265
1949	44, 228	16	513, 994	152	23, 420	688	32, 856	917
1950	487, 136	117	578, 818	144	54, 832	1, 561	69, 360	1, 985
1951	167, 618	56	594, 884	170	47, 842	1, 345	71, 871	2, 000
1952	85, 685	498	697, 989	956	55, 193	1, 501	75, 236	2, 048
1953	336, 220	1, 275	849, 394	2, 284	52, 951	1, 292	73, 259	1, 934
1954	362, 285	1, 858	668, 788	2, 576	60, 049	1, 381	81, 073	1, 886
1955	280, 313	2, 776	642, 113	3, 667	61, 099	1, 384	95, 432	2, 239
1956	488, 722	1, 979	887, 871	2, 905	56, 532	1, 217	86, 309	1, 949
1957	244, 125	1, 481	690, 052	2, 533	63, 929	1, 442	92, 438	2, 143
1958	333, 052	1, 671	661, 344	2, 844	65, 921	1, 413	93, 347	2, 065
1959	198, 232	1, 709	706, 395	3, 372	70, 662	1, 781	101, 541	2, 628
1960	150, 878	1, 502	587, 401	3, 080	68, 492	1, 763	97, 912	2, 674
1961	245, 275	2, 203	526, 007	3, 366	66, 127	1, 413	99, 044	2, 402
1962	64, 194	835	363, 016	1, 290	69, 034	1, 546	107, 702	2, 621
1963	----------	----------	102, 961	13	64, 536	1, 513	109, 323	2, 765
1964	(1)	(1)	242, 662	58	71, 145	1, 529	114, 729	3, 336
Total	9, 878, 889	24, 787	43, 016, 563	49, 057	1, 199, 364	29, 927	1, 977, 887	51, 352

[1] Data withheld to avoid disclosure of individual company information.

or sills in metamorphic rocks or in large granitic intrusions. Individual mineral grains and crystals range in length from an inch or less to many feet, and a large variation in grain size within a single pegmatite body is common.

Pegmatites range from small pods and thin seams to large masses hundreds of feet thick and thousands of feet long. In general they are tabular or lenticular bodies. Some pinch and swell either along strike, downdip, or both. Where pinch and swell are pronounced, the pegmatite body may appear to be a series of lenses following a narrow zone in the metamorphic country rock. Most lenticular bodies are discoidal, having one axis shorter than the other two, but some have one axis much longer and are best described as tonguelike or pipelike. In some pegmatite districts most of the deposits are concordant to the foliation of the enclosing country rock; in others, discordant bodies emplaced along joints or faults predominate. Large bodies that appear concordant to the regional structure may be discordant in detail and probably occupy shear zones. Branched, folded, or irregular bodies may be present in areas of complex structure. Elongate bodies and minor bulges or rolls in concordant pegmatites are generally parallel to the plunge of minor structures in the country rock.

Pegmatites are composed mostly of feldspar, quartz, and mica, but may contain accessory minerals such as garnet, tourmaline, apatite, and beryl and unusual or rare minerals of many types. Many rare pegmatite minerals are rich in cesium, lithium, molybdenum, niobium, rubidium, scandium, tantalum, thorium, tin, tungsten, uranium, yttrium, zirconium, and the rare earths. The many and unusual minerals found in some pegmatites make them favorite collecting sites for mineralogists and rockhounds.

Plagioclase is generally the most common feldspar in muscovite-rich pegmatite. Perthite or perthitic microcline, an intergrowth of plagioclase and microcline feldspars, is generally present and may be abundant in some pegmatites. The feldspars are discussed in greater detail in the section on "Feldspar" (p. 277).

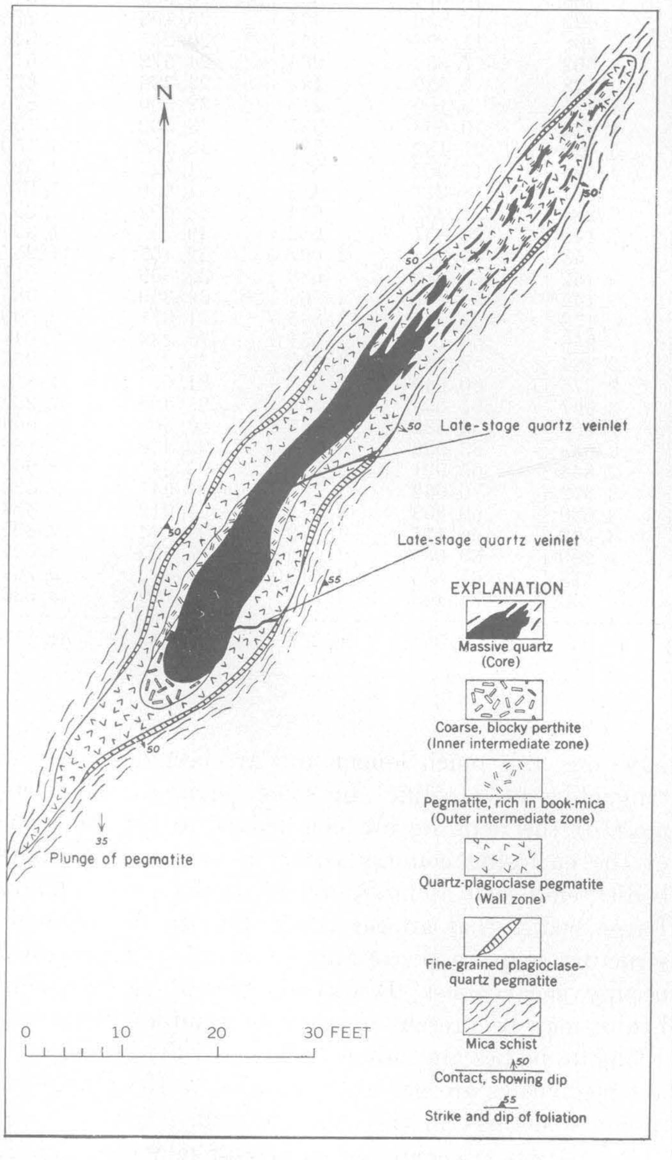


FIGURE 83.—Idealized plan of a typical Alabama pegmatite. Modified from Heinrich and Olson (1953, p. 410).

In pegmatite mined commercially, the book mica generally constitutes 2–6 percent of the rock mined. Local rich shoots or pockets might have as much as 40 percent muscovite, but large volumes of pegmatite have 2 percent or less.

In many pegmatites the minerals are more or less evenly distributed throughout, but in others the minerals are segregated into certain layers or parts of the body called zones. At places these zones can be mined selectively to recover the desired minerals by hand sorting and are, therefore, important economically. In general, zones are successive shells, complete or incomplete, that commonly reflect the shape or structure of the whole pegmatite body (fig. 83). Where best developed, the zones are concentric about an innermost zone or core, and the zones from the outermost inward to the core are called border zone, wall zone, and intermediate zones.

The structure of some zoned pegmatites is complicated by the presence of two other types of pegmatite units: fracture fillings, which are generally tabular masses of later minerals that cut previously formed zones, and replacement bodies, which are masses of later minerals that have taken the place of earlier formed minerals.

Recent studies have increased the general knowledge of the occurrence, origin, and economic importance of pegmatite deposits (Cameron and others, 1949; Jahns, 1955), and studies made during World War II have helped improve techniques of prospecting and exploration (Jahns and others, 1952; Norton and Page, 1956).

DISTRICTS IN APPALACHIA

The mica deposits of Appalachia are grouped into districts within each State (fig. 84). The largest and most productive districts for sheet mica not only in this region but also in the United States are the Spruce Pine and Franklin-Sylva districts of the Blue Ridge in North Carolina. Only moderate production has come from Alabama and Georgia and small production from South Carolina.

Most scrap mica produced in Appalachia comes from the Spruce Pine district in North Carolina where several companies have mining and milling operations. Scrap mica is also produced in the Franklin-Sylva district of North Carolina, the Pickens-Cherokee district in Georgia, and the Pinetucky district in Alabama. Outside the Appalachian Region, scrap mica is produced by several companies in the Kings Mountain area, North Carolina, one company in the Hartwell pegmatite district of Georgia, and one company in Lancaster County, S.C.

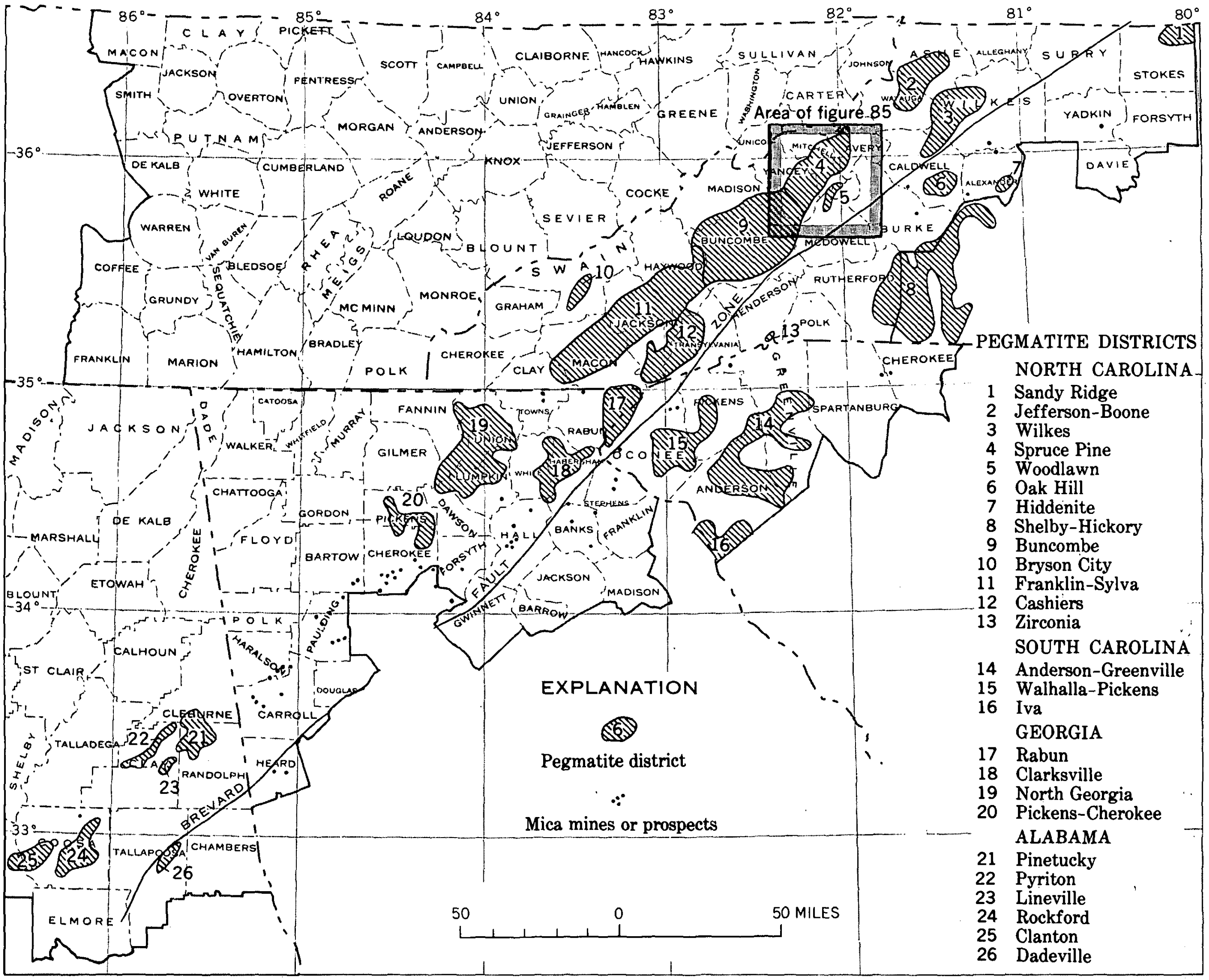


FIGURE 84.—Pegmatite districts and outlying pegmatites in the Appalachian Region.

NORTH CAROLINA

Sandy Ridge district

Some 13 known mines and prospects in Stokes County are part of the Sandy Ridge pegmatite district that extends north and east into Rockingham County, N.C., and Henry County, Va. (Griffitts and others, 1953). Many of the mines were worked intermittently during World War II and the 1950's, and several produced large amounts of sheet and scrap mica. Most pegmatites are zoned tabular bodies. Feldspar-quartz-muscovite wall zones, perthite intermediate zones, and discontinuous quartz cores are generally present. Ruby mica in unusually large books was recovered from several mines. The quality is fair. Some stain, "A" structure, cracks, and bending are found. Total production for the district is unknown but is probably greater than 200,000 pounds of sheet mica and a large amount of scrap mica.

Jefferson-Boone district

The Jefferson-Boone district in Ashe and Watauga Counties contains more than 70 mica mines and prospects (fig. 84). Mica mining probably began in Ashe County at the Hamilton and Tarkington mines as early as 1867. Some prehistoric mining was apparently done by Indians at the sites of the Little Phoenix and Walnut Knob mines (Sterrett, 1923, p. 172). More than 45 mines and prospects were opened or reopened during World War II, and about 20 mines were active at various times between 1951 and 1962. None of the mines was being worked in April 1962, and many of the older mines are difficult to find. The total production of the district from 1867 to 1962 is estimated to be 200,000–300,000 pounds of sheet and punch mica. There are no detailed production records prior to 1941 for this district, but few mines produced much more than 10,000 pounds of full-trimmed sheet mica. Although many of the deposits may still contain exploitable quantities of mica, it would be difficult and expensive to reopen the old mine workings.

The pegmatites in the Jefferson-Boone district are generally tabular or lenticular bodies of which most are concordant to the foliation of the enclosing metamorphic rock. They range from 1 to 70 feet in thickness and from less than 50 to more than 350 feet in length. The average is less than 10 feet thick and about 100 feet long.

The pegmatites are composed of medium- to coarse-grained plagioclase, quartz, perthite, and muscovite. Garnet, biotite, apatite, and beryl are common accessory minerals; vermiculite, pyrite, magnetite, hematite, and uraninite are rare. About one-third of the pegmatites have a plagioclase-quartz-muscovite wall zone and a quartz core; a few have a perthite-quartz core and several have a perthite core. In general the quality and quantity of the muscovite are only fair. The books tend to be small, many are deformed, and the concentrations are small. Most muscovite is reddish brown or ruby; some is green.

Wilkes district

The Wilkes district is along the Blue Ridge front in the western part of Wilkes County and the adjoining eastern edges of Ashe, Caldwell, and Watauga Counties (fig. 84). Work at 45 or more mines and prospects has been intermittent since 1895. During World War II, about 30 deposits were mined or prospected, and between 1951 and 1962, production came from 15 mines. Total production for the district is unknown but probably does not exceed 50,000 pounds of sheet muscovite. A few mines were operated for scrap mica.

The pegmatites of the Wilkes district are generally weathered and poorly exposed concordant tabular and lenticular bodies in mica schist. Most are less than 5 feet thick but several are 25 or more feet thick. Some are as much as 200 feet long. They are medium- to coarse-grained mixtures of plagioclase, quartz, and muscovite. Perthite is found in a few deposits. Garnet, biotite, magnetite, and tourmaline are reported from some of the mines as accessory minerals. A few of the pegmatites have a plagioclase-quartz-muscovite wall zone and a quartz core, but most seem to be poorly zoned.

The muscovite is mostly green, yellowish green, or brownish green. Some reddish-brown or ruby mica is found in the western part of the district. Much of the mica is bent or reeved and the average quality is only fair.

Spruce Pine district

The Spruce Pine district covers about 300 square miles in Avery, Mitchell, and Yancey Counties, N.C. (figs. 84, 85). The district has been active for many years and has consistently been the principal producer of mica and feldspar in North Carolina. Mica was mined by the Indians before arrival of the white settlers; traces of their pits and trenches found by the first white settlers were considered to be the workings of old Spanish silver mines (W. C. Kerr, 1881; Phillips, 1888; Simonds, 1896). In 1868, T. L. Clingman prospected the Sinkhole mine area in Mitchell County which had been the site of extensive Indian diggings. The prospect was abandoned, but the following year the Sinkhole mine was opened by the firm of Heap and Clapp of Knoxville, Tenn. Shortly thereafter the Ray mine was opened in Yancey County by G. D. Ray (Sterrett, 1923, p. 168), and within a few years there were more than a score of active mines.

Several thousand pegmatites are exposed in the district, but only a fraction contain minable deposits of sheet or scrap mica. Large masses of alaskite (granite) in the area are mined for scrap mica and feldspar.

Some information is available concerning 714 mines and prospects in the Spruce Pine district (F. G. Lesure, unpub. data, 1966), but probably there are as many more prospects and small mines about which little is known. Production data for the district prior to World War I are sparse. Incomplete production records for 130 mines for the period 1917–40 are given by Kesler and Olson (1942, table 11), and fairly complete records for the production from 703 mines and prospects for the period June 1942 through 1945 were kept by Colonial Mica Corp. More than 100 mines had a significant production during the period 1952–62. Most of the mines being operated for sheet mica only, however, were closed in June 1962 when the Government buying program ended.

Within the Spruce Pine district, 67 mines have a recorded individual production greater than 10,000 pounds of sheet mica, and 146 mines have produced more than 500 pounds but less than 10,000 pounds of sheet mica. Total production of sheet mica for the district from 1917 to 1962 is more than 6 million pounds.

Exploration during the period 1951–62 was very active in the Spruce Pine district, and much of this

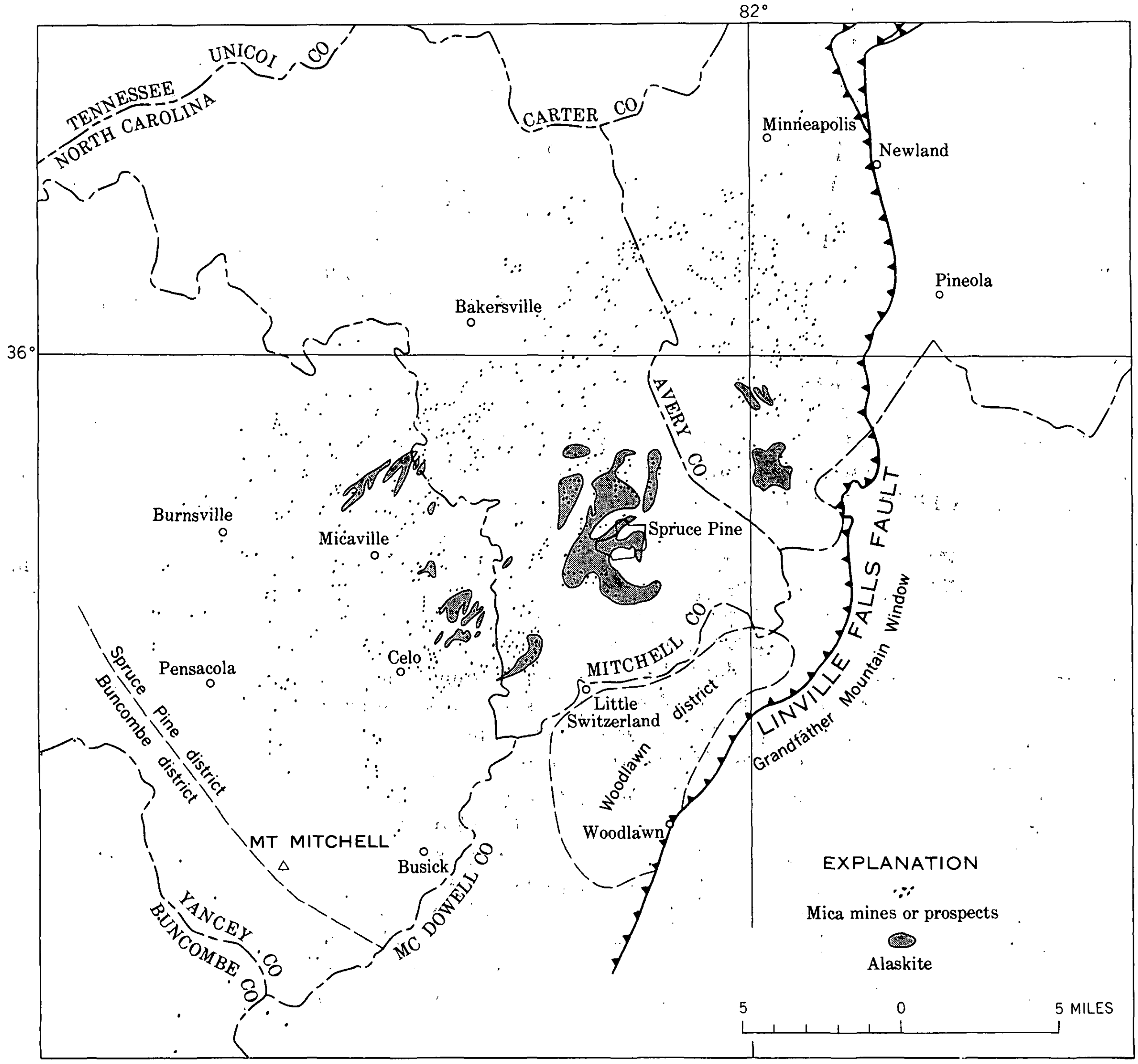


FIGURE 85.—Mica mines and prospects and alaskite bodies in the Spruce Pine and Woodlawn districts, North Carolina.

exploration was aided by the Defense Minerals Exploration Administration. A total of 322 applications for aid were received on 269 different pegmatite bodies. Of the 147 contracts granted, 22 were in Avery County, 80 in Mitchell County, and 45 in Yancey County. Thirty-five exploration projects were certified as discoveries, and three of these, the Cattail, Sinkhole, and R. B. Phillips mines, were among the largest producers in the 1950's.

The general geology of the Spruce Pine district has been described by Olson (1944), J. M. Parker (1952), Kulp and Brobst (1956), and Brobst (1962). The pegmatites are described by Sterrett (1923), Maurice (1940), Kesler and Olson (1942), Olson (1944), Parker (1952), and Brobst (1962). Recent mapping along the eastern edge of the district has added details concerning regional structure and metamorphism (Bryant, 1962; Reed, 1964a, b).

The most abundant rocks in the Spruce Pine district are interlayered mica and amphibole gneiss and schist. These are cut by large masses of fine-grained pegmatite or alaskite and by smaller bodies of coarse-grained pegmatite. About half the coarse-grained pegmatite bodies are in mica gneiss, one-fourth in interlayered mica and hornblende gneiss, and the rest cut the larger bodies of fine-grained pegmatite or alaskite. More than half the pegmatites are tabular, about a third lenticular, and the rest of irregular shapes. About 70 percent are concordant to the foliation of the enclosing country rock.

Contacts between pegmatite and country rock are generally sharp. Mica gneiss and schist have been little altered along contacts, but hornblende gneiss in contact with pegmatite has been altered to biotite schist for a few inches to a foot or more. Contacts between pegmatite and alaskite are generally gradational.

The sheet-mica-bearing pegmatites are generally not large; few are thicker than 100 feet or longer than 1,000 feet. Half the deposits are 10 feet thick or less and fewer than one-fourth are more than 20 feet thick. About two-fifths may be more than 200 feet long, but nearly half are less than 100 feet long. Some of the largest deposits have been mined downdip 300–400 feet, but many bodies pinch out at less than 100 feet in depth.

The internal structure of Spruce Pine pegmatites is relatively simple (Cameron and others, 1949, p. 62–64). Nearly three-fourths of them have no apparent internal zoning of contrasting mineral composition or texture. Of the ones that are zoned, two-thirds have a wall zone of feldspar-quartz mica and a core of massive quartz. The remainder have perthite-oligoclase-quartz cores, perthite-plagioclase cores, perthite-quartz cores, or perthite cores. About one-fifth of the zoned bodies have one or more intermediate zones of various proportions of feldspar, quartz, and mica. A few deposits have fracture fillings of fine-grained pegmatite or quartz cutting the earlier zones, and some have small bodies of fine-grained plagioclase replacing microcline and quartz.

The pegmatites have a simple mineralogy. The most abundant minerals are plagioclase, quartz, perthitic microcline, and muscovite. The accessory mineral content is less than 5 percent of the pegmatite mass. The most common accessories are garnet in two-thirds of the deposits and biotite in two-fifths. Apatite, pyrite, vermiculite, allanite and thulite are found in about a tenth of the deposits. Beryl has been reported in 28 deposits, epidote and tourmaline in 32, pyrrhotite in 12, and columbite in 10. The following minerals have been reported from fewer than 10 deposits: autunite, calcite, chalcopyrite, chlorite, clarkeite, cleavelandite, covellite, cyrtolite, gahnite, gummite, hyalite, kyanite, lepidolite, magnetite, monazite, samarskite, siderite, sphalerite, spodumene, torbernite, uraninite, uranophane, zircon, and zoisite.

Muscovite is present in all the pegmatites. It ranges from the fine-grained scaly form called sericite to large books several feet across. Total muscovite content may be as much as 15 percent, but sheet-quality muscovite probably forms from 2 to no more than 8 percent of any one deposit. The color, quality, and size of the mica vary widely in different parts of the district. Color ranges from light reddish brown (ruby) through light brown (rum) to light brownish green, light green, and dark green. Reddish-brown mica is found in 23 percent of the deposits, brown in 20 percent, and various shades of green in 55 percent. Both green and brown mica occur in 2 percent of the deposits. Some sheets are irregularly mottled; others have alternating colors. In areas of gneiss, reddish-brown and brown mica predominate, and in areas in or near the alaskite masses, brownish-green and green mica predominate. Green mica is more commonly associated with massive quartz units; reddish-brown mica is more commonly in plagioclase-rich units. With few exceptions, mica from pegmatites in which much biotite occurs is reddish brown.

Although much good-quality mica has been mined in the district, large amounts of the sheet mica contain defects. The principal defects include staining, mineral inclusions and intergrowths, "A" structure and reeving, bending, cracking, and ruling. Some form of staining (such as specks, spots, and streaks of magnetite, hematite, pyrite, limonite, and clay) is found in mica in more than half of the deposits, and intergrowths of muscovite with biotite or other minerals are found in about a tenth of the deposits. "A" structure and reeving are common defects in deposits of green mica, especially where the green mica is associated with large masses of quartz. Deformation of the mica crystals after formation has produced bending in two-fifths of the deposits and cracking and ruling in a third. The degree of deformation varies within the district. Near the center of the district around Spruce Pine, only a fifth of the deposits contain bent mica, but to the northeast near Plumtree and to the west near Black Mountain more than half the deposits contain bent mica.

Large bodies or groups of bodies of alaskite or fine-grained pegmatite occur in several parts of the Spruce Pine district (fig. 85). These bodies range in size from a few hundred feet long to masses 4,000 feet wide and 2 miles long. Their mineral composition is the same as that of the coarse-grained pegmatites and consists principally of plagioclase, quartz, perthitic microcline, and muscovite. Biotite and garnet are the principal accessory minerals. The average grain size is about half an inch. Inclusions of country rock and masses of coarse-grained pegmatite are common in most alaskite bodies.

Woodlawn district

The Woodlawn district in McDowell County contains at least 12 small mines in an area about 10 miles long and several miles wide. It is separated from the Spruce Pine district by an area 1–3 miles wide that contains few or no pegmatites (fig. 85). Very little is known about the deposits of this district or other deposits in McDowell County. The principal mining activity was apparently from 1894 to 1918, although no production records exist. Production came from 18 mines in McDowell County during 1942–45, some outside the Woodlawn district, and about 15 mines and prospects have been worked in the county since 1952.

The mica occurs in pegmatites which are generally deeply weathered, small, tabular or lenticular bodies 1–10 feet thick. The host rock is mica gneiss or schist. Plagioclase is the principal feldspar, but perthite is present in some of the deposits. Biotite and garnet are the principal accessory minerals. Most mica is green or greenish brown. Reddish-brown mica is present in at least two of the deposits. The quality of the sheet mica is poor and much is stained; the quantity is small.

Shelby-Hickory, Hiddenite, and Oak Hill districts

The Shelby-Hickory mica district (Griffitts and Olson, in Griffitts and others, 1953, p. 203–292) includes a broad area of the southwestern Inner Piedmont of North Carolina, most of which is outside the Appalachian Region (fig. 84). About 20 deposits in the western part of the district are in Rutherford County; 10 or more are in Burke County. At least 9 deposits are in the Hiddenite district of Alexander County, 11 or more are in the Oak Hill district of Caldwell County, and a few scattered deposits are in Yadkin and Wilkes Counties (Griffitts and Olson, in Griffitts and others, 1953, p. 203–292). Most of the deposits are well-zoned pegmatite dikes. Quartz cores and feldspar-quartz-muscovite wall zones are generally present. About half the deposits have intermediate zones. Good-quality ruby mica has been produced in all three districts. Clay and iron stains are widespread defects; reeves, "A" structure, bending, ruling, cracking, and mineral inclusions are not as common. Mining has been intermittent since before 1880, but no records of early production are available. The largest producers of the Shelby-Hickory district are in Cleveland, Gaston, and Lincoln Counties, outside the Appalachian Region.

Buncombe district

The Buncombe district is an area of widely scattered pegmatites that lies between the Spruce Pine and the Franklin-Sylva districts (fig. 84). The district is about 24 miles wide and 30 miles long in Buncombe, McDowell, Madison, and Yancey Counties. Ninety mines and prospects are known, but there may be many more small prospects that are lost and forgotten. Sterrett (1923, p. 184–188) described 11 deposits in Buncombe County. According to the Colonial Mica Corp. records, about 50 deposits were worked during the period 1942–45. At least 20 mines were active at various times from 1952 to 1962. Complete production records are not available, but probably no mine has had production greater than 10,000 pounds of sheet and punch mica. Most of the mines produced less than 500 pounds. Total production for the district may be no more than 50,000 pounds.

The pegmatites in the Buncombe district are similar to those in adjacent areas; most are weathered tabular (65 percent) or lenticular (27 percent) bodies in mica gneiss or schist. Three pegmatites are in hornblende gneiss, and three cut dunite. Nearly three-fourths of the pegmatites are less than 10 feet thick and only six are greater than 20 feet thick. About three-fifths are concordant to the foliation of the country rock. One-third of the pegmatites have a feldspar-quartz-mica wall zone and a quartz core; the rest have no apparent zoning. Three of the zoned pegmatites have a perthite intermediate zone. Plagioclase is the principal feldspar, but perthite is present in some deposits. Biotite is present in at least 40 percent of the deposits and may be the principal mica in some. Garnet is common, and allanite, apatite, beryl, sulfide minerals, tourmaline, and vermiculite are rare accessory minerals.

The muscovite is reddish brown (75 percent), brown (10 percent), and green (15 percent). In general the quality and quantity are only fair. At least 30 percent of the pegmatites have mica that is bent, cracked, ruled, or stained. The average size of the sheet mica is small.

Bryson City district

More than 150 feldspar-rich pegmatites are found near Bryson City, Swain County, west of the Franklin-Sylva district (Cameron, 1951). More than 30 mines have produced feldspar, but only a few prospects on the southeast side of the district have yielded small amounts of sheet mica and some scrap mica. The mica ranges from green to reddish brown and the quality is generally poor. Cracks, mineral inclusions, tanglesheet, ruling, reeving, and other defects are common.

Franklin-Sylva district

The Franklin-Sylva district is second to the Spruce Pine district in number of mines and in total production. The district is about 12 miles wide and 50 miles long in Haywood, Jackson, and Macon Counties and extends a short distance into Clay County (fig. 84). Most of the mica mines are centered about Franklin, Macon County, and Sylva, Jackson County. Although the number of mines and pegmatites decreases sharply away from the center of the district, the largest single producer is the Big Ridge mine in Haywood County, well away from the center of the district. This mine was opened in 1867 and is one of the first mica mines to be operated in North Carolina. As in the districts to the northeast, several of the large deposits were originally worked by Indains for mica (C. D. Smith, 1877, p. 441–443) and clay (Watts, 1913, p. 10; Griffiths, 1929). Clay mining in the district was started in 1888 near Webster (Watts, 1913, p. 10), but little clay has been mined in the district since the 1920's. Some feldspar has been produced sporadically, generally as a byproduct of mica mining.

Information has been assembled on 433 mica deposits in the district (F. G. Lesure, unpub. data, 1966), but several hundred others probably have been mined or prospected. Sterrett (1923) described more than 100 deposits in Haywood, Jackson, and Macon Counties. Records of the Colonial Mica Corp. show that from 1942 to 1945 some work was done at 24 mines in Haywood County, 189 in Jackson County, and 157 in Macon County. Olson and others (1946) show the locations of 326 mines and describe in detail 20 mines worked during World War II. More than 150 mines were active in the district from 1952 to 1962.

Production records for the district are not complete. During each major period of production about 10 percent of the mines produced 65–85 percent of the sheet and punch mica. Total production of sheet mica from 1922 to 1962 was more than 3 million pounds.

The pegmatite bodies in the Franklin-Sylva district are similar to those in the other districts in the Blue Ridge of North Carolina. Most of them are tabular dikes that cut quartz-mica gneiss. A few cut interlayered mica and hornblende gneiss or hornblende gneiss. The average dike is less than 10 feet thick and 200 feet long and has been weathered to a depth of 10–100 feet.

The pegmatites have simple internal structure. About two-thirds are zoned, and, of these, 92 percent have a quartz core, and the rest plagioclase-perthite-quartz, perthite-quartz, or perthite cores. Wall zones are generally feldspar-quartz-muscovite (60 percent), plagioclase-quartz-muscovite (20 percent) or plagioclase-perthite-quartz-muscovite (20 percent). About 10 percent have one or more intermediate zones of plagioclase-perthite-quartz, perthite-quartz, or perthite. A thin border zone of feldspar-quartz-mica or quartz-mica is present in some pegmatites. Late-stage fracture fillings or replacement units are rare. A few pegmatites contain cores that are sheared and have thin strips of biotite along fractures. Some have veinlets of quartz, quartz-muscovite, or plagioclase-muscovite that cut outer zones. Perthite is partly altered to plagioclase and muscovite along fractures in a few pegmatites.

The principal minerals are quartz, oligoclase, perthitic microcline, and muscovite. The principal accessory minerals are biotite and garnet. Pyrite, pyrrhotite, and apatite are present in a few pegmatites, and allanite, ankerite, beryl, chalcopyrite, epidote, kyanite, and tourmaline are reported from less than 2 percent of the pegmatites. Vermiculite, kaolinite, and limonite are common secondary minerals in the weathered pegmatites.

The muscovite in the Franklin-Sylva district is generally reddish brown (36 percent) or brown (44 percent). About 30 deposits contain both brown and green mica, and 55 deposits have only green mica. The quality of the mica is generally good, but nearly half the deposits contain some mineral-stained mica, and 12 percent contain muscovite with biotite intergrowths. Deformed mica is widespread, and nearly half the mines contain some mica that is bent, ruled, or cracked. In a few mines much of the mica is deformed and is only scrap quality. Comparison of production data from Franklin-Sylva (Olson and others, 1946, p. 18) with that of Spruce Pine (Kesler and Olson, 1942, p. 36) suggests that the average size of recoverable sheet mica is slightly smaller in the Franklin-Sylva district.

Cashiers district

The Cashiers district in Jackson and Transylvania Counties is an elongate area, 11 by 30 miles, trending northeast and separated from the Franklin-Sylva district to the west by an area several miles wide containing few prospects. Some 60 mines and prospects are known (Olson, 1952), but there may be others. Most pegmatites are tabular sills intruded into mica gneiss and schist and amphibolite (pl. 2, lower Precambrian metamorphic rocks) and associated with large sills and laccoliths of Whiteside Granite (Paleozoic(?) granitic rocks). Most are less than 15 feet thick, but several are more than 50 feet thick. All have a simple composition of perthite, plagioclase, quartz, muscovite, and garnet. Biotite, beryl, tourmaline, apatite, pyrite, and pyrrhotite are the principal accessory minerals. Internal structures are simple. Many pegmatites in the district are not zoned and contain no visible concentrations of valuable minerals. Most of those mined, however, have quartz cores and feldspar-quartz-muscovite wall zones. A few have perthite intermediate zones or perthite cores. Sheet mica occurs in feldspar-quartz-muscovite pegmatite in the outer wall zone or at the core margins, in quartz-muscovite pegmatite (burr-rock) as irregular masses or layers in various zones, and in thin quartz-muscovite-feldspar-garnet pegmatite streaks which may be fracture fillings.

Both brown and green mica are found. In pegmatites that contain both types, green mica is generally near the core margins, is either clear or stained, and commonly has "A" structure. The brown mica is near the walls and is commonly stained.

About 30 deposits were prospected during World War II, and a few mines produced good-quality mica (Olson, 1952, p. 9). Only a few mines and prospects were worked sporadically in the 1950's; production may have been as much as 1,000 pounds of sheet mica.

SOUTH CAROLINA

Mica-bearing pegmatites have been found in the metamorphic rocks of the Blue Ridge and Inner Piedmont belts in South Carolina (Overstreet and Bell, 1965, p. 69, 78) and are most abundant in the Walhalla-Pickens district, Pickens and Oconee Counties, the Anderson-Greenville district, Anderson and Greenville Counties, and the Iva district, Anderson County (Griffitts and others, 1953). Only a few scattered deposits have been found outside these districts. The total production of mica has been small. About 1,300 pounds of sheet mica was produced during World War II and 10,000 pounds in the 1950's. The principal producer of flake mica in South Carolina is in Lancaster County, outside the Appalachian Region.

The Walhalla-Pickens district contains about 24 mines and prospects in an area about 25 miles long and 3–12 miles wide; the Anderson-Greenville district contains at least 50 deposits in an irregular area more than 40 miles long and 15 miles wide. The Iva district is a triangular area of 90 square miles containing more than 20 deposits. It is an eastward extension of the Hartwell district of Georgia (Griffitts and others, 1953).

The pegmatites in these three districts are similar. They are chiefly mixtures of plagioclase, quartz, perthite, muscovite, and biotite. Garnet is the principal accessory mineral. Beryl has been found in one deposit in the Iva district. Most deposits have a quartz core and a plagioclase-quartz-muscovite wall zone. A few deposits have a perthite intermediate zone. The deposits are generally small and deeply weathered. They trend northeast, and most cut across the foliation of the enclosing metamorphic rocks.

Ruby muscovite is most widespread, but some deposits contain both ruby and green mica or only green mica. Both wall zone and core margin concentrations are present, but much of the mica is of poor quality and books are small. Clay stain, specks, wedge- and flat-"A" structure, and cracks are the principal defects. Only one mine, the Willimon, Greenville County, has been worked extensively.

GEORGIA

Mica deposits are found in many of the Blue Ridge and Piedmont Counties in Georgia, but the principal deposits are in Upson, Lamar, Monroe, Hart, and Elbert Counties, outside the Appalachian Region. West of the Brevard zone, mica deposits are concentrated in Rabun, Clarkesville, North Georgia, and Pickens-Cherokee districts and are scattered in several other counties (fig. 84). Deposits have been described by Galpin (1915), Sterrett (1923), Furcron and Teague (1943), and Heinrich and Jahns (1953). Total production for the entire area is not recorded, but some 47 mines produced 16,000 pounds of sheet mica during World War II. A few mines in Cherokee and Pickens Counties were operated intermittently for sheet mica during the 1950's, and one still-active mine in Cherokee County has been worked for scrap mica for a number of years.

About 15 mines and prospects are in an area 5 miles wide and 13 miles long in northeastern Rabun County (fig. 84, Rabun district). This district is probably a southern extension of the Cashiers district of North Carolina. The pegmatites are generally deeply weathered and poorly exposed. They contain perthite, plagioclase, quartz, and muscovite. Garnet, biotite, tourmaline, beryl, gahnite, and zircon are sparse accessory minerals. The muscovite is green or greenish brown and commonly has flat- or wedges-"A" structure. Much of the mica is stained, bent, and ruled.

More than 25 mica deposits are widely scattered in the Clarkesville district of Habersham and White Counties (fig. 84) (Hurst and Crawford, 1964, p. 65; Hurst and Otwell, 1964, p. 64). The deposits are generally weathered and poorly exposed. The mica is mostly green, small, and stained, and much of it has "A" structure. Production is unknown and probably small.

The North Georgia district contains more than 60 mines and prospects in Towns, Union, Lumpkin, and Fannin Counties (fig. 84). The pegmatites are generally thin tabular bodies consisting of quartz, plagioclase, perthite, and muscovite. The sparse accessory minerals include garnet, biotite, and apatite. Mica is commonly concentrated near the margins of massive quartz cores. It tends to be light brown or green and of poor quality. Bending, ruling, cracking, "A" structure, and stains are common. Mining was active during 1898–1908 and again shortly after World War I, but there has been little mining or prospecting since. Many of the mines are now overgrown and hard to find.

Mica-bearing pegmatites in Cherokee and Pickens Counties (fig. 84, Pickens-Cherokee district) are found in schist and gneiss mapped as lower Precambrian metamorphic rocks by Bayley (1928) and upper Precambrian metamorphic rocks by Fairley (1965). In general the deposits are thin tabular bodies conformable with the foliation of the enclosing metamorphic rocks. Quartz cores and core-margin mica concentrations are characteristic of the district (Heinrich and Jahns, 1953, p. 377). Plagioclase, perthite, quartz, and muscovite are the principal minerals. Tourmaline, apatite, and beryl are sparse accessory minerals. The mica is light-reddish brown to yellowish green and generally shows "A" structure. Mining probably began in 1889 and has been intermittent since then. Some 35 mines and prospects are known, but few have been worked extensively. Total production is unknown but is probably small.

A few scattered mica deposits are found in Hall, Forsyth, Cherokee, Paulding, Haralson, and Carroll Counties west of the Brevard zone and in Heard, Banks, Stephens, and Franklin Counties east of the Brevard zone (Galpin, 1915; Heinrich and Jahns, 1953). Very little is known about these deposits. In general they are small and deeply weathered. The mica is fair to poor quality, small, and scarce. Only one mine, in Hall County, has been worked extensively.

ALABAMA

The mica deposits in Alabama are concentrated in six districts in six counties (fig. 84). The pegmatites have been described by Clark (1921), Sterrett (1923, p. 28–43), F. R. Hunter (1944), U.S. Bureau of Mines (1946), Heinrich and Olson (1953), and T. A. Simpson (in Alabama Geol. Soc., 1964). The Pinetucky, Pyriton, Lineville, Rockford, and Clanton districts are in the western part of the area between the Whitestone and Brevard fault zones and are mostly in the Ashland Mica Schist (pl. 2, Paleozoic(?) metamorphic rocks) west of the main masses of Pinckneyville Granite (pl. 2, Paleozoic(?) granitic rocks). The Dadeville district is in an area of mica schist east of the Brevard fault zone.

Scrap mica is the principal product extracted from weathered pegmatite by two companies in Cleburne and Randolph Counties. The Geological Survey of Alabama, however, is currently investigating the potential for producing flake mica from mica schist in the Piedmont province.

The Pinetucky district in Clay, Cleburne, and Randolph Counties contains about 100 mines and prospects in a north-trending area 2–10 miles wide and 14 miles long. Most deposits are small tabular pegmatites less than 10 feet thick and as much as 100 feet long. At least three-fourths of them strike northeast and dip southeast, conformable or nearly so to the foliation of the mica schist host rock. A few deposits in the north end of the district are in hornblende schist. Most pegmatites are deeply weathered and composed of kaolinized feldspar, quartz, and muscovite. The minor accessory minerals include tourmaline in at least 34 percent of the deposits, biotite in 15 percent, garnet in 12 percent, apatite and pyrite in 5 percent, and beryl in 2 percent. The internal structure of the pegmatites is generally simple. Many deposits are unzoned, but some have a feldspar-quartz-mica wall zone and a quartz core or discontinuous tabular masses of quartz in feldspathic pegmatite (fig. 83). Muscovite is concentrated near the walls, near the core margins, or around the discontinuous quartz masses. The books of mica are commony brown with light-green borders. The quality is only fair, and many books are cracked, bent, or ruled. Many show "A" structure, are tied, or have mineral inclusions or stain. Some are soft and clay stained.

Although a few mines were worked by Indians before arrival of the white settlers, modern mica mining began in 1870 at the Pinetucky No. 1 mine and has continued intermittently since then. Important mining periods include 1893–1908, 1918–22, 1941–45, and 1952–56. Production has not been large, and in general fewer mines have been operated in each successive period. During World War II about 20 mines were worked, and during the 1950's about 15. Scrap mica was being produced in 1965 by two companies from several deposits in Cleburne and Randolph Counties.

The Pyriton district in Clay County contains about 50 mines and prospects in an elongate area 1–3 miles wide and 20 miles long just east of the Whitestone fault. Most pegmatites are in the Ashland Mica Schist, but a few are in hornblendic rocks of the Hillabee Chlorite Schist (Heinrich and Olson, 1953, p. 405). More than half the pegmatites are lenses or tabular bodies less than 5 feet thick, but a few are more than 10 feet thick, and one is as much as 25 feet thick. Most strike northeast and dip southeast, generally conformable to the foliation of the enclosing schist. In general, the deposits are a medium-grained mixture of feldspar, quartz, and muscovite with quartz cores or scattered platy quartz masses. Biotite, tourmaline, garnet, pyrite, apatite, beryl, kyanite, and graphite are the principal accessory minerals. The muscovite is generally brown with green borders. Quality and quantity are only fair.

The Lineville district in eastern Clay County is an area about 12 miles long and 1–4 miles wide that contains about 10 mica mines and prospects. The pegmatites are generally thin bodies in Ashland Mica Schist and are similar to those in the Pyriton and Pinetucky districts.

The Rockford district has many pegmatite bodies ranging from thin stringers to masses 100 feet wide and 3,000 feet long in an area 9 miles wide and 21 miles long that trends northeast along the western edge of the main mass of Pinckneyville Granite in Coosa County. Only 14 known mica deposits have been described (U.S. Bureau of Mines, 1946, p. 71–75; Heinrich and Olson, 1953, p. 453). The mica deposits are similar to the deposits in the Pyriton and Pinetucky areas. One deposit was worked during World War II and possibly four during the 1950's. Total production was small and consisted mostly of scrap.

The Clanton district is an area 5–10 miles long in western Coosa and eastern Chilton Counties, having six or more scattered mica deposits. Several of these were worked briefly in the 1950's, largely for scrap mica. The deposits are deeply weathered and poorly exposed but are probably similar to the pegmatites in the other districts of Alabama.

About 25 mines and prospects are included in the Dadeville district in an area 10 miles long and 1–6 miles wide, northeast of Dadeville, Tallapoosa County. Additional mica pegmatites are found for 6 miles or more south of Dadeville, but few have been prospected. The pegmatites are in mica schist east of the Brevard fault zone. Although the largest deposit is 370 feet long and 75 feet thick, most pegmatites are less than 200 feet long and 10 feet thick. All are deeply weathered. Quartz, feldspar, and muscovite are the principal minerals; garnet, biotite, and pyrite are the accessory minerals. The mica is commonly green or brownish green, cracked, ruled, and stained; some has "A" structure. Six mines were worked during World War II and one in the 1950's. Recent production has not been large.

RESOURCE POTENTIAL

Reserves of sheet mica in the Piedmont and Blue Ridge provinces of Appalachia cannot be calculated from the data available because no development work has preceded mining, and no mica-bearing rock is blocked out. An appraisal of the probable amount of sheet mica remaining in the ground, based on the premise that the abundance of pegmatite bodies at depth is almost certain to be almost the same as at the surface, indicates that at least as much mica remains as has been mined. Whether this mica will be found and mined depends largely on such economic factors as domestic market and prices, which influence the amount of prospecting. Under normal market conditions domestic sheet mica cannot compete with foreign imports.

During the last period of Government mica buying, 1952–62, most of the larger producing sheet-mica mines were ones that had been big producers in the past, and many of these were worked out or were left in a condition that will make further mining difficult. The rate of new discoveries was small during both World War II and the 1950's, even though exploration was encouraged by financial assistance from the Federal Government. The deposits exposed at the surface have generally been prospected, and the difficulty and cost of finding unexposed deposits are great. Detailed geologic studies of structural control and country-rock alteration, geochemistry, and geophysics should help locate additional pegmatites with recoverable sheet mica.

The scrap-mica resources in North Carolina, at least, are better known than sheet-mica resources. Scrap-mica reserves in the Spruce Pine district are 25,000,000 tons of ore containing 12–18 percent mica (Broadhurst and Hash, 1953, p. 15). In addition, reserves of scrap mica in kaolin deposits in the same district have been estimated as 7.5 million tons, and the amount of scrap mica that can be recovered as a byproduct from feldspar flotation is in excess of 38 million tons (Brobst, 1962, p. A15–A16). The scrap mica reserves of the Franklin-Sylva district are confined to a few large pegmatites containing more than 1 million tons of high-grade ore (Broadhurst and Hash, 1953, p. 15). Scrap-mica reserves of the other pegmatite districts of Appalachia have not been estimated. Much mica is present, but most of the deposits are probably too small to be mined for scrap mica alone.

Resources of flake mica in mica schist in the Blue Ridge and Piedmont provinces are large and will become more important with the increasing use of new methods of recovery. Further geologic investigation, such as is now being done in Alabama and North Carolina, may delineate reserves in this category.

OLIVINE

By D. M. Larrabee, U.S. Geological Survey, and
John W. Sweeney, U.S. Bureau of Mines

Natural olivine is a solid solution of forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). Pure forsterite contains 57.3 percent magnesia and 42.7 percent silica, and has a melting point of 3,450°F (1,900°C); the presence of iron in olivine lowers this melting point. Forsteritic olivine occurs mainly in peridotite; it is almost the sole constituent of dunite, and is the principal mineral in harzburgite, a variety of peridotite that contains pyroxene. In places dunite and other varieties of olivine-rich peridotite have been altered to serpentinite and other rocks, depending upon the nature of metamorphism to which they were subjected.

The olivine in most peridotite ranges from about 80 to 95 percent forsterite, and that used in refractories probably averages 85–90 percent forsterite. Only dunite is mined for olivine, because the pyroxene in other varieties of peridotite decreases the refractoriness of the rock.

Olivine is used chiefly as a refractory in so-called forsterite brick. Crude olivine blocks and prepared forsterite refractories were first used commercially in the United States in 1933 (Harvey and Birch, 1938). Forsterite bricks are used as checkers in regenerators of basic open-hearth furnaces and glass furnaces and as lining in the high-temperature zones of rotary and shaft lime kilns and in sprung-arch roofs of basic open-hearth furnaces. Crushed olivine is used as molding sand in foundries and glass factories and, recently, as a substitute for quartz as blast sand because it does not cause silicosis. It also has been used in fertilizers (L. R. Williams, in U.S. Bur. Mines, 1965a, p. 537–551). During World War II it was used to a small extent in the manufacture of magnesium sulfate and silica gel. The production of magnesium from olivine has been investigated several times but is not competitive with production from sea water. Magnesite and dolomite can be substituted for forsterite brick in certain applications; however, forsterite is reported to have sufficient distinct advantages under certain conditions that its increased use is anticipated.

Forsterite is used in refractories primarily because of its high melting point, its stability of volume and strength at temperatures up to 3,000°F, and its resistance to corrosion by most materials other than acid slags. Forsterite bricks are made by firing crushed olivine with added magnesia; under certain conditions a chemical binder may be added. During firing under oxidizing conditions, the ferrous oxide (FeO) of the fayalite oxidizes to ferric oxide (Fe_2O_3), and silica is liberated. This silica then unites with part of the added magnesia to form secondary forsterite. During this firing, any serpentine present forms secondary forsterite and silica, and the latter likewise combines with some of the added magnesia. The serpentine content of crude dunite must be low. Addition of alumina during firing results in a reaction of free magnesia and iron oxide from olivine to form a spinel solid solution, which is highly resistant to cyclic oxidation and reduction (McDowell, Scott, and Clark, 1962).

The finished forsterite brick has the following physical properties: true specific gravity, 3.30–3.40; apparent porosity, 18–25 percent; cold crushing strength of brick (set on end), 1,500–4,000 psi (pounds per square inch); and modulus of rupture, 700–1,300 psi. The composition of typical forsterite brick is 30–39 percent SiO_2, 1–11 percent Al_2O_3, 45–55 percent MgO, 7–11 percent Fe_2O_3, and 1–3 percent other oxides. The fired forsterite brick, under a load test of 25 psi, can withstand temperatures of 2,950–3,050°F (1,620°–1,675°C) (Harbison-Walker Refractories Co., 1961).

Dunite is mined in Washington, the leading producer in recent years, and in North Carolina; mining in the latter State began near Webster in 1930 (Tyler, 1935). Annual production from 1945 through 1953 averaged about 5,400 tons, which constituted most of the domestic production (Broadhurst, 1955). Although the total tonnage produced per year has not been great it has increased considerably since 1953, and hopefully will continue to do so at an even greater rate. In 1965, olivine was produced from three mines in western North Carolina: the Addie mine, in the Webster-Addie "ring dike," by Harbison-Walker Refractories Co.; Balsam Gap mine, by the Balsam Gap Co., reportedly a subsidiary of E. J. Lavino & Co.; and the Day Book mine near Burnsville, by Wiseman Mining Co. (Northwest Carolina Co.). According to the Oil, Paint and Drug Reporter, Dec. 27, 1965, the average price per ton of crude ore at the mine was $12; through 20 mesh, $15; and through 100 mesh, $20 per ton.

In the Piedmont and Blue Ridge provinces of Appalachia, several hundred ultramafic rock deposits are distributed in a zone extending southwest from Floyd County, Va., to Coosa County, Ala. (fig. 86). Although extending eastward as far as Cherokee County, S.C., most known deposits occur along the western margin of the zone. Within this broad zone, dunite and harzburgite deposits are concentrated chiefly in the metamorphic rocks of western North Carolina, but a few deposits occur in northeast Georgia. The bodies range from lenticular to ringlike and from a few feet to several square miles in area. Although olivine occurs sparingly in many other ultramafic rocks in the area, the major deposits are those indicated in figure 86. At present and for many years to come, only major dunite deposits such as these are or will be mined for olivine.

Resources of olivine in Appalachia are so great that at the present rate of mining they are virtually inexhaustible. However, reserves of individual deposits now being mined are measurable in terms of a few years or tens of years at present production rates. Distances to railroads, to finished-product manufacturing plants, and to market areas are important to the development of the industry, as are the quality of rock and the competitive position of the finished product. Appalachia contains many known deposits sufficiently pure and large to furnish a greatly increased demand from markets in the Eastern United States (table 118).

SALINES

By Dennis P. Cox, U.S. Geological Survey, and
Curt D. Edgerton, Jr., U.S. Bureau of Mines

Saline deposits of Appalachia comprise beds of rock salt (sodium chloride, NaCl) and brines containing chiefly sodium chloride with small amounts of calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), bromine (Br_2), and other elements.

Sodium chloride is an important mineral resource, ranking with sulfur, limestone, coal, and petroleum as a basic industrial raw material. It is used to make soda-ash, chlorine, sodium, and many other important chemicals, including caustic soda and hydrochloric acid. Sodium chloride is also important in soap manufacturing and dye setting and finds wide use in production, preservation, and preparation of foodstuff, for animal feeds, water softening, ice control, and roadbed stabilization. Calcium and magnesium chlorides are used as desiccants and refrigerants, in ice and dust control, and in adjusting the setting time of concrete. Bromine is used in gasoline additives, fumigants, pesticides, and sanitizers, and in the chemical, pharmaceutical and photographic industries.

More than $18 million worth of saline minerals are produced each year by nine companies operating in four States of Appalachia. The growth of the industry has been steady, and the outlook for future expansion is promising. Saline mineral resources are vast and are unexploited in large areas.

THE NATIONAL INDUSTRY

In the United States, about $274 million (1958 constant dollars) worth of salines was produced in 1964, including sodium chloride (common salt), bromine and bromine compounds, and calcium chloride and calcium magnesium chloride. Common salt was produced by 57 companies at 96 plants, whose 1964 output was 32 million short tons valued at about $200 million (1958 constant dollars). Texas was the leading producing State, followed closely by Louisiana, and appreciable quantities were produced in New York, Ohio, and Michigan. Twelve other States produced lesser quantities.

Although the United States could easily be self-sufficient in salt, 7.4 percent of the total 1964 plant production was based on imported salt or brine. Eighty-one percent of the imports came from Canada and Mexico. Nearly half the salt from Canada was in the form of brine and was transported by pipeline. In 1964, the United States imported 2.3 million short tons of salt and exported 594,000 short tons.

The three principal methods of producing salt today are: (1) evaporation of sea water and natural brines, (2) underground mining, and (3) solution mining, in which water is injected into underground salt deposits to create an artificial brine which is subsequently pumped to the surface (W. H. Kerns, in U.S. Bur. Mines, 1965a, p. 829). Fifteen percent of the salt produced in 1964 was evaporated from natural or artificial brines, 27 percent was mined as rock salt, and 58 percent was salt in brine, sold or used as such.

In 1964, the chemical industry was by far the largest consumer of salt, requiring 67 percent of the total U.S. production. The next major use was for deicing roads and stabilizing roadbeds, which consumed 13 percent of the production. The remaining 20 percent was used for a wide variety of purposes and products.

Bromine is produced from sea water, from brines obtained from either salt lakes or wells drilled expressly for the purpose of producing natural brines, and from brines produced concomitantly with oil from oil wells (W. C. Miller, in U.S. Bur. Mines, 1965a, p. 160). In 1964, the U.S. production of elemental bromine and bromine compounds totaled 283.5 million pounds, valued at $65.6 million (1958 constant dollars). Eight companies operated 11 plants in California, Michigan, Texas, and Arkansas.

Calcium chloride and calcium magnesium chloride are recovered from natural brines but also are synthesized. Eight plants in California, Michigan, and West Virginia extract calcium chloride from brines, and two plants, one in Onondaga County, N.Y., and the other in Summit County, Ohio, produce synthetic calcium chloride. Total production of natural calcium chloride and calcium magnesium chloride in 1964 was an estimated 500,000 short tons, valued at about $9 million (1958 constant dollars).

THE INDUSTRY IN APPALACHIA

Salines are produced in Appalachia from wells as either natural or artificial brine and from an under-

FIGURE 86.—Distribution of ultramafic rocks in the southeastern part of the Appalachian Region. Numbers indicate major olivine deposits and refer to table 118.

ground mine that exploits beds of rock salt. Natural brines are pumped directly from brine-bearing strata, whereas artificial brines are produced by solution mining. The locations of salt-producing operations in Appalachia are shown in figure 87.

Prior to the arrival of the first white settlers in America the Indians obtained salt from salt licks and from natural brines which seeped from the ground (F. E. Harris, 1952, p. 157). The American colonists at first imported their salt, but the imposition of a salt tax and high cost of transportation inspired them to start producing their own salt from local sources.

The Kanawha Valley of West Virginia (fig. 87, loc. 8) has had a long history of natural brine production. David and Joseph Ruffner completed a 58-foot well along the Kanawha River in 1808 and, by evaporating the brine in an open pan over a specially constructed furnace, they produced the first salt from a brine well drilled specifically for that purpose. By 1817, there were 15–20 brine wells and 30 furnaces in operation (P. H. Price and others, 1937, p. 7). The discovery of coal in the vicinity provided further impetus to the brine industry, as did the introduction of a continuous process for evaporating brine developed by George Patrick in 1833. Salt production reached a peak of 72,000 tons per year between 1845 and 1852

TABLE 118.—*Forsterite olivine resources*

[Data from Hunter, 1941, p. 42–117]

Location (fig. 86)	Name of deposit	Fresh dunite (tons)	Altered dunite (tons)	Other mineral commodities
1	Frank	2, 250, 000	9, 750, 000	Asbestos, vermiculite, talc.
2	Senia	------	800, 000	
3	Bakersville	50, 000	------	Asbestos (chrysotile), chromite.
4	Newdale	1, 560, 000	5, 090, 000	Soapstone, asbestos.
5	Day Book	3, 180, 000	6, 710, 000	Talc, chromite.
6	Holcombe Branch	3, 530, 000	17, 500, 000	Soapstone, chromite.
7	Democrat	2, 000, 000	25, 000, 000	Chromite, nickel minerals.
8	Newfound Gap	1, 310, 000	6, 640, 000	Chromite.
9	Hominy Grove	1, 000, 000	20, 000, 000	
10	Balsam Gap	17, 330, 000	32, 860, 000	Talc, chromite.
11	Dark Ridge	16, 550, 000	24, 500, 000	Do.
12	Middleton	500, 000	100, 000	Soapstone.
13	Addie	28, 350, 000	102, 450, 000	Talc, chromite.
14	Webster	58, 150, 000	167, 890, 000	Chromite, nickel minerals.
15	Cane Creek	1, 800, 000	3, 100, 000	Vermiculite, talc, asbestos, chromite.
16	Moores Knob	14, 000	42, 000, 000	Vermiculite, corundum.
17	Ellijay Creek	315, 000	315, 000	Do.
18	No. Nine	5, 020, 000	7, 020, 000	Chromite, vermiculite.
19	Corundum Hill	700, 000	6, 970, 000	Vermiculite, corundum.
20	Buck Creek	52, 820, 000	247, 180, 000	Corundum, chromite.
21	Norton	------	10, 000, 000	Asbestos.
22	Laurel Creek	1, 440, 000	17, 650, 000	Talc, asbestos.
------	Other deposits	35, 421, 000	193, 045, 000	
	Total	233, 290, 000	946, 570, 000	

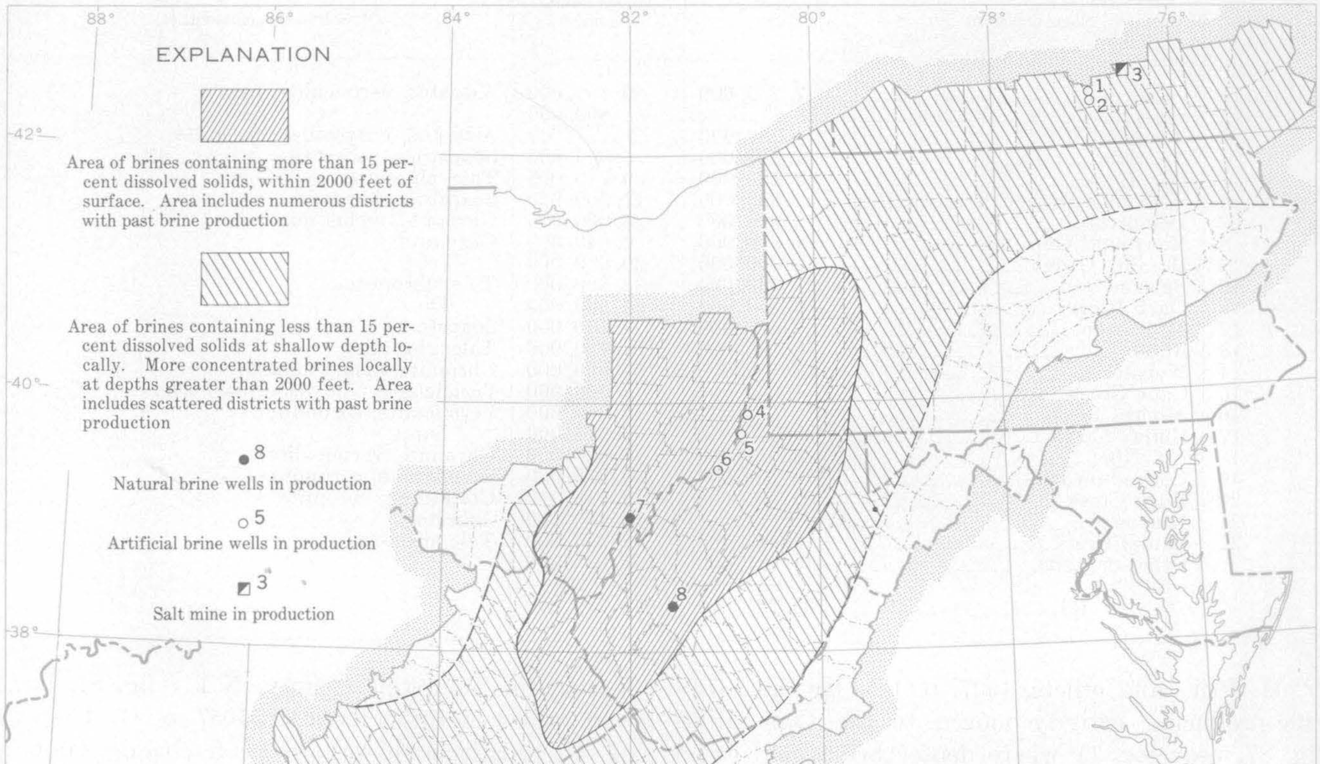
(P. H. Price and others, 1937, p. 17). By the 1870's, brine-producing activity moved to the Ohio River (fig. 87, near loc. 7) where denser brines and easier transportation to growing markets provided a competitive advantage.

The technology of brine recovery has improved as salt making has grown with the demands of an increasing population. In the Patrick continuous process, brine flowed continuously into a long flat pan which was heated by fires underneath. As the brine evaporated, the salt crystallized and was scooped out by hand. This process was the forerunner of the "grainer" process (so-called because the salt crystallized, or "grained") which is in use today (Salt Institute, 1962, p. 47). This method has been largely superseded by the vacuum-pan method, in which brine is evaporated at reduced pressure under carefully controlled conditions. A high-grade table salt is thus produced.

Rock salt was first discovered in Appalachia at Saltville, Va., (fig. 87, loc. 9) in 1840, when a shaft was sunk 215 feet and penertated a salt bed (Stose, 1913, p. 241). This district had been producing natural brines since the early 1800's and produces artificial brine to the present day. Rock salt was discovered in Wyoming County, N.Y. (outside Appalachia), in 1878, and many wells were drilled for the extraction of artificial brine during the next 12–15 years. The first shaft for underground mining of salt was sunk in Livingston County, N.Y. (outside Appalachia), in 1885. The only presently active salt mine in the Appalachian Region, in Tompkins County, N.Y. (fig. 87, loc. 3), was opened in 1917 (Kreidler, 1957, p. 4). The extent of salt beds beneath western Pennsylvania, Ohio, and West Virginia became known during the period of oil and gas activity in the 1890's, but exploitation of this salt in the Appalachian Region was not begun until 1943, when wells were drilled for the purpose of producing artificial brine from the salt beds in Marshall County, W. Va. (fig. 87, loc. 4) (Martens, 1943, p. 1, 13).

Production of salt in Appalachia from 1941 through 1964 has shown a marked increase. Production of artificial brine is mainly responsible for this increase; natural brine production which remained static for many years is now declining (Thomas Arkle, Jr., West Virginia Geol. Survey, unpub. data, June 1966). Rock-salt production although comparatively small, has experienced a steady, substantial rise which shows no sign of falling off.

Salt is produced in Appalachia by nine companies (fig. 87). Six companies produce artificial brine from wells in rock-salt beds in Schuyler County, N.Y., Marshall County, W. Va., and Smyth County, Va. Natural brine is produced by two companies, one in the Kanawha Valley of West Virginia and one in Meigs County, Ohio. One company mines rock salt underground in Tompkins County, N.Y. These operations accounted for about 9 percent of the total value of salt (sodium chloride only) produced in the United States in 1964.



EXPLANATION

▨ Area of brines containing more than 15 percent dissolved solids, within 2000 feet of surface. Area includes numerous districts with past brine production

▨ Area of brines containing less than 15 percent dissolved solids at shallow depth locally. More concentrated brines locally at depths greater than 2000 feet. Area includes scattered districts with past brine production

● 8 Natural brine wells in production

○ 5 Artificial brine wells in production

◪ 3 Salt mine in production

LIST OF PRODUCERS

1 Watkins Salt Co., Inc., The Watkins Glen (Schuyler County), N. Y.
2 International Salt Co., Reading Twp. (Schuyler County), N. Y.
3 Cayuga Rock Salt Co., Inc., Myers (Tompkins County), N. Y.
4 Solvay Process Division, Allied Chemical Corp., Moundsville (Marshall County), W. VA.
5 Pittsburgh Plate Glass Co., Chemical Division, near New Martinsville (Marshall County), W. Va.
6 Inorganic Chemicals Division, F. M. C. Corp., Bens Run (Tyler and Pleasants Counties), W. Va.
7 Excelsior Salt Works, Inc., Pomeroy (Meigs County), Ohio
8 Inorganic Chemicals Division, F. M. C. Corp., South Charleston (Kanawha County), W. Va.
9 Olin Mathieson Chemical Corp., Saltville (Smyth County), Va.

FIGURE 87.—Saline resources and producers in the Appalachian Region.

Bromine and calcium chloride are produced in Appalachia as byproducts of the brine industry. The first recorded production of bromine in the United States was in 1846, when brines were used as a source of bromine in Pennsylvania. Bromine has been produced intermittently in southeastern Ohio and West Virginia in small quantities. The last recorded production, in 1961, was from wells in the Kanawha Valley (fig. 87, loc. 8).

Calcium chloride (and calcium magnesium chloride) occurs in many natural brines but is also a byproduct of the Solvay process and other manufacturing processes. Demand for calcium chloride is easily met by the synthetic products and its production from brine has never been an important factor in the Appalachian saline industry. The production of calcium chloride from brine in 1964 came from one producer (fig. 87, loc. 8).

The actual value and the 1958 constant dollar value of salines produced in Appalachia from 1941 through 1964 are shown in table 119. The increase in the constant dollar value of salines production is, in general, more the result of the growth of production rather than of an increase in unit value, although prices have risen somewhat during the 24-year period.

Salt is a high-volume, low-unit-cost commodity and transportation costs are significant in the competitive relationships between different producers. The growth of the salt industry in Appalachia has been due to the proximity of the deposits to the markets.

TABLE 119.—*Value of salines produced in the Appalachian Region, 1941–64*

[Source: U.S. Bur. Mines]

Year	Value	
	Current dollars (thousands)	1958 constant dollars (thousands)
1941	4,218	8,369
1942	4,350	7,335
1943	4,934	7,685
1944	5,441	7,610
1945	4,876	6,424
1946	5,089	6,626
1947	6,360	7,691
1948	6,743	7,813
1949	6,947	8,004
1950	8,417	9,587
1951	9,675	10,271
1952	10,020	10,503
1953	10,663	11,307
1954	[1] 14,569	[1] 15,682
1955	16,442	17,891
1956	16,547	17,436
1957	15,763	16,020
1958	16,492	16,492
1959	16,959	16,725
1960	17,137	16,984
1961	17,203	17,100
1962	18,641	18,511
1963	18,249	18,176
1964	18,764	18,670

[1] Some of this increase reflects a change in reporting practice.

One important factor in growth of the industry is the increasing use of salt for roadbed stabilization and for ice and snow control in the northern part of Appalachia where winters are apt to be severe. As one example, in Pennsylvania, some 25,000 tons of salt were used for deicing in the early 1940's, whereas in 1964 about 300,000 tons were required. Salt producers in Appalachia are near this market and thus favored by low transportation charges. Salt has inherent disadvantages as a deicer because it is corrosive and because it contaminates local ground-water supplies. However, it is the cheapest and most effective material available, and its use in road deicing will continue to grow.

Another factor is the expansion of the chemical industry in northeastern United States, particularly along the Ohio River between Wheeling and Huntington, W. Va., and in the Kanawha Valley of West Virginia. Here the proximity of salt, coal, and petroleum raw materials, abundant water, and river and railroad transportation facilities have resulted in a thriving industrial complex. Most brines produced in this area and in southwestern Virginia are consumed in the manufacture of chemicals. Salt production is expected to expand with the chemical industry.

Salt is now used in increasing quantities for water softening, not only in industrial and municipal plants but also in domestic water softeners. Increasing amounts of salt are being used by livestock producers as a food supplement.

OCCURRENCES IN APPALACHIA

Beds of rock salt of Silurian age underlie southern New York, much of western Pennsylvania, eastern Ohio, and northern West Virginia. Rock salt of Mississippian age is found in southwestern Virginia. In addition, natural brine is found in wells in strata ranging in age from Cambrian to Pennsylvanian in Ohio, Pennsylvania, West Virginia, Kentucky, and Tennessee.

ROCK SALT OF SILURIAN AGE

Salt beds of Late Silurian age underlie the northern part of the Appalachian Plateaus province. They lie within 1,000 feet of the surface in parts of Steuben, Schuyler, and Tompkins Counties, N.Y., and dip south and southwest to a depth of more than 6,000 feet under the Appalachian Plateaus province in north-central Pennsylvania (fig. 88). The salt beds are part of a sequence of shale, dolomite, and evaporite, the distribution and facies of which are shown in figure 89. This sequence is referred to as the Salina

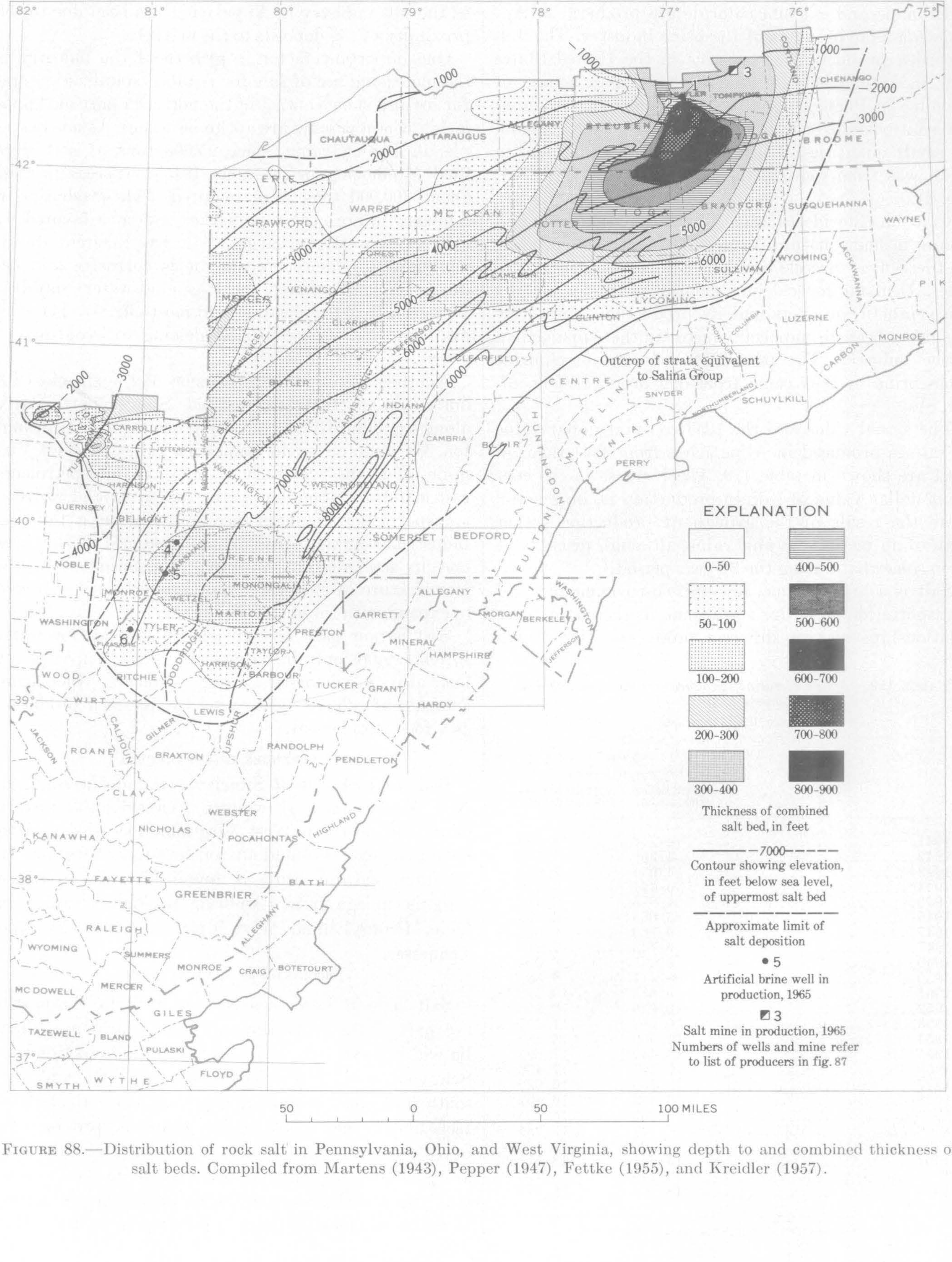


FIGURE 88.—Distribution of rock salt in Pennsylvania, Ohio, and West Virginia, showing depth to and combined thickness of salt beds. Compiled from Martens (1943), Pepper (1947), Fettke (1955), and Kreidler (1957).

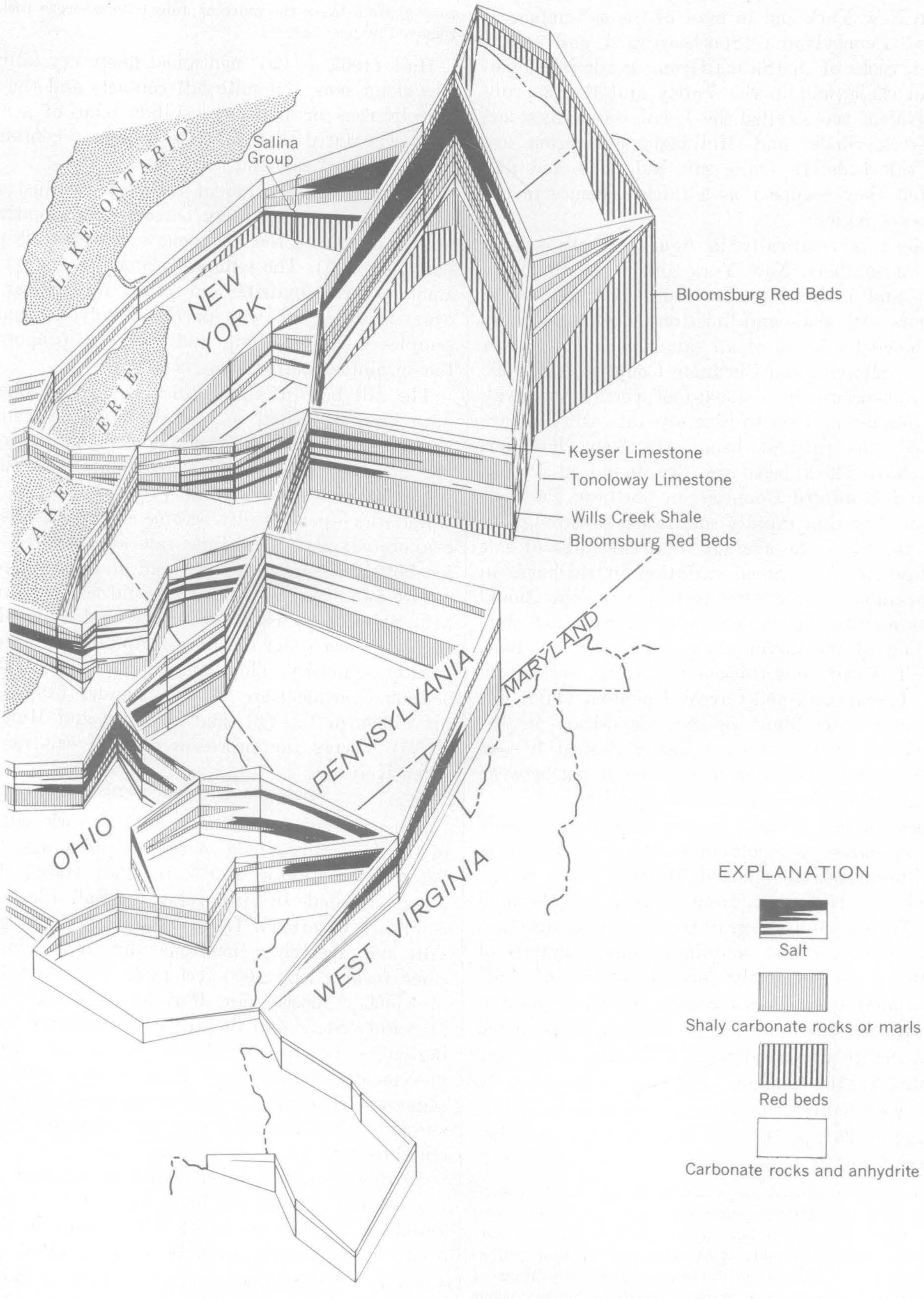


FIGURE 89.—Generalized fence diagram showing the principal salt beds and associated rocks in the northern part of the Appalachian Region. After Alling and Briggs (1961, p. 521).

Group in New York and in most of the subsurface in Ohio and Pennsylvania. Southeastward and southwestward, rocks of the Salina Group grade into limestone and shale, and in the Valley and Ridge province equivalent rocks called the Tonoloway Limestone, Wills Creek Shale, and McKenzie Formation are without salt beds. In Ohio, salt beds thin and disappear but they reappear as a thick sequence in the Great Lakes region.

As shown schematically in figure 89, the salt is thickest in southern New York and northern Pennsylvania, and it thins to the south and west as it interfingers with shale and limestone. Figure 88 shows the combined thickness of all salt beds in the Salina Group. In Schuyler and Chemung Counties, N.Y., 900 feet of salt occurs in a 1,300-foot vertical interval. Within this interval six to nine separate salt beds are recognized, the thickest being 548 feet (Kreidler, 1957, p. 35). Thick beds are also found in Potter, Tioga, and Bradford Counties, in northern Pennsylvania, but they thin rapidly southward so throughout most of the State the average total thickness of salt is roughly 100 feet. Some variation in thickness in New York and northern Pennsylvania is depositional and some may be due to flowage of the rock salt during folding of the surrounding strata (Fettke, 1933, p. 658). The salt beds thicken locally to 300 feet in Holmes, Tuscarawas, and Carroll Counties, Ohio. The approximate outer limit of salt deposition in the Salina Group is shown by a heavy dashed line in figure 88. Along this line, salt beds wedge out between carbonate rocks with shale and anhydrite.

The bedded salt deposits consist mainly of coarsely crystalline halite. No soluble saline minerals other than halite have been reported. Martens (1943, p. 32) described the rock salt from a core in Marshall County, W. Va., as light-gray translucent grains ⅛–2 inches in diameter and containing small crystals of anhydrite, a few perfectly formed crystals of dolomite and quartz, and black specks of organic matter. Very rare celestite and native sulphur were noted with the halite and anyhdrite. Dolomite, shale, and anhydrite are the common impurities that may be admixed with halite or may form discrete beds. Alling and Briggs (1961, p. 517–518) described the main impurities as follows:

> The dolomite recognized as evaporite by its closely associated anhydrite and salt is commonly light buff to gray and typically thinly bedded to laminar in texture. Massive fine-grained saccharoidal dolomite with anhydrite blebs or 'pull-apart' structures are common in the evaporite sections. Much of the anhydrite is phanerocrystalline although in the somewhat rare beds of anhydrite having thicknesses up to 10 feet the texture is massive and aphanitic. Locally in the groundwater zone gypsum takes the place of anhydrite whereas rock salt is removed by leaching.

Hall (1963, p. 29) mentioned finely crystalline pyrite along some dolomite-salt contacts and the strong petroliferous or hydrogen sulfide odor of some salt cores. He stated that dolomite beds may contain fracture fillings of salt and anhydrite.

Chemical composition of rock salt is illustrated in table 120. Rock salt may consist almost entirely of halite; if so, the NaCl content will exceed 98 percent (analyses 2, 3). The remaining analyses show varying amounts of anhydrite and other impurities; moreover, because salt was partly dissolved from some samples during drilling and washing, proportion of the insoluble matter was increased.

The salt beds of the Salina Group are believed to have been deposited in a shallow epicontinental sea that occupied much of the Appalachian Region during Silurian time. Circulation to and from the open ocean was restricted, possibly by bars or reefs. Sea water which periodically became entrapped was partly evaporated, and crystalline salt accumulated on the sea bottom along with lime mud and anhydrite. Layers of salt crystals eventually solidified to form rock salt. Salts of potassium, bromine, and other elements present in sea water did not precipitate, owing to their greater solubility. Thus large deposits of nearly pure sodium chloride were formed. Landes (1960), Stewart (1963, p. Y2–Y6), and Borchert and Muir (1964, ch. 5) discuss the processes of rock salt deposition extensively.

ROCK SALT OF MISSISSIPPIAN AGE

Near Saltville and Plasterco, Va., rock salt occurs in the Maccrady Shale of Mississippian age (fig. 87, loc. 9). Withington (1965, p. B30) stated that the Maccrady Shale lies just below the Saltville fault and is highly deformed. Large blocks of shale, gypsum, salt, and overlying limestone and underlying sandstone form a lens 2,000 feet thick, the lower 500 feet of which is mostly salt. Part of the thickness of the Maccrady Shale and the salt bed is believed by Withington to be due to plastic flowage accompanying movement along the fault. B. N. Cooper (1964, p. 94) suggested that the thickening occurred during deposition of the Maccrady and was localized by a synclinal trough.

In this area, salt is extracted by solution mining: the composition of the brine is shown in table 120 (analysis 7). The extent of salt deposits in the Maccrady Shale is not known. Withington (1965, p. B32) suggested that evaporite deposits might be found with the Maccrady Shale at other localities along the strike of the Saltville fault.

TABLE 120.—*Analyses by weight percent, of rock salt and artificial brines in the Appalachian Region*

Analysis	State, county	Material analyzed	Ca	Mg	Na	K	SO_4	Cl	Br	Insoluble residue	Total	Reference
1	New York: Schuyler	Average of analysis of brines from wells 1, 2, 3, 4, 6 and 7.	1.10	0.19	38.46	0.11	0.72	59.42	--------	--------	100	Phalen (1919, p. 224).
	Ohio:											
2	Stark	Core	.32	0	38.53	.04	.55	59.66	--------	--------	[1] 99.31	Stout and others (1932, p. 75, 76).
3	Wayne	Brine	.60	.02	38.53	--------	1.26	59.55	--------	--------	[2] 100	
	West Virginia:											
4	Harrison	Core	.26	Tr.	38.05	.13	.59	59.00	0	1.59	99.58	Martens (1943, p. 37).
5	Ritchie	Cable-tool cuttings	.57	Tr.	36.91	.37	1.30	57.47	Tr.	3.38	100	Do.
6	Marshall	Core; average of 12 analyses of 100 feet of core (One analysis with only 23 percent soluble salt omitted).	.94	Tr.	36.19	.19	2.51	56.29	0	3.53	99.65	Martens (1943, p. 39–40).
7	Virginia: Smyth	Evaporated brine	.65	--------	38.47	--------	1.53	59.34	--------	--------	99.99	Stose (1913, p. 241).

[1] Total includes 0.02 percent SiO_2, 0.01 percent Al, Fe; organic matter present.
[2] Total includes 0.04 percent HCO_3.

NATURAL BRINES

Natural brines are solutions of sodium chloride and other salts that, for the most part, were formed from sea water trapped with sedimentary rocks at the time of deposition. They are extracted from permeable sandstone and less commonly from other porous units at many horizons in the stratigraphic column. Some permeable formations, such as the Oriskany and Berea Sandstones, are extensive and retain their identity over large areas. Most brine-bearing units, called sands by drillers, are thin permeable aquifers of restricted extent. Brine-bearing sands occur throughout the Pennsylvanian System, but the most important economically are the Salt sands and the Maxton sand in the Pottsville Formation. In the Mississippian System the most important brine-producing sand is the Big Injun sand, a part of the Pocono Formation. The Upper Devonian shale sequence contains many sand beds that yield brines in Pennslyvania and West Virginia. The Oriskany Sandstone of the Lower Devonian contains concentrated brines in Pennsylvania, Maryland, Ohio, and West Virginia. Brine also occurs in the limestone sequence of Silurian and Devonian age in Kentucky (called the "Corniferous" by drillers). In Kentucky below the Silurian Salina Group lies the brine-bearing Newburg sand. Brines have been recorded in, but not produced from, Ordovician St. Peter Sandstone and Knox Dolomite (Upper Cambrian and Lower Ordovician). These and other units, many of which contain brine, are listed by R. F. Meyer and C. D. Edgerton in table 51 of this report (in pocket).

Brines containing 15–30 percent total dissolved solids are found in eastern Ohio, southwestern Pennsylvania, and in the northwest half of West Virginia, as shown in figure 87. Weak brines (less than 15 percent total dissolved solids) have been noted in various isolated areas in West Virginia, Kentucky, Tennessee, and Alabama. These brines have been reported in oil and gas wells throughout the areas delineated in figure 87. In Ohio, West Virginia, and Pennsylvania they have been actively exploited in the past.

Present production of natural brines is localized in three areas in Ohio and West Virginia. In Tyler and Pleasants Counties, W. Va. (fig. 87, loc. 6), brines are produced from the Big Injun sand at depths of 1,600–2,200 feet (Baltimore & Ohio Railroad, 1947?, p. 36). In Kanawha County, near South Charleston, W. Va. (loc. 8), the Salt sands and the Big Injun sand are exploited for brines at various depths from 600 to 1,200 feet. In Mason County, W. Va., brines were produced until 1963 from the Salt sands at 1,000–1,100 feet. Across the Ohio River in Meigs County, Ohio (loc. 7), brines are produced from the Big Injun sand between 1,000 and 1,200 feet below the surface (Landes, 1960).

Natural brines have a wide range of salinity, from as high as 30 percent dissolved solids to solutions more dilute than sea water. In general, brine-bearing layers high in the stratigraphic section contain the most dilute brines, partly because of dilution by fresh surface water. Successively older aquifers contain in general more concentrated brines. Table 121 shows this relationship.

Price, McCue, and Hoskins (1937, p. 112) stated that salinity increases with depth of burial. Poth (1962, p. 37) pointed out that brine concentration in the Oriskany Sandstone is about the same regardless of depth of burial, but determined that isolated sand lenses in Devonian shale have brines of widely varying composition. Great variation in salinity is caused by the natural influx of fresh water or by entrance of fresh water through wells that have leaky casings and improperly installed plugs (Poth, 1962, p. 38). Mixing of different brines also occurs when different horizons are penetrated by an uncased well.

TABLE 121.—*Total dissolved solids (in percent) in natural brines from selected strata in and near the Appalachian Region*

System	West Virginia (Price and others, 1937, p. 111)	Ohio (Stout and others, 1932, p. 111)	Pennsylvania (Poth, 1962, p. 50-51)
Pennsylvanian	Salt sand: 0.05–16.4, average 6.01 Maxton sand: 2.9–16.7, average 8.76	Maxton sand: 6–10, average 8.6	Pottsville Formation: 0.6–2.6, average 1.8
Mississippian	Big Injun sand: 0.01–18.1, average 9.98	Keener sand: 8–15, average 10.5 Big Injun sand: 10–15, average 11.5 Berea Sandstone: 6–14, average 9.2	Pocono Formation: 0.7–13.0, average 8.4
Devonian	Oriskany Sandstone: 0.7–28.0, average 25.27	Oriskany Sandstone: 12–26, average 19.9	Upper Devonian rocks: 5.5–17.7, average 8.7 Middle and Lower Devonian rocks: 29.3–31.2, average 29.7
Silurian		Newburg sand: 8–29.2, average 23.9	

Natural brines differ from artificial brines and rock salt in that they contain larger amounts of the elements calcium, magnesium, potassium, strontium, and bromides, in addition to sodium chloride. (See table 122 for nine selected brine analyses.) Sodium chloride is the major component in all brines; its concentration ranges from 5 to 20 percent in 460 analyses published in State survey reports. The maximum concentrations of the additional elements noted among these analyses are as follows:

Element	Concentration (percent)	Rock unit	State
Calcium	4.28	Oriskany Sandstone	Ohio.
Magnesium	.83	do	Pennsylvania.
Potassium	.48	do	West Virginia.
Strontium	.26	Salt sand	Do.
Barium	.18	do	Do.
Lithium	.02	Onondaga Limestone	Pennsylvania.
Bromine	.28	Newburg sand	Ohio.
Iodine	.004	Big Injun sand	West Virginia.
Fluorine	.002	Onondaga Limestone	Pennsylvania.

The relative concentration of the various elements in natural brines depends mainly on the concentration of total dissolved solids. Poth (1962) demonstrated that brines with concentrations of less than 14 percent show a linear increase of sodium, calcium, magnesium, and potassium with increasing total dissolved solids. In such dilute brines the sodium-calcium ratio is about 4:1, but at concentrations greater than 14 percent, the ratios become more erratic and the brines contain relatively less sodium and more calcium. In 25- to 30-percent solutions, the sodium-calcium ratio may approach unity. Analysis 2 (table 122) is an example of such a concentrated brine. The sodium-potassium ratio decreases from about 200:1 in dilute brines to be between 10:1 and 20:1 in concentrated brines. The chlorine-bromine ratio remains constant at about 130:1 for all concentrations. No broad correlations have been found between composition of brine and lithology of the brine-bearing bed or between composition and depth of burial.

It is noteworthy that whereas brine production at present is from the Pennsylvanian Salt sands and Mississippian Big Injun sand, much more concentrated brine containing larger proportions of calcium and potassium are available in the Oriskany Sandstone of Devonian age (table 122, analyses 2, 4, 6) and the Newburg sand of Silurian age. These beds lie 3,000–5,000 feet below the Big Injun sand. At deeper levels, Cambrian and Ordovician strata also contain highly concentrated brines. These brines represent an important untapped resource in the Appalachian Region.

The origin of brines has been the subject of many reports, and geologists agree that most brines are connate, that is, formed from sea water originally entrapped in the sediments during deposition. There is no general agreement to the mode of their concentration, a subject beyond the scope of this paper. The interested reader should see Mills and Wells (1919), Torrey (1934) and de Sitter (1947).

RESOURCE POTENTIAL

The outlook for the salt industry in Appalachia is promising, and the growth sustained over the past

TABLE 122.—*Analyses of natural brines in the Appalachian Region*

Analysis	State, county	Source	Fe, Al, SiO_2	Ca	Mg	Sr	Ba	Na	K	Cl	Br	I	Dissolved solids (percent of brine)	Density (g per cc)	Temperature[1] (° C)	Reference
	Ohio:															
1	Meigs (Coal Ridge Salt Co.).	Big Injun sand	0.01	0.48	0.13	0.013	0.021	3.08	0.005	6.02	0.012	Tr.	9.79	1.075	15	Stout and others (1932, p. 111).
2	Tuscarawas	Oriskany Sandstone.	.006	4.28	.68	.238	......	5.10	.281	17.90	.178	......	28.67	1.235	15	Do.
	Pennsylvania:															
3	Beaver	Berea Sandstone	.014	.879	.174	.006	......	2.85	.012	6.49	.037	.001	10.50	1.078	20	Poth, 1962, p. 50–51.
4	Clearfield	Oriskany Group (ss.).	......	3.74	.125	......	......	5.50	.278	15.40	.126	.0006	24.90	1.200	25	Do.
	West Virginia:															
5	Kanawha (Dickinson Salt Co.).	Salt sand	Tt.	.49	.11	.011	.049	1.922	.021	4.190	.006	.0003	6.81	1.074	21	Price and others (1937, p. 99).
6	Kanawha	Oriskany Sandstone.	.008	2.26	.24	.157	0	6.96	.485	15.99	.099	Tr.	26.22	1.210	......	Do.
7	Mason (Liverpool Salt Co.).	Salt sand	Tr.	.41	.13	.009	.021	2.48	.017	5.02	.035	......	8.13	1.061	25	Price and others (1937, p. 100).
8	Pleasants	Big Injun sand	.025	.92	.15	.008	.026	3.35	.027	7.26	.069	.0009	11.85	1.084	27	Price and others (1937, p. 101).
9	Kentucky: Laurence.	"Corniferous" limestone.	Tr.	.768	.225	.017	......	2.78	.129	6.498	.069	.001	10.49	1.078	......	McGrain(1953, p. 14).

[1] Temperature at which density was measured.

quarter century should continue. Major markets for salt are in close proximity to Appalachia's virtually inexhaustible salt resources, and practically all of these markets have been increasing.

Additional salt resources can be developed to satisfy the growing regional demand throughout the northern part of Appalachia. Rock salt at least 50 feet thick lies within 6,000 feet of the surface under an area of 20,000 square miles in Appalachia. In addition, brine-bearing beds lie at shallower depths over an equally large area. When these shallow brine accumulations are depleted, deeper drilling can tap large quantities of more highly concentrated brines richer in bromine, potassium, and other elements.

Careful study of existing subsurface data on rock salt and brine-bearing beds in Pennsylvania, Ohio, and West Virginia, and close attention to the problems of detecting and measuring rock salt and brine in future drill holes are necessary to present a detailed picture of the distribution of saline resources. Such knowledge would serve to attract a larger share of the chemical industry to Appalachia by aiding in the selection of sites for new plants using salt or brine as a raw material.

Research on the extraction and use of the minor components of brines, especially magnesium, potassium, bromine, strontium and barium, should result in increased diversification of the chemical industry in Appalachia and increased value of the brine resources.

SILICA

By W. D. CARTER, U.S. Geological Survey

INTRODUCTION

Silicon (Si) after oxygen (O_2) is the most abundant element in the earth's crust, and quartz (SiO_2) is one of the principal rock-forming minerals. Furthermore, most of the other minerals that form the major rock types are silicates, in which silica and oxygen combine with other elements, both common and rare.

Primary quartz concentrations of commercial value are found as veins in granite and as large massive cores in pegmatites. Sand, gravel, sandstone, conglomerate, and quartzite are secondary concentrations derived from erosion of quartz-bearing igneous rocks, veins, pegmatites, and older sedimentary rocks. Hydrous silica also occurs as opal, chert, flint, diatomaceous earth, and tripoli. Of these, sand, sandstone, and quartzite are most widespread and abundant, provide the greatest resources, and are generally considered together as "silica sand deposits." Because silica sand deposits provide most of the silica of commerce, they are also commonly referred to as "industrial sands."

The uses of silica and especially those of high-quality "industrial sands" are myriad and continually growing. Silica is the chief raw material in the manufacture of glass. It is used in large amounts for metallurgical flux, hydraulic-fracturing (hydrafrac) sand, abrasives, and molding sand, and in the manufacture of ferroalloys, ceramics, and refractories; it is used in lesser amounts as a paint extender, as mineral filler in fertilizers and insecticides, and as insulation. Metallic silicon is used to make semiconductors for electronic instruments, and also in the manufacture of silicones, a group of plastics with many unusual properties and uses.

Specifications for silica vary greatly according to use. For some uses, the physical properties of the raw material are most important; for others, the chemical composition of a deposit is the chief concern. Certain other uses require both high chemical purity and specific physical properties. To cite one example, glass sand should contain a minimum of 98 percent silica and less than 0.06 percent iron oxide; more iron tends to color the finished product. Uniformity of grain size is also important in the glass industry, because coarse material is more difficult to melt and extremely fine material produces "seeds" in the glass and creates dust problems. Grain sizes ranging from 20 to 100 mesh have proved to be most satisfactory.

High-grade silica sand, sandstone, and quartzite also are used in the manufacture of silicon carbide (SiC) which requires that Al_2O_3 content be less than 0.04 percent for "green grit" or a maximum of 0.20 percent Al_2O_3 for lower grade "black grit." Silicon metal is produced from crushed quartzite, quartz pebble, or highly indurated quartzose sandstone containing no more than 0.07 percent Fe_2O_3 and 0.25 percent Al_2O_3. Ferrosilicon has somewhat less stringent requirements allowing a maximum of 0.03 percent Fe_2O_3 and 0.15 percent Al_2O_3.

Sand and sandstone used for molding purposes in steel, brass, and aluminum foundries have more liberal chemical tolerances that are regulated largely by the temperatures used in casting. Requirements depend more on physical properties such as shapes of grains that permit close, firm packing. Naturally bonded molding sands are those containing 75–85 percent quartz and 15–25 percent naturally admixed clay. Such molding sands are generally found as unconsolidated stream deposits. Synthetic molding sands are made from sand or crushed friable sandstone to which fine clay or bentonite is added as a binding material.

Silica refractory brick manufacturers use quartzite, quartz pebble, or highly indurated quartzose sandstone as raw material because their dense texture of firmly interlocked grains help strengthen the product. Chemical requirements for silica brick are not as strict as those for glass sand. Rock containing 96 percent or more silica, less than 2 percent iron oxide, less than 1.5 percent alumina, and not more than 0.5 percent alkalies is considered suitable (E. W. Moore and Taylor, 1924, p. 17).

Filter sands must be carefully sized. Engine traction sands and abrasives require equal grain size and angular grains. Sand used to increase production of oil, gas, and water wells by hydraulic fracturing must be of uniform texture and in strong grains of nearly spherical shape for maximum porosity.

Additional data on the uses and specifications for high-silica raw materials can be found in E. W. Moore and Taylor (1924), Stone (1928), Murphy (1960a, b), Chandler (1960), C. B. Clark and McDowell (1960), and the American Society for Testing and Materials (1964).

PRODUCTION

Industrial sands and the other types of material used for the above purposes make up only a small fraction of the total sand and gravel production of the United States. In 1964 nearly 869 million tons of sand and gravel was produced, valued at $849 million. Of this, about 23 million tons, valued at $74.3 million, consisted of the high-purity and special-quality material discussed in this section. Other uses of silica, largely for construction purposes, are described in the foregoing sections on "Sand and Gravel" (p. 254), "Crushed Stone" (p. 188) and "Dimension Stone" (p. 191).

About one-third of the total industrial-sand production was used for molding, one-third for glass, and one-third for grinding and polishing, blast sand, fire or furnace sand, engine sand, filtration sand, hydrafrac sand, and other purposes. Of the total industrial-sand production in 1964, Appalachia produced about 3.5 million tons, valued at about $13.9 million.

The amount of sand, sandstone, conglomerate, and quartzite produced for industrial purposes in the Appalachian States in 1963 is shown in table 123. The records are not detailed enough to identify the part of this production that is actually from Appalachia, but they indicate the magnitude of the present industry. Pennsylvania was the leading producer that year followed closely by New York, West Virginia, and Ohio. Tennessee ranked fifth followed by Alabama and Virginia, with about equal production. The average price per ton was $2.64 and ranged from 50 cents for low grade unwashed unsorted material to as much as $20 for extremely pure, carefully sorted material destined for highly specialized use. The highest average value ($4.75 per ton) was in West Virginia where the glass industry uses large amounts of high-grade sand.

Most industrial sand produced in these States came from few areas and few geologic formations. In

TABLE 123.—*Production of sand, sandstone, conglomerate, and quartzite for industrial uses in the Appalachian Region, 1963*
[Quantities and values rounded to nearest thousand. Source: U.S. Bur. Mines, Minerals Yearbook, 1963]

State	Use	Quantity (short tons)	Value	Average price per ton
New York	Molding	162, 000	$632, 000	$3. 90
	Filtration	19, 000	25, 000	1. 31
	Other	1, 443, 000	875, 000	. 61
	Undistributed	52, 000	95, 000	1. 83
	Total or average	1, 676, 000	1, 627, 000	0. 97
Pennsylvania	Molding	122, 000	378, 000	3. 09
	Fire or furnace	168, 000	382, 000	2. 27
	Undistributed [1]	1, 533, 000	4, 914, 000	3. 21
	Total or average	1, 823, 000	5, 674, 000	3. 11
Ohio	Undistributed [2]	1, 100, 000	4, 400, 000	4. 00
Maryland	do	366, 000	801, 000	2. 18
West Virginia	do	1, 177, 000	5, 597, 000	4. 75
Kentucky	do	12, 000	8, 000	. 67
Virginia	do	533, 000	1, 139, 000	2. 13
Tennessee	Molding	246, 000	738, 000	3. 00
	Fire or furnace	7, 000	13, 000	2. 00
	Engine	1, 000	2. 000	1. 50
	Undistributed	457, 000	860, 000	1. 88
	Total or average	711, 000	1, 613, 000	2. 27
North Carolina	Undistributed [2]	539, 000	269, 000	0. 50
South Carolina	Engine	30, 000	95, 000	3. 16
	Undistributed	312, 000	994, 000	3. 18
	Total or average	342, 000	1, 089, 000	3. 18
Georgia	Undistributed	34, 000	28, 000	2. 29
Alabama	do	533, 000	1, 139, 000	2. 14
	Grand total or average	8, 846, 000	23, 384. 000	2. 64

[1] Includes glass, abrasives, filter, and other industrial uses.
[2] Same as footnote 1 and also includes molding, fire, and furnace sands.

Pennsylvania most production came from counties within Appalachia, led by Huntingdon County. There, the Tuscarora Quartzite of Silurian age was mined for ganister used in manufacturing silica brick, and the Ridgeley Sandstone (Oriskany Group), of Devonian age, was quarried for glass sand and many other purposes. Although New York was second in production of industrial sands, very little came from those counties included in Appalachia. Cattaraugus County, an exception, produced more than a million tons, of which most was molding sand. In West Virginia some production comes from the Ohio River area, where terraces are quarried and bottom sand is dredged. In addition, large tonnages of quartzose, commonly highly indurated sandstone, are mined from the Oriskany Sandstone near Berkeley Springs, Morgan County. Lesser amounts come from the upper part of the Connoquenessing Member of the Pottsville Formation, near Greer, Monongalia County. Although used primarily for the manufacture of glass, the material is prepared for many purposes. In eastern Ohio, in Carroll, Gallia, Lawrence, Perry, Scioto, Washington, and Tuscarawas Counties, production comes largely from Mississippian and Pennsylvanian sandstones and conglomerates. The material is processed for a variety of uses which include molding sand, abrasives, refractory silica brick, furnace lining, and glass. Table 124 lists producing companies in Appalachian States in 1963 and their source materials and manufactured product.

DEPOSITS IN APPALACHIA

Silica resources are abundant and widepread in Appalachia. The distribution of principal sandstone, conglomerate, and quartzite formations that are or can be utilized is shown in figure 90, and the approximate distribution of glass factories and companies presently mining silica in figure 91. Most silica producers are located as close to markets and rail transportation as possible, and the locations of glass-manufacturing plants are dependent on a combination of nearness to markets, fuel (coal and gas), power, transportation, and raw materials.

TABLE 124.—*Producers of industrial sand in the Appalachian States, 1963*

[Producers listed but not numbered are in counties near or bordering Appalachia and are not shown on fig. 91 p. 344. Those producers that are listed and numbered in this table and shown on fig. 91 outside the boundaries of Appalachia are included because of their effect on silica production in the Appalachian part of their respective States.]

County	Town or area	Location (fig. 91)	Operator	Stratigraphic unit	Rock type	Use
			Alabama			
Calhoun	Anniston	1	John B. Lagarde, Inc.		Sand	Molding.
	Ohatchee	2	Mohawk Silica Co.	Shades Ss. mbr. of Pottsville.	Sandstone	Molding, glass.
	Oxford	3	Harbison-Walker Refractories Co.	Weisner	Quartzite	Refractory brick.
Cherokee		4	Wolf Creek Sand Co.		Sand	Molding.
Chilton	Plantersville	5	Southeastern Sand & Gravel Co.			Filter, engine.
		6	Wade Sand & Gravel Co.			Do.
Colbert	Sheffield	7	Tennessee Valley Sand & Gravel Co.			Do.
Jefferson		8	Universal Atlas Cement		Sandstone	Refractory, molding.
		9	Sam P. Acton			
		10	Enos Vann			
			Georgia			
Chattooga		11	Wolf Creek Sand Co.		Sand	Molding.
De Kalb		12	Consolidated Quarries Div., Georgia Marble Co.		Granite	Silica sand.
Effingham		13	Dawes Silica Mining Co.		Sand	Blast, filler, filter.
Thomas	Thomasville	14	do		do	Molding.
			Kentucky			
Calloway		15	Murray Silica Sand Co.			Molding.
Daviess		16	Owensboro River Sand & Gravel Co.			Engine.
		17	Daviess County Sand & Gravel Co.			
			Maryland			
Allegany	Cumberland	18	Manley Sand Div., Martin-Marietta Corp.	Tuscarora	Quartzite	Glass, abrasive.
			New York			
Oneida	Boonville		Eastern Rock Products, Inc.			Molding, other uses.
	Clayville		Humphrey D. Jones			Do.
			Ludlow Sand & Gravel Co.			Do.
	Gravesville		Eastern Rock Products, Inc.			Do.
			George W. Bryant Core Sands, Inc.			Do.
	McConnellsville		Whitehead Bros. Co.			Do.
	Rome		Hanicker Bros.			Do.
	Verona		Watson Bros. Gravel Bed, Inc.			Do.
			North Carolina			
Mitchell	Spruce Pine	19	Lawson-United Feldspar & Minerals Co.		Pregmatite, quartz, and feldspar.	Glass, other uses.
		20	International Minerals & Chemical Corp.		do	Do.
	Kona	21	do		do	Do.

TABLE 124.—*Producers of industrial sand in the Appalachian States, 1963*—Continued

County	Town or area	Location (fig. 91)	Operator	Stratigraphic unit	Rock type	Use
			Ohio			
Carroll	Rose	22	Mineral City Sand Co.	Freeport	Sandstone	Molding.
Coshocton		23	Ayers Mineral Co.		Sand	Do.
		24	E. F. Meyer & Sons		do	Do.
		25	Zanesville Gravel Co.		do	Do.
Gallia	Kerns	26	The Keener Sand & Clay Co.		do	Do.
Holmes	Killbuck		Nicholl Stone Co.	Connoquenessing (Massillon) Mbr., Pottsville Fm.	Sandstone	Refractory.
Jackson	Jackson	27	Jacskon Sand Mining Co.	Sharon Mbr., Pottsville Fm.	do	Molding.
		28	Universal Sand Mining Co.	do	do	Molding(?).
Knox	Howard		The Millwood Sand Co.	Black Hand	do	Glass, other uses.
	Brinkhaven		Martin Sand Co.	Connoquenessing (Massillon) Mbr.	do	Molding.
Lawrence	Pedro	29	Lawrence Refractories Co.		do	Industrial uses.
Muskingum		30	Ayers Mineral Co.		Sand	Molding.
		31	Stemm Clay Co.		do	Do.
		32	Zanesville Gravel Co.		do	Do.
Perry	Glenford	33	The Central Silica Co.	Connoquenessing (Massillon) Mbr.	Sandstone	Glass, other uses.
	Hopewell		do	Sharon Mbr.	Conglomerate	Do.
	New Lexington	34	The Keener Sand & Clay		Sand	Molding.
		35	Industrial Minerals Co.		Sand	Molding.
Pike	Huchel	36	Ohio Mineral Co.	Sharon Mbr	Conglomerate	Do.
	Jackson	37	Sharon Silica Co.	do	do	Metallurgical pebble.
Ross	Richmond Dale	38	Southern Silica Co.	do	do	Glass.
Scioto	Minford	39	General Refractories Co.	do	do	Silica brick.
	Rush		Taylor Stone Co.	do		Refractory, other uses.
Tuscarawas		40	Harbison-Walker Refractories.	do	Conglomerate	Silica brick.
	Dundee (Wayne)	41	Industrial Silica Div., Pennsylvania Glass Sand Corp. (Coxee Works).	Connoquenessing (Massillon) Mbr.	Sandstone	Industrial uses.
				do		
		42	Superior Sand Co.	do	Sand	Molding.
		43	Tuscora Foundry Sand Co.(?)	do	do	Do.
Washington	Constitution (Warren).	44	Hall Grindstone Co.	do	Sandstone	Abrasive.
			Pennsylvania			
Bever	Ellwood City	45	Ellwood Stone Co.	Pottsville	Sandstone	Industrial.
Bedford	Hyndman	46	Leap Ganister Rock Co.	Tuscarora	Quartzite	Furnace.
	Weyant	47	Detwillers Industrials Inc.	Chemung	Conglomerate	Aggregate.
		48	Pittsburg Silica Co.	Oriskany	Sandstone	
Blair	Frankstown	49	General Refractories Co.	do	do	Silica brick.
	Sproul	50	do	Tuscarora	Quartzite	Do.
	do	51	J. L. Hartman	do	do	Do.
Cambria	Johnstown	52	Samuel Nicosia	Pottsville	Sandstone	Do.
Carbon	Little Gap	53	North American Refractories.	Oriskany	Conglomerate	Do.
	Palmerton	54	Alliance Sand Co.	Palmerton Ss. Mbr., Onondaga Fm.	do	Industrial, other uses.
		55	Stoney Ridge Silica Co.	do	do	Do.
Centre	Port Matilda	56	General Refractories Co.	Tuscarora	Quartzite	Silica brick.
Fayette	Connellsville	57	Dunbar Corp	Pottsville	Sandstone	
		58	General Refractories Co.	do	do	Silica brick.
	Scottdale	59	Connellsville Blue Stone Co.	do	do	Aggregate.

TABLE 124.—*Producers of industrial sand in the Appalachian States, 1963*—Continued

County	Town or area	Location (fig. 91)	Operator	Stratigraphic unit	Rock type	Use
Pennsylvania—Continued						
Huntingdon	Mapleton Depot.	60	Pennsylvania Glass Sand Corp. (Keystone Works).	Oriskany	Sandstone	Glass, other uses.
	Mount Union	61	Harbison-Walker Refractories Co.	Tuscarora	Quartzite	Silica brick.
	Three Springs	62	North American Refractories.	do	do	Do.
Lawrence		63	National Stone	Pottsville	Sandstone	
Lycoming	Montoursville	64	Lycoming Silica Sand Co.	Oriskany	do	Abrasive, molding, other uses.
Mercer	Greenville	65	White Rock Silica Sand Co.	Black Hand or Berea.	do	Various uses.
Mifflin	McVeystown	66	Pennsylvania Glass Sand.	Oriskany	do	Do.
	Hawstone	67	Haws Refractories Co.	Tuscarora	Quartzite	Silica brick.
Monroe	Kunkeltown	68	Sheesley's Minerals Inc.	Oriskany	Conglomerate	Aggregate.
Schuylkill	Andreas	69	Harbison-Walker Refractories. Co.	do	do	Silica brick.
	Summit Station.	70	Summit Quarries Inc.			Aggregate.
Venango	Utica	71	Industrial Silica Div., Pennsylvania Glass Sand Corp.	Pottsville	Sandstone	Molding, furnace.
Washington	Claysville	72	Fry Coal & Stone Co.		do	Aggregate.
South Carolina						
Cherokee	Blacksburg	73	Jobe Sand Co.			Various uses.
Spartanburg	Pacolet	74	Spartan Minerals Co.		Granite	Do.
Tennessee						
Campbell	Cove Lake State Park.	75	White Sand Silica Co.	Sewanee	Conglomerate	Abrasive.
Cumberland	Crab Orchard	76	Turner Bros. Stone Co.	do	do	Furnace.
Franklin	Monteagle	77	Sewanee Silica Sand Co.	do	do	Glass, other uses.
Hamilton	Fairmont	78	Dixie Sand & Gravel Co.	Vandever	Sandstone	
Knox		79	Knoxville Sand & Gravel Co.		Sand dredged from Tennessee River.	Abrasive. Engine.
		80	Oliver King Sand & Lime Co.			
Polk		81	Campbell Sand & Gravel Co.			Furnace.
Virginia						
Craig	New Castle	82	Castle Sands Co.	Oriskany	Sandstone	Filter, other uses.
Frederick	Gore	83	Virginia Glass Sand Corp.	do	do	Glass.
Rockbridge	Goshen	84	Locher Silica Corp.	do	do	Do.
	Natural Bridge	85	Mathews-Curtis Co.	Erwin	Quartzite	Metallurgy.
Wythe	Lots Gap	86	Silica Products Co.	do	do	Masonry.
	do		Locher Silica Corp.	do	do	Metallurgy.
West Virginia						
Brooke	Follansbee	87	Brilliant Materials Co.		Sand	Fire, furnace.
Fayette		88	Sun Sand Co.		do	
Kanawha	Charleston	89	Tony Pacifico Co.		Sandstone	Silica brick.
Monongalia	Masontown	90	Deckers Creek Sand Co.		Sand	Engine.
Morgan	Berkeley Springs.	91	Pennsylvania Glass Sand Corp.	Oriskany	Sandstone and quartzite.	Abrasive, other uses.
Tucker	Parsons	92	Fairfax Sand and Crushed Stone.	Pottsville	Sandstone	Building, paving.
Wayne	Fort Gay	93	Laval Sand Co.		Sand	Engine, aggregate.
Wyoming	Clear Fork	94	Tolers Sand Co.		do	Engine.

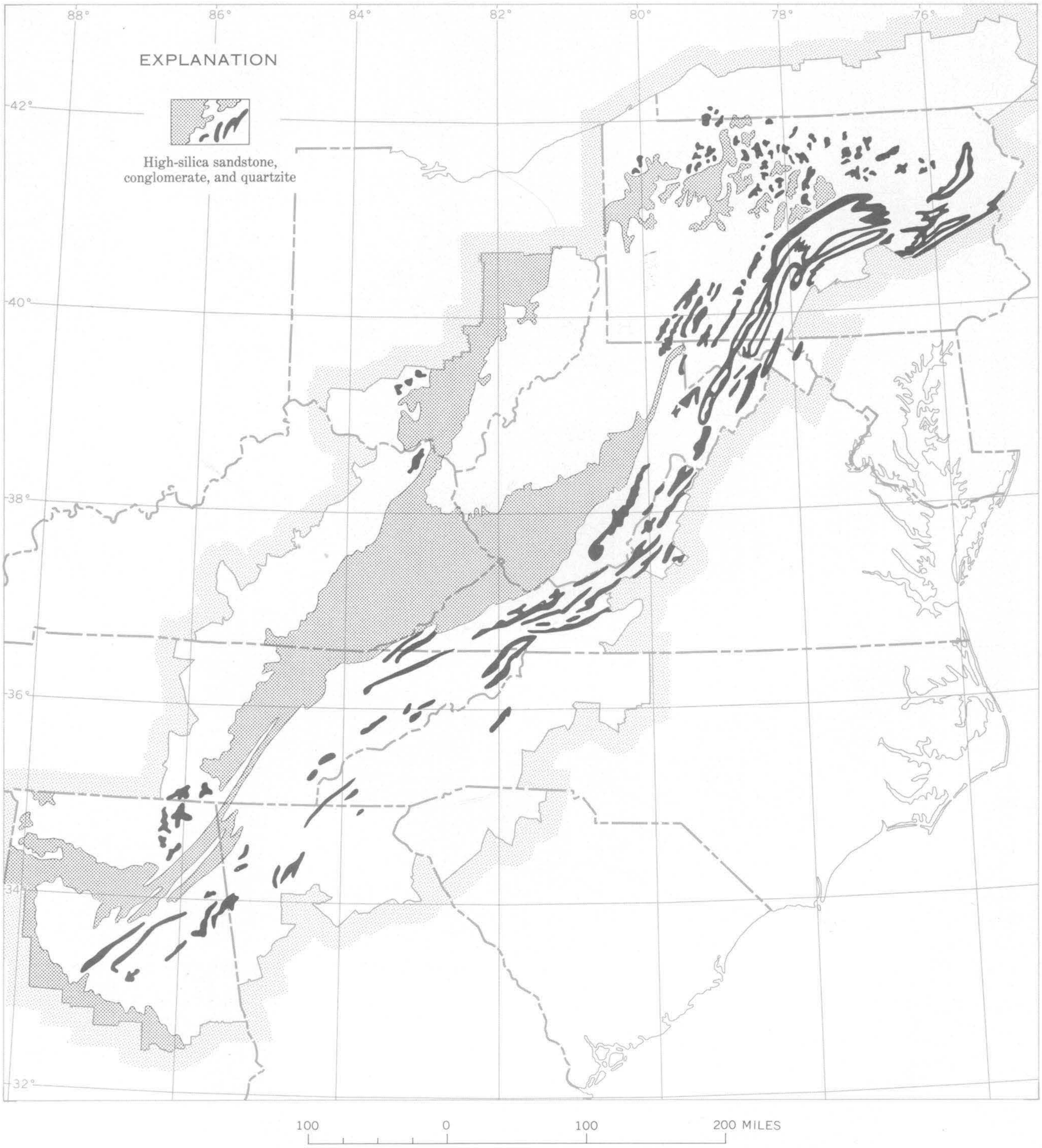
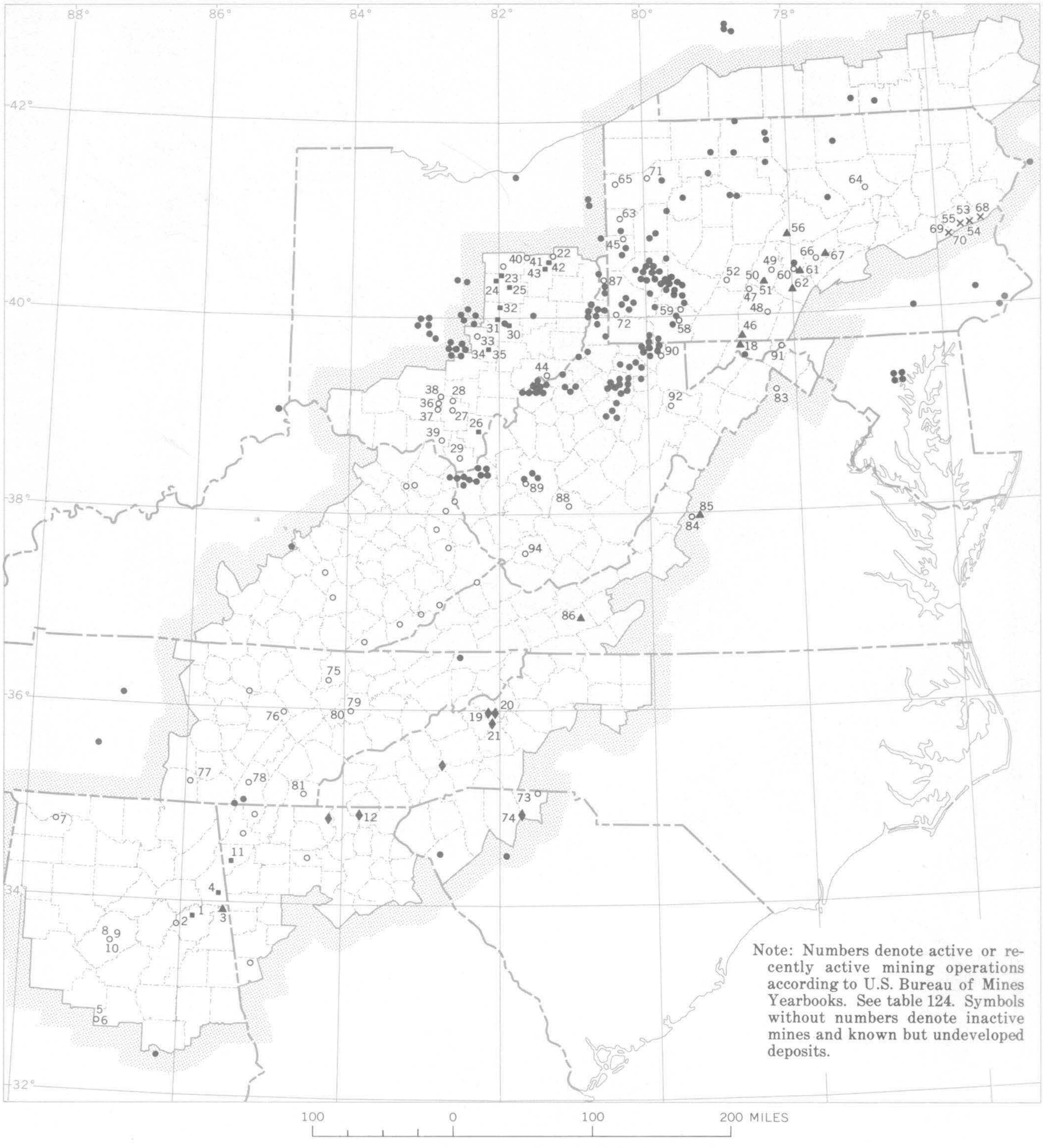


FIGURE 90.—Approximate distribution of high-silica sandstone, conglomerate, and quartzite in the Appalachian Region.



Note: Numbers denote active or recently active mining operations according to U.S. Bureau of Mines Yearbooks. See table 124. Symbols without numbers denote inactive mines and known but undeveloped deposits.

EXPLANATION

● Glass factory

SILICA DEPOSITS

■ Unconsolidated sand deposits, mainly used for molding sand

○ Sandstone and conglomeratic sandstone

× Conglomerate

▲ Quartzite

◆ Quartz vein, pegmatite, or granite

FIGURE 91.—Glass factories and high-silica deposits in the Appalachian Region (1964).

ALABAMA

Of the many sources of high-grade silica in the Appalachian part of Alabama, principal production has been from the Shades Sandstone, basal member of the Pottsville Formation of Pennsylvanian age, and the Tuscaloosa Group and overlying Eutaw Formation of Late Cretaceous age. Lesser amounts have been obtained from the Hartselle Sandstone of Mississippian age and the Weisner Quartzite of Early Cambrian age.

The Shades and Hartselle Sandstones crop out in the Appalachian Plateaus province of northeastern and north-central Alabama; the Tuscaloosa and Eutaw crop out in the Coastal Plain along the southern and western margins of Appalachia. These formations, and stream deposits derived mainly from them, were extensively mined until 1929 to provide molding sand for the foundry industry in the Birmingham area (Adams, 1929, p. 30). At one time the Hartselle Sandstone was mined for glass sand near Irondale (Adams, 1929, p. 30). Before 1930 annual production of molding sand in Alabama was about 140,000 short tons, valued at $140,000. By 1963, total industrial sand production was about 533,000 tons and included molding, filtration, and engine sands and sands for other uses (table 123). Production came mainly from Cherokee, Chilton, and Jefferson Counties.

Quartzite for refractory brick has been mined periodically near Piedmont, Cherokee County, from the Weisner Quartzite. The formation has been prospected in the Rock Run and Borden Springs area of neighboring Cleburne County.

Tripoli, finely divided silica from weathering of chert in the Fort Payne Formation has been mined along Bear Creek in Tishomingo County, northeastern Mississippi, and is known to crop out in the Bear Creek area, between Riverton and Margerum, Ala. (Gildersleeve, 1946e). Deposits near Waterloo, Lauderdale County, are under development for use in silica face brick (T. A. Simpson, 1966, oral commun.). Clayey tripoli deposits are currently being worked in other parts of the state, as described in the section on "Clay" (p. 167).

Silica resources of northern Alabama are considered to be extensive and suitable for industrial uses such as molding sand, engine sand, filler, and filtration. Because of their high content of iron oxide (2 percent or more Fe_2O_3) and clay (as much as 35 percent), formations ordinarily suitable for molding sand would have to be carefully washed, scrubbed, and classified to be suitable for glass or other industries that require high-purity sand.

Table 125 shows analyses of silica samples from various localities in Alabama. Most samples contain 95 percent or more silica and most could be upgraded by washing and scrubbing.

GEORGIA

High-silica resources in the Appalachian part of northern Georgia have been described in considerable detail by Teas (1921). They include massive quartz vein deposits in Fannin and Towns Counties, silica sand in Heard and Pickens Counties, and tripoli in Bartow and Chattooga Counties (Georgia Dept. Mines, Mining and Geology, 1940). According to current U.S. Bureau of Mines statistics, none of the deposits mentioned are being worked at present, and all industrial-sand production of the State is south of the area included in Appalachia. A small amount of quartz was mined for testing at the Bell Mountain silica deposit near Hiawassee, Towns County, by the Mauney Mining Co. of Murphy, N.C. The deposit, also referred to as "Bell Knob quartz," was recently the subject of a detailed geologic and market study financed by the Area Redevelopment Administration (Hurst and Horton, 1964). Results of initial exploration indicate that high-grade silica reserves range from 2 to 4 million tons containing 98.6–99.9 percent SiO_2, 0.005–1.2 percent Fe_2O_3 and 0.0001–.08 percent Al_2O_3. Because of the hardness of the rock and isolated location of the deposit, mining and freight costs are high and present markets are limited. Recent production has been sold for more than $30 per ton.

A similar but smaller deposit was worked about 1940 at the Hurtz quarry near Hempton Gap in eastern Fannin County. Most of the material produced was used as roadstone, but a small amount was reported to have been used in manufacturing glass and ferrosilicon.

Stream and bank deposits have been mined for molding sand along the Yellow River near Almon, Monroe County, and along Chickamauga Creek at Ringgold, Catoosa County (Teas, 1921, p. 69).

Pure white sandstone of the Red Mountain (Rockwood) Formation of Silurian age (Hayes, 1894) is exposed at Rocky Face and Chattogata Mountain, Whitfield County, and was mined about 50 years ago for use in glass manufacture (Teas, 1921, p. 364).

Remarkably pure sandstone, probably the Tusquitee Quartzite of Cambrian age, has been reported from the Payne property near Jasper in Pickens County (Teas, 1921, p. 360). Also known as the "Rhodes Silica Deposit," it has long been considered as a potential source of glass sand because analyses showed 99.7 percent or more SiO_2, 0.11 percent or less Al_2O_3,

TABLE 125.—*Selected partial chemical analyses of silica in Alabama*

[Samples 1-9 from TVA File Report 1376; samples 10-13 from Burchard (1907, p. 382); sample 14 from report on the Hunt-Beatty property dated 1929; sample 15 from Bowles, (1941, p.29)]

Analysis	County	Locality	Type	Percent—		
				SiO_3	Fe_2O_3	Al_2O_3
1	Franklin	Spruce Pine	Washed gravel	95. 66	2. 08	0. 86
2	do	Rockwood	do	97. 02	. 32	1. 10
3	Marion	Hackelburg	do	97. 14	2. 40	1. 30
4	do	Haleyville	do	98. 06	. 80	. 50
5	Calhoun	Anniston	Sand	99. 71	. 02	. 14
6	Marshall	Albertville	Sandstone	93. 1	1. 12	4. 06
7	Marshall	Boaz	do	94. 7	1. 44	2. 90
8		Herkin Branch	do	96. 9	1. 14	1. 22
9	Colbert	Margerum	Tripoli, −12 mesh, 59 percent.	99. 16	0. 30	
			Tripoli, −100 mesh, 23.8 percent.	98. 06	. 87	
10	Jefferson	Gate City	Sand	99. 80	. 31	. 75
11	do	Irondale	Sandstone	97. 93	. 19	1. 05
12	do	Trussville	Sand	98. 05	. 20	. 22
13	do	North Birmingham	Sandstone	97. 30	. 33	1. 39
14	Cleburne	Rock Run, Borden Springs	Weisner Quartzite (ganister).	97. 81	1. 01	. 84
15	Cherokee	Harbison Walker quarry	Ganister	98. 1	1. 3	

and 0.03 percent or less Fe_2O_3. Although reserves are considered extensive, the sandstone deposit apparently has not been developed, in part because of poor access.

A new development in the silica raw-materials field of Georgia is the recent production of a 60-percent feldspar and 40-percent quartz sand from granite by the Consolidated Quarries Division of Georgia Marble Co. at Lithonia, De Kalb County (Trauffer, 1965). This sand is used in glass manufacture by the company's glass plants in the Atlanta area. It is recovered from the crushed rock by a wet-dry separation process that includes froth-flotation. Coarse material is sold for aggregate, and the fines are sold as a flux for kaolin clay used in the manufacture of light-colored and white brick.

Tripoli is used as an abrasive inert filler and gunning refractory. The tripoli deposits in Georgia are entirely within Appalachia and were derived as a weathering product of Knox Dolomite. After discovery about 110 years ago, they were mined extensively near Dalton and Lyerly in Chattooga County. Murray, Walker, and Whitfield Counties also have recorded production but at present have no active mining. Similar deposits are known to be present in Catoosa, Gilmer, Floyd, Polk, and Bartow Counties. Although the deposits have not been studied in detail, reserves containing 90 percent or more SiO_2 are considered large and could compete with other sources of silica after proper milling, screening, and grading (Furcron and others, 1938, p. 92).

Table 126 shows partial analyses of samples from the better known deposits of Georgia. Best potential sources of material for glass and refractory silica brick are the Tusquitee and Weisner Quartzites and sandstone of the Red Mountain (Rockwood) Formation. Stream and bank sand deposits mainly derived from these formations are suitable for molding sand and other uses.

KENTUCKY

Industrial sand production in Kentucky in the early 1960's was about 20,000 tons per year averaging about $75,000 in value. Glass and molding sand, the principal products, were quarried and crushed near Elkhorn City, Pike County. Sand for miscellaneous uses was mined intermittently from small pits in Bell and Letcher Counties. The Elkhorn City operation currently (1966) is closed (Preston McGrain, written commun., 1966).

Silicia deposits of Kentucky were studied briefly by Burchard (1907), Richardson (1920), and most recently by McGrain (1952, 1956) and McGrain and Crawford (1959). McGrain sampled approximately a dozen areas within Appalachia, most in sandstone of the Lee Formation of Mississippian and Pennsylvanian age (table 127). Deposits near Lawton in Carter County, Pineville in Bell County, and the Bell Farm in McCreary County contain 95 percent or more SiO_2. All contain less than 0.2 percent Fe_2O_3 but 2–4 percent Al_2O_3 as clay. Most impurities can be removed by washing and scrubbing. The deposits are thinner (15–20 feet at Lawton, 50 feet at Pineville, and 13 feet at Bell Farm) and are more distant from existing glass markets than thicker deposits presently in use. These sands are suitable for other industrial purposes or glass, for that matter, if markets can be found.

TABLE 126.—*Selected partial chemical analyses of silica-rich rocks in Georgia*

[Source: GeorgiaDept. Mines, Mining and Geology (1940)]

Analysis	County	Locality	Percent—		
			SiO_3	Fe_2O_3	Al_2O_3
1	Whitfield	Rocky Face	97. 91	1. 91	2. 07
2	Heard	3 miles south of Franklin	98. 96	. 58	. 32
3	Pickens	Rhodes Silica	99. 82	. 03	. 07
4	Fannin	Big Stoney Battery	99. 16	. 03	. 48
5	Towns	Bell Mountain	98. 78	. 38	Not available.

TABLE 127.—*Selected chemical analyses of silica in deposits in eastern Kentucky*

[From McGrain, 1956]

Analysis	County	Locality	Percent—				Formation
			SiO_2	Fe_2O_3	Al_2O_3	$CaCO_3$, $MgCO_3$	
1	Carter	Lawton	96. 7	0. 118	2. 54	0. 125	Lee.
2	do	do	95. 5	. 126	4. 16	. 158	Do.
3	do	Olive Hill	97. 88	. 04	1. 78	. 19	Do.
4	Floyd	Prestonburg	75. 83	2. 73	16. 04		Breathitt.[1]
5	Bell	Pineville	95. 45	. 019	3. 486	. 166	Lee.
6	Harlan	Harlan	93. 42	. 052	4. 898	. 261	Do.
7	Johnson	Staffordsville	92. 09	. 159	5. 506	. 219	Do.
8	Laurel	Bernstadt	94. 2	. 178	4. 072	. 095	Corbin.
9	Lawrence	Busseyville	78. 7	1. 49	14. 6		Breathitt.[1]
10	Letcher	Hurricane Gap	94. 325	. 035	4. 135	. 249	Lee.
11	do	Whitesburg	92. 15	. 065	5. 810	. 125	Do.
12	McCreary	Bell Farm	95. 8	. 060	3. 14	. 273	Do.

[1] Breathitt Formation of Early and Middle Pennsylvanian age overlies the Corbin Sandstone Member of the Lee Formation.

MARYLAND

The principal sources of silica in western Maryland are the Ridgeley Sandstone of the Devonian Oriskany Group and the Tuscarora Quartzite of Silurian age. These formations crop out in long northeast-trending ridges, and estimated resources of high-grade silica are large.

The Tuscarora Quartzite has long been mined for railroad ballast, glass sand, and silica brick at The Narrows, west of Cumberland (Clark and others, 1900, p. 192). In recent years the Tuscarora was worked by the Cumberland Cement and Supply Co. In 1963 this operation was purchased by the Manley Sand Division of the Martin-Marietta Corp. (Eilertson, 1964, p. 533), and was expanded to supply greater amounts of silica sand to glass manufacturers. The nearest large glass-fabricating plant is that of the Pittsburgh Plate Glass Co., southeast of Cumberland, which has new facilities for producing high-quality plate glass.

Industrial sand has been produced from the Ridgeley Sandstone at Round Top, 4 miles southwest of Hancock, Washington County. Similar sand is exposed in Tonoloway Ridge to the west and Warm Spring Ridge of West Virginia to the east. Untapped reserves of Ridgeley Sandstone in Tonoloway Ridge appear to offer the best possibility for future glass sand production (table 128).

The Pottsville Formation of Pennsylvanian age, a potential source of silica, crops out mainly along the Allegheny Front. Conglomeratic sandstone units, more resistant to weathering than the rocks above and below, range from 30 to 125 feet in thickness and are, therefore, considerably thinner than the sandstones of the Tuscarora or Oriskany. No serious attempt has yet been made to utilize the Pottsville sandstone for industrial purposes in Maryland.

NEW YORK

Of the 37 million tons of sand and gravel produced in New York in 1963, more than 1.6 million tons was industrial sand (Feitler, 1964, p. 778). Molding sand from Cattaraugus County is the only industrial sand produced within the Appalachian part of the State.

New York has long been famous for glass manufacturing. There were 16 glass factories in 1953 according to the Glass Factory Yearbook of 1953, and, of these, the Corning Glassworks in Steuben County is

TABLE 128.—*Partial chemical analyses of Ridgeley Sandstone (Oriskany Group) in western Maryland*

[Analysis 4 from Grimsley (1916, p. 332). All other samples were collected by W. D. Carter and analyzed by chemists of the U.S. Geological Survey using X-ray fluorescence supplemented by methods described by Shapiro and Brannock (1962)]

Analysis	County	Locality	Percent—		
			SiO_2	FeO, Fe_2O_3	Al_2O_3
1	Allegany	Twiggtown	96.1	0.06	1.5
2	do	Flintstone	97.7	.05	.45
[1] 3	do	Rawlings	81.0	.43	1.6
4	Washington	Tonoloway Ridge	99.8	.016	.012
5	do	do	97.4	.17	1.3
6	do	Round Top	96.1	.04	1.3

[1] Calcareous rock.

probably the best known. All these plants import glass sand from Pennsylvania, West Virginia, and Ohio. None of the potential silica resources in the State, as described by Colony (1919), are low enough in iron and alumina to be suitable for high-quality glass manufacture. Some are suitable for other specific uses, as described by Broughton and others (1962, p. 36). All the potential sources that have been studied are outside Appalachia. The possibility of developing high-quality silica resources in the Appalachian part of New York is considered poor.

NORTH CAROLINA

All production of industrial sand in North Carolina is from counties outside Appalachia. In 1963, 500,000 short tons valued at $770,000 was produced. Most was used for blast sand, filtration sand, and other industrial purposes requiring cheap material.

Several quartzite formations are potential sources of silica in the Appalachian counties. The Cambrian Tusquitee Quartzite which crops out mainly in Cherokee, Graham, and Swain Counties is the only potential source of high-grade silica in western North Carolina. Other quartzites are found in the Nottely, Erwin, Nichols, Nebo, Kings Mountain, and Pilot Mountain of Wilson, Jewell, and Luther (1956) Formations of western North Carolina. They were studied by Broadhurst (1949), who sampled the Tusquitee, Erwin, and Kings Mountain Quartzites. Table 129 shows the approximate range in composition of 20 samples from these three formations. All are too high in alumina and iron to be considered for glass without treatment. Washing, scrubbing, grading, and possibly flotation would be needed to prepare a usable product for glass, refractory, or other uses with rigid chemical specifications.

The quartz cores of pegmatites in the Spruce Pine district of Avery, Mitchell, and Yancey Counties and the Franklin-Sylva district of Jackson and Macon Counties have provided silica for various purposes. In Avery County the Harris Clay Co. mines scrap mica, kaolin, and quartz from its Gusher Knob mine. In Mitchell County the Lawson-United Feldspar & Minerals Co. recovered crushed quartz from the milling of feldspar. Quartz is also recovered from pegmatites in the Franklin-Sylva district and is used as aggregate in prestressed concrete.

Other deposits of vein quartz have been described by J. B. Mertie, Jr. (1959), who studied the quartz crystal localities in southwestern Virginia and western North Carolina. Most are in Alleghany, Ashe, Avery, and Mitchell Counties, N.C. Keith (1907b, p. 13) shows a photograph of a vein of sugary, milky quartz reported to be 39–60 feet wide and one-eighth of a mile long. Known as "Shining Rock," it is on Pisgah

TABLE 129.—*Partial chemical analyses of silica-rich rocks in western North Carolina*

[Source: Broadhurst (1949)]

Formation (number of samples)	Range in composition, in percent					
	SiO_2		Fe_2O_3		Al_2O_3	
	Low	High	Low	High	Low	High
Tusquitee (7)	90.7	93.5	0.088	0.24	5.6	7.5
Erwin (7)	91.0	96.7	.11	.48	2.7	4.3
Kings Mountain (6)	69.8	96.3	.18	1.3	4.0	8.6

Mountain near the junctions of Haywood, Buncombe, Henderson, and Transylvania Counties. Although most vein deposits are small, they are widespread and constitute a potential source of high-grade silica. However, because they are costly to mine, they probably would not be able to compete for most purposes with the larger, more widespread deposits found in the Cretaceous Tuscaloosa Formation and Quaternary terrace gravels of eastern North Carolina.

OHIO

Between 1800 and 1957, Ohio produced nearly 93 million tons of sandstone (Hoover and Alberts, 1959, p. 21). Of the sand produced between 1914 and 1957, 54 percent was foundry sand, 17.4 percent was glass sand, 1.9 percent was used in abrasives, and most of the remainder (about 27 percent) was used in construction. In addition, between 1904 and 1957 nearly 578 million tons of sand and gravel was mined, of which 9.1 percent was used for industrial purposes (engine, filter, blasting, grinding, and polishing sand).

Industrial-sand production in Ohio totaled 1.1 million tons in 1963 and was valued at $4.4 million. Most came from seven counties within Appalachia and a few other counties along its margin. The industrial-sand companies presently active in Appalachia within Ohio are included in table 124; the sand produced was used mainly for molding, glass manufacture, and in furnace construction or repair (Krickich, 1964, p. 837).

Principal sources of high-silica material in Ohio are sandstone and conglomerate of the Black Hand Formation (Mississippian) and Berea Sandstone (Devonian or Mississippian) and the Connoquenessing (formerly the Massillon) and Sharon Members of the Pottsville Formation (Pennsylvanian age). These formations are flat lying, and crop out in wide parallel belts extending from south-central Ohio, north and eastward into Pennsylvania. Deposits of unconsolidated sand and gravel are widespread but are less pure; they consequently have limited uses as industrial sand.

The Berea Sandstone crops out in Ross, Highland, Pike, and Adams Counties of Appalachia. Most production from this formation, however, has been in northern Ohio near Amherst, Lorain County (outside Appalachia), for building stone, refractories, abrasives and other products (Bowen and Bowen, 1950, p. 2).

The Black Hand Formation is exploited in Ohio counties outside Appalachia. It contains lenses of medium- to coarse-grained friable sandstone worked mainly for molding sand in the Hocking Valley district of Hocking and Fairfield Counties, in the region between Newark and Tobasco, Licking County, and in eastern Knox, southeastern Richland, and southern Ashland Counties (Bowen and Bowen, 1950, p. 2). The sandstone is generally thin, but of good quality; material pure enough for glass manufacturing is being quarried near Millwood, Knox County (R. J. Bernhagen, written commun., 1960).

The Sharon Member of the Pottsville Formation constitutes the most important source of glass sand and molding sand in eastern Ohio. It is thickest (30–70 feet) in Portage County (outside Appalachia), northeastern Ohio, and in Jackson and Pike Counties, southeastern Ohio.

The Connoquenessing Sandstone Member of the Pottsville Formation is a gray to brownish-gray fine- to medium-grained crossbedded massive sandstone with pebbly layers. Its thickness, where it has been mined in Hopewell Township, Perry County, near Dundee in Tuscarawas County, and Brinkhaven in Knox County is 30, 35, and 50 feet, respectively. After washing, the sand contains 99 percent or more SiO_2 and is generally suitable as glass sand and for foundry sand if a bonding clay is added (Bownocker, 1939, p. 50; White, 1949, p. 86).

Table 130 shows analyses of silica sands in Ohio.

PENNSYLVANIA

Pennsylvania has long led all other States in the production of high-silica sand for industrial uses. In 1963 its production of nearly 2 million tons was valued at nearly $6 million (J. R. Kerr, 1964, p. 923). Most raw material came from counties in Appalachia and was used mainly to manufacture glass and refractories; some was used for grinding and polishing, blast and engine sand, and for manufacture of ferrosilicon.

The silica sand resources of Pennsylvania are well described by C. R. Fettke (1919), whose report has long been used as a guide by mining companies providing raw material for the glass industry. Fettke (1919, p. 150) pointed out that the two best sources of glass sand are the sandstones and conglomerates of the Oriskany and Pottsville Groups. He also discussed the possibilities of using Tuscarora Quartzite as a source of glass sand, pointing out that although it is extremely pure in SiO_2, abundant silica cement in many places prevents it from breaking down under weathering conditions (Fettke, 1919, p. 262). It therefore requires more drilling and blasting in the mining stage and more crushing in the milling stage than the other available sands. Furthermore, the sand grains are cemented together so well that crushing breaks across the grains and makes irregular chips and pow-

TABLE 130.—*Partial chemical analyses of Ohio silica sands*

[*, County outside Appalachia. Analyses 1-8 from E. F. Burchard (1907); 9, Central Silica Co., Zanesville, Ohio; 10, Millwood Sand Co., Zanesville, Ohio]

Analysis	County	City	Constituents, in percent				
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
1	Perry	Chalfants	98. 50	0. 09	--------	--------	0. 014
2	Stark	Massillon	97. 50	1. 50	0. 50	--------	. 50
3	do	do	99. 60	--------	. 02	0. 23	--------
4	Tuscarawas	Dundee	98. 45	. 77	. 14	--------	--------
5	do	Layland	98. 78	. 73	Tr.	. 12	. 04
6[1]	Trumbull*	Niles	99. 915	. 062	. 0019	. 021	Tr.
7[2]	do	do	98. 09	. 75	. 03	--------	. 16
8[3]	do	do	97. 10	2. 35	. 14	. 10	Tr.
9	do	Glass Rock	97. 87	1. 21	. 171	. 01	Tr.
10	do	Millwood	97. 39	1. 26	. 571	. 01	Tr.

[1] First grade, washed.
[2] First grade, not washed.
[3] Second grade, not washed.

der that are more difficult to grade. Its purity, mechanical strength, and behavior in burning, however, make it quite suitable for the manufacture of silica brick (Moore and Taylor, 1924, p. 18).

Stone (1928) described deposits of natural-bonded molding sands which occur as flood-plain and terrace deposits and as bottom sediments in drained glacial lakes. Artificially bonded molding sand is obtained from the Cambrian Chickies Quartzite and the Oriskany Group. Stone (1928, p. 43) suggested that the Tuscarora Quartzite of Silurian age and the sandstones of the Pocono (Mississippian) and Pottsville (Pennsylvanian) Groups could also supply molding sands.

The Ridgeley Sandstone of the Oriskany Group crops out widely in Pennsylvania and is mined for a variety of uses. It is a coarse sandstone and quartz pebble conglomerate in Carbon and Schuylkill Counties of northeast Pennsylvania where it is of high purity, friable, and mined mostly for refractory purposes. It is found extensively in the Valley and Ridge province of central Pennsylvania and is mined in Huntingdon, Bedford, and Mifflin Counties. In this region it generally crops out as low ridges along the base of higher ridges formed by the Tuscarora Quartzite. In most places the Ridgeley and Tuscarora are thick and continuous with moderate to steep dips. Part of the Ridgeley Sandstone is easily weathered to friable material that is relatively easy to mine. Some, however, is so firmly cemented by silica that it is virtually an orthoquartzite that requires extensive blasting and crushing.

The Ridgeley Sandstone is a major source of glass sand and is mined extensively in Huntingdon County, the leading industrial-sand-producing county of the State. It is 125–250 feet thick. The Pennsylvania Glass Sand Corp., the principal producer, operates several large open-pit mines near Mapleton Depot and smaller pits near McVeystown, Mifflin County, all in Ridgeley Sandstone. The Harbinson-Walker Refractories Co. and the North American Refractories Co. mine Tuscarora Quartzite at Mount Union and Three Springs, respectively, for manufacture of silica brick.

The Palmerton Sandstone of Swartz (1939; Middle Devonian age) crops out extensively in the vicinity of Palmerton, Carbon County, where it is mined by North American Refractories for ganister. It is very similar in lithology and physical characteristics to the Ridgeley Sandstone.

Sandstone layers of the Pottsville Group crop out in the Allegheny Plateau area of the western and northwestern part of the State. They are mined in Beaver, Bedford, Cambria, Fayette, Mercer, Venango, and Washington Counties. The layers are lenticular and are flat lying or have only gentle dips.

Elsewhere, these and other sandstones are mined as sources of industrial sands. The Ridgeley Sandstone is mined by General Refractories, Frankstown, Blair County; and Lycoming Sand Co., Montoursville, Lycoming County. Tuscarora Sandstone is mined by the Leap Ganister Co., Hyndman, Bedford County; J. L. Hartman, Sproul, Blair County; and Haws Refractories Co., Hawstone, Mifflin County. Companies mining sandstone of the Pottsville Group include Ellwood Stone Co., Ellwood City, Beaver County; Detwilers Industries Inc., Weyant, Bedford County; Samuel Nicosia, Johnstown, Cambria County; General Refractories, Scottdale, Fayette County; White Rock Silica Sand Co., Greenville, Mercer County; Pennsylvania Glass Sand Corp. (Industrial Silica Div.), Venango Works near Utica, Venango County; and Fry Coal and Stone Co., Claysville, Washington County.

TABLE 131.—*Partial chemical analyses of silica samples from Pennsylvania*

[Analyses 1–4, 6–12, 14–34 by U.S. Geological Survey chemists using X-ray fluorescence supplemented by methods described by Shapiro and Brannock (1962). Analyses 5, 13, 35 from Fettke (1919)]

Analysis	County	Locality	Percent—			Formation
			SiO_2	Fe_2O_3	Al_2O_3	
1	Bedford	Cypher	97.5	0.21	1.1	Ridgeley.
2	do	Eickelbergertown	97.6	.15	1.2	Do.
3	do	Everett	97.6	.10	.24	Tuscarora.
4	do	Hyndman	[1] 75.9	.68	1.6	Ridgeley.
5	do	do	99.54	.09	.35	Tuscarora.
6	do	Tatesville	97.8	.14	.98	Ridgeley.
7	do	Warrior Ridge 5 miles south of Everett.	97.7	.18	.95	Do.
8	do	Yellow Creek	96.7	.33	1.9	Do.
9	Blair	Frankstown	94.5	1.00	2.0	Do.
10	Carbon	Ashfield	97.6	.13	.70	Do.
11	do	Bowmanstown	95.7	.16	1.7	Do.
12	do	Little Gap	98.7	.12	.30	Do.
13	Elk	Daqucahonda	96.08	.37	2.35	Pottsville.
14	Fulton	Fort Littleton	94.0	1.54	1.5	Ridgeley.
15	do	Needmore	94.5	.90	1.6	Do.
16	do	Warfordsburg	88.4	1.7	6.1	Do.
17	do	Stillwell Ridge	95.9	.74	1.7	Do.
18	Huntingdon	Burnt Cabins	83.6	10.34	1.6	Do.
19	do	Huntingdon	97.4	.23	1.3	Do.
20	do	Mapleton	97.25	.07	.70	Do.
21	do	Old Woman's Gap	97.7	.08	.86	Tuscarora.
22	do	McConnellstown	92.4	1.2	2.8	Ridgeley.
23	Huntingdon	Saltillo	96.6	.33	2.0	Ridgeley.
24	do	Shirleysburg	97.4	.06	.67	Do.
25	do	do	98.1	.13	.59	Do.
26	Juniata	Port Royal	96.3	.11	1.3	Do.
27	Lycoming	Montoursville	97.3	.08	.65	Do.
28	Mifflin	Atkinsons Mills	96.2	.29	1.4	Do.
29	do	Fairview School	98.6	.12	.48	Do.
30	do	Mount Union	97.9	.08	.48	Do.
31	do	Newton-Hamilton	97.2	.08	.87	Do.
32	Monroe	Kunkletown	96.7	.19	.79	Do.
33	Perry	Pisgan Ridge	96.9	.08	.74	Do.
34	Schuylkill	Andreas	97.1	.09	.55	Do.
35	Venango	Kennerdal	98.35	.06	1.14	Pottsville.

[1] Also contains 10.7 percent $CaCO_3$.

Silica resources of Pennsylvania are large. As present supplies are depleted, new sources farther from present railroad lines are available to be utilized. The present trend of using lower grade raw material and more processing to upgrade it will continue.

Table 131 shows partial chemical analyses of silica deposits within the State and indicates there is a great deal of material containing 95 percent or more SiO_2.

SOUTH CAROLINA

Silica deposits of South Carolina that could be used for the manufacture of glass have been described by Buie and Robinson (1958). Only one of the 29 deposits described lies within the Appalachian Region. This deposit, a vein of milky white quartz, is near the Southern Railway about 0.3 mile south of Kings Creek Station, Cherokee County. The vein, about 30 feet wide, is in schist, and was mined for a length of about 60 feet and a depth of about 20 feet. It is reported to have been used in lump form to pack Glover's towers in the manufacture of sulphuric acid.

South Carolina has had a small glass industry for many years. Bottle plants first operated in Columbia under the State Liquor Dispensary program. When the program ended in 1910, the Laurens Glass Works was formed and has operated until the present. Most of the sand for this plant comes from Coastal Plain deposits near Nichols, Horry County. These same deposits, worked by the Locher Silica Corp., also supply silica sand for glass plants in Kingsport and Chattanooga, Tenn. (Buie and Robinson, 1958, p. 8, 9).

In 1963, South Carolina produced about 340,000 short tons of industrial sand for various purposes that was valued at about $1 million and that averaged about $3.20 per ton (Shirley and Johnson, 1964). The only producer in the Appalachian Region was the Jobe Sand Co. which worked stream-bank sand at Blacksburg in northeastern Cherokee County.

Other deposits of quartz and quartzite occur in the metamorphic rocks of the Piedmont province of the Appalachian Region, but most are small and costly to mine. It is doubtful that they could compete as a source of glass sand with the Cretaceous Tuscaloosa Formation and other deposits of the Coastal Plain.

TENNESSEE

Silica resources of Tennessee have been described by Hershey (1960), whose work also is discussed in reports by the Tennessee Valley Authority (1963). Annual industrial-sand production (1963) in the State is about 710,000 short tons valued at about $1.6 million (table 123). Roughly half comes from within the boundaries of Appalachia in eastern Tennessee. Principal production comes from the Sewanee Member of the Crab Orchard Mountains Formation of Pennsylvanian age. Lesser amounts have come from the Vandever Member of the Crab Orchard Mountains Formation and the Clinch Sandstone of Silurian age.

Analyses presented by Hershey (1960, p. 31) show that silica content of the Sewanee Member ranges from 93 to 98 percent but is generally about 95 percent. Iron oxide (Fe_2O_3) content ranges from 0.03 to 1.16 but is generally about 0.30 percent. Clay content (Al_2O_3) ranges from 0.62 to 4.06 percent but in general is about 1.80 percent. Excess clay and some iron is removed simply by washing. The Rockcastle Sandstone and the Vandever Member of the Crab Orchard Mountains Formation show similar compositions. The Clinch Sandstone contains about 98 percent SiO_2, 0.08 percent Fe_2O_3, and 1.28 percent Al_2O_3.

The Hesse Quartzite, uppermost unit of the Chilhowee Group, is exposed in the Oswald Dome area of Polk County and was mined years ago for smelter flux by the Tennessee Copper Co. (R. A. Laurence, written commun., 1960). The deposit, quarried on Gee Creek, near Starr Mountain, is accessible by road about 1 mile from the Louisville & Nashville Railroad in the Hiwassee River valley. Reserves are reported to be large. The Hesse, in Blount and Sevier Counties, and its partial equivalent, the Erwin in Johnson, Carter, and Unicoi Counties, are additional potential sources of silica.

It is probable that industrial-sand resources of Tennessee are sufficient for the foreseeable future. Most silica now being mined is used locally. Some silica has been imported from adjacent States.

VIRGINIA

Although industrial sand produced in Virginia totaled nearly 1 million tons and had a value of $1.5 million in 1963, very little came from the counties included in Appalachia (Metcalf and Calver, 1964, p. 1125). This sand was used for a variety of purposes which included glass, engine, filtration, and molding sands. The only industrial-sand production from within Appalachia came from New Castle, Craig County, where the Castle Sands Co. prepared sand for building, paving, filter beds, and other purposes. In some places, this sand is too coarse grained and too high in iron to be suitable for more refined use. Some sand is sold to the Lone Star Cement Corp., Botetourt County, Va., for use as a source of silica in cement raw-material mixtures.

Several formations of western Virginia are potential sources of high-grade silica. Included are the Erwin Quartzite (Cambrian?) and Antietam Sandstone (Cambrian) in the Blue Ridge; farther west in the Valley and Ridge province are the Clinch, Tuscarora, and Keefer Sandstones of Silurian age and the Ridgeley Sandstone of Devonian age. The Erwin ranges from 500 to 700 feet in thickness and the Antietam is about 250 feet thick. The Silurian sandstones range from 200 to 300 feet in thickness (Lowry, 1954, p. 11–12). In the northwestern corner of the State (Frederick County) the Ridgeley Sandstone crops out and is mined for glass sand by the Virginia Glass Sand Corp. at Gore. In southwest Virginia the Lee Formation of Pennsylvanian age and the Pocono and Price Sandstones of Mississippian age extend through Buchanan and Tazewell Counties southward into Scott County. Reports describing many of these occurrences include those by Stose and Miser (1922) and Lowry (1954).

Selected chemical analyses (table 132), mainly of the Ridgeley Sandstone, show considerable variation in silica content from place to place in Virginia. The sandstone contains more than 95 percent silica in many areas, and some of the less pure material can be upgraded by washing, scrubbing, and screening to make a suitable industrial sand.

Lowry (1954, p. 61) pointed out that the best immediate market for silica sand in Virginia is the foundry industry which gets most of its raw material from New Jersey. He suggested that more Virginia silica sand might be used by foundries but that extensive testing was required. Use for other purposes (sand-lime brick, filter sand, engine sand, abrasive and refractory sand) is also feasible. The Locher Silica Co. is producing quartzite of the Erwin Formation at Lots Gap, Wythe County, for metallurgical use. At present this product is being tested by industry for a standard source of material.

Glass sand is presently shipped out of the State. Reserves of raw material near Wytheville and at McAfee Knob, 6 miles north of Salem, appear to be adequate to supply a local glass industry. Additional silica-rich sandstones and conglomerates of Carbon-

TABLE 132.—*Partial chemical analyses of silica sands in western Virginia*

*County outside Appalachia. Samples 1–3, 5–8, 11–14, 18, 22 were collected by W. D. Carter and analyzed by U.S. Geological Survey chemists using X-ray [fluorescence and other methods described by Shapiro and Brannock (1962); Analysts: S. Boots, G. Chloe, L. Artis, H. Smith, J. Glenn. Samples 4, 15–17, 19–21, 23, 24 collected by W. D. Lowry (1954); analyses by Froehling & Robertson, Inc. Samples 9, 10 dump samples from iron mine]

Analysis	County	Locality	Percent—			Formation
			SiO_2	FeO, Fe_2O_3	Al_2O_3	
1	Alleghany	Callaghan	98. 1	0. 16	0.	Ridgeley.
2	do	Clifton Forge	92. 5	1. 54	2. 8	Do.
3	do	Earlhurst	96. 8	. 20	. 74	Do.
4	Augusta*	Little North Mountain	99. 30	. 06	. 33	Keefer.
5	Bath	Healing Springs	97. 4	. 48	. 00	Ridgeley.
6	do	Hotchkiss	94. 9	. 72	1. 5	Do.
7	do	Millboro Springs	96. 1	. 34	1. 2	Do.
8	do	Warm Springs	96. 1	. 38	. 94	Do.
9	Botetourt	Lignite	48. 5	39. 1	3. 8	Do.
10	do	do	96. 1	. 54	. 75	Do.
11	Craig	New Castle	95. 9	. 71	. 84	Ridgeley(?).
12	do	Paint Bank	96. 9	. 14	. 74	Ridgeley.
13	do	Peters Mountain	96. 6	. 08	. 94	Keefer.
14	Frederick*	Bear Garden Mountain	96. 1	. 18	1. 7	Ridgeley.
15	do	Gore (processed sand)	99. 16	. 029	. 43	Do.
16	Highland	Monterey Mountain	99. 60	. 07	. 13	Tuscarora.
17	Roanoke*	Catawba Mountain	98. 20	. 56	. 17	Clinton(?).
18	Rockbridge*	Goshen	93. 4	4. 9	1. 4	Ridgeley.
19	do	Middle Mountain	99. 21	. 41	. 11	Tuscarora(?).
20	do	North Mountain	99. 56	. 14	. 18	Keefer.
21	Scott	Silica, Clinch Mountain	99. 34	. 05	. 77	Clinch.
22	Shenandoah*	Orkney Springs	96. 5	. 16	1. 00	Ridgeley.
23	Wythe	Silica Products Co. (Wytheville).	99. 46	. 06	1. 00	Erwin.
24	do	Sand Hill School	98. 02	. 15	. 97	Erwin.

iferous age occur in Dickenson and Wise Counties (Lowry, 1954, p. 62), but additional studies would have to be made to evaluate their suitability for use as industrial sand.

WEST VIRGINIA

Industrial-sand production in West Virginia in 1963 was nearly 1.2 million tons valued at about $5.6 million (table 123). The sand is used for a variety of purposes including glass, molding, furnace, refractory, blast, abrasive, engine, and filler sand as well as other industrial uses. Principal production in 1963 came from Hancock, Morgan, Tyler, Wood, Ohio, and Brooke Counties, in descending order. All but Morgan County deposits border the Ohio River Valley, and production in these counties is mainly from mining terrace deposits and dredging of river-bottom deposits. In Morgan County, production came mainly from open-pit quarrying of the Ridgeley Sandstone on Warm Springs Ridge near Berkeley Springs. More recently, production has increased in Monongalia County where the upper part of the Connoquenessing Sandstone Member of the Pottsville Formation is mined near Greer, mainly for glass and engine sand.

The Ridgeley Sandstone near Berkeley Springs has long been a major source of glass sand in the Appalachian Region. It crops out as a prominent ridge of white to yellowish-brown iron-stained sandstone, dipping to the east, that extends from the Potomac River southward for a distance of more than 14 miles. The sandstone has been worked extensively in the area north of Berkeley Springs, where large quarries of the Pennsylvania Glass Sand Co. extend a distance of 3 miles along the west side of U.S. Highway 522.

The Tuscarora Quartzite, which crops out mainly in Cacapon Mountain and New Creek south of the Potomac River, also has been worked for high-silica sand. Two glass-sand mines in the Tuscarora were operated by the Silica Sand Co. of Pittsburgh in about 1910 on Cacapon Mountain, 1½ miles west of Berkeley Springs, Morgan County (Grimsley, 1909). A treatment plant established to process the quartzite had to be abandoned because of the hardness of the rock.

The mountains of the Cumberland Plateau also contain sandstone suitable for industrial purposes. Principal sources are conglomeratic sandstones of the Pottsville Formation and the Droop Sandstone of Reger (1926) of Mississippian age. In northern West Virginia (Preston County and vicinity) the Pottsville Formation (Hennen and Reger, 1914, p. 177) includes the Homewood Sandstone, Connoquenessing Sandstone, and Sharon Members. Much of the sand and gravel mined from terrace and bottom deposits of the Ohio River are derived from these formations. In

TABLE 133.—*Partial chemical analyses of sandstones of West Virginia*

[Analyses 1, 7 from Grimsley (1916, p. 341). All others are from samples collected by W. D. Carter and analyzed by U.S. Geological Survey chemists using X-ray fluorescence supplemented by methods described by Shapiro and Brannock (1962)]

Analysis	County	Locality	Percent			Formation
			SiO_2	Fe_2O_3	Al_2O_3	
1	Berkeley	Gerrardstown Gap	98. 76	0. 18	0. 54	Tuscarora.
2	Hampshire	Romney	97. 0	. 14	. 75	Ridgeley.
3	Hardy	Bass	93. 7	. 24	3. 0	Do.
4	do	Mathias	96. 6	. 08	. 84	Do.
5	do	Wardensville	97. 6	. 23	1. 0	Do.
6	Morgan	Berkeley Springs	97. 3	. 09	. 71	Do.
7	do	Cacapon Mountain	99. 86	. 66	. 23	Tuscarora.
8	do	Cacapon State Park	96. 6	. 18	1. 4	Ridgeley.
9	do	Jones Spring	96. 6	. 09	1. 0	Do.
10	do	Hazel Atlas pit	98. 0	. 16	. 00	Do.
11	do	do	93. 6	. 23	3. 8	Do.
12	Pendleton	Moatstown	96. 4	. 10	1. 2	Do.
13	Pocahontas	Dilleys Mill	97. 2	. 20	1. 1	Do.

southern West Virginia the Raleigh Sandstone Member of the New River Formation crops out mainly in Webster, Nicholas, Fayette, Raleigh, Wyoming, and McDowell Counties. The Droop Sandstone of Reger (1926) crops out mainly in Pocahontas, Greenbrier, Summers, Monroe, and Mercer Counties.

Table 133 shows partial chemical analyses of Ridgeley and Tuscarora Sandstones in West Virginia.

RESOURCE POTENTIAL

Silica resources of the Appalachian States are considered to be substantial and adequate to meet most local indsturial needs for several generations. The glass industry, with its rigid specifications for silica raw materials, is most difficult to supply. Most States (mainly Pennsylvania, Ohio, West Virginia, Virginia) now providing raw materials to glass manufacturers will be able to continue to do so for some time even though costs will probably rise as present mines are depleted and new, more remote sources, are developed. Other States such as Maryland, eastern Kentucky and Tennessee, northern Alabama, North and South Carolina and Georgia should, in most cases, be able to provide high-grade silica as population growth and industrial expansion develop new requirements. Development, however, will depend heavily on locations of power and fuel sources, on rail, highway, and barge transportation as well as location of new markets. In addition, the raw materials producer may be required to consider special processes or treatments to guarantee a premium product of consistant quality in order to compete with other, better established producers elsewhere.

STRONTIUM

By DENNIS P. COX, U.S. Geological Survey

United States consumption of strontianite (strontium carbonate) and celestite (strontium sulfate) was 16,232 short tons in 1963 and 21,617 short tons in 1964 (E. C. Peterson, 1965, p. 1015). All was imported, domestic strontium mining having been inactive since 1959. Strontium minerals are used in various ways in the ceramic, metallurgical, chemical, and pyrotechnic industries. The largest deposits of strontium minerals in the United States are in Texas and California.

Because of high demand for strontium for military uses, celestite was mined in Tennessee between 1942 and 1944 (Floyd, 1965, p. 25). The deposit is in Buffalo Cove, Fentress County, halfway up the western escarpment of the Cumberland Plateau. Kesler (1944) stated that the celestite occurs as coarse white to bluish-white crystals along with chert, dolomite, and rare pyrite in ellipsoidal aggregates or geodes. The geodes occur sporadically in the upper part of the Mississippian Bangor (or Glen Dean) Limestone just below the Pennington Shale. Kesler (1944, p. 303) noted 177 geodes within a limestone bed 4.4 feet thick exposed in a quarry face 33 feet long. He calculated that the exposed bed would contain 5.89 percent celestite. Celestite production from the deposit is not known.

Celestite has been reported from several other localities in Appalachia. Floyd (1965, p. 27) noted six localities with sufficient concentrations of celestite to warrant prospecting in Fentress, Overton, and Warren Counties, Tenn. This celestite is in the upper part of the Bangor Limestone. Taylor B. Lewis of Birmingham, Ala., reported (written commun., 1943) the occurrence of celestite and strontianite in the Bangor Limestone in Jackson County, Ala. Mitchell and Pharr (1960) described celestite and calciostrontianite (Sr, Ca)CO_3 in Wise County, Va., occurring in vugs in the Silurian Hancock Dolomite. Strontianite and celestite occur in Silurian and Devonian limestone in Mifflin County and in Devonian shale in Blair County, Pa. (Gordon 1922, p. 142).

Other sources of strontium of possible interest in the future are the strontium-bearing barite deposits in the Central district, Kentucky, and in the Middle Tennessee district (table 104). According to Brobst (1958, p. 80), two samples of barite from Sweetwater, Tenn., contain 2.0 percent strontium. Some brines in West Virginia and Pennsylvania contain as much as 0.24 percent strontium (table 122).

Because known deposits of strontium minerals in Appalachia are small and low grade and because demand is small except during wartime emergencies, strontium does not have great potential for development in Appalachia. The possibility of recovering strontium as a byproduct of the large barite production in Tennessee should be investigated.

TALC, SOAPSTONE, PYROPHYLLITE, AND SERICITE SCHIST

By HELMUTH WEDOW, JR., U.S. Geological Survey and JOHN W. SWEENEY, U.S. Bureau of Mines

INTRODUCTION

Talc, a hydrous magnesium silicate, is a soft, white to greenish-gray mineral. Formerly the terms "steatite" and "soapstone" were used synonymously to designate massive talc, but present usage limits the name of steatite to grades of talc suitable for making electron tube spacers and insulators. Soapstone includes all the less pure massive gray to bluish- or greenish-gray talcose rocks which, with a few exceptions, feel soapy and can be carved easily with a knife. Pyrophyllite is a hydrous aluminum silicate similar to talc in its properties and in most of its applications. Sericite schist, a metamorphic rock, can be substituted for talc, soapstone, and pyrophyllite for some purposes.

Talc, soapstone, and pyrophyllite are used chiefly as finely ground material in the ceramic, paint, rubber, insecticide, roofing, and paper industries. Sawed and shaped slabs of soapstone are used for sinks, electrical base plates, and bench tops. Crayons and carvings are made from lump talc. Block steatite talc is used primarily for electronic insulators (T. R. Wells, in U.S. Bur. Mines, 1965a, p. 919–927).

Domestic production of talc, soapstone, and pyrophyllite in 1964 totaled 890,000 short tons valued at $6.2 million (1958 constant dollars) (table 134). Talc was produced in 1964 in Alabama, California, Georgia, Maryland, Montana, Nevada, New York, North Carolina, Texas, and Vermont; soapstone was produced in Arkansas, California, Maryland, Nevada, Texas, Virginia, and Washington; pyrophyllite was produced in California and North Carolina, and an important quantity of sericite schist, reported as pyrophyllite, was mined in Pennsylvania (J. R. Wells, 1965b). Sericite schist is also being produced in Georgia and South Carolina.

The United States is self-sufficient in all grades of these materials except block steatite talc and block pyrophyllite. Talc quality is the governing factor which determines end use. The talc and soapstone of Appalachia are suitable for many applications and will continue to supply a significant amount of the national demand. Chemical and physical properties differ in individual deposits, and determine the use that can be made of these materials.

Talc, soapstone, pyrophyllite, and sericite schist are competitive with each other and with kaolin, fuller's earth, limestone, and other nonmetallic fillers for a variety of uses.

From 1910 to 1964, production of talcose materials from Appalachia was 1.5 million tons valued at $20.4 million (1958 constant dollars). In 1964, 63,000 tons, or about 7 percent, of the domestic talc, soapstone, and pyrophyllite production came from Appalachia.

Talc and soapstone are produced from three areas in Appalachia: Talladega County, Ala.; Murray County, Ga.; and Cherokee County, N.C. The only significant Alabama production has come from Talladega County, where the American Talc Co. has been producing ground talc from the Winterboro deposit since 1955. This deposit also produced about 1,000 tons in 1930–31. Deposits of high-grade talc in Georgia are limited to two areas, one near Chatsworth, Murray County, and the other in Fannin, Gilmer, and Cherokee Counties. Most past and present production has been from the deposits in Murray County. Production was reported from 1872, when the deposits were discovered, to 1891, and from 1898 to 1964; it totaled 1.3 million tons in the period 1910-64. In 1964, the only talc produced in Georgia was mined and processed by the Georgia Talc Co.

In North Carolina, talc mining began in 1859 in the Murphy marble belt in Cherokee and Swain Counties, and intermittent production has continued to the present (1966). Many small bodies of talc and soapstone occur in Alleghany, Ashe, Buncombe, Jackson, McDowell, Madison, Mitchell, Swain, Watauga, Wilkes, and Yancey Counties, some of which have been exploited. Production of talc in the Appalachian part of North Carolina has been continuous from 1906 to 1964, excluding the years 1925, 1926, and 1928. The Hitchcock Corp. is now mining talc in Cherokee County.

Table 134 shows the production of talc, soapstone, and pyrophyllite in Appalachia and in the United States, 1910–64.

TABLE 134.—*Production of talc, soapstone, and pyrophyllite 1910–64*

[W, Withheld to avoid disclosing individual company data. No pyrophyllite produced in Appalachia. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1910	2,698	248	150,716	5,524
1911	2,470	211	143,551	5,514
1912	2,898	225	159,270	5,445
1913	1,938	155	175,833	5,877
1914	2,113	170	172,296	5,390
1915	187	17	186,891	3,652
1916	2,829	227	212,961	5,387
1917	4,694	240	218,848	4,815
1918	1,891	163	208,307	4,853
1919	3,312	227	184,843	3,765
1920	1,559	125	210,635	4,128
1921	1,185	26	121,986	2,388
1922	1,571	71	198,684	4,605
1923	2,037	102	196,692	5,000
1924	2,728	116	203,821	6,048
1925	5,022	129	W	W
1926	4,246	165	W	W
1927	3,110	77	W	W
1928	4,888	154	W	W
1929	5,184	272	W	W
1930	4,527	197	W	W
1931	4,919	222	W	W
1932	3,695	150	131,788	3,234
1933	4,552	199	166,023	4,122
1934	7,110	247	138,505	3,231
1935	9,122	323	172,716	4,213
1936	14,020	433	216,191	5,365
1937	16,027	480	229,999	5,585
1938	16,135	328	212,775	4,928
1939	20,344	400	253,976	5,861
1940	20,318	483	281,375	6,467
1941	32,017	899	416,369	9,310
1942	32,624	921	387,963	7,987
1943	38,457	741	412,868	7,938
1944	33,711	587	398,863	6,974
1945	33,042	429	398,384	7,083
1946	39,631	666	457,066	8,378
1947	51,992	952	516,094	9,218
1948	60,277	1,012	518,746	9,505
1949	54,688	1,053	461,896	8,651
1950	76,541	1,353	620,750	12,002
1951	83,475	1,342	636,068	12,002
1952	62,437	1,139	593,147	11,801
1953	64,970	326	631,538	3,735
1954	59,485	331	618,994	3,738
1955	63,450	267	725,708	4,878
1956	68,145	259	739,039	5,102
1957	60,516	255	684,453	4,844
1958	50,393	228	718,165	4,718
1959	66,885	258	791,558	5,528
1960	53,759	240	734,473	5,324
1961	64,030	131	762,380	5,224
1962	62,740	144	771,728	5,225
1963	59,300	142	804,358	5,450
1964	63,334	194	889,949	6,156
Total	1,513,228	20,451	19,239,239	286,168

Sericite schist is currently being produced from deposits near North Canton, Cherokee County, Ga., by The Georgia Talc Co. of Chatsworth and by Thompson-Weinman Co. of Cartersville. Production figures are withheld to avoid disclosing individual company data.

GEOLOGIC FEATURES OF TALC AND SOAPSTONE

Chidester and Worthington (1962, p. 1) characterize talc and soapstone deposits as follows:

> Deposits of talc and soapstone are virtually restricted to areas of folded and metamorphosed rocks and are characteristic of such terranes of various ages in many parts of the world. Within the conterminous United States, they are scattered throughout the eastern and western cordilleras and in the south-central states.
>
> Commercial deposits are of two classes: those derived from or associated with sedimentary rocks; and those derived from or associated with ultramafic and mafic igneous rocks. Dolomite is the characteristic host rock for talc deposits in sedimentary rocks, but many deposits are in quartzite, phyllite, mafic volcanic rocks, and even in adjacent granitic rocks. Most of the talc associated with ultramfic and mafic igneous rocks is derived from serpentinite; in a few places, mafic igneuos rocks are altered extensively to soapstone-type deposits.
>
> Talc deposits are products of both contact and regional metamorphic processes. In many of the deposits in carbonate rocks and in some deposits in ultramfic rocks, adjacent or nearby bodies of igneous rock, including both granitic rock bodies and diabase sills and dikes, were clearly the source of heat and of introduced constituents. Many, perhaps most, deposits associated with serpentinite, and many deposits in sedimentary rocks, appear to have formed under conditions in which both the heat and the introduced constituents were of regional metarmorphic origin.
>
> Talc deposits formed by regional metamorphism of carbonate rock commonly have a complex history of progressive and retrograde metamorphism, and the mineralogy of the deposits may therefore be correspondingly complex; many such deposits contain abundant tremolite, serpentine, and other silicates. Deposits formed by contact metamorphism of otherwise relatively unmetamorphosed carbonate rock commonly are mineralogically simple and contain a large proportion of relatively pure talc rock. Deposits formed by regional metamorphism of ultramafic rocks differ greatly, but many contain a relatively thick inner zone of talc-carbonate rock surrounded by a thin shell of virtually carbonate-free talc rock. Contact metamorphic deposits in serpentinite, such as those adjacent to granitic pegmatites, consist largely of talc rock that contains relatively little carbonate. Deposits in mafic igneous rock commonly are mineralogically complex; most contain only small to moderate proportions of talc and large proportions of chlorite, amphibole, and other silicates.
>
> Although there is considerable variation in each class of deposit, talc associated with sedimentary rock tends to be whiter and purer than talc associated with ultramafic igneous rock. By far the most important commercial sources of high-quality talc are in dolomitic marble, but some deposits of very pure talc are in quartzite and granite. Fibrous varieties of talc consist largely or entirely of tremolite and are in dolomitic marble. The talc in most deposits in ultramfic rock is relatively high in iron, both as disseminated very fine grained magnetite and in the form of Fe^{+2} substituting for Mg in the talc itself.

DEPOSITS ASSOCIATED WITH MAFIC AND ULTRAMAFIC ROCKS

Most of the talc and soapstone deposits in Appalachia (fig. 92) are associated with mafic and ultramafic rocks (table 135, No. 1). Most talc bodies are small, ranging from thin selvages surrounding the intrusive bodies to deposits which rarely contain more than a few thousand tons. The largest production from these deposits has come from mines in McDowell, Madison, and Mitchell Counties, N.C. (Hunter and Gildersleeve, 1946, p. 74–75, 77–79). In addition to talc and soapstone, the ultramafic and mafic rocks have been the source of asbestos, chromite, corundum, olivine (see respective sections on these minerals, p. 268, 372, 262, 326) and vermiculate ("Lightweight aggregate" section, p. 220).

Deposits recently rediscovered in the Dadeville district, Tallapoosa County, Ala. (table 135, No. 2), consist of talc and anthophyllite (an asbestos mineral) occurrences in an arcuate belt as much as 8 miles long and a mile wide. A less-known parallel belt lies several miles to the southeast. T. L. Neathery (oral commun., 1965), of the Geological Survey of Alabama, interprets the belts as outcrops of a highly altered mafic flow or sill exposed on two limbs of a syncline. The talc-bearing rocks are deeply weathered, and many talc and anthophyllite fragments of varying sizes are scattered through the residuum or saprolite. The deposits are currently being investigated by the Geological Survey of Alabama, with assistance from the U.S. Bureau of Mines, particularly with reference to beneficiation problems.

DEPOSITS ASSOCIATED WITH CARBONATE ROCKS

By far the greatest amount of talc produced in Appalachia has come from a relatively few deposits associated with carbonate rocks located in Talladega County, Ala., in the Chatsworth district, Georgia, and in the Murphy marble belt of North Carolina and Georgia (fig. 92).

Winterboro (Alpine) deposits, Talladega County, Ala.

The Winterboro, or Alpine, talc deposits in Talladega County, Ala. (table 135, No. 3), were known and prospected prior to World War I and were further explored in 1930 by drilling. About 1,000 tons of talc was produced in 1930 and 1931. Geologic studies of the deposits and beneficiation tests were later made by the Geological Survey of Alabama and the Tennessee Valley Authority (McMurray and Bowles, 1941). Exploration drilling by the U.S. Bureau of Mines in 1948–49, added to the reserves (A. H. Reed, Jr., 1950b). Since 1955, the American Talc Co. has mined and sold ground talc from this area. The Winterboro occurrence differs from other Appalachian talc deposits in that it lies in an area of relatively unmetamorphosed rocks. The talc exhibits little foliation and, in fact, strongly preserves the crystalline texture and other features of the Cambrian and Ordovician dolomite from which it was formed. In order to assess the potential of the Winterboro area for additional deposits of this unusual type, more detailed geologic studies must be made.

Chatsworth district, Murray County, Ga.

Most talc produced in Appalachia has come from the deposits of the Chatsworth district, Murray County, Ga. (table 135, No. 4), which lie in the eastern part of the county along an 8-mile-long, roughly accurate belt centered 3–4 miles east of Chatsworth. The deposits, described by Furcron and Teague (1947), are apparently closely associated with dolomite bodies in their Cohutta Schist of Precambrian age. The dolomite occurs as lenses in and is intruded by their Fort Mountain Gneiss, which in turn has been intruded by the Corbin Granite. The metamorphic and igneous rocks are overlain unconformably by the Ocoee Series. Furcron and Teague (1947, pl. 1) show these rocks to be part of a complex thrust sheet faulted westward over younger Cambrian sedimentary rocks. The talc bodies are generally lenticular and dip eastward parallel to the bedding or foliation of the enclosing country rock. In plan, the major deposits are roughly elliptical, extending hundreds of feet in length and breadth; their thicknesses range from but a few feet to more than a hundred feet.

The most common impurities of the Chatsworth talc deposits are chlorite, dolomite, and serpentine. Other impurities include: fibrous asbestoslike minerals of several types, magnetite, pyrite, chromite, quartz, and a variety of feldspars. Most of the talc is massive and generally is foliated or schistose. Four general varieties are recognized: (1) crayon talc or "saw rock", a massive fine-grained to cryptocrystalline variety; (2) "Blue John," similar to crayon talc but much harder because it contains large percentages of such impurities as chlorite, dolomite, quartz, pyrite, and magnetite; (3) white-grinding talc, generally a mixture of about half talc and half dolomite; and (4) dark-grinding talc, a mixture of talc, chlorite, serpentine, and dolomite. The talcose chlorite schist surrounding the purer talc bodies is ground for roofing talc.

Although earlier writers (Hopkins, 1914, p. 213–214) suggested that the Chatsworth talc deposits were formed by the alteration of mafic intrusives, Furcron and Teague (1947, p. 6–9, 11–12, 41–44) believe that the talc was formed by metamorphism of dolomite bodies of sedimentary origin in their Cohutta Schist. On the other hand, R. D. Bentley of the Georgia Geological Survey (written commun., 1965) tentatively considers the deposits to have formed by alteration of an ultramafic igneous body.

Talc deposits of the Murphy marble belt, North Carolina and Georgia

The Murphy marble belt in western North Carolina and northwestern Georgia (table 135, No. 5) has produced more than 200,000 tons of talc since mining began in 1859. The Hitchcock Corp. now produces about 10,000 tons of talc annually and makes about 85 percent of the talc crayons used in the United States (Tennessee Valley Authority, 1965b, p. M6).

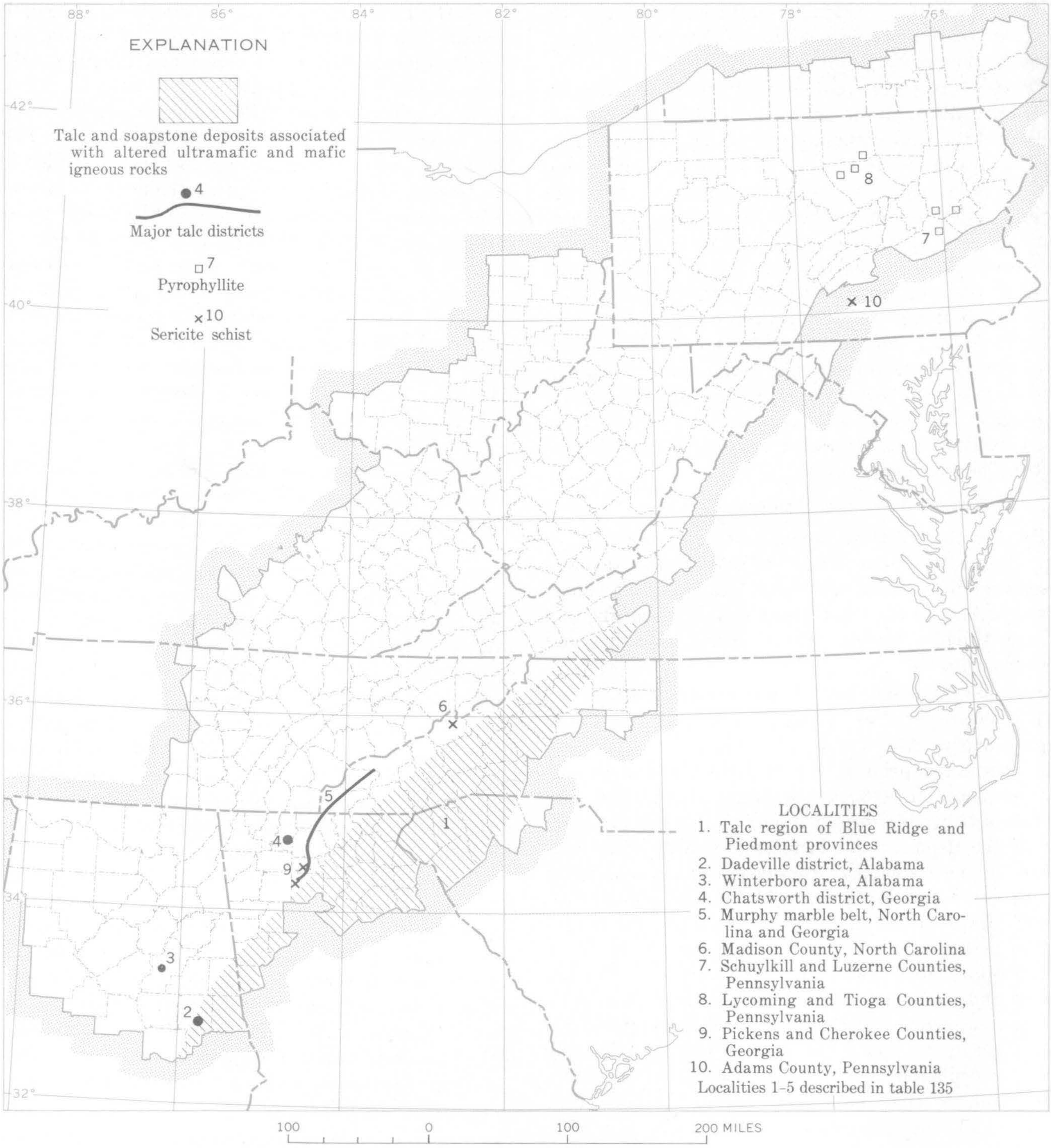


FIGURE 92.—Talc, soapstone, pyrophyllite, and sericite schist in the Appalachian Region.

TABLE 135.—*Talc and soapstone localities in the Appalachian Region*

No. (fig. 92)	Area, district, or locality	Description of mode of occurrence	Host rock	Remarks	References
1	Southern Blue Ridge and Piedmont crystalline belts in Alabama, Georgia, South Carolina, North Carolina, and Virginia.	Generally small irregular bodies of talc and (or) soapstone along altered border zones of mafic or ultramafic intrusives; locally, some of the smaller intrusive bodies may be completely altered to talc or soapstone. Some soapstone bodies are elongate tabular masses that may have formed from mafic sills. Some occurrences may also be highly altered impure dolomitic rocks.	Most talc and soapstone bodies are associated with mafic or ultramafic intrusives of either Paleozoic or Precambrian age intrusive into Paleozoic or Precambrian metamorphic rocks.	----------------------	Pratt and Lewis (1905, p. 36–59); Watson (1907, p. 292–293); Sloan (1908, p. 117–120); Hopkins (1914, p. 267–301); Maynard and others (1923); Jones (1928a, p. 119–120); Hunter (1941); Hunter and Gildersleeve (1946, p. 74–75, 77–79); Stose and Stose (1957, p. 214–215); Dietrich (1959, p. 94–95, pl. 1); Chidester and Worthington (1962).
2	Dadeville district, Tallapoosa County, Ala.	Irregular bodies to tabular zones containing talc and anthophyllite; also residual accumulations of these minerals in soil and saprolite.	Mostly in a belt of mafic or ultramafic rock from several hundred feet to as much as a mile wide extending from Jackson Gap to Dudleyville; dips southeast; a second, generally narrower but parallel belt several miles to southeast may be same zone exposed by synclinal fold.	Clarke (1964) stated that the talc and anthophyllite were formed by weathering of ultramafic intrusives. T. L. Neathery (oral commun., 1965) believes these minerals were formed by hydrothermal alteration of a metamorphosed mafic sill or flow because of their large areal extent.	Maynard and others (1923); Jones (1928a, p. 119–120); Clarke (1964, p. 30–33).
3	Winterboro or Alpine area, Talladega County, Ala.	Two large lenticular bodies of massive talc in clay residuum of dolomite bedrock; stringers of clay and a few relict boulders of dolomite and silicified dolomite are scattered through the deposits; locally the ore bodies bottom directly on dolomite.	Cambrian or Ordovician dolomite.	Talc is believed to have formed by metasomatic replacement of dolomite bedrock. Only the larger northeastern deposit is being mined currently; nearly all production is cosmetic grade.	McMurray and Bowles (1941); Reed (1950b).
4	Chatsworth district, Murray County, Ga.	Highly foliated to massive talc rock containing variable amounts of talc, chlorite, dolomite, and serpentine, and minor amounts of other minerals. The major deposits are roughly elliptical, extending hundreds of feet in length and breadth with thicknesses of from but a few feet to more than a hundred feet.	Precambrian Cohutta Schist of Furcron and Teague (1947), which occurs as lenses in their Fort Mountain Gneiss	Believed to have formed by metamorphism of dolomite lenses in the Cohutta Schist (Furcron and Teague, 1947) or by alteration of ultramafic igneous rocks (Hopkins, 1914; R. D. Bentley written commun., 1966). More than 15 deposits have been mined or prospected in the district; current production is chiefly from the Georgia, Fort Mountain, and Earnest mines, all operated by The Georgia Talc Co.	Hopkins (1914, p. 243–267); Furcron and Teague (1947). Furcron (oral commun., 1966).

TABLE 135.—*Talc and soapstone localities in the Appalachian Region*—Continued

No. (fig. 92)	Area, district, or locality	Description of mode of occurrence	Host rock	Remarks	References
5	Murphy marble belt, Swain, Graham, and Cherokee Counties, N.C., and Fannin, Gilmer, Pickens, and Cherokee Counties, Ga.	High-grade foliated talc in lens-shaped bodies 2–3 times as long as thick, with local pinchout, interfingering, or transition into marble. Most of the commercial talc bodies occur in a central (to the marble belt) dense fine-grained locally silicified zone of white dolomitic marble.	Murphy Marble	Talc bodies probably formed by hydrothermal alteration of marble along shear zones. Principal production from about 8 mines; current production is chiefly from the Nancy Jordan mines 3 and 4 in the vicinity of Murphy, operated by the Hitchcock Corp., and from a mine about 3 miles northeast of Murphy operated by The Georgia Talc Co.	Hopkins (1914, p. 235–243); Van Horn (1948); Hurst (1955, p. 51–53, 128–131); Tennessee Valley Authority (1965, p. M5–M7).

Van Horn (1948, p. 22–29) stated that the Murphy talc deposits are elliptical bodies localized in fracture zones; they formed by hydrothermal replacement of the dolomite in the Murphy Marble. He described (p. 30–51) more than 40 mines and prospects in the North Carolina sector of the marble belt. The Georgia sector of the marble belt has three main areas containing talc prospects, the Sweetgum, Mineral Bluff, and Blue Ridge areas (Hopkins, 1914, p. 235–239; Chidester and Worthington, 1962, p. 3). Talc is also reported near the southwestern end of the marble belt in the vicinity of Ballground, Cherokee County (Hopkins, 1914, p. 241, 243). Although Van Horn's report gives much information about the talc in the Murphy marble belt and suggests prospecting techniques, more detailed geologic studies are needed to select target areas for future exploration.

PYROPHYLLITE IN APPALACHIA

The major deposits of pyrophyllite in Eastern United States are in the slate belt of central North Carolina, east of Appalachia (Stuckey, 1928, 1958). According to Stuckey these deposits were formed by the local replacement of highly aluminous volcanic rocks. The resulting pyrophyllite bodies are massive lenticular, irregular, or bedded.

Minor occurrences of pyrophyllite are reported in the Buck Mountain anthracite bed (fig. 92, No. 7) near Mahanoy City, Schuylkill County, Pa. (Genth, 1880), and in the vicinity of Drifton and Gowan, Luzerne County, Pa. (Genth, 1882, p. 401–402). The pyrophyllite occurs as thin layers and seams within the anthracite and as layers or lenticular patches more than 1 inch thick on slate splits within the anthracite.

Pyrophyllite "slates" have been reported in northern Pennsylvania (Meyer, 1893) at several localities in Lycoming and Tioga Counties (fig. 92, No. 8). Such rock occurs in the Chemung Formation (Devonian) and the Catskill Formation (Devonian and Early Mississippian). Most pyrophyllite-bearing beds appear to be only a few inches thick, although Meyer cited two localities in the Catskill Formation in Lycoming County where they are as much as 5–8 feet thick.

SERICITE SCHIST IN APPALACHIA

Deposits of high-purity sericite schist have been exploited as a substitute for talc, soapstone, or pyrophyllite in Georgia, South Carolina, and Pennsylvania. Deposits in Pickens and Cherokee Counties, Ga. (fig. 92, No. 9), were mined in the early part of the 20th century (Hopkins, 1914, p. 304–309). Two companies are currently (1966) processing material from sericite schist deposits near North Canton, Cherokee County, S.C. Sericite schist is also being produced in Adams County, Pa. (fig. 92, No. 10; J. R. Wells, 1965b), not far outside Appalachia.

Sericite is a common mineral in much schist of the metamorphic terranes of the Blue Ridge and Piedmont provinces in the Appalachian Region. Rocks containing minable sericite schist in Georgia extend into Alabama and into the Carolinas. Systematic prospecting of this region would undoubtedly lead to the discovery of other high-purity sericite schist deposits. The sericite schist deposits of Pickens and Cherokee Counties were investigated as a source of potash during World War. I. (See section on "Fertilizer Raw Materials, p. 281).

A deposit near Hot Springs in Madison County, N.C. (fig. 92, No. 6), reported as pyrophyllite by Hunter and Gildersleeve (1946, p. 71–72), was mapped as sericite schist by Oriel (1950, pl. 1). Oriel believes that this and other sericite schist occurrences in the area were formed by the hydrothermal alteration of Precambrian basement rocks in a highly sheared thrust fault zone. Hunter and Gildersleeve (1946, p. 71–72) described the material as a light-green compact rock with slaty cleavage in a bed about 5 feet thick. Hunter later reported (unpub. data, 1948) that the material from this deposit bloats to several times its original volume on firing at 1540°C and thus might be of interest for certain types of lightweight highly refractory or acid-resistant ceramic products.

RESOURCE POTENTIAL

The outlook for the discovery of commercial deposits of talc and soapstone in the Appalachian Region appears to be excellent. Talc and anthophyllite occurrences in deeply weathered, highly altered mafic rocks are being investigated in Alabama. If the talcose material from these deposits can be satisfactorily beneficiated to provide a commercial-grade ground product, similar belts of deeply weathered mafic rocks in Alabama, Georgia, the Carolinas, and Virginia should be prospected. Additional study of the distinctive Winterboro deposit in Alabama should reveal more about its habit and origin and perhaps furnish geologic guides for further exploration. Detailed geologic mapping of the Chatsworth district of northwestern Georgia should furnish data useful in exploring for new deposits and for more efficient mining of known deposits. The possibility for finding new talc deposits in the Murphy marble belt is excellent, but effective search for these deposits will require extensive geological and, perhaps, geophysical investigations.

The resource potential for pyrophyllite in Appalachia is unknown. The old reported occurrences in Pennsylvania should be investigated in more detail to determine their size and grade and to develop geologic guides for the search for other deposits in the area.

Search for high-purity sericite schist in selected metamorphic formations would assuredly lead to the discovery of new deposits which could be exploited.

ZIRCONIUM

By HELMUTH WEDOW, JR., U.S. Geological Survey, and ROBERT G. HOBBS, U.S. Bureau of Mines

INTRODUCTION

Zircon, the only source of zirconium in the United States, is a hard silicate of zirconium ($ZrSiO_4$), colorless, gray, or yellow to brown, having a high specific gravity (about 4.7) and high resistance to abrasion. It has a high luster, and clear unblemished crystals are used as gem stones. Zircon occurs chiefly as a fine-grained accessory mineral in granitic rocks and in the sediments derived by the erosion of these rocks. Large crystals of zircon are found only in pegmatites.

Most zircon is used in its mineral form as foundry sand, in refractories, and in the production of ceramics and abrasives. Some is used to produce zirconium, a white soft ductile malleable metal, used for nuclear powerplant applications, ferrous and nonferrous alloys, and in the chemical industry where resistance to corrosion is necessary. Stainless steel, aluminum, niobium, vanadium, and titanium may be substituted or used as alternate metal in place of zirconium in many of its applicaions. Additional information about zirconium is given by Eilertsen (in U.S. Bur. Mines, 1965a, p. 1105–1111).

Measured reserves of zircon exist in 13 States (Mertie, 1958, p. 23); however, the deposits in 11 of these States are not commercially exploitable at present. The only domestic producer of zircon exploits heavy-mineral-sand deposits of Florida and Georgia where economic recovery is possible because zircon is recovered as a coproduct of ilmenite and rutile. Annual production figures are withheld to avoid disclosing individual company data.

Zircon and zirconium products are processed in many plants in Appalachia. Zirconium oxide is produced by the Norton Co., Huntsville, Madison County, Ala.; and zircon refractories are made by The Chas. Taylor Sons Co., South Shore, Greenup County, Ky.; Harbison-Carborundum Corp., Falconer, Chautauqua County, N.Y.; Lava Crucible Refractories Co., Zelienople, Butler County, and Harbison-Walker Refractories Co., Mount Union, Huntingdon County, Pa.; and Corhart Refractories Co., Buckhannon, Upshur County, W. Va. The Nuclear Materials & Equipment Corp., Apollo, Armstrong County, Pa., produces zirconium powder, and Carborundum Metals Climax, Inc., Parkersburg, Wood County, W. Va., produces zirconium sponge and ingot. Zirconium alloys are produced by the Vanadium Corp. of America, Cambridge, Guernsey County, Ohio, and by the Union Carbide Corp., Alloy, Fayette County, W. Va. The Ceramic Color & Chemical Manufacturing Co., New Brighton, Beaver County, Pa., uses zircon in the manufacture of colors and chemicals for the enamel, glass, and pottery industries.

No production of zircon in Appalachia has been recorded since 1911. Production from a pegmatitic-type deposit in Henderson County, N.C., started in 1888 and continued for a few years, but the quantities shipped in this early period were not recorded (Pratt, 1916, p. 15). In 1902, shipments were resumed and continued to 1911 with the exception of 1908 and 1910. During this period, a total of 20,512 pounds of zircon was produced and shipped (Pratt, 1916, p. 19). The North Carolina zircon deposits have not been mined since 1911; they evidently are not economic under present conditions.

DEPOSITS IN APPALACHIA

Although zircon-bearing rocks, such as granite, gneiss, and pegmatite, are widespread in the Piedmont and Blue Ridge provinces of Appalachia (fig. 93), the average quantity of zircon in these rocks is exceedingly low. Concentrations of zircon are found only in a few rock bodies and in placer deposits resulting from the erosion of zircon-bearing rocks. The most important zircon deposits of this region are shown on figure 93 and described briefly in table 136.

Zircon crystals have been found in pegmatites of the Zirconia district, Henderson County, N.C. (fig. 93). These pegmatites and associated placer deposits were the sources of the zircon produced in the late 19th and early 20th centuries. Zircon from the Jones and Freeman mines of this district was described by Olson (1952, p. 20) as follows:

> Gray to brown zircon crystals, mostly 0.1 to 0.25 inch in diameter, make up as much as 3 percent of very small parts of the pegmatites at the Jones and Freeman mines, but they are considerably less than 1 percent of the total rock excavated at these two deposits. A rough comparison of the amount of pegmatite mined at the Freeman mine with the recorded pro-

TABLE 136.—*Zircon deposits in the Appalachian Region*

Locality (fig. 93)	Location	Type or mode of occurrence	Host rock	Remarks	References
Shaded area.	Blue Ridge and Piedmont metamorphic belts in Alabama, Georgia, South Carolina, North Carolina, Tennessee, and Virginia.	Disseminated zircon in granitic rocks, gneiss, and pegmatites; locally concentrated in placers derived from these rocks.	Intrusive and metamorphic rocks.	Most commonly associated with monazite, ilmenite, rutile, and, locally, gold in the stream placers.	Pratt (1916, p. 15–18, 39, 46); Mertie (1953, p. 11, 28); Mertie (1958, p. 16–21); U.S. Bur. Mines, Northwest Electrodevel. Lab. (1956, p. 4).
1	Zirconia district, Henderson County, N.C.	Disseminated crystals of zircon as much as one-fourth in. across, chiefly in wall and border zones of pegmatites; recorded production suggests total zircon content of rock mined was probably less than 0.5 percent.	Pegmatite in granitic schist and gneiss.	Early production was mostly from residual concentrations but stream placers were also worked; the Jones and Freeman pegmatite mines were the major producers.	Pratt (1916, p. 15–16); Olson (1952, p. 17–22).
2	Mars Hill area, Madison County, N.C.	Zircon crystals associated with large crystals of monazite in pegmatite, most of which is weathered to saprolite.	Pegmatitic granite and gneiss.	---------------------	Pratt (1916, p. 17, 47, 48); Mertie (1953, p. 26).
3	Snowbird Mountain, Cocke County, Tenn.	Probably ancient "fossil" beach placers. At several localities, laminated sandstone contains 30–60 percent heavy minerals of which 90 percent is ilmenite-rutile and zircon in about a 6:1 ratio. High-grade zones are generally less than 10 ft thick, but intermediate-grade zones may aggregate several tens of feet.	Sandstone of the Snowbird Group of the Precambrian Ocoee Series.	Moderately radioactive with some samples containing as much as 0.2 percent equivalent uranium.	S. W. Maher and G. D. Swingle (unpub. data, Tenn. Div. Geology, 1955); E. C. Chao (unpub. data, U.S. Geol. Survey, 1957); R. H. Carpenter (unpub. data, TVA, 1964); Carpenter, Wedow, and Maher (1966).
4	Walnut Mountain area, Carter County, and Pearson farm, Johnson County, Tenn.	Vein deposits of radioactive minerals, possibly pegmatitic.	Precambrian metamorphic and intrusive rocks.	Semiquantitative spectrographic analyses show radioactive vein material to contain as much as 7 percent Zr.	S. W. Maher (unpub. data, Tenn. Div. Geology, 1955); G. W. Walker (unpub. data, U.S. Geol. Survey, 1957); J. W. Adams (unpub. data, U.S. Geol. Survey, 1966).

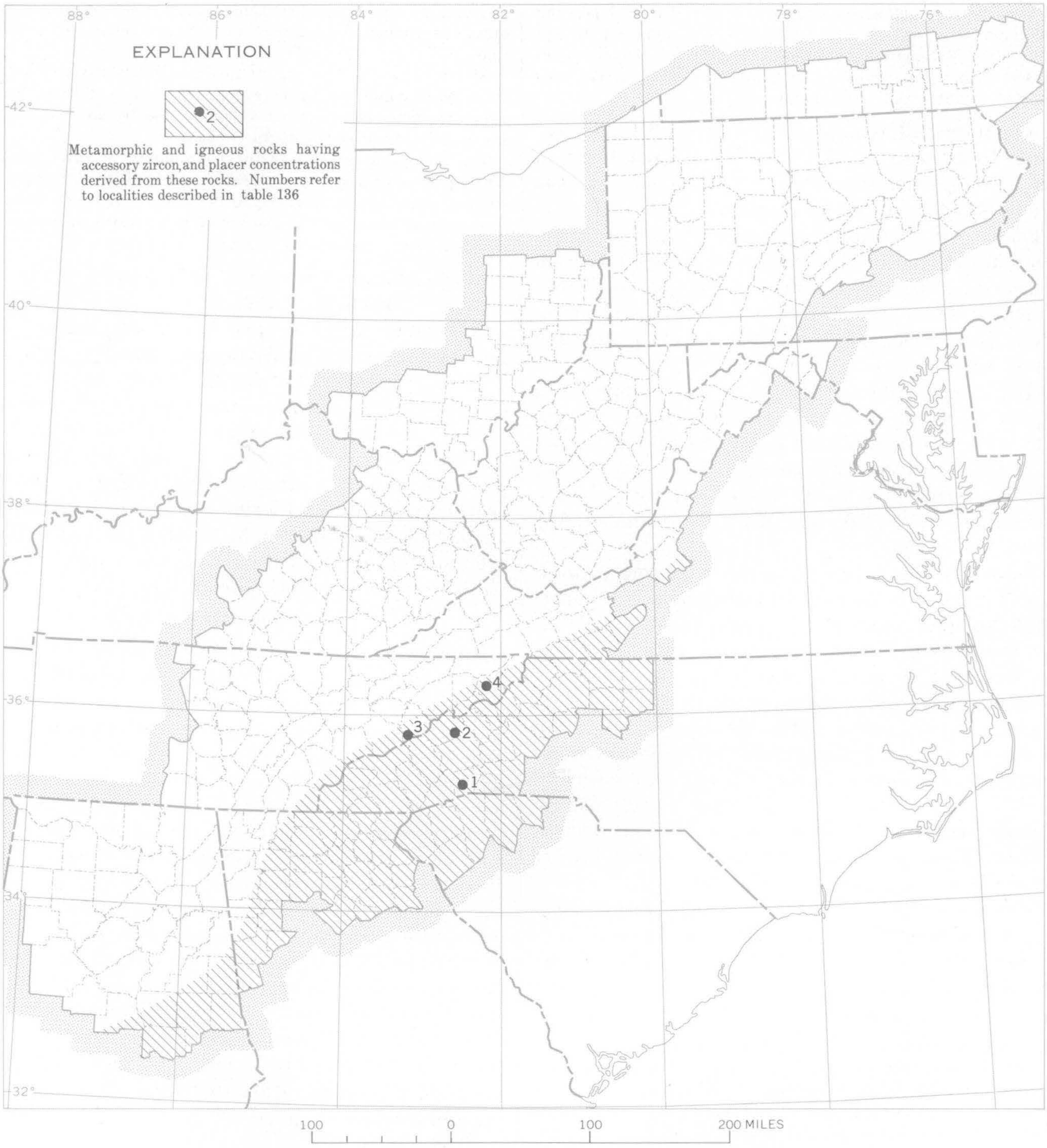


FIGURE 93.—Zircon in the Appalachian Region.

> duction indicates a zircon content of less than 0.5 percent. The common crystal faces are the prism and pyramid. In one part of the Freeman mine, cruciform twins of zircon, superficially resembling twinned staurolite crystals have been reported (Hidden and Pratt, 1898).

In the Mars Hill area, Madison County, N.C., according to Pratt (1916, p. 17), "* * * zircon was found in well developed crystals associated with large masses of monazite that occur in pegmatite."

The largest amounts of placer zircon in Appalachia occur in the gold-bearing placers of Burke, Caldwell, McDowell, Polk, Rutherford, Yancey, and Henderson Counties, N.C. (U.S. Bur. Mines, Northwest Electrodevel. Lab., 1956, p. 4) and the Carolina monazite placer belt.

Hunter and Gildersleeve (1946, p. 87) reported a deposit of zircon near Asheville, Buncombe County, N.C. A deposit in Mitchell County, N.C. (U.S. Bureau of Mines, Northwest Electrodevel. Lab., 1956, p. 4) contains cyrtolite, a highly altered variety of zircon containing almost 11 percent of hafnium oxide (HfO_2) (Hess, 1962, p. 28).

Zirconium also occurs in deposits in northeasternmost Tennessee in association with radioactive minerals. A "composite vein sample" from the Walnut Mountain area, Carter County, obtained by S. W. Maher of the Tennessee Division of Geology, assayed 7 percent Zr by semiquantitative spectrographic analysis (G. W. Walker, unpub. data., 1957). Another sample, also shown to contain 7 percent Zr by semiquantitative spectrographic analysis, was collected and described by J. W. Adams (unpub. data, 1965) as "radioactive granitic material" from the Pearson farm in Johnson County. These prospects may well be worth further study as a source of zirconium.

In 1956, Oscar Rodgers discovered zircon-bearing "fossil" beach sands of Precambrian age in the vicinity of Snowbird Mountain in Cocke County, Tenn. (fig. 93, table 136). Carpenter, Wedow, and Maher (1966) described the deposits as follows:

> Pelitic sandstones of the Snowbird Group of the Ocoee Series contain 30 to 60 percent heavy minerals at several localities on the north slope of Snowbird Mountain, Cocke County, Tennessee. Medium- to coarse-grained sandstones typically are laminated. Dark bands composed mainly of ilmenite-rutile, zircon, magnetite-hematite, and biotite alternate with light bands consisting of quartz, feldspar, and muscovite with scattered grains of ilmenite-rutile and zircon. Some specimens show penecontemporaneous deformation structures. Fine-grained sandstones generally are unlaminated. The steep angle between bedding and the incipient foliation shown by oriented biotite flakes indicates metamorphism. The sutured outlines of the ilmenite grains suggest modification of grain shape by metamorphism.
>
> Ilmenite-rutile and zircon (ilmenite-zircon ratio about 6:1) comprise approximately 90 percent of the heavy mineral assemblage, the remainder being magnetite-hematite, an unidentified radioactive mineral, and trace amounts of tourmaline.
>
> All the deposits thus far studied are sufficiently radioactive to be readily detected by scintillometer ground traverse. Small magnetic anomalies that can be delineated by ground surveys are associated with some of the deposits.
>
> The mineralogical and textural similarity of these ancient placers to geologically more recent beach deposits suggests a shallow-water origin. Reworking of sands in a beach environment may account for the absence of those heavy minerals less resistant than ilmenite and zircon.

Much additional work will be necessary before the economic potential of these "fossil" beach sands can be evaluated. Zircon content is relatively high in the localities tested, generally ranging from 4½ to 9 percent of the rock. The zircons contain hafnium; an essentially pure zircon fraction from one site, analyzed recently for R. H. Carpenter at the Oak Ridge U.S. Atomic Energy Commission facility, was shown to contain 2.06 percent hafnium. This Hf:Zr ratio is 0.043, nearly twice that of Florida and Australian alluvial zircon (Fleischer, 1955, p. 5; Mertie, 1958, p. 20; Hess, 1962, p. 27). Such a hafnium content would add materally to the value of the zircon.

RESOURCE POTENTIAL

The Piedmont and Blue Ridge provinces of southern Appalachia have many low-grade deposits of zircon, mostly as placer deposits but a few as pegmatites. One or two high-grade deposits having as much as 9 percent zircon are associated with appreciable ilmenite that may be Precambrian "fossil" beach sands. The low-grade placer deposits do not contain sufficient zircon to warrant exploitation for zircon alone, either now or in the foreseeable future, but these deposits also contain concentrations of minerals such as monazite, ilmenite, rutile, and native gold which together may prove recoverable. Pegmatites may yield crystals of zircon as a byproduct of mining operations for such minerals as mica and feldspar, but recoverable zircon from this source is small. The "fossil" beach sands may rank among the highest grade zircon deposits of the world. If they prove to be large enough to support a sustained mining operation, they should become a very important source of zircon.

METALS

ALUMINUM—METAL AND RAW MATERIALS

By Sam H. Patterson, U.S. Geological Survey, and John W. Sweeney, U.S. Bureau of Mines

This section on "Aluminum" is divided into three parts: "The Aluminum Industry," "Bauxite," and "Aluminous Rocks other than Bauxite." The threefold division is necessary for an orderly discussion because, unlike most other metals, aluminum is made in a two-step process, and present and possible future mineral raw materials are quite different. Although three American companies are integrated from mining through production of semifabricated aluminum products, the two-step process splits the industry into two units, and each, in a sense, is an industry in itself. Alumina (Al_2O_3) is reduced to metal, the second step, on a large scale in Appalachia, but all alumina extraction from raw material, the first step, is done outside the region. Bauxite is the ore now used in making alumina in the United States. Bauxite is mined on a small scale in Appalachia, but it is used for purposes other than making aluminum. Bauxite resources in Appalachia are too small to provide significant amounts of raw material for metal, but very large resources of aluminous rock such as shale, saprolite, and clay occur in the region, and some of these may be used for making aluminum in the future.

THE ALUMINUM INDUSTRY

Aluminum is the second most widely used metal in the United States and is surpassed only by iron in tonnage consumed annually. It is used in many products because of its high strength-to-weight ratio, high electrical and thermal conductivity, reflectivity, and other physical properties. The construction and transportation industries use approximately 50 percent of the aluminum consumed domestically for such items as roofing, siding, curtain walls, flashing, insulation, hardware, screening, window frames, aircraft, truck trailers, buses, and freight cars. The remaining aluminum is consumed by a wide variety of industries in making such items as furniture, appliances, power tools, utensils, electrical and communications equipment, machinery, automobiles, ships and pleasure craft, and containers and packaging for food and beverages.

The primary aluminum produced in the United States in 1964 was 2.5 million short tons valued at nearly $1.2 billion (Stamper, 1965a, p. 185–186). Most of the alumina from which this metal was made was extracted from bauxite in eight domestic plants, and only relatively small tonnages of alumina were imported. Alumina is reduced to metal in 23 plants operated by 7 companies (J. W. Stamper, in U.S. Bur. Mines, 1965a, p. 28). Four of these plants having a total capacity of 672,000 short tons, or nearly 25 percent of the U.S. total capacity, are in Appalachia. The operating companies in Appalachia are as follows: Ormet Corp., Hannibal, Ohio; Reynolds Aluminum Co., Listerhill, Ala.; Aluminum Co. of America, Alcoa, Tenn.; and Kaiser Aluminum, Ravenswood, W. Va.

The reduction of alumina to aluminum is influenced by all the economic, social, and political factors that bear on all metal industries. The most critical factors, however, are the costs of raw materials, electricity, and transportation. Together they control the location and efficiency of plants, and all four aluminum plants in Appalachia are favorably located with respect to one or more of these factors. The plants in Ohio and West Virginia are on the Ohio River where barge transportation and coal for electricity are available. Plants in Alabama and Tennessee are in areas where low-cost electric power can be obtained.

The largest cost item in producing aluminum is the cost of raw material. The cost of calcined alumina has ranged in recent years from $63.5 to $69.8 per ton (L. R. Williams, in U.S. Bur. Mines, 1965a, table 5), and 1.93 tons is required to produce 1 ton of metal. In addition to alumina, the production of each pound of aluminum requires 0.02–0.03 pound of cryolite, 0.02–0.03 pound of aluminum fluoride, 0.003 pound of fluorspar, 0.55 pound of anode carbon, and 0.02 pound of cathode carbon (Stamper, in U.S. Bur. Mines, 1965a, table 5). The cost of alumina is approximately 30 percent and cryolite, fluoride, and carbon together amount to 15–20 percent of the total cost of producing aluminum. Some of these raw material costs vary appreciably depending on the location of production facilities and the degree of additional processing of the various materials after purchase.

From 7 to 8 kilowatt-hours of electricity are required to produce 1 pound of aluminum (Stamper, in U.S. Bur. Mines, 1965a, table 5), corresponding to 20 percent of its total cost; the industry consumes about 3 percent of the total power generated in the United States. Inasmuch as the cost of electricity varies considerably, it commonly is a decisive factor in establishing the location of aluminum production facilities. Before 1950, plants were built at localities near sources of low-cost hydroelectric power such as the Niagara Falls area, the Tennessee Valley region, and the Columbia River. Most plants constructed since 1950 have been near natural gas, lignite, or bituminous coal for thermally generated power.

Cost of transporting both raw materials and metal influence the industry. Raw-material transportation costs are high because many plants producing alumina are located far from those reducing it to metal. Cost of shipping aluminum to consumers is of relatively minor importance except for plants at appreciable distances from markets, which ordinarily must have other economic advantages to compensate for shipping costs.

BAUXITE

Bauxite is the raw material used in making aluminum, and it is also used for several other purposes.

About 90 percent of the bauxite consumed in the United States is used for alumina, and about 94 percent of the alumina is reduced to aluminum; the remainder is used in abrasives, refractories, and chemicals. The 10 percent of the bauxite not processed into alumina is used for abrasives, refractories, chemicals, high-alumina cement, low-density insulating materials, as an absorbent and as catalysts in refining petroleum, and as a flux in making steel and ferroalloys (L. R. Williams, in U.S. Bur. Mines, 1965a).

THE INDUSTRY

All bauxite mined in the United States is the trihydrate type and consists chiefly of gibbsite, $Al(OH)_3$, but it also contains some kaolinite, $(OH)_8Si_4Al_4O_{10}$, and other minerals. The aluminum monohydroxide, diaspore, $AlO(OH)$, is used as bauxite in Europe, but in the United States is used only for refractories. Iron-bearing minerals are present in variable amounts in most bauxite, and minor quantities of titanium minerals are also present. Bauxite mined in the United States contains 45–55 percent Al_2O_3, 5–20 percent SiO_2, 1.7–2.7 percent TiO_2, and 2–6 percent Fe_2O_3. Although gibbsite is the principal mineral from which alumina is recovered, some plants treating domestic ores also recover part of the alumina from kaolin.

Bauxite is imported from Surinam, Guyana, and Jamaica. Ore from Surinam and Guyana is largely the trihydrate type. Most is low in silica and part of it is very low in iron oxide. Jamaica bauxite contains 18–20 percent Fe_2O_3, much more than in either the domestic or imported trihydrate type. It also contains appreciable quantities of boehmite, a monohydroxide bauxite mineral.

Domestic production of bauxite in 1964 was 1.6 million long dry tons equivalent, valued at $17.8 million (table 137). Consumption in the United States in 1964 was 12.5 million long tons dry equivalent (Williams, 1965, table 1). Arkansas produced 98 percent of the domestic ores, and 2 percent was mined in Alabama and Georgia. Two large integrated companies mined bauxite in Arkansas to supply their own alumina plants, and reduced this alumina to metal in other plants. Four companies produced Arkansas bauxite for uses other than in making aluminum. Four companies mined bauxite in Alabama and Georgia, producing 39,000 long dry tons in 1964, valued at $444,000. Except for a small amount mined in Floyd County, Ga., all came from outside Appalachia.

Transportation is a major cost item in bauxite supply because most bauxite consumed in the United States is mined overseas. To reduce transportation costs, some bauxite is upgraded by washing out impurities and drying before shipment. Transportation costs are also reduced by locating alumina plants close to bauxite sources. Most plants using imported ore are located close to deep-water ports in southern States. Two plants using domestic ore are near bauxite deposits in Arkansas.

TABLE 137.—*Production of bauxite, 1889–1964*

[W, Withheld to avoid disclosing individual company data. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Long tons	Value, in 1958 constant dollars (thousands)	Long tons	Value, in 1958 constant dollars (thousands)
1889	728	9	728	9
1890	1,844	26	1,844	26
1891	3,301	52	3,593	52
1892	10,518	153	10,518	153
1893	9,179	141	9,179	141
1894	11,066	180	11,066	180
1895	28,135	232	17,069	232
1896	18,364	260	18,364	260
1897	20,590	320	20,590	320
1898	25,149	397	2,540	397
1899	30,235	548	35,280	640
1900	19,739	370	23,184	433
1901	18,038	347	18,905	365
1902	22,677	437	27,322	524
1903	22,374	340	48,087	728
1904	21,913	446	47,661	975
1905	15,173	300	48,129	949
1906	25,065	469	75,332	1,405
1907	19,762	367	97,776	1,798
1908	14,464	266	52,167	963
1909	22,227	416	129,101	2,416
1910	38,526	587	148,932	2,486
1911	33,435	483	155,618	2,520
1912	42,710	642	159,865	2,457
1913	40,370	466	210,241	3,080
1914	24,071	270	219,318	3,099
1915	28,244	279	297,041	2,930
1916	49,190	681	425,100	5,506
1917	62,134	828	568,690	6,552
1918	42,829	570	605,721	6,258
1919	43,076	558	376,566	3,540
1920	40,029	479	521,308	4,442
1921	14,700	185	139,550	1,218
1922	42,810	531	309,600	3,245
1923	28,810	294	522,690	5,244
1924	3,800	95	347,570	3,693
1925	2,000	17	316,540	3,398
1926	1,000	15	392,250	4,415
1927	---	---	320,940	3,616
1928	460	4	375,426	4,120
1929	---	---	365,777	4,018
1930	---	---	330,612	3,486
1931	---	---	195,895	2,324
1932	---	---	96,349	1,269
1933	---	---	154,176	2,203
1934	---	---	169,362	2,526
1935	---	---	245,445	3,563
1936	---	---	380,311	5,044
1937	---	---	425,076	5,338
1938	---	---	310,916	3,882
1939	---	---	375,307	4,709
1940	---	---	439,207	5,546
1941	---	---	937,050	10,633
1942	399	5	2,602,034	21,890
1943	2,740	23	6,232,883	47,756
1944	6,574	48	2,823,724	20,143
1945	9,447	65	981,009	7,366
1946	787	7	1,104,054	8,975
1947	---	---	1,202,055	8,325
1948	---	---	1,457,148	10,077
1949	---	---	1,148,792	7,809
1950	---	---	1,334,527	8,762
1951	4,263	18	1,848,676	13,247
1952	9,290	97	1,667,047	11,295
1953	4,697	54	1,579,739	14,251
1954	5,855	15	1,994,896	17,656
1955	W	W	1,788,341	15,824
1956	17,120	77	1,743,586	15,920
1957	W	W	1,416,172	13,078
1958	W	W	1,310,685	12,815
1959	W	W	1,700,235	17,480
1960	W	W	1,997,827	20,919
1961	W	W	1,228,032	13,853
1962	W	W	1,369,007	15,500
1963	W	W	1,515,000	17,165
1964	W	W	1,600,722	17,786
Total	1,138,315	14,966	53,215,684	497,218

Processes used to extract alumina from bauxite vary with the type and grade of the ore. Imported trihydrate ore is treated by the Bayer process which is based on the solubility of aluminum hydrates in caustic soda. High-silica domestic ore is treated by the combination process which is a modification of parts of the Bayer and a lime-soda-sinter process. The combination process requires more raw materials and fuel than the Bayer process, as illustrated in the following table.

A comparison of the Bayer and combination process raw material and fuel requirements per net ton of alumina

[From U.S. Business and Defense Administration (1956, p. V-5)]

	Process		
	Bayer A	Bayer B	Combination C
Raw materials:			
Bauxite..........net tons dry..	2. 0	3. 0	2. 2
Soda ash..............net tons..	. 08	. 40	. 12
Lime....................do....	. 06	. 30	. 10
Limestone...............do....	....	....	. 70
Natural gas........1,000 cu ft..	9. 0	10. 0	23. 0
Bauxite quality:			
SiO_2....................percent..	3	13	13
Al_2O_3....................do....	55	50	50
Expected recovery:			
Bauxite....................do....	50	33	45
Al_2O_3....................do....	91	66	90

A. Imported trihydrate bauxite.
B, C. Domestic trihydrate bauxite.

The value of bauxite for products other than alumina vary considerably with different uses. The iron oxide content may not exceed 6 percent for most abrasives, or 2 percent for use in chemical and refractory products (L. R. Williams, in U.S. Bur. Mines, 1965a, p. 15–26, table 1). Appreciable silica can be tolerated in production of some chemicals. Because the bauxite from Appalachian deposits is sufficiently low in iron oxide, it is used chiefly in production of chemicals.

BAUXITE DEPOSITS IN APPALACHIA

History and Mining

Bauxite was discovered in the United States in 1887 in Floyd County, Ga. (Watson, 1904, p. 25), within the limits of Appalachia. It was discovered in Cherokee County, Ala., in 1889, and shortly thereafter in adjoining Calhoun County. By 1921, nearly all the bauxite districts in Appalachia (fig. 94; table 138) were known; however, additional deposits have been discovered in some districts since then. The first bauxite mined in the United States was on the Holland property, Hermitage district, Floyd County, Ga., in 1888, and the first shipments were made the following year. During the period from the first mining to 1928 when bauxite last was produced in the Chattanooga district, Tenn., bauxite was mined in the following counties in Appalachia: Calhoun, Cherokee, De Kalb, and Talladega, Ala.; Bartow, Chattooga, Floyd, and Polk, Ga.; Hamilton and Carter, Tenn.; and Botetourt, Va. From 1940 to 1942, 800 tons was mined in St. Clair County, Ala. During this period, bauxite was also mined in the Spottswood district, Augusta County, Va., east of Appalachia. Since World War II, bauxite has been mined intermittently in Appalachia only in northwest Georgia, but small tonnages have been mined in each of the last 14 years. In 1964 the only bauxite produced in Appalachia came from American Cyanamid Co. mines in Floyd County, Ga.

Occurrences

The many small bauxite deposits in Appalachia are widely scattered (fig. 94; table 138), but most have similar geologic settings. Deposits in the Margerum district in northwestern Alabama are associated with gently dipping strata of Cretaceous age. All others occur in folded rocks of Paleozoic age in the Valley and Ridge province from west-central Virginia to northeastern Alabama. Most deposits occur in residuum that accumulated in sinkholes or other depressions in carbonate rocks of Cambrian or Ordovician age. Plant fossils occurring in a few deposits suggest bauxite formation took place in early Tertiary time.

The bauxite deposits in Appalachia, as described by Bridge (1950), Clarke (1961), and Overstreet (1964), are small pockets or lenses of bauxite that are enveloped by clayey and cherty residuum derived from weathering of the enclosing carbonate rocks. Many bauxite masses and the residuum that envelops them are oval or circular pipelike bodies with vertical walls. Some are funnel-shaped bodies whose walls dip steeply inward, and some are elongate and resemble steeply dipping veins. Deposits range in size from a few feet to 200 feet across, and some extend to depths of 200 feet. Deposits in some districts are elongated and alined along faults or joints, some of which extend through two or more neighboring deposits. In these, the longest dimension of the deposits tends to be parallel to these fractures. This alinement probably results from the favorable conditions for groundwater movement and sinkhole development along faults and joints in carbonate rocks.

Best grade bauxite commonly occurs in the center of residual deposits, and is enclosed by irregular zones of siliceous bauxite, bauxitic clay, and kaolin, which is separated from the country rock by zones of cherty kaolin and cherty or sandy residuum. Most bauxite is light gray or buff, but some is brown and red. The clay in siliceous bauxite and the inner part of the

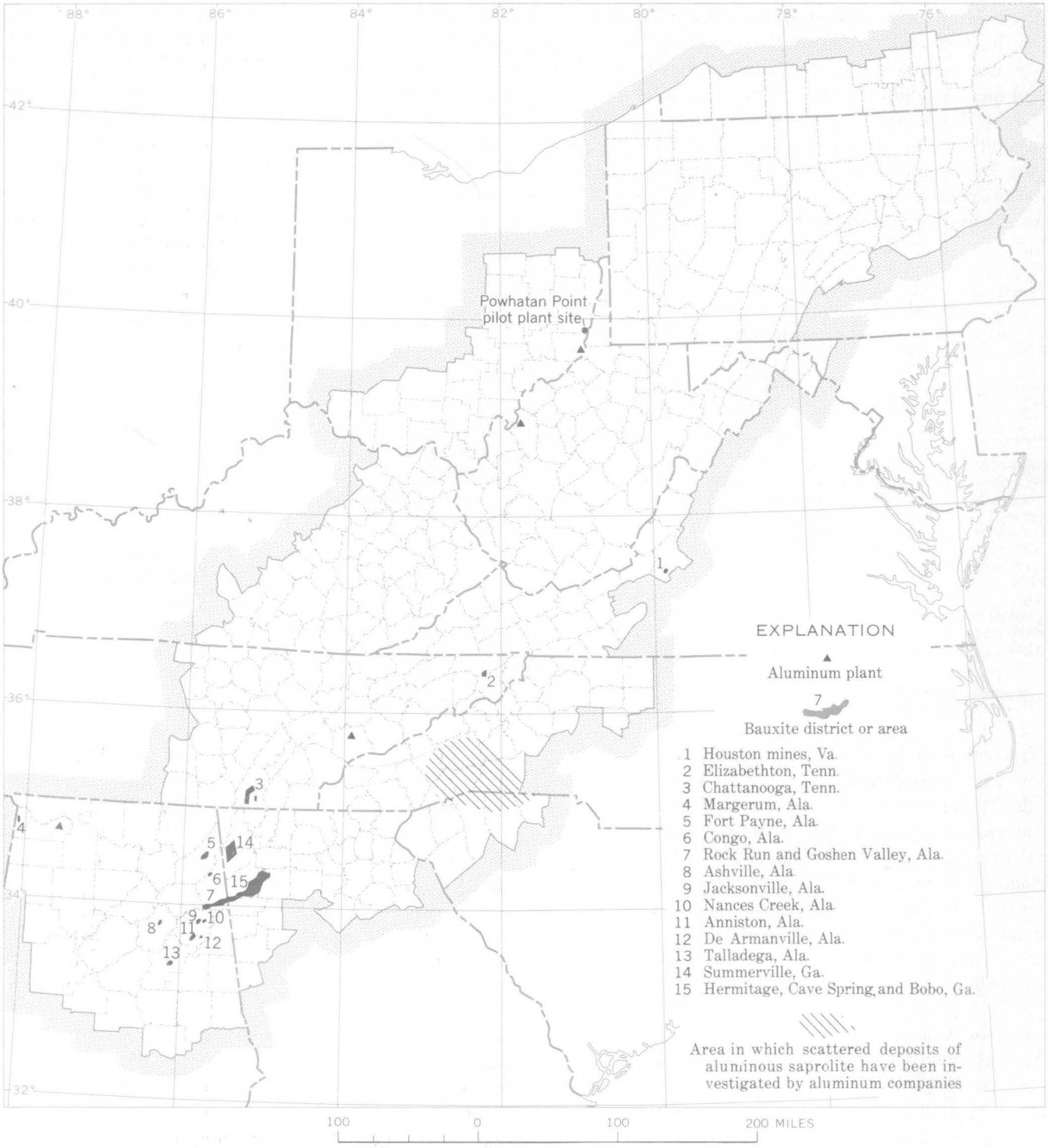


FIGURE 94.—Bauxite deposits and aluminum plants in the Appalachian Region.

TABLE 138.—*Bauxite in the Appalachian Region*

District or area (location on fig. 94)	County, State	Occurrence	Production	Resources	References
Houston mines	Botetourt, Va.	Bauxite occurs with clay in manganiferous residuum from dolomite of Early Cambrian age.	Eight carloads shipped in 1915.	Deposits are presumably exhausted.	Warren, and others (1965).
Elizabethton	Carter, Tenn.	Bauxite occurs in clayey residuum, which is manganiferous locally, in depressions on Shady Dolomite of Early Cambrian age.	Approximately 20,000 tons of bauxite shipped from Watauga mine, 1912–22; Red Bird Hill mine also produced a small tonnage.	Remaining bauxite resources are very small.	King and Ferguson (1960, p. 102); Dunlap and others (1965).
Chattanooga	Hamilton, Tenn.	Bauxite is associated with kaolin in fillings of sinkholes in Copper Ridge Dolomite of Late Cambrian age.	Bauxite was produced from 1907 to 1928, chiefly from the Perry or Isabella Stewart mine.	Only small bodies of bauxite and kaolin remain, and some of these are in residential areas.	Whitlatch (1939); McIntosh (1949); Dunlap and others (1965).
Margerum	Colbert, Ala.	Bauxite is associated with kaolin in small pockets in Gordo Formation of Late Cretaceous age.	No production reported	Deposits that are high in silica and iron and contain 30–45 percent Al_2O_3 are estimated to amount to 100,000 tons.	Jones (1940); Coulter (1948b); Bergquist and Overstreet (1965).
Fort Payne	De Kalb, Ala.	Bauxite occurs with kaolin, lignite, and lignitic clay fillings of ancient sinklike depressions in Chepultepec Dolomite of Early Ordovician age.	Approximately 300 tons produced 1917–18.	Deposits are presumably exhausted.	Jones (1940, p. 31–32); Cloud (1966).
Congo	Cherokee, Ala.	Pisolitic kaolin clay occurs in red sandy loam.	No production	No valuable deposits known to be present.	Denson and Waagé (1966).
Rock Run, Goshen Valley	Cherokee and Calhoun, Ala.	Bauxite associated with kaolin occurs in depressions on the Knox Group of Late Cambrian and Early Ordovician age. Bauxite occurs in scattered small bodies, many of which contain less than 10,000 tons.	Approximately 300,000 tons produced 1891–1923. Nearly 95 percent of the production came from the Rock Run area.	Reserves of high-grade bauxite estimated to be 28,000 long wet tons. Total material of all grades including bauxitic clay and bauxitic material in old mine dumps estimated to be 1.4 million tons.	Jones (1940); Coulter (1948a); Cloud (1967).
Ashville	St. Clair, Ala.	Bauxite occurs with residuum in depressions on the Longview or Chepultepec Dolomite of Early Ordovician age.	During 1940–42, 800 tons shipped for use in water purification.	Deposits are presumably exhausted, but small deposits of high-iron bauxite may still exist.	Cloud (1966).
Jacksonville	Calhoun, Ala	Small bauxite deposits associated with iron ore occur in rocks that may be remnants of early Tertiary continental accumulations.	No production	If any resources are present, they are very small.	Denson and Waagé (1966).
Nances Creek	Calhoun, Ala.	Small bauxite deposits occur with bauxitic clay and kaolin. The deposits probably overlie carbonate rocks of the Knox Group of Late Cambrian and Early Ordovician age.	No production reported	One small low-grade and four very low grade bauxite deposits occur in area. Total known resources are small.	Jones (1940, p. 64–65); Denson and Waagé (1966).
Anniston	Calhoun, Ala.	Bauxite occurs with kaolin and iron deposits in depressions on Shady Dolomite of Early Cambrian age.	do	Deposits are probably too small to be of value.	Jones (1940, p. 63); Cloud (1966).
De Armanville	Calhoun, Ala.	Bauxitic material overlies Shady Dolomite of Early Cambrian age.	No production	Deposits are probably small and have little value.	Denson and Waagé (1966).
Talladega	Talladega, Ala.	Bauxite and kaolinitic clay occur in residuum that overlies carbonate rocks of probable Cambrian age.	Approximately 500 tons shipped to Canada, 1918–19.	Deposits are presumably exhausted or nearly so.	Jones (1940, p. 66); Denson and Waagé (1966).
Summerville	Chattooga, Ga.	Bauxite occurs in pods and lenses with kaolin in area underlain by carbonate rocks of the Knox Group of Late Cambrian and Early Ordovician age.	Small tonnages of bauxite were produced in early 1900's.	Deposits are presumably exhausted.	Watson (1904, p. 113–117); W. S. White and Denson (1966, p. 33–40).
Northwest Georgia, Hermitage, Cave Springs, Bobo.	Bartow, Floyd, Polk, Ga.	Bauxite associated with kaolin occurs in depressions on the Knox Group of Late Cambrian and Early Ordovician age.	Production from 1889 through 1929 is estimated to have been approximately 400,000 tons. Production since 1930 has been small and figures are unavailable; however, the only bauxite mining in Appalachia in recent years has been in this area.	Small bauxite deposits occur at scattered localities in northwest Georgia.	Shearer (1917); Lewiecki (1949); White and Denson (1952; 1966, p. 1–32).

enclosing clay envelope is commonly the same color as the bauxite. This clay ordinarily grades outward into red clay or *terra rossa* (Knechtel, 1963) and red and brown residuum. Most of the bauxite is pisolitic, but some is claylike and some is vesicular. The bauxite in Appalachia is the gibbsitic trihydrate type. The siliceous bauxite is a mixture of gibbsite and kaolinite.

Reserves and suggestions for prospecting

The reserves of bauxite, siliceous bauxite, and bauxitic clay in Appalachia are not large. The total measured, indicated, and inferred reserves in deposits in the Valley and Ridge province were estimated (Overstreet, 1964, p. A16–A17) as of 1960 as follows: metal-grade bauxite containing 54 percent or more Al_2O_3 and 15 percent or less SiO_2, 50,000 long tons; siliceous bauxite, containing more than 15 percent SiO_2, but at least 24 percent "available alumina" (the percent of alumina less 1.1 times the percent of silica), 235,000 long tons; and bauxitic clay, including all material other than bauxite in which alumina exceeds silica, 650,000 long tons. The iron oxide content of these different grades of material varies appreciably but is less than 2 percent in much of it and less than 1 percent in some. Most of the reserves are in the Rock Run and Goshen Valley areas, Alabama, and the Hermitage, Cave Springs, and Bobo areas, northwest Georgia. In addition to the above residual deposits, the Margerum district, Alabama, which is in the Coastal Plain province, contains approximately 100,000 long tons of low-grade bauxite and kaolin (Bergquist and Overstreet, 1965, p. 23).

The total resources of all grades of bauxite in Appalachia are probably adequate to sustain mining at a rate somewhat greater than the present production for several decades. However, deposits of high-grade bauxite in Appalachia are too small and scattered to be of value as a major source of aluminum. Resources of siliceous bauxite and bauxitic clay could be used in several products requiring an aluminous raw material low in iron oxide, but not necessarily low in silica. The bauxite now mined in Appalachia is used chiefly in making alum, and other aluminous chemicals could be made from this material. Much of the bauxitic clay and clay associated with the bauxite is suitable for use in aluminous refractories, and some of the better bauxite probably could be used in making some types of abrasives and catalysts.

New bauxite resources may be discovered in Appalachia, but the discovery of large bauxite deposits is unlikely. All known deposits are small and more or less isolated, and much of the region has been prospected without success. Additional small deposits probably occur in known bauxite districts or areas (fig. 94), and some may be present in other areas. Favorable sites for undiscovered bauxite are blanketed by soil, other residual debris, and vegetation. That small undiscovered bauxite deposits exist under such cover seems almost a certainty, but intense prospecting and exploration would be needed to locate them. Several geologic guides can be applied in a search for bauxite, as outlined by White and Denson (1952, p. 10–11). Most favorable areas for accumulation of bauxite are: (1) presence of carbonate rocks of the Knox Group; (2) topographic situations that favor the accumulation of residual debris rather than its removal by erosion, including the bottoms of broad ravines and valleys and the lower slopes of hills; and (3) highland areas with subsurface drainage. In plateau areas, like the Hermitage district in northwest Georgia, favorable areas are on the dip-slope sides of cuestalike ridges at plateau rims. Particularly favorable areas for bauxite accumulation lie on extensions of any alinement of known deposits, because of the tendency for bauxite to occur in solution depressions formed along faults and prominent joints.

ALUMINOUS ROCKS OTHER THAN BAUXITE

Several rocks and minerals other than bauxite have, at various times, been considered as potential resources from which alumina could be produced, including aluminous saprolite, aluminous shale, high-alumina clay, igneous rock, and minerals of the sillimanite group that are common in some metamorphic rocks. Rocks other than bauxite that have been considered as potential resources of aluminum in Appalachia are aluminous saprolite, diaspore clay, and shale. These rocks and high-alumina clay, which is also a potential source of alumina but has not been investigated thoroughly, will be discussed briefly. Aluminous igneous rocks in Appalachia have smaller alumina content and are at scattered localities, so are not considered to have the potential of large masses outside the region. Minerals of the sillimanite group, including kyanite, sillimanite, and andalusite (each having the composition Al_2SiO_5 and containing 63.2 percent Al_2O_3), are exceptionally rich in alumina, but are too costly to compete with bauxite as a raw material for aluminum. They are described in the section on "Kyanite Group of Minerals" (p. 307).

ALUMINOUS SAPROLITE

Aluminous saprolite is a soft, thoroughly weathered rock in which nearly all the original minerals have been replaced by others formed during weathering, but which preserves many original textures and structures. It occurs throughout large areas in the Piedmont region in the southeastern and southern parts of Appalachia. Large deposits between Spartanburg, S.C., and Rutherfordton, N.C. (fig. 94), were investigated in 1957 by major aluminum companies (Chemical Week, 1957, p. 39–40). The area lies mainly within an extensive belt of metamorphic rocks containing sillimanite and biotite schists and other types of aluminous metamorphosed rocks (Overstreet and Griffitts, 1955). The saprolite extends to considerable depths, and its uppermost weathered part is rich in iron- and alumina-bearing minerals, but also contains residual quartz and other minerals.

Little information on the Carolina saprolite has been published, and the only basis for appraising the deposits are the results of two reconnaissance-type investigations. Councill and Llewellyn (1959) briefly summarized the results of chemical analyses of 99 samples of saprolite, mostly from a large area in South Carolina lying south and east of the one investigated by the aluminum companies. These samples are from saprolite developed on various types of mica schist and other rocks of the volcanic slate belt, including granite, pegmatite, sillimanite schist, and hornblende-bearing rocks. They contain 2–16 percent free alumina and 2–11 percent iron oxide; total alumina ranges from 8 to 26 percent. The senior author of this section collected 12 samples of saprolite in the vicinity of Shelby, N.C., and northwest of Gaffney, S.C., within areas prospected by the companies. He analyzed them by X-ray fluoresnce methods. The results indicate 25–36 percent Al_2O_3, but the standards used may not have been comparable and these percentages may be excessively high. More than enough gibbsite, as identified by X-ray diffraction methods, is present in some samples to explain the small percentage of free alumina reported by Councill and Llewellyn. In addition to gibbsite, the saprolite contains halloysite, altered mica, quartz, and iron-bearing minerals. Most of the gibbsite is very fine grained and intimately associated with clay minerals and would be extremely difficult to concentrate. The saprolite in the region where these samples were collected also contains minor quantities of monazite, zircon, ilmenite, sillimanite, and garnet (Overstreet and others, 1963).

No information on the total size of the deposits in the Carolinas is available, but they are known to extend irregularly over many tens of square miles, and contain aluminous saprolite amounting to many hundred million tons. The total alumina content in much of this rock is probably 20–30 percent.

In addition to the Carolina deposits, appreciable quantities of gibbsite occurs in saprolite in the Piedmont belt in Alabama (Bryant and Dixon, 1964), and aluminous saprolite is almost certainly present in the part of Appalachia in Georgia. The deposits in Alabama and Georgia have not been investigated as possible sources of alumina.

ALUMINOUS SHALE

The North American Coal Corp. constructed a pilot plant, having an annual capacity of 40,000 tons, at Powhatan Point, Ohio, in the early 1960's in an attempt to produce aluminum sulfate from shale and sulfuric acid (Higbie and others, 1963, p. 291). Tests were conducted on shaly coal-mine waste, consisting chiefly of the roof stone of the Pittsburgh coal bed. The plant produced a small quantity of aluminum sulfate, but profitable extraction was not achieved and it was dismantled. The grade of the shaly material used at Powhatan Point has not been published, but Pennsylvanian shales similar to the roof stone tested commonly range from 18 to 22 percent Al_2O_3.

Aluminous shale in Appalachia is virtually inexhaustible. Deposits extend nearly the entire length of the region, and very large quantities are present in perhaps half of the region. This very large shale resource has never been appraised as a potential source of alumina, but undoubtedly many billions of tons containing 15–22 percent alumina exist.

HIGH-ALUMINA CLAY

Clay containing more than 25 percent Al_2O_3, but not more than the theoretical alumina content of kaolinite which is 39.5 percent, occurs at many places in Appalachia. Most is underclay below coal beds, and consists of kaolinite and variable quantities of other clay minerals and nonclay impurities. Clay of this type is now mined extensively for use in refractory and other clay products, as described in the section on "Clay" (p. 167). Its use as a source of alumina has not been attempted in Appalachia, though clay of similar composition in other regions has been investigated for this purpose. Billions of tons of such clay occur in the Appalachian coal basin, according to recent estimates of the staff of the U.S. Bureau of Mines.

DIASPORE-BEARING CLAY

Kaolinitic clay containing diaspore, AlO(OH), and minor quantities of boehmite, AlO(OH), occurs in the Mercer fire clay in the Clearfield district, Pennsylvania. The clay bed ranges from a few inches to 20 feet in thickness. Diaspore occurs chiefly in nodules and pisolites scattered through the clay. Part of the clay is high in iron oxide, and iron-bearing minerals occur in nodules, grains, and as finely disseminated material.

Diaspore clays are used extensively in making fire brick (see "Clay," p. 167), and the largest and best grade deposits are earmarked for use by the refractory industry. This industry uses low-iron clay, however, and deposits containing more than 5 percent Fe_2O_3 have been bypassed in mining. The quantity of diaspore clay containing 5 percent or more iron oxide and 45–50 percent Al_2O_3 was estimated during World War II to be 5 million tons (Conley and others, 1947, p. 4). Probably appreciable tonnages of high-iron clay have been discovered during the last 20 years by companies exploring for refractory-grade clay.

Possibilities for extracting alumina from diaspore clay in the Clearfield district were investigated by the U.S. Bureau of Mines. After detailed laboratory and numerous pilot-plant tests on carload lots, the Bureau concluded (Conley and others, 1947, p. 4) that 87–90 percent of the Al_2O_3 in this clay could be extracted by a lime-soda-sintering process. In obtaining 1 ton of alumina by this process, 360 pounds of soda ash, 1.88 tons of limestone, 1.6 tons of coal, and 47.3 gallons of fuel oil would be consumed. No attempts have been made to extract alumina from these clay deposits on a commercial scale.

POSSIBILITIES FOR USE

The possibilities for use of aluminous rocks other than bauxite as sources of aluminum cannot be evaluated now because information on numerous complicated and interrelated geologic, technologic, and economic factors is incomplete. The large-scale use of aluminous saprolite, aluminous shale, diaspore clay, or high-alumina clay in the immediate future does not seem likely, but extraction of alumina from some of these rocks may eventually become a large industry in Appalachia. A plant to extract alumina from high-grade kaolin clay is contemplated (American Metal Market, 1965) in a part of Georgia outside Appalachia. If such a plant were built, it could generate sufficient research activity to solve several of the problems now impeding the use of aluminous rocks in Appalachia.

CADMIUM

By HELMUTH WEDOW, JR., U. S. Geological Survey

Cadmium is a silver-white soft malleable metal which together with its compounds has a wide range of industrial uses. Only its relative rarity and consequent high price prevent more extensive use. The major uses of the metal are in the plating of fabricated steel products, to give them superior corrosion resistance, and in low-melting point alloys. The chief use of cadmium compounds is as pigments where cadmium sulfide, sulfoselenide, and lithopone make up the color range of yellow, orange, and red in corrosion-resistant paints. Other cadmium compounds used in industry include the stearate in vinyl plastics, the nitrate in cadmium-nickel batteries, and the phosphors of television tubes. (See H. J. Schroeder, in U.S. Bur. Mines, 1965a, p. 165–173.)

The United States became the world's leading producer of cadmium during World War I and has remained so ever since. In 1964 it produced approximately 10.5 million pounds of cadmium or nearly 38 percent of the world total. Cadmium is produced only as a byproduct of the smelting of zinc sulfide concentrates from base-metal ores; no ores are mined solely for their cadmium content, and none are mined in which cadmium is a major metal. In 1964, 11 domestic plants produced cadmium metal. Two of these plants are in Appalachia, both in Pennsylvania; one plant is operated by the New Jersey Zinc Co. at Palmerton, the other by the St. Joseph Lead Co. at Josephtown (See Schroeder, 1965a).

Data on the production of cadmium from the zinc ores mined in the Appalachian Region are not available. However, if the cadmium content of the concentrates produced from these ores is considered to average 0.35 percent, then the zinc ores mined in Appalachia in 1964 ("Zinc and Lead" section, p. 450) contained more than 1½ million pounds of cadmuim metal. Much of this cadmium was recovered at the smelters, so the Appalachian Region may have produced more than 10 percent of the national total.

Cadmium occurs in solid solution in sphalerite or as minor amounts of the mineral greenockite (CdS), coating sphalerite; more rarely it is found as cadmium oxide or carbonate in the secondary ores of zinc. Its production is a function, consequently, of the amount of zinc mined and the amount of cadmium associated with sphalerite. Inasmuch as zinc output from Appalachia is expected to increase over the next few years, the amount of cadmium byproduct should also increase. Because of cadmium's close association with zinc, the geology of the deposits and the resource outlook are discussed in section on zinc and lead.

CHROMIUM

By T. P. THAYER, U.S. Geological Survey, and ROBERT G. HOBBS, U.S. Bureau of Mines

Although chromium is popularly known as a silver-white hard metal used in plating, about 60 percent of the total national consumption is used as an alloy in steel. Chromite, the only ore of chromium, also is used directly in high-temperature refractories, and as a source of chromium compounds for the chemical industry. U.S. consumption of chromite ore during the last 10 years has averaged about 1,400,000 short tons annually, all of which was imported. Although magnesite may be substituted for chromite in some refractories and other metals and plastics can be used in place of chromium alloys for certain purposes, no substitute has been found for chromium or chromite in most essential uses.

The total U.S. production of 2,100,000 short tons of chromite is equivalent to about 16 months use at the 1965 rates, and most of it was produced during World War II and the Korean War in response to Federal purchase programs. No chromite has been mined in this country since 1961. Remaining domestic chromite deposits are low in grade and high in iron, and can be mined and concentrated only at costs two to three times world prices for ore of comparable grade. For more complete information, the reader is referred to R. W. Holliday (in U.S. Bur. Mines, 1965a, p. 211–225) and to U.S. Business and Defense Services Administration (1962).

The largest chromite deposits within Appalachia are in western North Carolina (fig. 95) (J. V. Lewis, 1921; Thayer and Miller, 1962). Some ore was produced from five of these deposits during World War I as shown in the table "Production of chromite in North Carolina" and, in addition, production was attempted about 1896, 1909, 1939, 1941 (Hunter and Gildersleeve, 1946, p. 11–13), and 1930 (Hunter and others, 1942, p. 14). A chromite deposit has been reported in Towns County, Ga. (Hunter, 1938, p. 20).

Chromium ores are mixtures of the mineral chromite and gangue minerals, mostly olivine, serpentine, and magnetite, in various proportions. The chromite contains all the chromium, but in addition may contain iron, manganese, and aluminum. The chromium content of an ore depends, then, on two factors, the ratio of chromite to gangue and the composition of the chromite mineral. Ores that contain too much gangue can be raised to usable grade by grinding the ore and separating the chromite by one of several physical processes, but if the chromite itself is too low in chromium, commercial grade cannot be attained. The principal demand is for ores of the metallurgical type, for which conventional specifications require 48 percent Cr_2O_3, a Cr:Fe ratio of 3:1, and a SiO_2 content of not more than about 5 percent. The ores shipped from North Carolina were upgraded to these specifications by a minimum of hand sorting (Lewis, 1921).

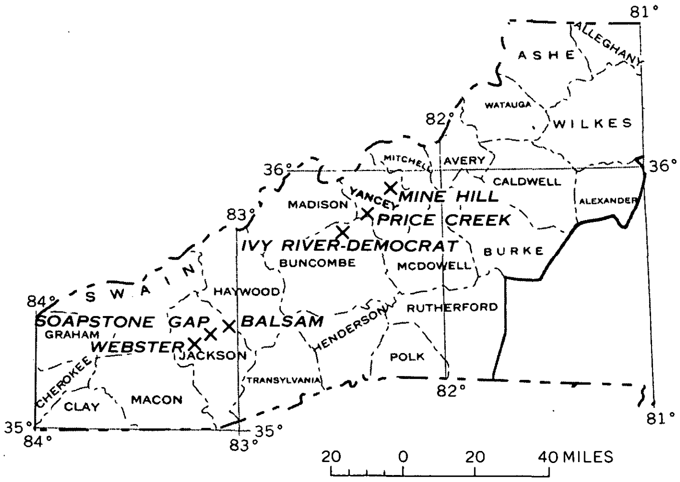


FIGURE 95.—Principal chromite deposits in western North Carolina.

The deposits in North Carolina are of two kinds, (1) lenses and pods in more or less altered peridotite and (2) alluvial deposits derived from the bedrock deposits by weathering. The bedrock deposits range in grade from massive chromite to grains of chromite disseminated in otherwise barren rock. The massive ore lenses "are small, the great majority containing from a few hundred pounds to a few tons each and only exceptional pockets yielding as much as 15 or 20 tons" (Lewis, 1921, p. 114). Commonly ore is interbanded in streaks and layers, at most a few inches thick, with barren peridotite, to form composite lenses a few feet wide and a few tens of feet long. Recovery of the chromite from such deposits requires costly

Production of chromite in North Carolina

County	1909		1917		1918		Total (short tons)
	Mines	Production (short tons)	Mines	Production (short tons)	Mines	Production (short tons)	
Buncombe	0	0	0	0	1	42	42
Jackson	0	0	1	60	3	253	313
Yancey	1	20	0	0	1	85	105
Total	1	20	1	60	5	380	460

grinding and separation processes. The chromite in disseminated deposits as a rule contains more iron than that in massive deposits and is therefore of less value. Sand chromite in stream deposits is a natural concentrate; some recovered near Democrat, N.C., had a Cr:Fe ratio of only about 1.4:1, although it contained about 49 percent Cr_2O_3.

In view of the lack of any production of chromite for the Government purchase programs at two or three times world prices during World War II and the Korean War, the outlook for Appalachian chromite mining is not promising. The massive or high-grade lenses have been mined, and no disseminated deposits large enough to justify the cost of milling plants have been found. Possibly chromite might be recovered as a byproduct of processes to produce magnesium metal or chemicals from olivine rock, but the amount recovered would not exceed 1–2 percent of the olivine processed.

COBALT AND NICKEL

By H. R. CORNWALL and J. S. VHAY, U.S. Geological Survey, and DONALD J. FRENDZEL, U.S. Bureau of Mines

INTRODUCTION

Cobalt and nickel are tough silver-white metals with similar melting points (about 1,500°C), densities, and other physical properties. Both metals are widely used to produce alloys of great strength and resistance to high temperatures and corrosion. They commonly occur together in nature associated with sulfides of iron and copper and in laterite formed by weathering of nickel-bearing mafic and ultramafic igneous rocks. The most common cobalt and nickel minerals are cobaltite, CoAsS, pentlandite, $(Ni,Fe)_9S_8$, safflorite, $(Co,Fe)As_2$, linnaeite, $(Co,Fe,Ni)_3S_4$, siegenite, $(Ni,Co)_3S_4$, skutterudite, $(Co,Ni)As_3$, and smaltite $(Co,Ni)As_{3-x}$.

The United States produces only small amounts of cobalt and nickel to supply only a fraction of its requirements. Although these metals occur in small amounts in many localities in Appalachia, they have never been produced in this region. All cobalt produced in the United States in 1964 came from mines in Pennsylvania just outside Appalachia.

Most cobalt is used in high-temperature alloys, hard-facing alloys, alloy steels, permanent-magnet alloys, driers for paints, and ground-coat frit for enameling (Bilbrey, 1962). Cobalt is also used to color ceramics blue and to neutralize yellow tints caused by iron and other impurities. It has been used as a coloring agent for 4,000 years, but it was not isolated as a metal until 1742 (Bilbrey, 1962, p. 1). Early in the 20th century, cobalt began to be used in alloys, and as the use of these alloys increased, world production rose from 400 tons in 1920 to 5,550 tons in 1940 and 15,500 tons in 1964 (Lim, 1965a, p. 156).

Production of cobalt in the United States reached a maximum of just over 2,000 tons of cobalt in ore in 1958, mostly from the Blackbird mine in Idaho. This production represented 14 percent of free-world output and 53 percent of domestic requirements (Bilbrey, 1962, p. 22). The Blackbird mine closed in 1960, and in 1964 the United States produced less than 2 percent of the free world's cobalt and imported more than 90 percent of its requirements.

Cobalt occurs in a variety of deposits, mostly as a minor constituent associated with other metals. Virtually all cobalt being produced at present is recovered as a byproduct of copper, nickel, and iron ores. The copper mines of the Congo (Kinshasa) and Zambia supply the greatest amount of cobalt and have the largest reserve, but significant amounts are also recovered from the nickel-copper ores of Canada and the iron deposits in Pennsylvania. The largest known high-grade deposit of cobalt in the United States is that at the Blackbird mine, Idaho, which has yielded ores of cobalt and copper.

In 1964, the only domestic producer of primary cobalt metal was Pyrites Co., Wilmington, Del. This company treated a sulfate solution obtained by leaching calcined cobaltous pyrite concentrate from the Bethlehem Cornwall Corp. iron ore mines in Berks and Lebanon Counties, Pa., just outside Appalachia. Production in 1964 was about 250 tons of cobalt (Lim, 1965a, p. 156). Cobalt is processed in Appalachia by the Chase Chemical Corp., Allegheny County, Pa., which uses hydrate to produce driers, and the Ceramic Color & Chemical Manufacturing Co., Beaver County, Pa., which makes hydrate and salts from cobalt metal.

Most primary nickel consumed in the United States goes into the manufacture of ferrous and nonferrous alloys. Stainless steels are the largest single end use of the metal. Nickel is also used in electroplating and for high-temperature and electrical-resistance alloys.

Until about 1880, nickel was obtained from small mines scattered throughout the world, including the Gap mine in eastern Pennsylvania. Mining of nickel from the large deposits in New Caledonia began in 1874 and at Sudbury, Ontario, in 1886. Production of nickel has kept up with each new use and the expanding needs in stainless steel and other alloys. In 1964, the free world produced 315,000 tons of nickel and the Communist-bloc countries about 110,000 tons (Lim, 1965b, p. 95). Most nickel used in the United States is imported from Canada. In 1964 the sole

U.S. nickel producer was the Hanna Nickel Co., Riddle, Oreg., with an output of 15,000 tons.

The Huntington Alloy Products Division of the International Nickel Co. is the single largest consumer of nickel in the United States, operating its rolling mill, the largest in the world devoted exclusively to production of nickel base alloys, at Huntington, Cabell County, W. Va.

DEPOSITS IN APPALACHIA

In Appalachia, nickel with minor amounts of cobalt occurs in nickeliferous laterite in southwestern North Carolina (Worthington, 1964). The largest laterite deposits, with more than 0.5 percent nickel, are near Webster, Jackson County (fig. 96; Pawel, 1939; Ross and others, 1928). The laterite formed from the weathering of dunite, which occurs as an elliptical dike that intruded gneiss and schist. The laterite deposits are scattered over the dunite in small, discontinuous bodies. Nickel occurs in the silicate minerals garnierite and genthite, both in the lateritic soil and also in the underlying weathered dunite. The nickel content ranges from 0.5 to 1.9 percent, and cobalt is about 0.16 percent in residual soil and weathered dunite. Pawel (1943, p. 278) estimated that the laterite deposits contain 1 million tons of material averaging 1 percent nickel. Exploration in 1951–52 of one deposit, the Nickel Plant Tract, by the Olivine Products Corp. under a Defense Minerals Exploration Administration contract, indicated a marginal resource of 450,000 tons of material averaging 0.74 percent nickel. Several other laterite deposits that have been studied in southwestern North Carolina (Worthington, 1964) are too small and too low in grade to be economically attractive.

Nickel with minor cobalt also occurs in a deposit, near Lick Fork, Floyd County, Va. (fig. 96), which consists of disseminations and irregular masses of pyrrhotite and minor amounts of other sulfide minerals in a compound dike of pyroxenite, gabbro, and andesinite (Ross, 1935, p. 103–105). Associated with pyrrhotite are subordinate amounts of chalcopyrite, pentlandite, and violarite (Ni_2FeS_4). The sulfides occur mainly in the pyroxenite. Watson (1908, p. 686–687) stated that the mine dumps contained a large amount of material containing at least 1.75 percent nickel, a fraction of a percent of copper, and as much as 0.4 percent cobalt but averaging considerably less than 0.4 percent. Ross (1935, p. 103) concluded: "The ore body was found to be small and discontinuous and low in nickel, and no commercial production was attained."

In addition to the above occurrences, cobalt is a minor constituent in massive pyritic sulfide deposits (P. S. Smith, 1918; Ross, 1935; Pardee and Park, 1948; and Espenshade, 1963) and in manganese oxide deposits (Pierce, 1944) in Appalachia. The sulfide deposits are described in the section "Copper and Sulfur," (p. 377) and are located on figure 98; manganese oxide deposits are described in the section "Manganese," (p. 416). The sulfide bodies containing cobalt and nickel are lenticular and mostly elongated parallel to the schistosity of the surrounding Precambrian and Paleozoic gneisses and schists.

Espenshade (1963, p. 15–16) quoted from a report on an investigation of the cobalt content of sulfide minerals from several of these deposits as follows:

> * * * pyrite from Ducktown, Tenn., had the largest cobalt content, 0.4–0.5 percent; pyrrhotite from Ducktown contained 0–0.007 percent cobalt; the one chalcopyrite sample from Ducktown that was analyzed contained a trace of cobalt. In specimens from various deposits in Alabama, Georgia, and North Carolina, the cobalt content was found to range from 0.002 to 0.05 percent in pyrite, from 0 to 0.08 percent in pyrrhotite, and from 0 to 0.02 percent in chalcopyrite.

Possibly, or even probably, it will be feasible to recover byproduct cobalt from some of the Appalachian sulfide deposits in the future and, if so, the amount of cobalt available would be substantial. Byproduct cobalt together with copper and gold has been recovered from the magnetite deposit at Cornwall, Pa., for more than 20 years; this ore averages about 0.05 percent cobalt, contained mostly in the small amounts of pyrite.

Manganese oxide deposits, some of which are cobaltiferous, extend southwestward in Appalachia from Virginia through Tennessee, Georgia, and into Alabama (fig. 106, p. 420). These deposits are supergene, having resulted from the weathering of manganiferous sedimentary rocks, mainly carbonates. The cobalt content of the manganese oxides ranges from 0 to 4.84 percent, and commonly is 0.4–1.25 percent (Hewett and Fleischer, 1960, p. 17). Pierce (1944, p. 265) examined cobaltiferous manganese oxide deposits in southern Appalachia and estimated that they contained 7,900 tons of manganese oxides having 0.75–1.5 percent cobalt, or 165,000 pounds of cobalt. He estimated that about 25,000 tons of manganese oxides in other deposits contain 0.2–0.3 percent cobalt or 140,000 pounds of cobalt. It is thus evident that the amount of cobalt available in cobalt-rich manganese deposits is small.

In conclusion, small amounts of cobalt and nickel are present in sulfide ores in Appalachia and may be economically recoverable as byproducts; nickel and cobalt in manganese oxides and laterite are not presently recoverable.

FIGURE 96.—Cobalt and nickel in the Appalachian Region.

COPPER AND SULFUR

By Arthur R. Kinkel, Jr., U.S. Geological Survey, and Stanley A. Feitler and Robert G. Hobbs, U.S. Bureau of Mines

Copper and sulfur are discussed together in this report because most sulfur produced in Appalachia has come from copper-bearing massive sulfide ores. Sulfur also has been produced as a byproduct of lead and zinc ores. Some iron sulfide deposits have been mined solely for their sulfur content, but production from such ores has been relatively small. Economic factors, which varied with time and location, determined whether small amounts of copper contained in a deposit mined for sulfur were recovered and whether sulfur contained in a base-metal deposit was recoverable.

COPPER

THE NATIONAL INDUSTRY

Except for 1934, the United States has been the world's largest producer of copper since 1883. The total recorded production from 1911 through 1964 was 43.2 million short tons, valued at $25.5 billion (1958 constant dollars). Three States, Arizona, Utah, and Montana, have accounted for most of the production, and 13 other States have produced the balance. The total value of copper output ranks second to iron among the major metals.

The principal uses of copper are dependent upon its special physical properties, including high electrical and thermal conductivity, ductility, malleability, strength, and corrosion resistance. For some uses, copper alloyed with other metals results in an improvement of certain basic properties, principally in brass and bronze. The greatest consumption of copper is in electrical applications such as power generation and transmission, communications, industrial and home electrical equipment, electronics, and the electrical systems of transportation equipment (marine, air, and land). Other applications of copper and copper alloys include pipe and tubing for air conditioning, plumbing, and fluid and gas transmission lines. Additional uses are in jewelry, home utensils, and in furnishings utilizing its decorative properties.

Aluminum is the principal alternate or substitute for copper, especially in power transmission lines and equipment, in radio, telegraph, and telephone equipment, engine electrical equipment, and metal stampings. Stainless steel, copper-clad steel, other copper-clad metals, plastics, and other materials compete with copper in a great variety of end products. Additional details are given by F. L. Wideman (in U.S. Bur. Mines, 1965a, p. 263–296).

THE INDUSTRY IN APPALACHIA

Although copper production has been recorded from 19 counties in 6 States within Appalachia, three mines or districts produced 99.75 percent of the total. These are the Ducktown district in Polk County, Tenn., the Ore Knob mine, Ashe County, and the Fontana mine, Swain County, N.C. Only the Ducktown district has been of major and continuing economic importance. Table 139 shows the copper production in Appalachia and the United States for the period 1911–64.

Table 139.—*Production of copper, 1911–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1911	9,425	7,907	557,381	467,600
1912	9,279	9,784	624,547	658,472
1913	9,695	9,276	617,534	590,848
1914	9,369	7,224	574,216	443,735
1915	9,023	6,108	744,036	503,690
1916	7,742	9,134	1,002.938	1,183,330
1917	8,543	9,801	947,717	1,087,067
1918	7,599	6,812	955,011	856,226
1919	7,817	4,675	606,167	362,526
1920	8,364	4,211	612,275	308,233
1921	7,542	2,662	233,095	82,270
1922	7,120	3,101	482,292	210,030
1923	9,376	4,579	738,870	360,837
1924	9,168	4,148	803,083	363,395
1925	9,894	4,803	839,059	407,338
1926	10,037	5,138	862,638	441,581
1927	10,192	4,855	824,980	392,994
1928	12,291	6,413	904,898	472,122
1929	14,869	9,279	997,555	622,569
1930	17,279	8,124	705,074	331,495
1931	11,085	4,107	528,875	196,042
1932	5,279	1,540	238,111	69,448
1933	6,252	1,910	190,643	58,237
1934	8,784	3,144	237,401	84,974
1935	8,462	3,215	380,491	144,531
1936	9,197	3,881	614,516	259,339
1937	9,165	4,841	841,998	444,898
1938	7,299	3,063	557,763	234,089
1939	6,198	2,802	728,320	329,324
1940	8,162	3,967	878,086	426,760
1941	7,610	3,563	958,149	448,452
1942	7,760	3,167	1,080,062	440,756
1943	8,680	3,515	1,090,818	441,755
1944	8,052	3,796	972,549	367,255
1945	7,022	2,498	772,894	274,937
1946	6,985	2,947	608,737	256,814
1947	6,830	3,469	847,563	430,446
1948	6,693	3,366	834,813	419,807
1949	6,489	2,946	752,750	341,694
1950	6,851	3,246	909,343	430,868
1951	7,069	3,632	928,330	746,989
1952	7,620	3,866	925,359	557,412
1953	7,829	4,765	926,448	563,900
1954	9,087	5,771	835,472	530,588
1955	9,911	8,045	998,570	810,561
1956	10,449	9,359	1,104,156	988,931
1957	12,676	7,755	1,086,859	664,953
1958	12,739	6,701	979,329	515,127
1959	15,624	9,461	824,846	499,465
1960	17,888	11,382	1,080,169	687,296
1961	18,200	10,854	1,165,155	694,898
1962	17,905	10,952	1,228,421	760,347
1963	13,717	8,416	1,213,166	744,320
1964	13,889	9,010	1,246,780	808,030
Total	522,082	302,986	43,200,563	25,819,601

The Ducktown district was discovered in 1843, and the first shipment of ore of about 16 tons was in 1847. The ore was hauled by mule train to Dalton, Ga., and shipped to the Revere Smelting Works, Boston (Tennessee Copper Co., 1966, p. 24). This district has produced continuously from 1850 to the present time with only two interruptions—the first during the Civil War from 1862–1865 and the second in 1887. In 1964, the Ducktown district produced 13,889 short tons of copper, or 1.1 percent of total U.S. production.

Other mines are very much smaller. The Ore Knob deposit was discovered and began production in 1856. During the period 1873–83, it was one of the largest copper producers in the United States. The mine was closed from 1883 until 1955 when it was reopened by Appalachian Sulphides, Inc. The mine produced a total of about 35,000 short tons of copper, 9,400 ounces of gold, and 145,000 ounces of silver before closing in 1962 (Kinkel, 1967). The Fontana mine produced a total of 41,500 short tons of copper from 1926 to 1944 (Espenshade, 1963). It was closed because of flooding by the Fontana Reservior. Reportedly, during the period 1874–79, copper was produced from Cleburne and Randolph Counties, Ala. Other production in Appalachia has been small and sporadic, much of it during the depression period of the 1930's and World Wars I and II.

Copper-bearing sulfide deposits exist in northeast Alabama, northern Georgia, western North Carolina, western Virginia, and Pennsylvania. Few have been successfully exploited commercially, although rich secondary copper ore was shipped from mines along the Gossan Lead in Carroll County, Va., in the early days of mining.

SULFUR

THE NATIONAL INDUSTRY

Production and consumption of sulfur in all forms in the United States in 1964 were 7.1 million long tons. The value of shipments was about $149 million. Four companies produced approximately 5.2 million long tons by the Frasch (hot water) process from salt domes in Louisiana and Texas. About 1 million long tons was produced from hydrogen sulfide removed from sour natural gas and petroleum refinery gases while the iron sulfides pyrite, marcasite, and pyrrhotite (commonly called pyrites), base-metal smelter gases, and other byproduct sulfur compounds yielded more than 800,000 long tons (Ambrose, 1965, p. 1022).

From 80 to 85 percent of the sulfur produced was consumed in the manufacture of sulfuric acid (Kerr and others 1965, p. 35; Ambrose, 1965, p. 908), and the remainder was used in agriculture as a soil conditioner and in making pulp and paper, chemicals, pesticides, rubber, and other products.

It is estimated (Ambrose, 1965, p. 908) that 60 percent of all sulfuric acid was consumed in the preparation of fertilizers and chemicals. In addition, large quantities of acid are used in making inorganic pigments, iron and steel, rayon and cellulose film, petroleum products, and synthetic detergents. Smaller quantities of sulfuric acid are used in the manufacture of many other essential commodities. The uses of sulfuric acid in industrial processes are so varied and widespread that consumption of sulfuric acid is considered to be a reliable indicator of industrial activity. During the period 1947–64, new sulfuric acid production grew at the rate of 4.3 percent per year.

Except in locations where iron sulfides have special market, transportation, or cost advantages, elemental sulfur has displaced them as a raw material for sulfuric acid manufacture. Sulfuric acid and (or) sulfur dioxide are recovered from base-metal sulfides not only as part of the metal smelting process, but also to avoid release of roaster gases to the atmosphere.

Because high transportation cost ordinarily limits the distance to which acid may be shipped economically, few sulfuric acid plants are as far as 250 miles from consuming areas. Shipments of acid are generally by truck for distances of 100 miles or less and by railroad to more distant points. Only about 50 percent of manufactured sulfuric acid is shipped; the remainder is consumed at the point of manufacture.

Elemental sulfur recovered from sour natural gas and petroleum has become an important factor in the sulfur supply because it is a byproduct which is readily available in significant quantities, and greatly increased output is indicated for the future.

Sulfides may soon become an important source of sulfur in many areas because of rapidly increasing demands for sulfuric acid.

THE INDUSTRY IN APPALACHIA

The entire output of sulfur from Appalachia is derived from pyrites and the processing of base-metal sulfide ores. No native sulfur is produced in the area. Since the beginning of the 20th century, total output has exceeded 21 million long tons of pyrites valued at more than $117 million at current values.

Iron sulfides, for use as a source of sulfur, have been produced in Appalachia both as a primary ore and as a byproduct of base-metal ores. Iron sulfides were mined for the sulfur content near Galax, Carroll County, Va., by the General Chemical Division of Allied Chemical Corp. from 1905 until 1962 when operations were discontinued. A small amount of sulfur also was recovered from coal washing in Fentress County, Tenn.

The Tennessee Copper Co. recovers iron, sulfur, copper, and zinc from massive sulfide deposits in Polk County, Tenn. The output of sulfur (SO_2) is used at the nearby company-owned chemical plant. Except for Tennessee and Virginia, no iron sulfides have been produced in Appalachia since 1925. During the first quarter of the century and earlier, iron sulfides were also mined in Appalachian areas of Alabama, Georgia, North Carolina, Ohio, and Pennsylvania. Production was intermittent and small, rarely exceeding 20,000 long tons annually from a single State.

Tennessee Copper Co., Polk County, Tenn., the largest producer of copper in the eastern United States, mines ore containing pyrite, pyrrhotite, chalcopyrite, and sphalerite. The ore is beneficiated and separate concentrates are made of chalcopyrite (copper-iron sulfide), pyrite and pyrrhotite (iron sulfide), and sphalerite (zinc sulfide). Blister copper is produced from the copper concentrate at the company's Ducktown smelter. The iron sulfide concentrate is roasted, and the iron oxide residue is sintered. Sulfur-rich gases generated in processing are piped to the company's sulfuric acid plants at Copperhill and Isabella where liquid sulfur dioxide and sulfuric acid are produced. Part of the output is consumed in the company-owned chemical complex and part is sold. The sphalerite concentrate is shipped to zinc smelters for recovery of zinc and sulfur.

The New Jersey Zinc Co. mines and concentrates sphalerite at Friedensville, Susquehanna County, Pa. Zinc is recovered at the company's Palmerton smelter in Carbon County, Pa., where sulfur dioxide, generated by roasting the zinc sulfide, is converted to sulfuric acid which is sold to industry. The company also mines zinc-lead sulfide ore at the Austinville and Ivanhoe mines, Wythe County, Va. Separate zinc and lead concentrates are made at the Austinville mill; most of the concentrates are shipped to the company's Palmerton smelter for treatment.

Zinc concentrates are produced by five companies in eastern Tennessee. Some of these concentrates are shipped to smelters in Pennsylvania where sulfur is recovered.

Sulfur is not recovered from natural gas or crude petroleum in Appalachia because gas and petroleum produced in the area are sweet, containing little sulfur. A gas treatment plant in Kanawha County and a petroleum refinery in Monongalia County, both in West Virginia, are equipped to recover sulfur, but the sulfur recovery facilities are used only when sulfur-bearing gas and petroleum produced in other areas are piped into Appalachia.

Coke oven gas is a source of sulfur, but the quantities potentially recoverable are relatively small. Three coke plants equipped to recover sulfur are located in Kanawha and Monongalia Counties, W. Va., and in Allegheny County, Pa., but no sulfur has been recovered since 1959.

Sulfuric acid and (or) sulfur dioxide are essential reagents for the large chemical, metals, and fertilizer industries in Appalachia. To satisfy this market, 13 companies make sulfuric acid in 20 plants in 8 of the 12 Appalachian States. Figure 97 shows the location of sulfuric acid plants in Appalachia. Table 140 gives additional information about these plants. Acid is made from Frasch elemental sulfur at 16 plants, and one plant uses Frasch sulfur and also reprocesses waste acid. Zinc sulfide is the only source of sulfur at the Palmerton smelter, but St. Joseph Lead Co. uses Frasch sulfur as well as zinc sulfide at its Josephtown, Pa., smelter. Iron and copper sulfides are the source of sulfur at the Copperhill, Tenn., acid plant of the Tennessee Copper Co.

COPPER AND IRON SULFIDE DEPOSITS OF APPALACHIA

The copper deposits of Appalachia and nearby areas are of several fairly distinct geologic types (Weed, 1911). These types are distinguished mainly by their mineralogy, by their mode of occurrence or form, and by their geologic environment. Principal types of deposits are cupriferous massive sulfides (fig. 98), disseminations of copper and iron sulfides, sulfide-bearing quartz veins, native copper deposits, and copper in sediments of the red-beds type. All minable copper and sulfur deposits in Appalachia are in the form of primary sulfides, although secondary deposits have been worked in the past. Minor amounts of native copper occur in altered lavas in the Blue Ridge province northeast of the area of Appalachia. Chalcopyrite ($CuFeS_2$) is the principal copper sulfide, although bornite (Cu_5FeS_4) is found in a few deposits. The iron-bearing sulfides that have been mined for sulfur are pyrite (FeS_2) and pyrrhotite ($Fe_{1-x}S$). Surface weathering enriched many of the exposed deposits of copper sulfides, but these enriched zones extended only to shallow depths. Probably all important bodies of high-grade enriched copper ore, being easily located, were removed in early days of mining in the region. The primary (unenriched) sulfide ore beneath the weathered zone is of much lower grade, but it may extend to great depths.

Gradations are found from one type of deposit to another, as is common in most mineral belts. Disseminated copper deposits are associated with massive iron sulfide bodies, particularly where replacement has been incomplete at their borders or extensions. Disseminated copper of this type is commonly of ore grade. Disseminated sulfides, commonly with a low

FIGURE 97.—Sulfuric acid plants in the Appalachian Region. Numbers refer to table 140.

TABLE 140.—*Sulfuric acid plants in the Appalachian Region, 1962*

[Ch, chamber process; Co, contact process; HS, hydrogen sulfide; Cap, captive; Mer, merchant; Py, pyrite; S, sulfur; W, waste acid; ZnS, smelter gasses]

Location (fig. 97)	Plant	County	Process, status, raw material
	Alabama		
1	E. I. duPont de Nemours & Co.	Jefferson	Co, Cap, S
2	Reichhold Chemicals	Tuscalossa	Co, Cap, S
3	Tennessee Corp.	Talladega	Co, Mer, S
4	Virginia-Carolina Chem. Corp.	Jefferson	Co, Cap, S
5	do	do	Ch, Cap, S
	Georgia		
6	Virginia-Carolina Chem. Corp.	Floyd	Ch, Cap, S
	Kentucky		
7	E. I. duPont de Nemours & Co.	Greenup	Co, Mer, S, W
	Pennsylvania		
8	General Chemical Division, Allied Chemical Corp.	Fayette	Co, Mer, S
9	New Jersey Zinc Co.	Carbon	Co, Mer, ZnS
10	Pittsburgh Coke & Chemical	Allegheny	Co, Cap,[1] S
11	St. Joseph Lead Co.	Beaver	Co, Mer, ZnS, S
12	L. Sonneborn Sons, Inc.	Butler	Co, Cap,[1] S
13	U.S. Steel Corp.	Washington	Ch, Mer,[2] S
	South Carolina		
14	Anderson Fertilizer Co.	Anderson	Ch, Cap, S
15	International Minerals & Chem. Corp.	Spartanburg	Ch, Cap, S
16	Virginia-Carolina Chem. Corp.	Greenville	Ch, Cap, S
	Tennessee		
17	Tennessee Copper Co.	Polk	Co, Mer,[2] Py
	Virginia		
18	General Chemical Division, Allied Chemical Corp.	Pulaski	Co, Mer, S
	West Virginia		
19	General Chemical Division, Allied Chemical Corp.	Kanawha	Co, Mer, S
20	Union Carbide Corp.	do	Co, Cap, S

[1] Also sells significant quantities on the open market.
[2] Also consumes a significant quantity in own operations.

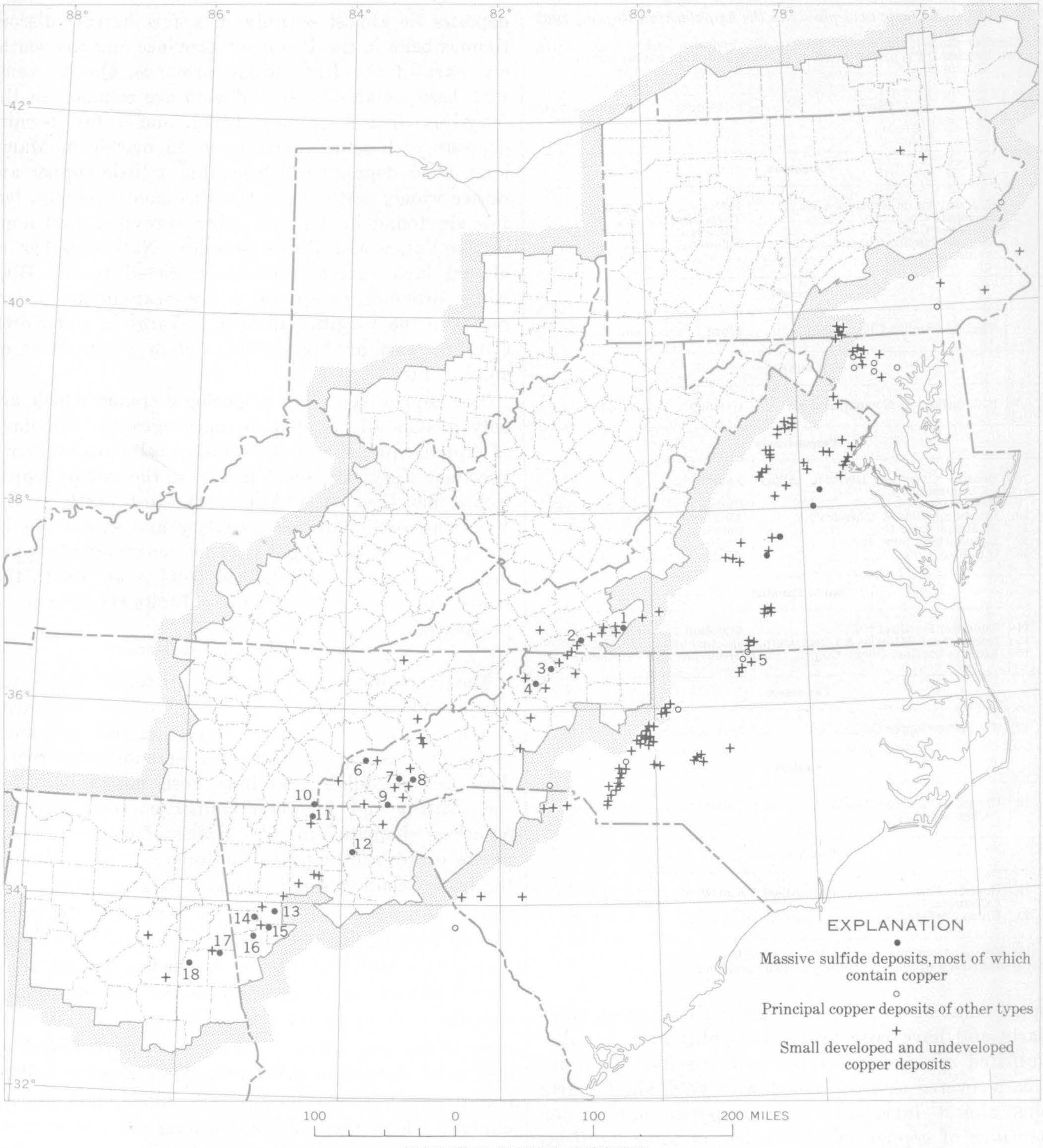
copper content, occur in shear zones that contain gold-quartz and have been mined for gold; in a few disseminated zones of this type there is sufficient copper to be recovered as a coproduct with gold. Gold-quartz veins almost invariably contain pyrite and minor quantities of copper sulfides which, at some localities can be recovered as a byproduct. Exploration thus far in the Appalachian Region has indicated that the massive sulfide type of copper deposit contains by far the largest amount of copper and forms the only minable sulfur ore. This type of deposit is shown separately on figure 97.

The different types of deposits are, with some exceptions, in separate geographic areas. Massive sulfide deposits lie almost entirely in a few narrow discontinuous belts in the Piedmont province and the southern part of the Blue Ridge province. Quartz veins with base metal sulfides and gold are common in the Virgilina district (Laney, 1917), and a few bornite deposits with some quartz occur in marble in Maryland. Gold deposits which contain a little copper are rather widely scattered in the Piedmont province, but few are found in the Blue Ridge province, and none in the Valley and Ridge province. Native copper in altered lava (greenstone) is restricted to the Blue Ridge province, except for a few near-surface occurrences in the Virgilina district in Virginia and North Carolina, east of Appalachia, and in a few dikes of amphibolite.

The copper belts follow geologic trends which are only incidentally related to the geographic boundary of Appalachia. The most extensive belts are in Pennsylvania, Maryland, and Virginia to the east of Appalachia, but they enter Appalachia just north of the Virginia-North Carolina boundary and extend southward into Alabama (fig. 98). The occurrence of copper deposits in rather well-defined belts is an aid to the search for new ore bodies, for it limits the area to be prospected.

CUPRIFEROUS MASSIVE SULFIDES

Massive sulfide deposits are restricted to the metamorphosed rocks of the Blue Ridge and Piedmont provinces. These rocks were largely derived from sediments but include some volcanic and intrusive rocks. The massive sulfide ores have been mined both for their sulfur and for their copper content. The ore occurs as elongate lenticular bodies of copper-bearing pyrite or pyrrhotite-pyrite in foliated rock. Some of the bodies contain small amounts of gold, silver, and zinc. The ore bodies generally lie parallel to the foliation or bedding of the enclosing rocks, and have therefore been called conformable ore bodies. Lenses more than 1,000 feet long have been found that are almost entirely massive sulfides with little or no admixed rock or gangue minerals. Some have been mined to depths of more than 2,000 feet. Some massive sulfide bodies grade into a mixture of sulfide and silicate minerals along their strike, forming ore bodies minable for as much as a mile in length. In some deposits, such as the Gossan Lead in Virginia, minable bodies composed largely of iron sulfides lie within a much longer zone of sulfide-bearing rock that is not of minable grade (Stose and Stose, 1957). These bodies contain minor copper and zinc; they were worked for copper in early days and for sulfur alone during the last half of the period of mining.



PRINCIPAL COPPER DEPOSITS

1	Southerland and Toncrae mines
2	Gossan Lead (Monarat mine)
3	Ore Knob mine
4	Gap Creek (Copper Knob) deposit
5	Virgilina district
6	Hazel Creek and Fontana mines
7	Savannah mine
8	Cullowhee mine
9	Otto (Cabe) deposit
10	Ducktown district
11	Number 20 mine
12	Chestatee mine
13	Little Bob mine
14	Tallapoosa mine
15	Villa Rica mine
16	Reeds Mountain mine
17	Stone Hill mine
18	Pyriton district

FIGURE 98.—Copper deposits in the Appalachian Region.

The primary ore minerals of the massive sulfide deposits are pyrrhotite and pyrite in varying amounts, together with chalcopyrite, and locally minor galena and sphalerite. The gangue minerals are quartz, feldspar, amphibole, chlorite, sericite, biotite, calcite, dolomite, and garnet occurring in varying but generally small amounts in different deposits. Where primary ore is exposed at the surface, a leached zone of iron oxide (gossan) generally extends 20–60 feet below the surface. Between the gossan and the primary ore there commonly is a thin zone of enriched copper ore.

The massive sulfide deposits are much alike, but relatively minor differences in the amounts of the different sulfides have greatly affected their economic potential. Deposits which contain very little copper, such as those of the Prince William and Louisa County sulfide belt in Virginia, the Gossan Lead in Carroll County, Va., the Villa Rica, Standard and Swift, and Reeds Mountain deposits in Georgia, and mines in the Pyriton district, Alabama, were mined for their sulfur content, because the amount of copper was too small to repay cost of recovery except in the zone of secondary enrichment. Mines in which the iron sulfide was mainly pyrite contained more sulfur than deposits in which the sulfur occurred mainly in pyrrhotite. Many deposits which contained only small amounts of copper were mined largely before separation of copper sulfide by flotation methods was developed. The flotation process would now make recovery of copper profitable from some ore of low copper content. On the other hand, other competitive sources of sulfur were much more limited at the time such deposits were mined, and many deposits formerly mined for sulfur could not now be operated economically for sulfur alone. The low-cost production of native sulfur from areas outside of Appalachia decreases the economic potential of sulfur production from sulfide ores, but the demand for sulfur is increasing, and existing supplies could be augmented with sulfur from the sulfide deposits and from sulfide-rich tailings of gold or copper mines in Appalachia.

The massive sulfide deposits of the Tennessee Copper Co. at Ducktown, Tenn., are the largest in the Appalachians and among the largest in the world. Ore that is composed principally of massive pyrrhotite occurs in lenticular to tabular bodies over a length of 6 miles and has been mined to a depth of more than 2,400 feet. The principal products are copper, sulfur, and iron, but small amounts of many other metals are also recovered (Emmons and Laney, 1926; Ross, 1935).

The country rocks in the Ducktown district consist of graywacke, conglomerate, mica schist, slate, staurolite schist, and garnet schist, all units of the Great Smoky Group, of late Precambrian age. These are cut by several gabbro dikes. The rocks have been intricately folded, but the major pattern consists of three northeastward-plunging anticlines on which are superimposed numerous drag folds (Emmons and Laney, 1926, p. 14, 24). Three fault systems older and younger than the ore cut the rocks (Simmons, 1950, p. 68). Whereas Emmons and Laney (1926, p. 64) believed the ores to be replacements of carbonate beds in mica schist, Ross (1935, p. 40–43, 97–101) believed them to be multistage hydrothermal vein deposits. Subsequent work has confirmed neither hypothesis nor clearly established the origin of the deposits. The Ducktown ores are of three types: surficial gossan, rich in hydrous iron oxides; secondary sulfide ore, just below the water table; and the primary sulfide ore. The primary minerals are pyrrhotite, chalcopyrite, pyrite, sphalerite, and minor amounts of galena, bornite, magnetite, and arsenopyrite. Gangue minerals in the primary ore are actinolite, tremolite, garnet, and some zoisite, quartz, calcite, and dolomite. In the secondary ore, chalcocite is the most abundant ore mineral. Covellite, marcasite, and several copper sulfates are present in minor amounts (Emmons and Laney, 1926, p. 41–51). Small amounts of gold and silver occur in the primary and secondary sulfide ores (Emmons and Laney, 1926, p. 76).

The Toncrae mine in Virginia, the Ore Knob, Fontana, and Cullowhee mines in North Carolina, the Number 20, Mobile, Chestatee, Tallapoosa, Little Bob, and Rich (Canton) mines in Georgia, and the Stone Hill mine in Alabama were mined primarily for their copper content. Byproduct sulfur was produced in some, either by treating sulfur-bearing tailings or by recovery of sulfur from concentrates at the smelter.

DISSEMINATIONS OF COPPER AND IRON SULFIDES

Two types of disseminated ores occur in the Blue Ridge and Piedmont provinces, and although both types may contain copper, neither has been an important producer of copper. One type is that commonly associated with massive sulfide, as described above, in which the rock adjoining massive sulfide ore is incompletely replaced. Pyrite or pyrrhotite is the most common sulfide mineral, but locally the deposits may contain enough chalcopyrite to form a minable copper ore. The other type (described more fully in the section on "Gold") is represented by mineralized shear zones that have been mined for their gold content but which also contain some copper and other sulfides. They consist of stringers and lenses of vein quartz with gold and sulfide minerals, mainly pyrite. The quartz bodies, which commonly contain remnants of schist, have either sharp boundaries or indefinite boundaries grading into silicified schist (Pardee and Park, 1948). Some shear zones are silicified but contain few quartz bodies. Larger amounts of chalcopyrite, sphalerite, and silver-bearing galena are present in siliceous zones than in the gold-quartz veins, and other minerals such as tennantite ($(\mathrm{(CuFe)_{12}As_4S_{13}})$), tetradymite ($\mathrm{Bi_2Te_2S}$), chalcocite ($\mathrm{Cu_2S}$), pyrrhotite, and molybdenite ($\mathrm{MoS_2}$) occur sparingly. The gangue is mainly schist composed of quartz, sericite, feldspar, ankerite, chlorite, magnetite, calcite, and locally tourmaline.

A possible third type is the recently explored Hatchet Creek copper prospect, Clay County, Ala., consisting of small veinlets and disseminations of pyrite and chalcopyrite in the Hillabee Chlorite Schist (O. M. Clarke, Jr., in Alabama Geol. Soc., 1964, p. 30–33).

SULFIDE-BEARING QUARTZ VEINS

Few quartz veins that contain the copper sulfides bornite or chalcocite are known within Appalachia, but veins of this type have been mined in rocks of the Piedmont province a short distance to the east. There is no apparent geologic reason why additional veins of this type should not be found in Piedmont rocks within Appalachia. Most deposits are small to moderate, but the copper content of the ore is generally higher than in ore of the massive sulfide type. The outcrop of this type of deposit is marked by green and blue copper stains rather than by iron oxide gossan of deposits having more abundant iron sulfide minerals.

Copper sulfides occur with quartz as veins and as irregular replacements in marble in Maryland (Weed, 1911; Heyl and Pearre, 1965) and in gold-quartz veins in mafic lava in the Virgilina district on the Virginia-North Carolina boundary. In the Virgilina district the veins formed partly by filling and partly by replacement along fractures. They generally follow the foliation of the rocks, but in places they cut across the foliation. Many veins pinch and swell and resemble lenses joined by stringers of quartz. The primary ore minerals are bornite and chalcocite, with smaller amounts of chalcopyrite, pyrite, klaprothite ($\mathrm{Cu_6Bi_4S_9}$), argentite ($\mathrm{Ag_2S}$), and gold. The most abundant gangue mineral is quartz, with smaller amounts of calcite, epidote, chlorite, hematite, sericite, and albite. Parts of some veins were mined for copper and other parts for gold. Some veins in the Virgilina district have been mined as deep as 450 feet, and the veins continued beyond this depth.

NATIVE COPPER DEPOSITS

Small deposits of native copper and associated copper minerals are in altered mafic lavas in the Blue Ridge province in Pennsylvania and Virginia (Weed, 1911). Copper minerals are irregularly distributed in areas of strong epidote and chlorite alteration along shear zones. They are chiefly cuprite ($\mathrm{Cu_2O}$) and native copper, with small amounts of malachite ($\mathrm{Cu_2(OH)_2CO_3}$) and azurite ($\mathrm{Cu_3(OH)_2(CO_3)_2}$) and very small amounts of bornite and chalcopyrite. Native copper occurs in veinlets of quartz, as films on fracture planes, and as grains disseminated through the epidotized rock. Few of the deposits have been explored to depths greater than 50 feet (Weed, 1911; Watson, 1923). Only a small amount of copper has been mined from the known occurrences.

COPPER IN SEDIMENTS OF RED-BEDS TYPE

Copper occurs in early Paleozoic sediments of the red-beds type in northwestern Pennsylvania. They have not been explored because of the low grade of the copper contained in shale and sandstone (Weed, 1911; Butler, 1938; J. F. McCauley, 1957). The copper-bearing bed is thin (Weed reported a maximum thickness of 4 feet), but it has been found in many places in Bradford and Wyoming Counties, Pa. It contains minor amounts of uranium at some places. This type of deposit resembles those in sedimentary rocks of about the same age in nearby Warren County, N.J., where the Pahaquarry mine was operated in 1905 (Cornwall, 1945). Although very little is known about these deposits, they would seem to deserve additional study because of their apparently wide distribution.

IRON AND COPPER SULFIDES IN SEDIMENTARY ROCKS OF THE VALLEY AND RIDGE PROVINCE

Disseminated pyrite in quartzite of Cambrian age was mined on Stony Creek, Carter County, Tenn. (King and others, 1944, p. 188), and similar deposits in Madison County, N.C., have been explored. Copper sulfides occur locally in Paleozoic rocks of Virginia, Tennessee, Georgia, and Alabama, but in such small amounts as to have little or no economic value.

RESOURCE POTENTIAL AND PROSPECTING

Copper-bearing pyrite and pyrrhotite deposits, a source of sulfur as well as copper, are numerous in the region of the Blue Ridge and Piedmont provinces from northeastern Alabama to Pennsylvania. As can be seen in figure 98, these deposits are found within Appalachia only in the region extending southward from southwest Virginia. Many others are along the border but outside Appalachia. Only a few were being worked in 1964, and sulfur was recovered only from the deposits of the Ducktown district of southeastern Tennessee. Sulfur was also recovered from zinc ores from Pennsylvania, southwestern Virginia, and eastern Tennessee.

The potential for finding exploitable deposits of copper and pyrite-pyrrhotite, particularly of the massive sulfide type, in the Blue Ridge and Piedmont provinces is excellent. A systematic search for these deposits should be made using modern techniques of geochemistry and geophysics in conjunction with systematic geologic mapping.

The main effort of prospecting for these deposits should be in the search for hidden or "blind" ore bodies which do not show at the surface or which are covered with weathered or alluvial material. Massive sulfide or heavily mineralized rock which is exposed at surface weathers to a prominent rusty gossan, and probably most exposed ore deposits have been located and explored or mined. Geologic characteristics of the massive sulfide ores suggest that undiscovered ore bodies of this type lie below the present erosion surface. The most favorable places to explore for "blind" ore bodies is in the vicinity of known ore or scattered mineralization, and along the trend of mineral belts. Bodies of sulfides that lie a short distance below the surface can generally be detected by various geochemical and geophysical techniques, although as yet these can give limited information on the size of the deposit or its content of valuable metals. Veins commonly lie along faults or fracture zones which can be detected by geophysical means.

Geological study of both the principal and the minor mineral belts in Appalachia would delimit areas where geophysical and geochemical studies should be made. The gaps along the trend between areas known to contain mines appear particularly worthy of exploration. Such studies may indicate areas where exploration by drilling would be justified.

Sulfide-rich areas that contain only small amounts of copper appear to be more common than those that contain minable copper ore. The low-grade copper ores would probably not be minable for their copper content alone under present conditions, but high-sulfur sulfide ores may be minable for copper and sulfur in the future as the demand for sulfuric acid increases.

Little is known about the red-beds copper deposits of northeastern and northwestern Pennsylvania. They should be explored to determine whether they contain exploitable ores.

GOLD

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INTRODUCTION

Gold is a yellow ductile metal which commonly occurs in the metallic state in nature, and is not affected by air, water, or ordinary acids. Its principal use is as a monetary reserve of governments and central banks to give stability to paper currencies and to settle international trade balances. Gold is also used in the manufacture of jewelry, in dentistry, and for electrical and electronic components in defense and aerospace equipment (Ryan, 1965, p. 558). Nearly 75 percent of the 1964 total of 4.8 million troy ounces of gold consumed by U.S. industry was used for jewelry or other artistic purposes. Additional information about use of gold is given by J. P. Ryan (in U.S. Bur. Mines, 1965a, p. 387–397).

In 1964, gold was mined in 15 States of which 8 States accounted for 97 percent of the total domestic gold production of 1.45 million troy ounces valued at $51 million (1958 constant dollars). In order of production, these 8 States were: South Dakota, Utah, Arizona, Washington, Nevada, California, Alaska, and Colorado.

The value of gold recovered in Appalachia in 1964 was about $5,000, less than 0.01 percent of the value of national production. Annual gold production, from 1905 through 1964, in the United States and in Appalachia is shown in table 141. The total value of gold mined in Appalachia from 1905 through 1964 was $5.2 million (1958 constant dollars). Since 1945, the value of total output has been only $360,000 (1958 constant dollars).

Gold differs from all other metals in that it has an unlimited market at a fixed price. This price was set at $35 per ounce by the President's proclamation of 1934 (Henderson, 1934, p. 32). Rising costs in the face of this fixed price have resulted in the closing of most gold mines in the United States. In 1963, world gold output was 51.7 million ounces, the tenth successive annual increase and an all-time record high. The United States, on the other hand, produced only 1.45 million ounces in 1963, the lowest peacetime production in more than 100 years. At a time when world demand for gold is increasing, the United States gold-mining industry, plagued by rising costs and depletion of high-grade deposits, is steadily declining. Production in the United States probably will continue to decline slowly as production costs continue to rise and as economically minable gold reserves gradually become depleted (Ryan, 1965).

TABLE 141.—*Production of gold, 1905–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Troy ounces	Value, in 1958 constant dollars (thousands)	Troy ounces	Value, in 1958 constant dollars (thousands)
1905	2, 394	196	4, 264, 734	348, 461
1906	2, 290	181	4, 703, 000	371, 068
1907	4, 284	332	4, 227, 499	327, 302
1908	4, 680	353	4, 435, 163	334, 606
1909	4, 085	301	4, 798, 314	352, 987
1910	3, 049	219	4, 584, 903	329, 089
1911	2, 914	202	4, 685, 620	325, 034
1912	2, 062	136	4, 465, 511	294, 922
1913	1, 834	117	4, 311, 103	275, 055
1914	1, 936	116	4, 418, 062	264, 728
1915	2, 614	105	4, 754, 475	190, 100
1916	2, 044	102	4, 417, 007	218, 965
1917	912	40	3, 900, 209	169, 376
1918	528	20	3, 212, 673	120, 531
1919	312	10	2, 753, 282	91, 503
1920	303	9	2, 382, 987	67, 389
1921	299	8	2, 345, 010	66, 315
1922	297	10	2, 293, 251	76, 461
1923	352	12	2, 404, 913	82, 580
1924	367	13	2, 444, 331	87, 268
1925	650	23	2, 307, 374	81, 534
1926	566	21	2, 232, 526	84, 372
1927	481	18	2, 107, 032	79, 194
1928	654	24	2, 148, 064	80, 443
1929	856	31	2, 058, 994	75, 465
1930	1, 473	55	2, 138, 724	79, 947
1931	789	33	2, 224, 729	93, 666
1932	627	30	2, 330, 020	111, 494
1933	999	65	2, 303, 709	113, 654
1934	4, 639	362	2, 778, 788	217, 264
1935	5, 090	408	3, 236, 951	259, 249
1936	5, 761	462	3, 782, 667	303, 657
1937	3, 657	279	4, 117, 078	314, 623
1938	3, 553	266	4, 267, 469	319, 828
1939	706	54	4, 673, 042	355, 555
1940	977	74	4, 869, 949	366, 549
1941	671	47	4, 750, 865	329, 917
1942	387	23	3, 457, 110	204, 040
1943	441	24	1, 363, 815	74, 350
1944	248	12	998, 394	48, 872
1945	153	7	954, 572	44, 018
1946	117	5	1, 574, 505	71, 756
1947	379	16	2, 109, 185	89, 265
1948	175	7	2, 014, 257	81, 687
1949	189	8	1, 991, 783	80, 316
1950	160	6	2, 394, 231	95, 446
1951	111	4	1, 980, 512	73, 588
1952	241	9	1, 893, 261	69, 458
1953	295	11	1, 958, 293	72, 680
1954	218	8	1, 837, 310	69, 219
1955	221	8	1, 880, 142	71, 602
1956	189	7	1, 827, 159	67, 385
1957	800	28	1, 793, 597	63, 799
1958	1, 000	35	1, 739, 249	60, 874
1959	1, 064	37	1, 602, 931	55, 329
1960	1, 783	62	1, 666, 772	57, 818
1961	2, 059	72	1, 548, 270	53, 864
1962	574	20	1, 542, 511	53, 610
1963	137	5	1, 454, 010	50, 686
1964	133	5	1, 456, 308	50, 716
Total	80, 779	5, 153	169, 168, 205	9, 320, 529

The gold production of the United States is closely related to production of base metals. In 1963, 36 percent of the gold produced nationally was recovered as a byproduct of base-metal ore. In Appalachia, over the last 25 years, it has been recovered almost entirely as a byproduct of copper ore.

PRINCIPAL GOLD DEPOSITS OF APPALACHIA

Most gold deposits of Appalachia are found in metasedimentary rocks and associated granitic intrusive rocks that crop out in the Piedmont province and in placers derived from erosion of these rocks. Although the Piedmont province extends from northern Virginia southwestward to Alabama, only the southwestern part extends into the area designated as Appalachia. As a consequence, most gold deposits of Virginia and North and South Carolina are east of Appalachia.

Only those deposits that have yielded a total of at least 10,000 ounces of gold are discussed here. This arbitrary limit is set to distinguish deposits with economic potential from those that have never been especially productive, even under the most favorable economic conditions. However, in order to give an idea of overall gold distribution, complete lists of gold deposits, including those of minor importance, have been compiled for the Appalachian counties of each of the States (tables 142–145).

The gold deposits are distributed in well-defined zones, generally parallel to the northeast-trending structural grain of the country rock. The metasedimentary rocks are of Precambrian(?) and Paleozoic (?) age, and the granitic rocks were intruded near the end of the orogeny that closed the Carboniferous Period in this region. It is believed that the gold is genetically related to the granitic rocks (Pardee and Park, 1948, p. 50).

CHARACTERISTICS OF THE DEPOSITS

Gold deposits may be conveniently grouped into two main classes, placers and lodes. Most placers are unconsolidated gravel deposits in which gold has been separated and concentrated by gravity through the action of moving water. Some placers in the southern Piedmont are residual; that is, the gold was concentrated more or less in place by weathering away of the less durable constituents of the host rock.

The lode deposits are of two types. The most common are tabular veins, whereas others are irregular mineralized zones having indefinite boundaries. According to Pardee and Park (1948, p. 33–39), veins are most numerous in granite or granitic gneiss. They range in length from a few feet to more than 2,000 feet and in width from a few inches to as much as 20 feet. They are coarse textured and many are brecciated and show distinct banding of vein minerals. The mineralized zones are aggregates of small stringers and lenses of ore and gangue minerals in shear zones. Some have sharp but irregular contacts with the country rock; others grade imperceptibly into the country rock.

The mineralogy of veins and mineralized zones is similar, but the amount of individual mineral species present in any given deposit or type of deposit is variable. The gangue minerals are quartz, sericite, biotite, carbonate, chlorite, and locally, garnet, amphibole, and tourmaline. Pyrite, pyrrhotite, gold, chalcopyrite, galena, sphalerite, and arsenopyrite are the most common metallic minerals.

With the exception of several deposits in North Carolina, which are outside Appalachia, and the deposits of the Ducktown district in Tennessee, gold is the most important recoverable mineral of the lode deposits. The gold, which was deposited late in the sequence of minerals, occurs as minute particles in fractures that cut other minerals, as intergrowths in quartz, along cleavage planes in sulfides, and in thin seams along foliation planes in altered schist (Pardee and Park, 1948, p. 39, 40). The ore shoots are generally small. Large ore bodies may be found locally, as at the Haile mine in South Carolina, where one shoot contained about 40,000 tons of low-grade ore, averaging $3 per ton (Pardee and Park, 1948, p. 44). High-grade ore shoots are small and most of those mined in Appalachia contained considerably less than 1 ounce of gold per ton.

In most deposits of the southern Piedmont, ore bodies are localized by structural features such as tension cracks, fracture zones, foliation planes, and crests of rolls. The original chemical composition of the host rock seems to have had little effect on the distribution of ore; rather, it was the degree of fracturing related to the brittleness of the rock that determined the ease of movement of the mineralizing solutions and amount of gold deposition (Pardee and Park, 1948, p. 44).

DEPOSITS IN TENNESSEE

Almost all of Tennessee's gold has come from placer deposits in the Coker Creek area, Monroe County, and from copper ores of the Ducktown district, Polk County (fig. 99), both of which are in the southeastern corner of the State.

Gold was discovered on Coker Creek in 1827, and by 1854 a total of $46,023 worth of gold had been extracted from placers in this area (Ashley, 1911, p. 83, 84). Sporadic small-scale operations in this area resumed after the Civil War and continued until about 1911. A substantial, but abortive, effort to mine gold was made in the 1920's. At present a very small amount is produced and fabricated into souvenirs for sale to tourists. Total production from the Coker Creek area has been about 9,000 ounces of gold, mostly from placers (R. A. Laurence, written commun., 1962). According to Rove (1926, p. 25–29), four types of deposits were mined in the Coker Creek area: fissure veins, high-terrace gravels, present stream gravels, and alluvial cones. The vein deposits are too low grade to be of economic value at present.

The search for gold in the early 1840's led to discoveries of copper ores, and mining of rich chalcocite deposits began in 1847 at Ducktown. By 1879 these ores were exhausted. Though there were large reserves of primary sulfide ore, the status of copper metallurgy and prices at that time made further mining unprofitable (Emmons and Laney, 1926, p. 31). After 1890 new separation techniques were developed; the mines were reopened, and production has been continuous to the present.

Gold ores, as such, have not been mined in the Ducktown district, but small amounts of gold and silver have been recovered from the sulfide ores since 1904. Although early records are incomplete and inaccurate, the best available data indicate that Tennessee's gold production from 1831 through 1964 was about 24,370 ounces, of which 15,442 ounces were recovered from the Ducktown ores (R. A. Laurence, written commun., 1962; U.S. Bur. Mines, Minerals Yearbooks, 1962–64).

The Ducktown district is described in the section on "Copper and Sulfur" (p. 377).

DEPOSITS IN ALABAMA

Nearly all gold mined in the Appalachia counties of Alabama has come from the Arbacoochee and Hog Mountain districts (fig. 99), but small amounts have been produced from the many localities shown on table 142.

Arbacoochee district

The Arbacoochee district, in southern Cleburne County (fig. 99), contained the richest placers of Alabama. The district was very active in the 1830's, but by 1874 only a few miners were still at work (Adams, 1930, p. 21). Although several attempts at lode mining were made in the late 1800's, by 1900 the mines were idle (Adams, 1930, p. 22, 23). Brewer (1896, p. 85) credited the Arbacoochee district with most of the $365,300 in gold (17,700 ounces) produced by Alabama prior to 1879; after 1890 this district became almost inactive.

Most of the gold came from residual placers in the vicinity of Gold Hill and from gravel deposits along Clear Creek (Adams, 1930, p. 21, 22). Bedrock in the southern part of the district consists of Ashland Mica Schist and, in the northern part, of rocks of the Talladega Formation. The two units are separated by the Hillabee Chlorite Schist, which was intruded along an old thrust fault plane (Adams, 1930, p. 18). Gold-bearing quartz veins with pyrite occur in the Hillabee

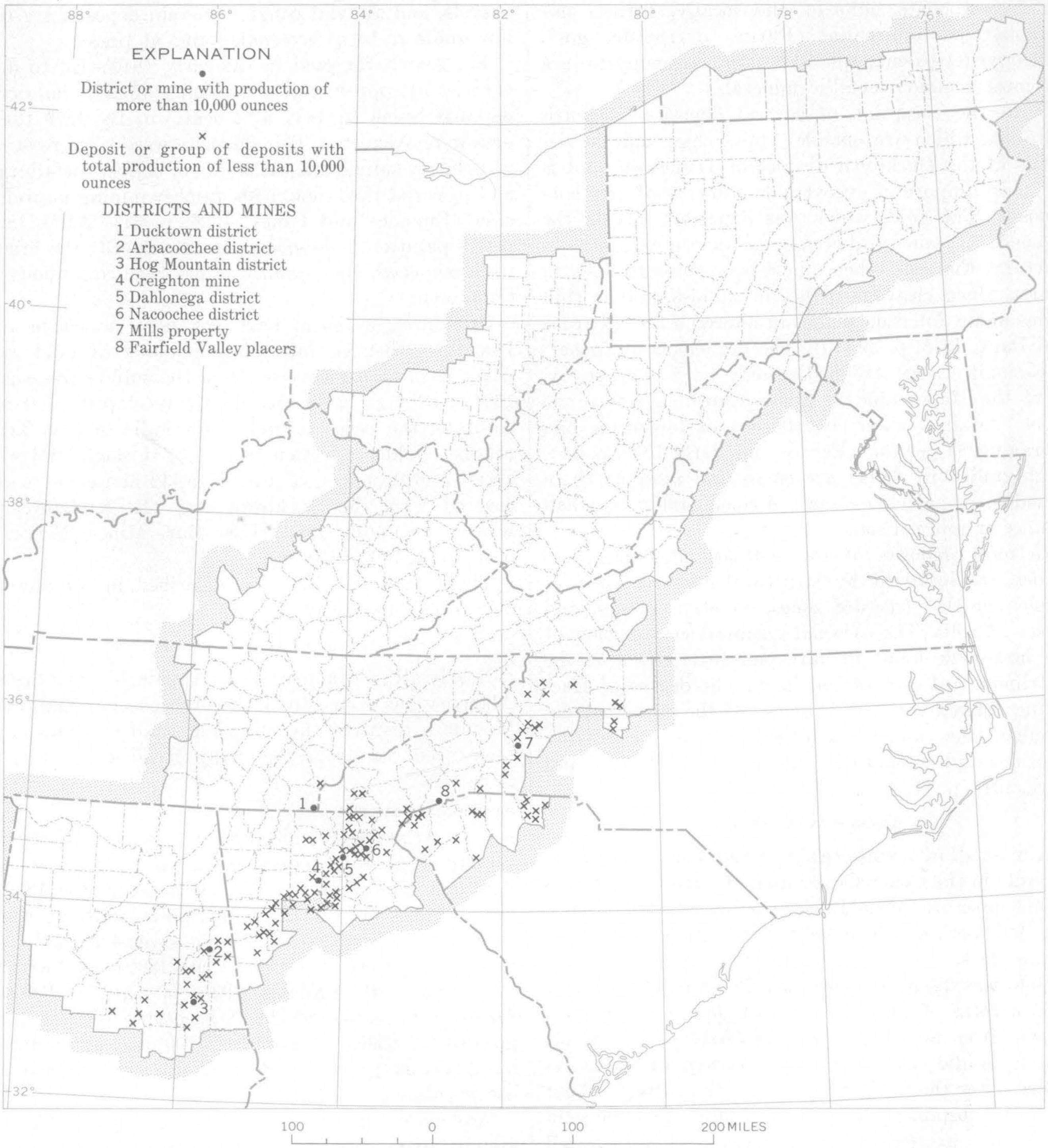


FIGURE 99.—Principal gold-producing areas in the Appalachian Region.

TABLE 142.—*Gold-mining properties in Appalachian counties of Alabama*

[Locations given by county and district only. Data from Pardee and Park (1948 p. 144)]

County	District	Property
Chilton		B. T. Childers.
		Franklin (Jemison).
		Mulberry Creek placer.
		Rippatoe placer.
		Rocky Creek placer.
Clay	Idaho	Alabama Gold Mine & Mica Co.
		Ashland Mining Co.
	Cragford	Benjamin.
	Idaho	Brown prospect.
		California.
		Chinca Pina.
	Cragford	Dawkins.
	Idaho	Eley.
	Cragford	Farrar.
	Idaho	Franklin.
	Cragford	Grizzel.
	Idaho	Haraldson.
		Harall.
		Hobbs.
		Horns Peak.
	Cragford	Lashley.
	Idaho	Laurel.
	Cragford	Manning placer.
Cleburne	Arbacoochee	Anna Howe (Anna Howe Extension, Crutchfield).
		Arbacoochee placer.
		Ayers.
		Bennefield.
	Chulafinnee	Carr Creek.
		Chulafinnee.
	Arbacoochee	Clear Creek.
		Crown Point.
		Crumpton.
		Eckles.
		Golden Eagle (Prince).
		Hicks-Wise.
	Chulafinnee	Higginbottom.
	Arbacoochee	Jack Talley.
	Chulafinnee	Johnson.
		King.
		Rev. Mr. King.
	Arbacoochee	Lee.
		Lucky Joe.
		Marion White.
		Middlebrook.
		Mossback.
		Pritchet.
	Chulafinnee	Striplin.
		Sutherland.
	Arbacoochee	Valdor.
Coosa		Alum Bluff.
		Flint Hill locality.
		Gold Ridge prospect.
		Hatchett Creek placer.
		Rockford placer.
		Rockford prospect.
		Stewart (Parsons) posspect.
		Weogufka Creek placer.
Randolph	Cragford	Bradford Ridge prospect.
		Goldberg prospect.
		Gold Ridge prospect.
		Morris property.
		Pine Hill prospect.
		Pinetucky mine.
		Teakle prospect.
		Wild Cat Hollow.
Talladega	Riddles Hill	Gold Log (Story, Warwick, and Cogburn).
		Riddles.
		Woodward tract.
Tallapoosa	Devils Backbone	Alabama King prospect.
	Goldville	Birdsong.
	Devils Backbone	Blue Hill.
		Bonner Terrel prospect.
	Goldville	Tine Burnett property.
		Chisholm prospect.
		Croft Pits.
	Devils Backbone	Dent Hill prospect.
	Goldville	Duncan property.
		Dutch Bend prospect (Ulrich, Romanoff).
		Early pits.
		Germany pits.
		Goldville pits.
	Eagle Creek	Greer prospect.
	Devils Backbone	Gregory Hill.
	Eagle Creek	Hammock prospect.
	Goldville	Hawthorne prospect.
		Hog Mountain (Hillabee).
	Devils Backbone	Holly prospect.
	Goldville.	Houston pits.
	Eagle Creek	Jennings property.
		Johnson prospect.
	Goldville	Jones pits.
		Log pits.
		Lowe property.
		Mahan pits.
	Devils Backbone	Silver Hill property.
	Goldville	Stone pits.
		Tallapoosa (Hood) prospect.
	Eagle Creek	Tapley prospect.

Chlorite Schist, but they are too low in grade to be of economic value.

Hog Mountain district

The Hog Mountain district in Tallapoosa County, Ala., has been the principal gold producer in the State since about 1890. The only workings of any consequence in this district are those of the Hog Mountain or Hillabee mine, which was opened in 1839 and operated on a small scale until 1893, when larger ore bodies were found and production increased. From 1893 to 1916, the mine produced $250,000 (about 12,100 ounces) in gold (Adams, 1930, p. 50). The mine was closed in 1916 because of high operating costs and was not reopened until 1933. From 1934 through 1937 the Hog Mountain mine was the largest producer in Alabama, but it was closed in 1938. Total gold production of the district through 1964 was about 24,300 ounces, about half of which was produced during 1934–37.

Bedrock in the Hog Mountain district consists of schist of the Wedowee Formation (Paleozoic) and quartz diorite (Park, 1935, p. 4–6). The schist is dark gray, graphitic, and complexly folded and may be cut by thrust faults. The quartz diorite, which may be related to the Pinckneyville Granite of post-Carboniferous age, intruded the deformed Wedowee Formation.

The largest gold-bearing veins of the district are along shear zones in the quartz diorite. Quartz is the most abundant vein mineral, but moderate amounts of pyrrhotite and small amounts of chalcopyrite, pyrite, arsenopyrite, gold, sphalerite, galena, bismuth minerals, and native silver also occur (Park, 1935, p. 12, 13).

DEPOSITS IN GEORGIA

Of the many gold properties and districts in the Appalachian counties of Georgia listed on table 143, only three—the Creighton mine, the Dahlonega district, and the Nacoochee district—have had any significant output.

Creighton (Franklin) mine

The Creighton lode mine, 7 miles southeast of Ball Ground, on the Etowah River in eastern Cherokee County, is one of the oldest and most successful lode mines in the State. It was worked profitably as early as 1840. Early operations were restricted to mining the residual mantle of decomposed bedrock (McCallie, in Yeates, McCallie, and King, 1896, p. 176); after these ores were exhausted, the gold-bearing sulfide ore in the unweathered bedrock was mined. The mine was active in the early 1900's when it was considered the most important in the State, but in 1909 it was flooded by a cave-in beneath the reservoir on the Etowah River (Pardee and Park, 1948, p. 129). No record was found of any subsequent mining. Total gold production of the property was $750,000–$1,000,000 (about 35,400–48,500 ounces (Pardee and Park, 1948, p. 129).

TABLE 143.—*Gold-mining properties in Appalachian counties of Georgia*

[Locations given by counties only. Individual properties cannot be shown at scale of map (fig. 99); map symbols represent distribution of deposits rather than location of individual mines. Data from Pardee and Park (1948, p. 125–128)]

County	*Property*
Bartow	Allatoona mine (Tudor).
	Avery.
	Eiseman.
	Glade prospect.
	Goings property.
	Gold Branch placer.
	Howard.
	McDaniel prospect.
	Robertson.
Carroll	Astinol.
	Bonner prospect.
	Chambers prospect.
	Clompton (Clopton).
	Davis prospect.
	Hart prospect.
	Hixon prospect.
	Jones placer.
	Lassetter prospect.
	Southern Klondyke.
	Stacy prospect.
Cherokee	Bailey property.
	Bell property.
	Bentley prospect.
	Burt's prospect.
	Burty prospect No. 1.
	Burty prospect No. 2.
	Casteel property.
	Cherokee mine.
	Clarkson prospect.
	Coggins (Case & Campbell).
	Cox property.
	Creighton (Franklin) mine.
	Culp property.
	Evans (Cobb).
	Georgianna prospect.
	Granville prospect.
	Haynes prospect. No. 1.
	Haynes prospect. No. 2.
	Keeter placer.
	Kellogg prospect.
	Kitchens prospect.
	LaBelle prospect.
	Latham (Chester) prospect.
	Latham (Stringer) prospect.
	Lovingood prospect.
	Macou prospect.
	McCandless prospect.
	McGill property.
	McLain property.
	M. D. Smith prospect.
	Nesbit prospect.
	Old Bell cut.
	Owl Hollow (Davis) prospect.
	Poor prospect.
	Priest placer.
	Putnam placer.
	Richards property.
	Roach prospect.
	Rudicil prospect.
	Sandow prospect.
	Sixes.
	Southern Star (Cox) properties.
	Standstill property.
	301 (Farrar) mine.
	Tripp property.
	Turner prospect.
	Westbrook placer.
	Whorley prospect.
	Williams property.
	Williamson placer.

TABLE 143.—*Gold-mining properties in Appalachian counties of Georgia*—Continued

County	*Property*
Cobb	Fisher prospect.
	Freeman mine.
	Garrison property.
	Hamilton prospect.
	Hathaway and Kemp properties.
	Mason prospect.
	Payne, Kendrick, Randall, and House properties.
	Van prospect.
Dawson	Baby placer.
	Barrett (Dolly McGehee).
	Church lot.
	Crawford property.
	Dawson gold mines.
	Ellsworth (Fraction) properties.
	Emerson property (placer).
	G. E. Russell property.
	Hammond prospect.
	Hayes prospect.
	Howard prospect.
	Kin Mori mine.
	Long property.
	Looper property.
	Magic prospect.
	McGuire prospect.
	McIntosh placer.
	Missing Link prospect.
	Morse property.
	Palmour prospect.
	Scott (Old Steele) property.
	Shelton prospect.
	Spike Hill prospect.
	Thompson property.
	Turner prospect.
Douglas	Bagget property.
	Carnes property.
	McManus property.
	Owen prospect.
	Pine Mountain mine.
	Roach placer (Fowler).
	Triglone placer.
	212 prospect.
Fannin	Granny Hill (Ganet) prospect.
	Hackney placer.
	Rantze Hill property.
Forsyth	Ad Campbell property.
	B. L. Fowler property.
	Buice property.
	Charles prospect.
	Collins and Adams prospect.
	Cowpens Branch placers.
	Faver prospect.
	Little prospect.
	Lyons lot.
	Montgomery prospect.
	Settles property.
Forsyth—Continued	Strickland prospect.
	Suwannee Mountain property.
	W. T. Fowler placer.
	Young Deer Creek placer.
	Zamoda gold prospect.
Gilmer	Cartecay (Lucky Eight) property.
	Holt placer.
	Turkey Pen property.
	Whitaker property.
	White Path mine.
Gwinnett	Brogden prospect.
	Harris prospect.
	Hawking placer.
	Level Creek placers.
	Moore and Brogden property.
	Owens prospect.
	Piedmont (Newton) prospect.
	Richland Creek placers.
	Roberts property.
	Shelly property.
	Suwannee (Percy, Simmons, Level Creek) prospect.
Habersham	Bean property.
	Black kyanite placer.
	Bowen placer.
	Crow Heirs placer.
	Crow Heirs prospect No. 2.
	Crow prospect.
	Edwards property.
	Hood (Habersham, Holland) placer.
	LaPrade placer.
	M. F. Wilson placer.
	Nichols placer.
	Soque River placer.
	Tailor Wood prospect.
	U.S. Forest land placers.
	Weikle Brothers prospect.
	Willbanks property.
	Wilson placer.
Hall	Banks property.
	Big Joe prospect.
	Black Hill prospect.
	Boggs prospect.
	Brenau College land.
	Byrd prospect.
	Cool Spring Church prospect.
	Currahee prospect.
	Dean prospect.
	Elrod mine.
	Glades prospect.
	Gould prospect No 1.
	Gould prospect No. 2.
	Ivy Mountain prospect.
	Johnson property.
	Jones prospect.
	Longstreet prospect.

TABLE 143.—*Gold-mining properties in Appalachian counties of Georgia*—Continued

County	*Property*
Hall—Continued	Mammoth prospect.
	Maynas prospect.
	McClesky prospect.
	Merck prospect.
	Moore prospect.
	Muddy Creek prospect.
	Odom prospect.
	O'Shields prospect.
	Parks prospect.
	Pass property.
	Potosi prospect.
	Prater placer.
	Rogers and Anderson prospect.
	Savage placer.
	Smith prospect.
	W. P. Smith.
	Stockeneter Creek placer.
	Stowe prospect.
	Georgia Univ. land.
	Vickers prospect.
Haralson	Dean placer.
	Edwards placer.
	Hollis prospect.
	McBrayer property.
	Pole Branch placer.
	Royal Gold mine (Holland).
	Thomason property.
Lumpkin	Baggs Branch placer.
	Barlow mine (Pigeon Roost).
	Barsheba Woody.
	Bast mine.
	Battle Branch mine.
	Beers property.
	Belle prospect.
	Benning prospect.
	Betz mine.
	Bluffington prospect.
	Boly Field property.
	Bowen lot.
	Boyd.
	Briar patch placer.
	Bunker Hill.
	Calhoun mine.
	Capps prospect.
	Cavender Creek property.
	Chestatee placer.
	Cleveland property.
	Columbia prospect.
	Consolidated mine.
	Conway lot.
	Cora Lee property.
	Crescent prospect.
	Crown Mountain mine.
	Danae prospect.
	Dry Hollow prospect.
	Duncan Branch placer.
	Early.
Lumpkin—Continued	Etowah property.
	Findley mine.
	Fish Trap prospect.
	Free Jim property.
	Garnet prospect.
	Gold Hill prospect.
	Gordon property.
	Greenfield prospect.
	Griscom prospect.
	Hedwig property (Chicago and Georgia).
	Hightower prospect.
	Horner prospect.
	Ivey mine.
	Jones prospect.
	Jumbo prospect.
	Keystone prospect.
	Lawrence (Street) prospect.
	Liberty Bell property.
	Lockhart prospect.
	Long Branch property.
	Mary Henry prospect.
	McAfee-Lynn (Rutherford) prospect.
	McDonald prospect.
	McIntosh prospect.
	Miller placer.
	Norrell-Stewart prospect.
	Old Columbia.
	Parker lot.
	Preacher mine.
	Ralston property.
	Reliance Mining Co. property.
	Rider prospect.
	Rufus E. Wood property.
	Saltonstall.
	Saprolite prospect.
	Shockley lot.
	Singleton (Standard) property.
	Skyrme prospect.
	Smith prospect.
	Stegall placer.
	Tahloneka Branch placer
	Tanyard Branch placer.
	Teal prospect.
	Todd lot.
	Topabri (Josephine) property.
	Turkey Hill prospect.
	Wells prospect.
	Whim Hill property.
	White Rabbit.
	Woods prospect.
	Woodward prospect.
	Yahoola prospect.
Madison	Carrington place (placer).
	C. M. Smith placer.
	Parham, Ridgeway property.
	Webb-Threlkeld-Oliver property.

TABLE 143.—*Gold-mining properties in Appalachian counties of Georgia*—Continued

County	*Property*
Murray	Cohutta prospect.
	Gold Mine Creek and Chicken Creek placer.
Paulding	Austin prospect.
	Barton prospect.
	Dunnaway prospect.
	Greenfield property.
	Hobbs prospect.
	Hodges prospect.
	H. W. Brown prospect.
	Mathews prospect.
	Nelson Dockery prospect (placer).
	Schofield prospect.
	Sheffield (Heidt) property.
	Twillery (Dockery) placer.
	Yorkville prospect.
Rabun	Barclay prospect.
	Blalock placer.
	Bowers placer.
	Bright Evans prospect.
	Dillard placer.
	Hamby placer.
	Hedden placer.
	H. W. Bentley prospect.
	Lamar placer.
	Ledford placer.
	Ledford prospect.
	Moore Girl prospect.
	Page property.
	Powell prospect.
	Reeves prospect.
	Rocky Bottom Smith placer.
	Screamer Mountain placer.
	Smith prospect.
	Stone Sypher prospect.
Towns	Brown prospect.
	Chastain Branch placer.
	Eller prospect.
	E. R. Brown.
	Hooper and Berong prospect.
	Horse vein.
	Kerby prospect.
	Malden prospect.
	Murdock (Hiawassee Mining Co.).
	Nancy Brown.
	Newton placer.
	Oldfield prospect.
	Pittsburg prospect.
	Skeet Hooper placer.
	Smith placer.
	Struby prospect.
	Willis Creek placer.
Union	Brown prospect.
	Butt prospect.
	Coosa Creek placer and lode.
Union—Continued	Crumly Creek placer.
	Gum Log prospect.
	Hunt (Princeton) prospect.
	J. H. Brown prospect.
	Killian prospect.
	Killian and Rhodes prospect.
	Lot 20.
	Legal Tender prospect.
	Martin prospect.
	Mauney prospect.
	Old Diggings.
	Rogers and Stevens property.
	Ross prospect.
	Stannick prospect.
	Teague prospect.
	Wellborn Hill prospect.
	Wellborn prospect.
	Wellborn-Robinson prospect.
White	Ashbury prospect.
	Atkinson (Nix) prospect.
	Baker placer.
	Bell Creek placer.
	Bell Creek prospect.
	Bell property.
	Blake prospect (Sprague).
	Butts prospect.
	Castleberry property.
	Childs (Jarret) placer.
	Conley prospect.
	Courtney placer.
	Cox Bottoms placer.
	Damforth (Longstreet).
	Dean (St. George) mine.
	Dukes Creek placer.
	Dunbar placer.
	Eaton-Shostmile-Boston-Mercer properties.
	Entries prospect (placer).
	Flennigen prospect.
	Franco-American property.
	Franklin and Glenn prospect.
	Gayton placer.
	Glover placer.
	Hardeman property.
	Henderson placer.
	Hudson cut (Whitner).
	Hudson placer.
	Jo Creek placer.
	Jones mine (Craig).
	Lewis prospect.
	Long Hungry prospect.
	Long Hungry prospect. No. 2.
	Lot 10.
	Loud prospect.
	Lunsden placer.
	Martin property (Hamby).
	McAfee placer.
	Merritt prospect.
	Mingo placer.

TABLE 143.—*Gold-mining properties in Appalachian counties of Georgia*—Continued

County	*Property*
White—Continued	Monroe Lowlands (Candler and Thompson).
	Nicks property.
	Old Childs placer (Stevensons).
	Old Matthews prospect.
	Old Office cut.
	Old Thomas Leadford prospect.
	Park (McMillian property).
	Plattsburg (Old English).
	Poland prospect.
	Reaves property.
	Reynolds (Hamby) prospect.
	Roberts prospect.
	S. J. Cox placer.
	Sprague prospect (Blake).
	Stovall placer.
	Thurman prospect.
	Twiner property.
	White County (Thompson) mine.
	White-McGee (Oliver) prospect.
	Will Hood prospect.
	York (Herd) property.

Pardee and Park (1948, p. 129), who summarized the findings of earlier workers, noted that the country rock in the Creighton mine area is mica schist with layers of amphibole gneiss. Two major vein systems, the Franklin and McDonald, contain the deposits. The Franklin was the more productive. The deposits consist of aggregates of quartz stringers parallel to the strike and dip of the foliation of the schist and gneiss. Gold occurs in pyrite associated with the quartz stringers and disseminated in the wall rock. Calcite, muscovite, and chalcopyrite occur in minor quantities.

Dahlonega district

Gold was dicovered in 1828 or 1829 near the town of Dahlonega, in the south-central part of Lumpkin County. Deposits here were worked until 1849, when many miners moved to California (Yeates, in Yeates, McCallie, and King, 1896, p. 271–274). In the post-Civil War period, lode mining and dredging of placers yielded steady production though not at the prewar scale. The increased price of gold caused a marked revival of mining in the mid-1930's, but by 1938, activity declined to small-scale operations.

Lumpkin County, especially the Dahlonega district, yielded most of the total gold output of Georgia. Exact figures could not be found, but the total production through 1964 probably was 400,000–500,000 ounces. The Findley mine, one of the most important of the Dahlonega district, produced $200,000 in gold before the Civil War (Yeates, McCallie, and King, 1896, p. 373).

Four general rock types can be recognized in the district—mica schist, feldspathic gneiss, hornblende schist, and granite (Eckel, 1903, p. 58, 59). The mica schist and feldspathic gneiss are the oldest rocks and are thought to be Precambrian or early Paleozoic in age. They were intruded by diorite which later was metamorphosed to the bornblende schist. The granite, which is exposed in some of the mines, is the least sheared rock in the area and may therefore be the youngest.

The earliest worked deposits were stream placers. Later the free-milling gold of the saprolite was mined by hydraulic methods, and still later the veins in the underlying bedrock were mined by underground methods. The gold in the saprolite was released by weathering from the sulfides with which it occurs in the quartz veins. The quartz veins seem to be best developed and richest in gold along the contact of the mica schist with either granitic rock or the sheared hornblende schist.

Nacoochee district

The first discovery of gold in White County—and probably in Georgia—was in 1828 near the town of Nacoochee, at the junction of the Nacoochee and Chattahoochee Rivers in the east-central part of the county (Yeates, McCallie, and King, 1896, p. 33). Small-scale sporadic production continued until the outbreak of the Civil War and was resumed after the war on a slightly larger and better organized level. Records of activity in the late 1800's and early 1900's are sketchy, but in the early and mid-1930's (Pardee and Park, 1948, p. 141–143), a few lode mines were opened in the district, and some of the alluvial placers were worked by hydraulic methods.

The total production of this district could not be ascertained with any degree of accuracy. Estimates by King (in Yeates, McCallie, and King, 1896, p. 33–79) of production from a few mines in the district range from $600,000 (30,000 ounces) to $1,000,000 (50,000 ounces) in gold. In this century the only recorded production was from 1935 to 1940, when the placer mines in White County, probably the Nacoochee district, yielded 2,235 ounces of gold. Therefore, total production of the district through 1940 probably was 35,000–52,000 ounces. From 1940 through 1964 no production was reported from the Nacoochee district.

The rocks of the district comprise gneiss, mica schist and hornblende schist which grade into one another along the strike and are cut in places by a coarse-grained granitic rock (King, in Yeates, McCallie and

King, 1896, p. 35). Most exposures are saprolitic, but in some stream valleys fresh rock can be found (Pardee and Park, 1948, p. 142). The gold deposits are in saprolite, alluvial placers, and lodes. The lodes consist of closely spaced gold-bearing quartz stringers in the schist.

DEPOSITS IN NORTH CAROLINA

Most gold produced from the Appalachian counties of North Carolina has come from the Mills property and the Fairfield Valley placers (fig. 99). Other properties listed in table 144 have yielded relatively insignificant amounts of gold.

TABLE 144.—*Gold-mining properties in Appalachian counties of North Carolina*

[Locations given by counties only. Data from Pardee and Park (1948, p. 62–65)]

County	*Property*
Ashe	Copper Knob (Gap Creek).
Buncombe	Cane Creek.
Burke	Brown Mountain. Caroline Queen. Hancock placer. Hedge (Hodge). Hunts Mountain. Glen Alpine placer. J. C. Mills. White Bank and Magazine.
Caldwell	Baker. Bald Knob. Bee Mountain. Corpening. Flemming. Francis. Michaux. Old Miller. Pax Hill (Packs Hill). Scott Hill.
Cherokee	Marble Creek. Shuford (Catawba). Tathour Creek. Valley River placers.
Clay	Warne mine.
Davie	Butler (County line). Callahan Mountain. Gray. Issac Allen.
Henderson	Boylston (Baylston Creek).
Jackson	Georgetown Valley placers.
Macon	Ammons Branch (Horse Cove). Sugartown River placer. Whiteners Valley.
McDowell	Brackettown. Cane Creek. Granville (Marion Bullion). Huntsville. South Muddy Creek placer. Sprouse. Vein Mountain.
Polk	Adams. Carpenter. Double Branch. Hamilton. MacIntire. L. A. Mills. Neal. Patty Abrams. Ponder. Prince (Price). Red Springs. Riding. Smith. Splawn. Tom Arms. Wetherbee.
Rutherford	Biggerstaff. Carson. Double Branch. Elwood. Glendale. Golden Valley. Idler (Alta, Monarch). Jones. Leeds. Melton.
Transylvania	Fairfield Valley placers.
Watauga	Hardins. Howards Creek.
Wilkes	Bryan's Gap (Trap Hill). Flint Knob. Roaring River placer. Trap Hill.
Yadkin	Dixon. Gross.

Mills property

The Mills property, also known as the Brindletown placers, in Burke County, 13 miles southwest of Morganton, was worked as early as 1828, and by 1916 had yielded an estimated $1 million (50,000 ounces) in gold (Pardee and Park, 1948, p. 65). A few small quartz veins were worked for a time, but most production was from placers. The only activity in this district in recent years was an unsuccessful attempt in 1953–54 to mine placer monazite containing by-product gold, on the upper part of the First Broad River, about 8 miles southeast of Brindletown, at the southern end of Richland Mountain. Apparently little if any gold was produced (W. C. Overstreet, written commun., 1962).

This region is underlain by mica and hornblende schists and gneisses, locally garnetiferous, which are cut by dikes of granite, pegmatite, diorite, and gabbro (Bryson, 1936, p. 133, 134). The schists and gneisses are cut by small veins of milky quartz containing decomposed sulfides and small amounts of gold. Weathering has progressed to great depths, resulting in extensive saprolites.

Fairfield Valley placers

The Fairfield Valley placers are in southern Transylvania County, in the northern drainage area of the Toxaway River. This area has been only briefly described in the published literature. Most of the production was in the 1800's; deposits have been idle for many years. According to Nitze and Hanna (1896, p. 191–192), the gravels along Georgetown Creek, one of the tributaries of the Toxaway, yielded between $200,000 and $300,000 in gold (about 10,000 to 15,000 ounces).

DEPOSITS IN SOUTH CAROLINA AND VIRGINIA

Although South Carolina has produced more than 300,000 ounces of gold, all her major deposits are east of Appalachia. Table 145 lists the minor deposits in the five Appalachian counties.

The major gold deposits of Virginia are outside Appalachia, but some gold has been recovered from placers in northern Floyd County (Dietrich, 1959, p. 135–137), and minor occurrences are reported in Carroll and Grayson Counties (Watson, 1907, p. 564) within Appalachia.

RESOURCE POTENTIAL

The known gold deposits of Appalachia occurring mainly in the Piedmont province of the Carolinas, Georgia, and Alabama, were found long ago before any geologic mapping or organized geologic investigations were made. Consequently, there is pressing need for modern geologic mapping and geochemical and geophysical studies to assess the gold potential of this area. Furthermore, a better understanding of the extent and nature of gold mineralization could be achieved by use of recently developed exploration tools such as rapid spectrographic analysis and the new field tests that can detect gold, silver, mercury, and tellurium in amounts as low as a few parts per billion.

TABLE 145.—*Gold-mining properties in Appalachian counties of South Carolina*

[Location by county only. Data from Pardee and Park (1948, p. 105)]

County	*Property*
Anderson	Henderson.
Cherokee	Crocker. Darwin (Wilkens, Phillips). Hammet. Kennedy (Flint Hill). Love, Jas. (Flint Hill). Love. Love Springs (Palmer) Nott Hill (Norris, Nuckolls). Phillips (Darwin). Wilkins (Darwin).
Greenville	DeSoto. Fountain Inn. McBee (Carson). Westmoreland. Wild Cat. Wolf and Tiger.
Oconee	Cochran. Cox. Henckel. Jesse Lay. Pickens. Sitton. Eastern Fork Cherokee. Keowee River. Kuhtman. Sloan.
Pickens	Calhoun.

The potential for finding new deposits of gold is considered to be good, especially for large low-grade deposits that might be exploited by modern large-scale mining methods. Smaller higher grade deposits may aso be found.

IRON AND STEEL

By WILNA B. WRIGHT and PHILIP W. GUILD, U.S. Geological Survey, and GEORGE E. FISH, JR., and JOHN W. SWEENEY, U.S. Bureau of Mines

The steel industry became firmly entrenched in the Appalachian Region (especially in the Pittsburgh and Birmingham areas) during the period of rapid growth of the industry in the late 19th and early 20th centuries because of availability of raw materials, manpower, and markets in and near the region. Originally the Appalachian steel industry was self-sufficient, having abundant supplies of nearby iron ore, fuel, limestone, and water. During the 20th century, competition from imported iron ores, which are both cheaper and of higher grade, has brought about a decline in the importance of the iron ore industry in Appalachia; on the other hand, its offspring, the steel industry, has expanded and flourished. Only technologic changes in iron ore beneficiation can now reestablish this waning Appalachian industry.

Mining of iron ore and smelting in small charcoal-fired furnaces began in the early Colonial days, nearly 350 years ago. Output of iron was measured in pounds or hundredweight. By the time of the Revolutionary War a few furnaces had been erected in the eastern part of Appalachia, but even a century later, after the Civil War, total cumulative production of iron ore from the entire United States was less than 50 million tons. The development of improved methods of producing iron and steel, the discovery of new sources of iron ore, the rapid economic and industrial expansion of the Nation, and the great population increase combined to raise output of iron ore from 5 million tons in 1870 to more than 115 million tons in 1951. Appalachia played an important role in this expansion both as a source of raw materials and as a producer of finished products.

TECHNOLOGY OF IRON AND STEEL

Extraction of iron from the ore, the first step in iron- and steelmaking, is achieved by heating the ore in contact with a reducing agent to remove oxygen and with fluxes to combine with and to carry off some of the impurities present. This reduction can be done in various ways, but the blast furnace process is the most efficient under most circumstances and is used for nearly all the iron produced in the United States. Iron ore, coke, and limestone (or dolomite) are introduced at the top of the furnace, a strong blast of hot air near the bottom. The coke provides heat and acts as the reducing agent; the iron melts and separates from the impurities, which collect in a slag floating on a pool of iron that is periodically withdrawn from the base of the furnace. New raw materials are constantly charged to the furnace, which normally continues in blast for a number of years before repairs are needed. Some modern furnaces have produced more than 4 million tons of iron in a single "campaign" (McGannon, 1964, p. 423). Uniformity of feed is essential to efficient operation; the need to provide ever-increasing quantities of ore with more and more stringent chemical and physical specifications has had great impact on the iron-ore industry. This trend has drastically reduced the production of iron ore in Appalachia.

The blast furnace yields pig iron, which generally contains 0.5–3.50 percent silicon, 3.5–4.4 percent carbon, and small amounts of other impurities, of which phosphorus is the most critical because it is difficult and expensive to remove. Pig iron is an intermediate product; more than 90 percent of the U.S. production of pig iron goes to the steel furnaces, the rest is either made into wrought iron or cast iron.

Sponge-iron processes, in which the ore is reduced at temperatures below the fusion point of iron, and direct iron processes, in which the ore is reduced at a temperature slightly higher than the fusion point, are alternative methods for producing iron. Though some of these processes are attractive under certain economic and technologic conditions where there is a scarcity of coking coal or an abundance of other fuels, such as natural gas and electricity, most iron ore is still smelted in blast furnaces (H. T. Reno, in U.S. Bur. Mines, 1965a, p. 463–464).

Common steel is, essentially, an alloy of iron and carbon in amounts of as much as 1.7 percent, that is ordinarily prepared by removing part of the carbon from pig iron (in combination with other ingredients such as steel scrap, iron ore, and fluxes) by one of several processes described below. Like wrought iron, steel is malleable and can be rolled, forged, or otherwise worked into many forms; unlike wrought iron, it can be hardened and modified by heat treatment; in general, it is also much stronger. The physical properties of steel are greatly affected by the nature and amount of other elements present, and research is constantly increasing the number of special steels designed for particular uses. In general, the high-strength low-alloy steels are those with relatively small contents of manganese, chromium, nickel, molybdenum, vanadium, or any of about a dozen more elements in various proportions and combinations; high-alloy steels have larger amounts; and the stainless steels and especially the new super-alloy steels for high-temperature use may have as much or more chromium, nickel, cobalt, or other metals than they do iron.

Until about a century ago, steel was a comparative rarity, difficult and costly to produce by primitive methods and used almost exclusively for weapons and tools. Development of new methods has so completely changed this, however, that today steel is by far the most common engineering material. There are four principal steelmaking processes, each of which has various modifications; the quantities produced by each during the period 1920–65 are shown graphically in figure 100.

The Bessemer process, patented in 1856 and put into commercial practice in 1864, uses a "converter," a steel vessel lined with a siliceous refractory that is open at

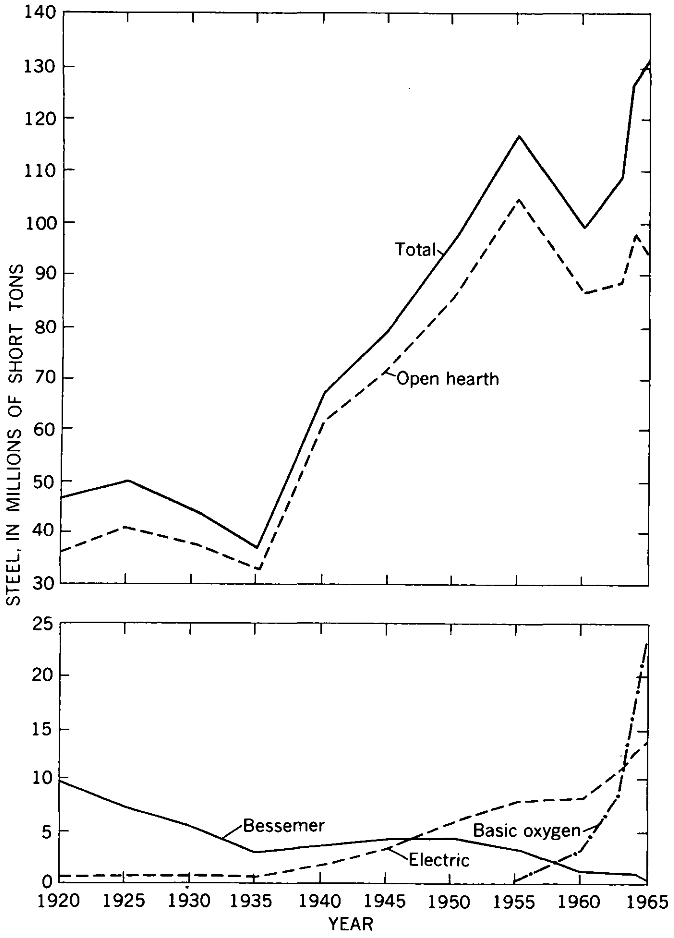


FIGURE 100.—Comparison of U.S. steel output by various steelmaking processes. Sources: R. A. Whitman (in U.S. Bur. Mines, 1965a, p. 854), American Metal Market (1966).

one end and has small holes at the other for introducing air. The converter is so suspended that it can be rotated; after molten pig iron and a small proportion of scrap are introduced while the converter is horizontal, it is tilted upright and air is blown into the charge through the perforated bottom. Silicon, manganese, and carbon are rapidly burned and removed from the iron, which is converted to steel in a matter of minutes and poured into ladles for further processing to shapes. The carbon content can be controlled quite closely by the length of the "blow," and good-quality steel suitable for many purposes is produced quickly and relatively inexpensively. The acid converter, as it is called because of the siliceous lining, cannot remove phosphorus, however, so only low-phosphorus ores are suitable for making the pig iron used in it. A basic process using limestone as the refractory lining was developed in Europe in 1879 for high-phosphorus pig but was never used in the United States because the ores are unsuitable (McGannon, 1964, p. 448). The Bessemer process furnished the greater part of all the steel produced from 1870 to 1910 (McGannon, 1964, p. 438); its importance declined rapidly thereafter, and today (1966) less than 1 percent of steel is made in this way in the United States.

Most steel is now made in the open-hearth furnace, originally patented in England by Siemens in 1856 and modified by many improvements since then. Scrap, iron ore, molten pig iron, and fluxes are heated in a low furnace by gases burning above the charge, which lies on a shallow hearth and is covered by a refractory roof. Normal processing time is 10 hours, which gives time for analyzing the product and adjusting its composition closely; consequently the open-hearth furnace is able to produce many of the modern steels to the increasingly close tolerances now required. A basic hearth lining is used in most furnaces, although acid hearths are used for a few types of steel; as with the acid converter, the latter require pure and costly raw materials. Oxygen increases the speed of the reactions in the furnace and cuts down appreciably on the time and fuel costs for a "heat"; its use in the open-hearth process is just one of several new developments that are sweeping the steel industry.

The open-hearth furnace can operate with any proportions of cold to hot metal, but a charge of about half and half is most satisfactory and the common practice. Both "home scrap" generated elsewhere in the plant and purchased "old scrap" are melted. The open-hearth process has allowed a large increase in the proportion of steel to pig iron production, which had risen from about 1:1 in 1915 to 1.5:1 during World War II and continued at about these proportions to 1963 (Whitman, 1964, fig. 1, p. 635). From the standpoint of both conservation of natural resources and reduction of the "junk yard" problem, the open-hearth furnace is a great boon to the Nation.

The most recent advance in steelmaking technique is the basic oxygen process, which employs a basic-lined vessel much like the Bessemer converter in that it is rotated to fill and pour but uses pure oxygen directed downward in a high-pressure jet rather than air blown in from below to oxidize impurities and refine the charge. Phosphorus is slagged off. The method is fast, heats being completed in about 22 minutes, and flexible enough in operation to accommodate almost any kind of pig iron. The product is equal or superior to open-hearth carbon steel for most purposes. Since the method was introduced to the United States from Europe in 1954, its output has climbed rapidly (fig. 100) and is expected to surpass that from open-hearth furnaces before long, possibly within the next decade. Somewhat less scrap can be melted than in the open hearth, so scrap usage has declined percentagewise as basic oxygen capacity increased. Research is finding ways to overcome this disadvantage, however, and the average scrap charge has now risen to about 30 percent of the total.

The electric furnace process, developed in the late 1800's, uses electric energy rather than fossil fuels to make steel. Use of this process has gradually increased to about 10 percent of total steel production (fig. 100). Because higher temperatures and closer control are possible than in any other process, the electric furnace process is used especially for alloy steels; it also uses light scrap unsuitable for the open-hearth furnace. In most countries, however, the electric furnace cannot compete with other processes for ordinary steel, chiefly because of the cost of electricity.

Figure 101 summarizes graphically the chief steps and principal methods of steelmaking. Combinations of two or even three processes (known as duplexing or triplexing) are used in some plants to take advantage of the characteristics, such as speed and economy of some and close control and high-alloy capabilities of others.

GEOLOGY AND MINERALOGY OF IRON ORE

Iron is one of the most abundant metallic elements, constituting about 5 percent of the earth's crust (Clarke, 1924, p. 36). Various natural processes have concentrated it into deposits ranging in grade to as high as 70 percent; at present the lower economic limit is about 25 percent iron, but additional beneficiation is performed before this grade material is smelted. Depending upon their mode of origin and subsequent geologic history, iron deposits vary greatly in size, shape, attitude, mineralogy, and associated elements; all of these factors affect their value.

By far the largest deposits have accumulated as iron-rich marine sediments, interstratified with sand, silt, carbonates, or, in places, with volcanic rocks. These deposits characteristically extend for considerable distances parallel to the bedding of the enclosing rocks and are thin in comparison with their length and breadth. Because they are laid down contemporaneously with the other sediments, many are tilted, folded, or faulted, and they may have been altered (metamorphosed) by heat and pressure or even intruded by igneous rocks. Most iron in sedimentary deposits was precipitated from sea water, either directly or by replacement of minerals on the sea floor, but some is made up of particles of iron minerals derived by erosion of preexisting rocks and deposited near an old shoreline. Most sedimentary deposits are not rich enough to constitute ore without further concentration by natural processes; this concentration may take place by solution of the iron and redeposition in favorable areas or by leaching and removal of contaminating minerals with consequent residual enrichment. Although the total quantity of iron in sediments is enormous, only part of it is in deposits that can be economically exploited in competition with other richer, thicker, or more favorably situated deposits.

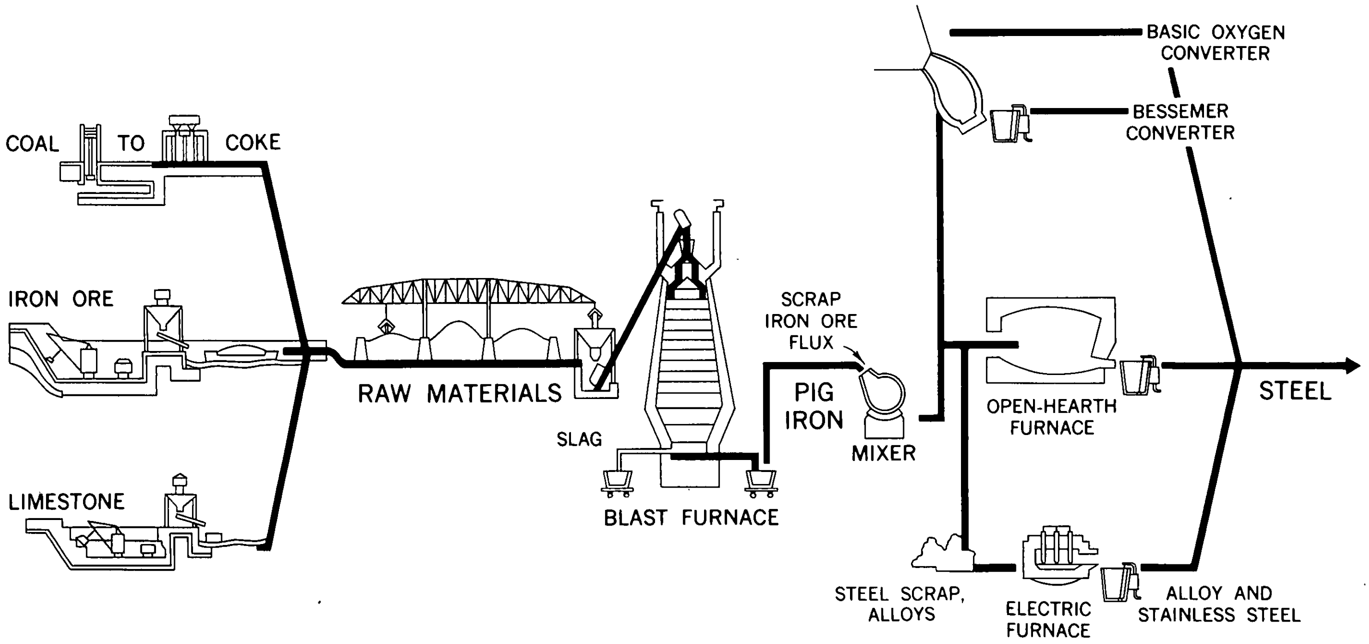


FIGURE 101.—Flow chart of steelmaking. Modified from Am. Iron and Steel Inst. (1950, p. 50).

Sedimentary iron deposits are very widespread, especially in the Precambrian areas of the world, as in the Lake Superior district, Canada, South America, Africa, and Australia. They commonly occur as a sequence of iron-rich layers separated by layers of chert or quartz. Subsequent to deposition they have been subjected to metamorphism, that formed specularite, magnetite, and other new minerals, generally increased their grain size, and otherwise affected their amenability to concentration by either natural or artificial methods. In the Lake Superior region, long-continued leaching of the nonferruginous minerals at or near the surface and downward concentration of the iron produced many deposits of "direct-shipping" ores that constituted our major supply for many decades. The unweathered lower grade materials now remaining in this region constitute the extensive iron-formations known as taconites (generally magnetite-bearing material) and jaspilites or semitaconites (generally nonmagnetic hematite-bearing material). The importance of these lower grade ores is increasing rapidly in the world iron picture because their size and mineralogic characteristics make them particularly suitable for the production of high-grade concentrates, principally pellets.

Sedimentary iron ores in Appalachia are chiefly in the Clinton Formation of Silurian age. The Clinton ores are unmetamorphosed and not readily amenable to ordinary methods of concentration, and consequently their use has declined sharply.

Igneous processes have concentrated iron minerals into veins, lenses, and irregular masses in or adjacent to various types of intrusive and volcanic rocks. Some are very high grade; others are readily amenable to beneficiation and therefore constitute an important class of iron ore deposits. Some iron ore bodies of igneous origin are very large, containing billions of tons, but most are small in comparison with the major sedimentary ores. Examples are the Kiruna deposit of Sweden, the deposits of the St. Francois Mountains in Missouri, and the Cornwall and Grace deposits of eastern Pennsylvania. The largest known deposit of this type in Appalachia, that at Cranberry, N.C., is much smaller. Deposits associated with basic igneous rocks, gabbros and anorthosites, commonly carry moderate to large amounts of titanium and minor vanadium; they grade into the deposits that are discussed in the section on "Titanium" (p. 437).

Ground water has concentrated iron in various ways and has formed many deposits which are near a surface of long-continued weathering that is ordinarily, but not necessarily, the present one. Because such deposits tend to be at shallow depths, they are among the first to be exploited in the industrial development of any region. In addition to the enrichment of lower grade deposits by leaching and concentration, ground water has moved iron from source areas and redeposited it elsewhere as veins or irregular replacements in nonferruginous rocks, or as concentrations in surficial blankets on rocks which originally contained only small quantities of iron. Most near-surface deposits have been affected to a greater or lesser extent by ground-water action. Appalachian deposits are no exception; the soft Clinton ores and the brown ores have formed in this manner. The laterite ores of the tropics and the "gossan" ores of Ducktown, Tenn., and elsewhere in Appalachia are examples of iron concentrated from silicates and sulfides, respectively, by oxidation and residual enrichment.

Because of iron's chemical affinity for other elements, it practically never occurs in metallic form in nature. Instead it combines with oxygen, silicon, carbon, sulfur, or any of a number of other elements in minerals, of which the oxides are by far the most important as ores. Iron has two common oxidation states (valences): bivalent and trivalent, which form respectively ferrous and ferric compounds. Ferrous iron is relatively soluble and capable of being transported in solution. It oxidizes readily, however, to the trivalent state which is much less soluble; because this transformation frequently takes place near the surface, it is one of the principal factors in concentrating iron into surficial ore deposits.

The chief iron ore minerals are:

1. Magnetite (Fe_3O_4 or $FeO \cdot Fe_2O_3$) is a black magnetic hard mineral containing 72.4 percent iron. It occurs disseminated in igneous rocks and in deposits of igneous origin, in metamorphosed (and less commonly in unmetamorphosed) sedimentary iron-formation, and as detrital grains in clastic sedimentary deposits. Its magnetic property facilitates beneficiation. Long-continued weathering causes some magnetite to oxidize and lose its magnetic character; this characteristic complicates mining and processing of some ore deposits. Some magnetite ores contain titanium either in the magnetite crystal lattice or as inclusions so intimately mixed as to be inseparable by commonly used beneficiation techniques.
2. Hematite (Fe_2O_3, 69.9 percent iron) in its coarse crystalline form (specularite) is a steely gray, hard, heavy mineral, but in its finely divided or earthy form it is soft with a characteristic deep-red color. It is nonmagnetic. Hematite occurs in metamorphic and sedimentary deposits, rarely in igneous deposits; it is the principal mineral of

the Clinton ores and is responsible for the term "red ore" frequently applied to them.

3. The hydrous oxides, known collectively as limonite, consist of one definite mineral species, goethite, and mixtures of iron hydroxides with varying amounts of adsorbed water. The composition of goethite is frequently given as FeO(OH), but it should more properly be considered as $Fe_2O_3 \cdot H_2O$ because the iron is in the ferric state. Goethite has 62.9 percent iron and 10.1 percent water; limonite may have less than 60 percent iron and commonly contains various impurities such as manganese and phosphorus. Limonite is brown or yellowish brown and is the principal constituent of the brown ores formed under surficial conditions. Limonite may occur as an original constituent of some of the geologically younger sedimentary ores, but most limonite ore deposits originate from alteration of rocks containing iron-bearing carbonates, sulfides, and silicates.
4. Siderite ($FeCO_3$) theoretically contains 48.2 percent iron; calcium, magnesium, and manganese commonly substitute for some of the iron, however, and reduce its content to 40 percent or less (H. L. James, 1966, p. W3–W4). Siderite is abundant in some sedimentary rocks, particularly in the carbonate-facies iron-formations and some coal measures; it also occurs in vein deposits, but these are much less important as a source of iron ore.
5. Pyrite (FeS_2), the most common iron sulfide, is a hard brass-colored mineral containing 46.6 percent iron. Marcasite, also FeS_2, and pyrrhotite, near FeS in composition and having about 60 percent iron, occur less abundantly. Pyrite and other sulfides form vein or replacement deposits that may contain copper, zinc, and other valuable metals; the sulfur content precludes its direct use as an iron ore, but near-surface oxidation and leaching have formed limonite or occasionally hematite cappings (gossans) that have been mined. Byproduct sinter from sulfuric acid plants, as at Ducktown, Tenn., is a valuable "ore." Pyrite also is the chief iron-bearing mineral of the sulfide-facies iron-formations; these have not been exploited extensively to date.

ORE TYPES AND GRADES

The value of an iron ore depends upon both chemical and physical factors. Although iron can be smelted from material ranging in grade to as low as 25 percent or even less, costs increase sharply as grade decreases because additional fuel and flux are needed and the furnace output per unit of time decreases. Standard American practice until recently was to use ores containing somewhat more than 50 percent iron, 6–10 percent silica, and minor quantities of alumina and other constituents. The most noteworthy exception was in the Birmingham district, Alabama, where some ores containing 40 percent or less iron had enough lime, as calcium carbonate, to be self-fluxing and hence could be smelted economically.

Materials charged to the blast furnace must be capable of supporting the weight of the overlying burden without crushing and packing down to cut off the circulation of gases. Excessive proportions of fine sizes tend to clog the furnace, and blending of ores from different sources has long been practiced to ensure proper structure, as well as uniform composition. Formerly, most ores were "direct shipping," that is, were used essentially in the form in which they were extracted from the mine, but now increasing amounts are treated by washing, gravity and (or) magnetic separation, and, for some, by pelletizing, sintering, or other means of agglomeration. Table 146 shows average analyses and proportions of each type shipped in 1964; in 1954 direct-shipping and other untreated ores constituted 62 percent of the total (Reno, 1958, p. 567) as compared with only 22 percent 10 years later.

Beneficiation not only improves the chemical characteristics of the ore substantially by raising the iron content and reducing the amount of impurities that must be removed in the furnace, but it also sharply increases the output of the blast furnace by providing

TABLE 146.—*Average analyses of iron ores shipped from U.S. mines in 1964*

[Iron on natural basis (including moisture); silica, alumina, manganese, and phosphorus on dry basis. Source: Am. Iron Ore Assoc. (1964, p. 101—102)]

Type	Shipments (long tons)	Percent of total	Average analyses, in percent					
			Iron (natural)	Silica	Alumina	Manganese	Phosphorus	Moisture
Ores not treated	18, 297, 659	22. 3	51. 75	7. 21	1. 98	0. 55	0. 157	10. 42
Treated ores [1]	30, 729, 259	37. 3	54. 63	8. 08	1. 14	. 44	. 074	5. 72
Agglomerates	33, 256, 581	40. 4	62. 22	7. 29	. 65	. 20	. 030	1. 88
Total or average	82, 283, 499	100. 0	57. 06	7. 57	1. 13	. 37	. 075	5. 22

[1] Not subsequently agglomerated.

stronger, more uniform material that is reduced more quickly with less coke. Thus, beneficiation results in substantial savings in operating costs and has the effect of increasing overall capacity of the industry without the expense of constructing new furnaces. Perhaps even more important is the long-range effect on the iron-ore mining industry: many deposits of low-grade material that previously were unusable now constitute the most desirable ore, and, conversely, some high-grade ore bodies have lost much or all of their value because they cannot be beneficiated economically.

Iron ores are categorized in many ways, depending upon their mineralogic nature, the processing they have undergone, and their uses and composition. These characteristics are, of course, interdependent, so no single firm classification can be made. Mineralogically the ores are reported as hematite, magnetite, brown (limonite), and spathic (siderite) ores. They may be direct shipping (untreated or as-mined); treated (concentrated by screening, washing, gravity separation, or magnetic separation, or by combinations of these processes); or agglomerated (by sintering, nodulizing, or pelletizing). A minor but distinct class is byproduct sinter from sulfuric acid plants treating pyrite or pyrrhotite. By use the ores are divided into blast-furnace ore, steel-furnace (open-hearth lump) ore, cement, paint, or other ore. There are numerous categories by composition; some of the more common are:

Bessemer (phosphorus not more than 0.045 percent).
Low-phos non-Bessemer (phosphorus 0.045–0.180 percent).
High-phos non-Bessemer (phosphorus more than 0.180 percent).
Manganiferous (manganese 2 percent or more).
Siliceous (silica 18 percent or more).

Decline in production of steel by the Bessemer process (fig. 100) has reduced the importance of the distinction between Bessemer and non-Bessemer ores because the phosphorus can be removed in the basic steel furnace. However, a low phosphorous content is still advantageous and a premium price is offered for Bessemer ores. Shipments from U.S. mines and mills in 1964 were 33 percent Bessemer, 55 percent low-phos non-Bessemer, 9 percent high-phos non-Bessemer, and only 3 percent for other types (Am. Iron Ore Assoc. 1964, p. 91). About 94 percent of all iron ore consumed in 1963, including agglomerates, was used for blast furnace feed and 5½ percent went directly into steel furnaces. Only ½ of 1 percent was used for cement, paint, pigments (ocher), high-density concrete, and as a heavy medium in coal-processing plants (Reno, 1964, p. 612).

THE NATIONAL INDUSTRY

The United States produces about one-fourth of the world's steel. More than 85 percent of the U.S. production is from Pennsylvania, Ohio, Indiana, Michigan, Illinois, Maryland, and New York; the remainder comes from plants in nearly every State. In all, there are 218 companies and 422 plants, which employ more than 500,000 people and have an annual payroll of about $5 billion (R. A. Whitman, in U.S. Bur. Mines, 1965a, p. 847).

From the small beginnings in Colonial and pre-Civil War days, when iron and steel production was minute by present standards, output has risen to 131.5 million tons of steel ingots in 1965. In 1860, the first year of recorded production, 13,280 tons of steel were produced. It took 68 years (to 1928) to make the first billion tons, 18 years (to 1946) to make the second billion, and only 10 years each (to 1956 and 1966) to pour the third and fourth billion tons, respectively. Raw-material demands of the iron and steel industry have increased proportionately. In tables 147–149 an attempt is made to indicate in simplified fashion the raw materials used and the products of the industry. The total number of categories is so large and there are so many variables in the recycling of intermediate products such as scrap, slag, and mill scale that no precision is claimed. The tables distinguish between the iron- and steel-making steps; most but not all of the product of the former goes to the latter. The data have been derived from the Minerals Yearbooks of the U.S. Bureau of Mines, with the assistance and

TABLE 147.—*Principal raw materials used to make pig iron in the United States in 1964*

[Thousands of short tons unless otherwise specified]

New metalliferous materials:			
Iron ore, including agglomerates, and so forth		130, 958	
Scrap, exclusive of recycled		4, 630	
Total [1]			135, 588
Fuels:			
Coke (made from about 80 million tons of coal)[2]			55, 782
Natural gas	billion cu ft		40.5
Oil	million gal		46.6
Coal			13
Fluxes:			
Limestone		15, 620	
Dolomite		7, 428	
Total [3]			23, 048
Oxygen	billion cu ft		9.7

[1] Home scrap, mill scale, slags, and other recycled materials, not included here, totaled perhaps 10 million tons.

[2] The coal also provided 3.4 billion feet of coke-oven gas to the blast furnaces.

[3] Additional quantity of fluxes used in agglomerates made at mines not known.

TABLE 148.—*Materials used to make steel in the United States in 1964*

[Thousands of short tons unless otherwise specified]

Metalliferous materials:		
Pig iron	78, 925	
Iron and steel scrap	64, 348	
Iron ore (including agglomerates)	9, 209	
Ferroalloys	1, 819	
Total		154, 301
Fluxes:		
Limestone	5, 746	
Lime	2, 422	
Fluorspar	295	
Other fluxes	482	
Total		8, 945
Oxygen billion cu. ft.		90.6

TABLE 149.—*Principal products of the iron and steel industry in the United States in 1964*

[Thousand short tons]

Pig iron		85, 458
Castings:		
Gray iron	14, 316	
Malleable iron	1, 001	
Steel	1, 835	
Total		17, 152
Ingots:		
Carbon steel	114, 442	
Alloy steel	11, 191	
Stainless steel	1, 443	
Total		127, 076
Slags used by industry for—		
Cement	3, 254	
Construction aggregate	12, 387	
Other uses	5, 328	
Total		20, 969

advice of Robert A. Whitman, Commodity Specialist, Division of Minerals, Bureau of Mines.

Oil and gas used as fuel in the open-hearth furnaces and energy used in the electric steel furnaces are not known. The water use for the iron and steel industry is estimated at 4,350 billion gallons, equivalent to about 30,000 gallons per ton of steel produced. An additional 252 billion gallons was used in iron ore mining and beneficiation in 1962 (W. H. Kerns, in U.S. Bur. Mines, 1965a, p. 1062–1063).

Output of the industry, not including the coke-oven byproducts, are shown in simplified manner in table 149.

The sources of iron ore used by the domestic iron and steel industry in 1964 are shown in table 150. The figures are approximate in that changes in stocks are not shown, and exports of nearly 7 million tons are not taken into account. Consumption indicated in tables 147 and 148 of 140 million short tons is equivalent to about 125 million long tons, so the balance is fairly close.

TABLE 150.—*Shipments of usable iron ore from mines in the United States, by districts, and imports for consumption, 1964*

[Direct shipping, beneficiated, and agglomerated ore, exclusive of ore containing 5 percent or more manganese; in thousands of long tons]

District or country	Quantity	Percent of domestic shipments (or of imports for consumption)	Percent of total
Domestic:			
Lake Superior	64, 021	75	50
Southeastern	2, 461	3	2
Northeastern	4, 944	6	4
Western	6, 218	7	5
Undistributed	7, 540	9	6
Total	85, 184	100	67
Imported:			
Canada	24, 854	(58. 8)	19. 5
Brazil	1, 055	(2. 5)	. 8
Chile	2, 712	(6. 4)	2. 1
Peru	580	(1. 4)	. 5
Venezuela	9, 954	(23. 4)	7. 8
Sweden	93	(. 2)	. 1
Liberia	2, 873	(6. 8)	2. 3
Mauritania	133	(. 3)	. 1
Other	154	(. 4)	. 1
Total	42, 408	(100)	33
Grand total	127, 592		100

Two-thirds of the iron ore was of domestic origin and one-third imported. The Lake Superior district continues to furnish the great bulk of domestic ore and one-half the total ore used; vast reserves of taconite and jaspilite exist and will continue to be the principal source of iron ore in the United States in the foreseeable future.

THE INDUSTRY IN APPALACHIA

The iron industry in the United States began with the construction of small furnaces that utilized nearby iron ores and charcoal from the surrounding forests. The products were simple cast and wrought iron shapes for local consumption. The first furnaces of record in Appalachia were built in Maryland in 1765, in Virginia at about the same time, and in North Carolina in 1780. Production began west of the Allegheny Mountains at the close of the Revolutionary War and spread rapidly to western Pennsylvania in 1789, Tennessee and what is now West Virginia in 1790, Kentucky in 1791, and eastern Ohio in 1811. Alabama's first blast furnace was built at Russellville in 1815; subsequently other small furnaces were built in southern Appalachia.

The early iron producers had few marketing problems; but, as transportation improved, competition between producers became keener, and only those having access to cheap fuel or better ore survived. With the discovery of the vast deposits in the Lake Superior region in 1844 and the completion of the

Sault Sainte Marie Canal in 1855, the importance of the Appalachian iron ore industry declined relative to the national industry. However, the increasing pace of industrialization caused an increase in total Appalachian production, especially in southern Appalachia beyond the reach of competition from Lake Superior ores. Fewer and larger furnaces based on abundant supplies of coke were constructed, and recorded ore output in Appalachia expanded from 36,000 tons in 1880 to nearly 1,700,000 tons in 1890 and more than 2,500,000 tons in 1900. Figure 102 shows the annual production from 1900 to 1965; table 151 lists the iron ore production and value in Appalachia from 1863 to 1965.

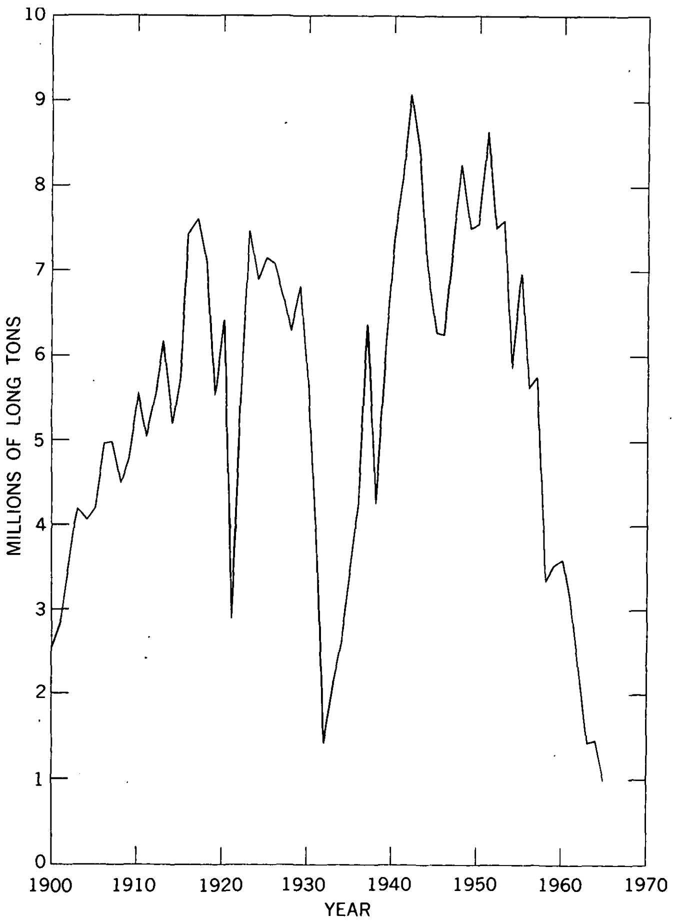


FIGURE 102.—Annual iron ore production in the Appalachian Region, 1900–65. Production figures for years 1900–11 exclude Virginia, West Virginia, Pennsylvania, and Ohio.

Because production statistics are incomplete for the early period, the total output of iron ore in Appalachia cannot be stated precisely. However, production may have exceeded 350 million tons, of which at least 275 million came from the Birmingham district, Alabama (table 153). Total U.S. production has been about 4½ billion tons; Appalachia's share is therefore only about 8 percent. Until World War II, annual production of iron ore in Appalachia generally was more than 10 percent of national annual production; since the war it has declined steadily to the present level of less than 2 percent of the national annual output and only about 1.2 percent of the consumption.

TABLE 151.—*Iron ore production and value in the Appalachian Region, 1863–1965*

[Source: U.S. Bur. Mines]

Year	Quantity (long tons)	Value	
		Current dollars	Constant 1958 dollars
1863	1,000	500	(1)
1864	2,000	1,000	(1)
1865	1,000	500	(1)
1866	1,000	500	(1)
1867	1,250	600	(1)
1868	1,250	600	(1)
1869	1,250	600	(1)
1870	1,250	600	(1)
1871	1,250	600	1,361
1872	1,250	600	1,402
1873	3,750	1,900	4,600
1874	--------	--------	--------
1875	--------	--------	--------
1876	1,250	600	1,893
1877	2,500	1,200	4,068
1878	5,000	2,000	6,897
1879	5,000	3,000	10,753
1880	36,000	18,000	64,057
1881	94,000	47,000	165,492
1882	136,000	73,500	259,720
1883	319,000	201,500	738,095
1884	324,000	225,000	865,395
1885	378,000	307,000	1,232,943
1886	464,000	430,000	1,799 163
1887	531,000	510,000	2,188,818
1888	984,000	984,000	4,223,131
1889	1,349,985	1,383,346	6,014,512
1890	1,697,297	1,728,000	7,512,998
1891	1,787,783	1,787,783	7,772,923
1892	2,015,904	1,945,000	8,761,253
1893	1,634,720	1,384,000	6,497,603
1894	1,512,453	1,284,360	6,421,800
1895	2,289,978	1,586,451	8,349,809
1896	2,108,700	1,492,793	8,247,532
1897	2,177,133	1,627,386	8,991,145
1898	2,341,727	1,615,654	8,548,425
1899	2,432,801	2,422,449	12,296,593
1900	2,555,473	2,561,881	12,316,755
1901	2,874,970	2,807,687	12,820,460
1902	3,625,089	4,198,819	18,335,403
1903	4,174,504	4,574,305	19,465,040
1904	4,068,872	4,232,882	17,491,115
1905	4,215,533	4,890,591	19,330,550
1906	4,969,173	6,492,795	24,781,700
1907	4,972,481	6,436,999	24,108,492
1908	4,465,978	5,422,828	19,791,153
1909	4,884,717	5,829,951	20,747,047
1910 [2]	5,521,425	7,112,548	24,696,189
1911	5,041,456	6,714,642	22,532,324
1912	5,605,688	7,312,914	23,364,029
1913	6,153,691	8,093,138	24,978,661
1914	5,128,088	6,922,374	20,065,193
1915	5,770,575	7,937,955	15,353,593
1916	7,444,250	12,018,808	28,822,303
1917	7,650,000	14,431,632	30,317,973
1918	7,075,370	18,602,514	33,761,703
1919	5,511,159	14,215,055	22,853,544
1920	6,448,056	18,280,865	25,008,223
1921	2,902,409	5,278,864	7,221,486
1922	5,447,813	9,227,626	14,883,238
1923	7,457,949	17,042,824	28,309,835
1924	6,934,155	14,884,928	25,707,759
1925	7,175,987	14,808,333	25,313,364
1926	7,098,470	14,421,505	26,365,395
1927	6,744,453	13,555,943	24,647,416
1928	6,344,097	12,053,494	21,836,110
1929	6,795,548	13,005,899	23,059,459
1930	5,726,077	11,228,828	20,305,090
1931	3,650 742	5,071,839	10,329,814
1932	1,473,010	2,442,153	5,653,096

See footnotes at end of table.

TABLE 151.—*Iron ore production and value in the Appalachian Region, 1863–1965*—Continued

[Source: U.S. Bur. Mines]

Year	Quantity long tons)	Value	
		Current dollars	Constant 1958 dollars
1933	2, 152, 389	3, 244, 486	7, 743, 290
1934	2, 703, 383	4, 334, 804	9 697, 390
1935	3, 513, 007	5, 715, 041	13, 077, 728
1936	4, 261, 175	6, 843, 723	15, 696, 763
1937	6, 355, 424	10, 760, 546	23, 494, 576
1938	4, 289, 677	7, 351, 221	15, 741, 170
1939	5, 988, 635	9, 989, 812	21, 716, 852
1940	7, 389, 220	12, 706, 799	27, 325, 971
1941	8, 059, 762	18, 529, 087	36, 763, 562
1942	9, 066, 929	19, 561, 773	32, 987, 018
1943	8, 454, 470	21, 979, 922	34, 235, 927
1944	7, 091, 323	18, 397, 064	25, 730, 134
1945	6, 316, 176	15, 413, 425	20, 307, 187
1946	6, 286, 009	18, 504. 335	24, 094, 495
1947	7, 510, 330	24, 504, 839	29, 631, 251
1948	8, 295, 879	33, 321, 737	38, 609, 897
1949	7, 547, 759	28, 290, 371	32, 593, 336
1950	7, 609, 969	29, 670, 005	33, 794, 136
1951	8, 738, 669	37, 301, 372	39, 599, 137
1952	7, 563, 813	39, 419, 034	41, 319, 031
1953	7, 642, 412	56, 445, 882	59, 855, 213
1954	5, 936, 009	33, 192, 209	35, 728, 094
1955	7, 007, 062	45, 471, 924	49, 478, 001
1956	5, 669, 219	34, 329, 309	36, 172, 793
1957	5, 829, 658	38, 298, 582	38, 922, 849
1958	3, 357, 113	21, 870, 706	21, 870, 706
1959	3, 551, 574	20, 831, 878	20, 544, 398
1960	3, 633, 680	20, 193, 868	20, 014, 143
1961	3, 145, 502	18, 173, 794	18, 064, 751
1962	2, 278, 000	14, 354, 097	14, 253, 618
1963	1, 450, 440	8, 524, 616	8, 490, 518
1964	1, 495, 880	8, 771, 593	8, 727, 735
1965	1, 028, 443	5, 833, 277	5, 886, 360

[1] No price deflators available for years prior to 1871.

[2] No Appalachia data available for the states of Virginia, West Virginia, Pennsylvania, New York, or Ohio, prior to 1911.

Figure 103 shows the locations of the iron- and steelmaking centers in and near Appalachia and the sources of fuel and flux. Of the 238 blast furnaces in the United States, 88 are in Appalachia and an additional 64 are nearby. The relative importance of the production centers in Appalachia is indicated by the numbers of blast furnaces in each (table 152 keyed to fig. 103). Because the furnaces vary widely in capacity and some are periodically idle or shut down, this measure of importance is only a rough yardstick.

Birmingham, Gadsden, and, to a lesser extent, Rockwood are the only centers now using Appalachian ores. Until a decade ago nearly all ore used in these centers came either from Appalachia (chiefly the red Clinton ore) or from nearby areas. Higher grade ores imported from more distant areas have been used increasingly in recent years, however, and in 1964 their consumption in Alabama exceeded that of domestic ore for the first time (59 percent imported to 41 percent local, of which part came from nearby areas outside Appalachia).

IRON ORES IN APPALACHIA

Sedimentary ores constitute by far the greatest part of Appalachian iron ores, in terms of both total quantity still available (resources) and past production. Ores concentrated by weathering processes are second in importance, and igneous ores are relatively unimportant. Table 153 summarizes the historical data, grade, and estimated remaining material, most of which is not ore today in the economic sense. Figure 104, keyed to this table, shows the locations of the deposits.

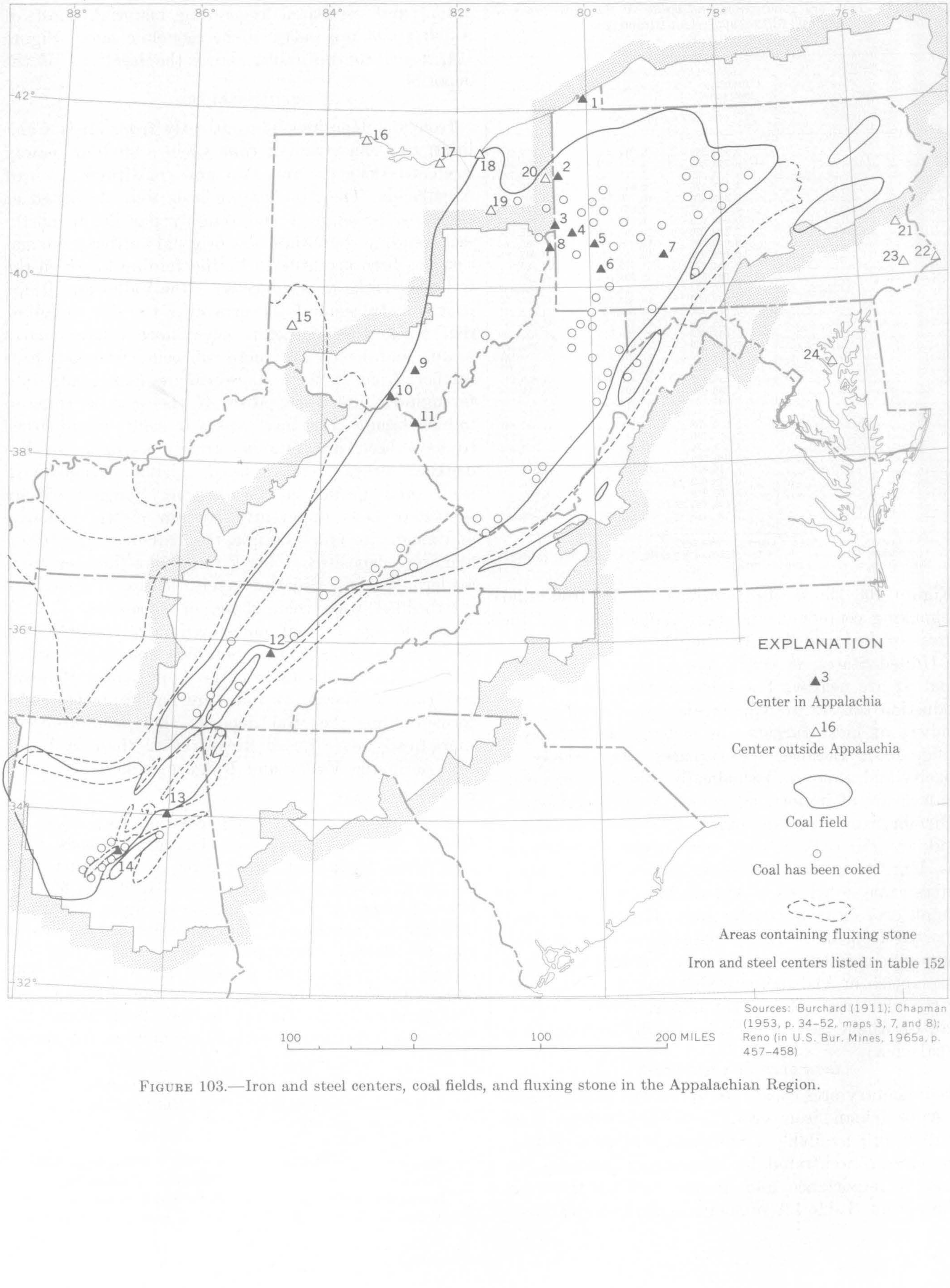
SEDIMENTARY ORES

Iron was deposited intermittently from Early Cambrian to Pennsylvanian time when a shallow seaway stretched along the area that now constitutes much of Appalachia. The iron-bearing beds were deposited as elongated lenses near and roughly parallel to northeast-trending shorelines. The original northeast elongation has been accentuated by the folding to which the Paleozoic rocks were subjected in the Valley and Ridge province. In general the ores near the old shoreline, that is, to the southeast, have more clastic quartz grains and hence are more siliceous, whereas those farther from it have more calcite and grade into ferruginous limestone. Most of the iron is believed to have been carried into the sea in solution and either to have been precipitated directly as oxide or hydroxides or to have replaced calcium carbonate in shells and grains on the bottom. Some nearshore lenticular beds apparently contain clastic hematite and magnetite (for example, the Talladega gray ores) and were deposited as black sands like those on some modern beaches. Siderite layers, lenses, and nodules interbedded with coal, shale, or limestone of Late Paleozoic age formed under reducing conditions in low-lying swamps which contained abundant organic matter. These rocks underlie the Appalachian Plateaus and Interior Lowlands and were not appreciably deformed; thus the iron deposits they contain occur sporadically over broad areas rather than in linear belts as in the Valley and Ridge province.

Clinton iron ores

The most extensive iron deposition took place in Middle Silurian time, when ferruginous beds were laid down from New York State to Alabama (fig. 104, locs. 3, 8, 9, 11, 12, 14, 18–25, 31, 35, 36, 38, and 39). Although at the small scale of figure 104 these beds appear continuous, they actually are lenticular and not strictly contemporaneous. Stratigraphic nomenclature varies from place to place (pl. 3). The name Clinton was first applied to the Silurian iron ores in the Clinton Group in New York State; the following formations elsewhere are more or less equivalent:

Pennsylvania	Clinton Formation.
Maryland, West Virginia, north and central Virginia.	Rose Hill Formation.
Southwestern Virginia	Clinton Formation or Shale.
Tennessee	Rockwood Formation.
Kentucky and Ohio	Brassfield Formation.
Alabama and Georgia	Red Mountain Formation.



Sources: Burchard (1911); Chapman (1953, p. 34–52, maps 3, 7, and 8); Reno (in U.S. Bur. Mines, 1965a, p. 457–458)

FIGURE 103.—Iron and steel centers, coal fields, and fluxing stone in the Appalachian Region.

TABLE 152.—*Iron and steel centers in and near the Appalachian Region that have blast furnace operations*

[Source: Reno, in U.S. Bur. Mines, 1965a, p. 457–458]

No. (fig. 103)	Location	Blast furnaces
	In Appalachia	
	Northern district	
	Pennsylvania:	
1	Erie	1
2	Sharpsville-Farrell	4
3	Midland	3
4	Aliquippa	5
5	Pittsburgh area	30
6	Monessen	3
7	Johnstown	6
8	Ohio-West Virginia: Steubenville-Weirton	9
	Ohio:	
9	Jackson	1
10	Portsmouth	2
11	Kentucky: Ashland	3
	Southern district	
12	Tennessee: Rockwood	2
	Alabama:	
13	Gadsden	2
14	Birmingham area	17
	Peripheral to Appalachia	
	Ohio:	
15	Middletown-New Miami	3
16	Toledo	2
17	Lorain	5
18	Cleveland	11
19	Canton-Massillon	2
20	Youngstown area	17
	Pennsylvania:	
21	Bethlehem	5
22	Fairless Hills	3
23	Swedeland	2
24	Maryland: Sparrows Point	10

The ferruginous beds have been eroded away east of the easternmost outcrop lines shown on figure 104, which probably also mark the approximate limit of any significant iron deposition in Silurian time. To the west and north the beds are covered by younger rocks and, in most places for which there is information, show a decrease in iron content. On the flank of the Cincinnati Arch in the southern Kentucky and central Tennessee parts of Appalachia, Silurian rocks were not preserved. They are present, however, in central Kentucky and in Ohio, and ferruginous beds have been mined in one small area in Kentucky (fig. 104, loc. 6).

The principal iron mineral of the Clinton ores is hematite, which imparts a distinctive dark-red color to the ores. The Clinton ores are appropriately called red ores, in contrast to the gray magnetite and specularite ores and brown limonite ores. The hematite occurs in three forms: (1) more or less flattened flaxseedlike particles (oolites), (2) replacements of fossil remains that preserve the shapes of the original calcium carbonate shells, and (3) cementing material coating and filling in around original sand grains, oolites, and fossils. Where unweathered (below the water table), the ore is hard and compact and contains calcium carbonate in amounts generally ranging from 25 to 50 percent of the total weight; the content of silica and alumina in the ore generally increases as the carbonate decreases and tends to be greatest in the oolitic ores. Leached or weathered ore is soft, is generally higher in grade, and is yellowish brown because of hydration of part of the hematite to limonite. It has greater amounts of the relatively insoluble constituents than unweathered ore. Table 154 illustrates the progressive change in composition found by Burchard (1913, p. 76) in samples of different types of ore from the same bed.

The soft near-surface, richer ores have been most extensively mined, and generally mines were abandoned when the lower grade, hard ores were penetrated at depth. Some of the hard ores contain the proper proportions of carbonate and silica, however, to be "self-fluxing" and consequently can be used economically even though the iron content is lower than that ordinarily used. Some ores with excessive carbonate also have been blended satisfactorily with siliceous ores. As a result, where these ores occur in beds thick enough to be mined at reasonable cost and are close to a market, they have been exploited extensively.

The Clinton ores attain their maximum development in Alabama, and particularly near Birmingham (fig. 104, loc. 36), where several overlapping ore beds (seams) and zones of ferruginous sandstone are present in the upper part of the Red Mountain Formation. These beds vary laterally in character, grade, and thickness. The so-called Big Seam ranges in thickness from 16 to 30 feet, although only about half is of ore grade in most places; the Irondale seam is 5–9 feet thick, and the Ida-Hickory Nut seam, which has not been mined, is generally 2–6 feet thick. The higher grade, soft ore parts of these seams have been mined out; oolitic and fossiliferous material with abundant calcium carbonate and with 35–39 percent iron content constitutes the commercial hard ore remaining at depth. The ferruginous sandstone zones interbedded with these seams are as much as 50 feet thick (Burchard and Butts, 1910, p. 27; Thoenen and others, 1953, table 2, p. 13).

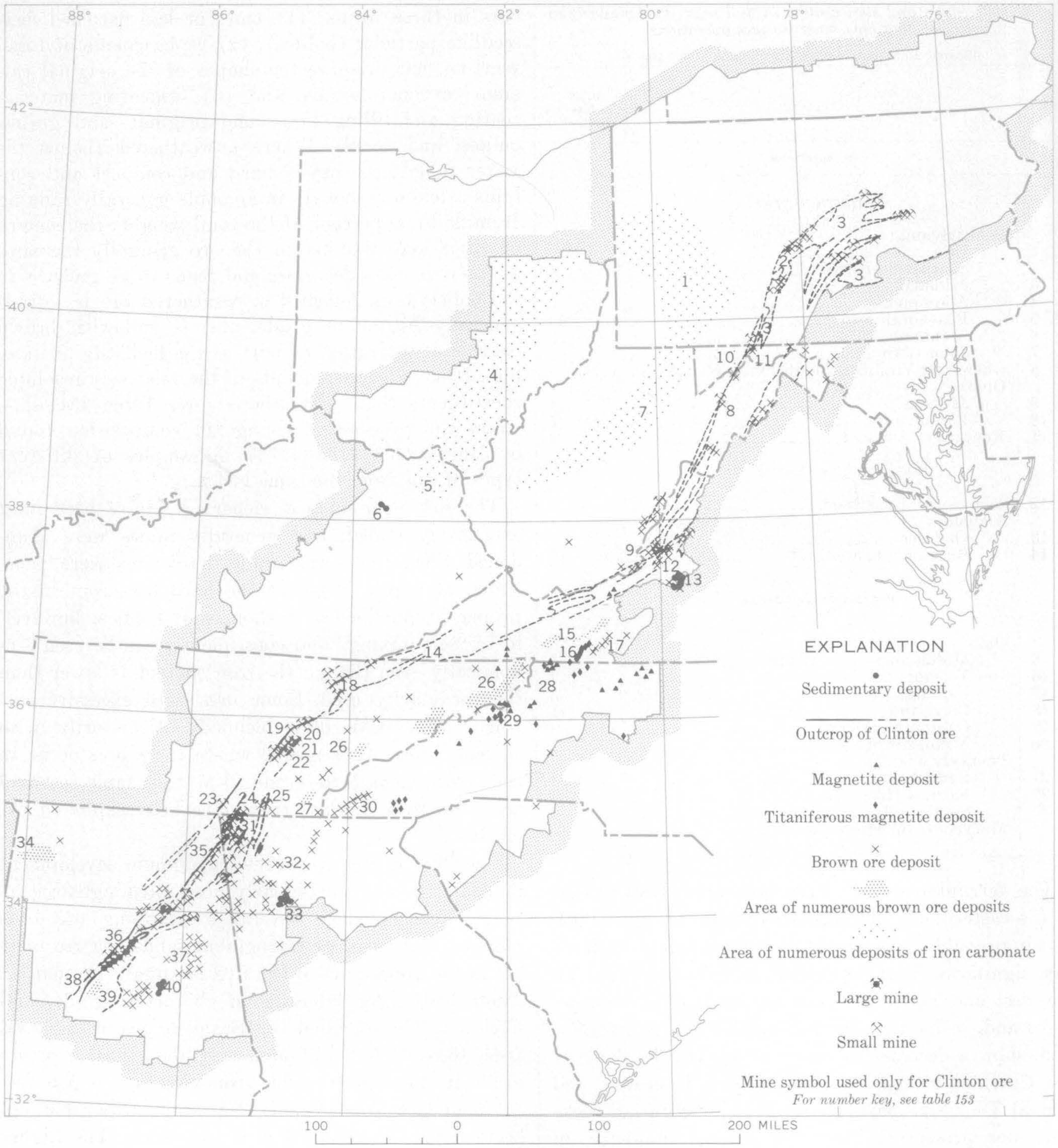


FIGURE 104.—Iron ore deposits in the Appalachian Region.

TABLE 153.—*Estimated past production and future potential of Appalachian iron ores, by geologic type*

Locality (fig. 104)	Location of deposit(s)	Iron[1] (percent in ore)	Active period	Production (millions of long tons)	Reserves[1] (millions of long tons)	Resources[1] (millions of long tons)	References
	SEDIMENTARY ROCKS **Clinton ores**						
	Alabama:						
35	Northeastern	25–40	1890–1957	6.1[2]	51	2,120	Whitlow (1962).
36	Birmingham district	25–39	Early 1800's to present.	+275.0	1,855	2,680	Burchard and Butts (1910); Chapman and others (1953, p. 35–40); Thoenen and others (1953).
38, 39	Bucksville-Woodstock areas	36–48	1903 to present	+0.16	11.2	7.2	A. H. Reed, Jr. (1953).
31	Georgia: Northwestern	20–35	1890–1957	1.93[2]	19	1,820	Whitlow (1962).
6	Kentucky: Rose Run iron area	32 (avg)	1892–1914	+0.63	1.1		Julihn and Moon (1945, p. 10); Muir (1950).
11	Maryland: Evitts, Tussey, and Wills Mountains.	23–37	Prior to 1870	Small		25.3	Singewald (1911, p. 291–308); deWitt and Colton (1964, p. 10–17, 83).
3	Pennsylvania: Central	20–50	Prior to early 1900's.	do		55	Hayes (1909, p. 84–90); Pennsylvania Bur. Statistics and Information (1944, p. 95).
	Tennessee:						
18	Northeastern, including La Follette.	26–32	1820–1960	0.67[2]	Unknown	1,255	Burchard (1913, p. 135–150); Whitlow (1962).
	Central and southeastern:						
19	Rockwood-Cardiff	33–40	1896–1921	3.73[2]	36.0	55	Burchard (1913, p. 83–135); Whitlow (1962).
20	Glen Alice	30–40	1921–30	0.674[2]			
21	Chamberlain-Barnardsville.	25–50	1907–63	0.855[2]			
22	Euchee	26–32	1881–1957	0.233[2]			
23	Inman	25 (avg)	1891–1905	1.55[2]			
24	North Chattanooga (Hill City-Moccasin Bend).	30 (avg)		Unknown			
25	Ooltewah (Whiteoak Mountain)	30–50		do			
	Virginia:						
12	Clifton Forge iron district	45 (avg)	1880–1906	Small		Unknown	Gooch (1954, p. 4, 13); Lesure (1957).
14	Lee-Wise district	40 (avg)	1825–1900	do		Small	Gooch (1954, p. 4, 12).
	West Virginia:						
8	Northeastern	24–57	1800's	do		Large	Grimsley (1909, p. 1–285); Price and others (1938, p. 337).
9	Southeastern	42–52	1800's	do		Unknown	Grimsley (1909, p. 1–285); Price and others (1938, p. 337); Reeves (1942); Julihn and Moon (1945, p. 14).
	Iron carbonate						
	Kentucky:						
5	Northeastern	29–48	1800's	Small		60	Hayes (1909, p. 94–95).
6	Rose Run iron area	31–48	1800's	do		Small	Julihn and Moon (1945, p. 10); Muir (1950).
10	Maryland: Western	35 (avg)	1800's	do		Unknown	Singewald (1911, p. 232–253).
4	Ohio: Southeastern	29–35	1800's	do		500	Ireland (1944); Stout (1944); Bengston and others (1950).
1	Pennsylvania: Western	30–35	1800's	do		46	Hayes (1909, p. 94–95).
7	West Virginia: Central	29–35	1800's	do		Unknown	Grimsley (1909, p. 1–285); Price and others (1938, p. 395).
	Metasedimentary iron-formation						
40	Alabama: Talladega area	34 (avg)	Early 1900's	Small	20	20	P. S. Smith (1907); Julihn and Moon (1945, p. 7, 10); D. F. Reed (1949b); Chapman and others (1953, p. 47).
33	Georgia: Cartersville area	52 (avg)	Late 1800's	do		Moderate	Kesler (1950).
13	Virginia: Blue Ridge district	35–40	1880–1930	do		do	Harder (1909a, p. 224–228); Woodward (1932, p. 106); Gooch (1954, p. 4, 14).
	IGNEOUS ORE						
	North Carolina:						
28	Ballou belt	46 (avg)		Unknown		+0.6	Bayley (1922, p. 242–252; 1923, p. 134–160).
29	Cranberry belt	20–25	1820–1882 188[illegible]–1930 1959 to present	Small 1.5 Small	0.8–1.0	Moderate	Bayley (1922, p. 213, 231; 1923, p. 97–132); Goldich and Wedow (1943); Kline and Ballard (1948).
16	Virginia: Carroll-Grayson district	50 (avg)	Late 1800's	Unknown		Unknown	Gooch (1954, p. 3, 9); Stose and Stose (1957, p. 198–202).
	BROWN ORE						
	Alabama:						
34	Russellville district	40–57	1887–1945 1946 to present	10.0 (concentrate). 6.0	11.0	6.0	Burchard (1960).
37	Eastern	47–52	1849–1957	4.3[2]	4.0	5.8	Burchard (1938, p. 183–184); Andrew Brown (1948, p. 8–36, 49–60).
39	Woodstock area	40–50	1850's to present	+5.0 (concentrate).	1.2	1.2	Andrew Brown (1948, p. 37–44); Chapman and others (1953, p. 43).
	Georgia:						
32	Northwestern	47–52	1890 to present	7.1[2]	20.0	6.0	Lewiecki (1948); Robertson (1948); Chapman and others (1953, p. 44–45).
33	Cartersville area	47–52	1890 to early 1960's.	5.52[2]	Nearly depleted.		Kesler (1950).

See footnote at end of table.

TABLE 153.—*Estimated past production and future potential of Appalachian iron ores, by geologic type*—Continued

Locality (fig. 104)	Location of deposit(s)	Iron [1] (percent in ore)	Active period	Production (millions of long tons)	Reserves [1] (millions of long tons)	Resources [1] (millions of long tons)	References
	BROWN ORE—Continued						
11	Maryland: Evitts, Tussey, and Wills Mountains.	36–46	Early 1800's	Small		Unknown	Singewald (1911, p. 179–188); deWitt and Colton (1964, p. 30–40, 83).
30	North Carolina: Nottely and Valley River belt.	41–58	1840–1920	+0.13	4.0	do.	Bayley (1925); Robertson (1946); Stuckey (1965, p. 314).
2	Pennsylvania: Central, including Scotia.	41–53	Prior to 1850's	1.7	4.7	Large	Butts and Moore (1936, p. 96–98); Pennsylvania Bur. Statistics and Information (1944, p. 95–97); Julihn and Moon (1945, p. 9, 13).
	Tennessee:						
26	Eastern	47–55	Early 1800's–1960.	0.77	1.2	1.5	Chapman and others (1953, p. 44); Maher (1964a, p. 10, 17–19).
27	Ducktown district	43 (avg)	Late 1800's–1907.	1.5	Brown ore depleted; large tonnage of iron sulfides remains.		Emmons and Laney (1926).
	Virginia:						
12	Clifton Forge iron district	43 (avg)	1820's–1930	13.0		5.0+	Gooch (1954, p. 3, 7); Lesure (1957).
15	Pulaski-Smyth district	40–45	Late 1800's to early 1900's.	Small		Unknown	Harder (1909a, p. 233–245); Gooch (1954, p. 3, 9).
17	Great Gossan Lead belt	35–45	1850's–1908	do.	Small	do.	Kline and Ballard (1949); Gooch (1954, p. 3–4, 11); Stose and Stose (1957, p. 211–213).
	West Virginia:						
8	Northeastern	24–59		Unknown		do.	Grimsley (1909, p. 1–285); Price and others (1938, p. 301–302).
9	Southeastern	37–59	1840's–1940's	Small		+1.6	Grimsley (1909, p. 1–285); Price and others (1938, p. 301–302); Reeves (1942); Julihn and Moon (1945, p. 14).
Total				+346	+2,037	+8,650	

[1] Information mainly derived from Carr and Dutton (1959, p. 89–94); Chapman and others (1953, p. 50).

[2] U.S. Bur. Mines figures, in U.S. Geol. Survey and U.S. Bur. Mines (1959, p. 19–22).

TABLE 154.—*Analyses of hard, semihard, and soft iron ore from the Rockwood Formation, Chamberlain, Tenn.*

[Data from Burchard, 1913, p. 76]

	Hard	Semihard	Soft, near dividing line	Soft
Fe	27.22	37.32	52.55	50.79
SiO_2	5.00	7.92	7.63	7.62
Al_2O_3	2.82	3.07	3.64	4.31
$CaCO_3$[1]	44.40	24.50	3.00	.70
P	.44	.57	.74	.53
H_2O+	4.72	5.52	8.15	9.35

[1] Recalculated from CaO.

An unusually favorable geological setting is the reason for the importance of the Birmingham area in the steel industry. Abundant Cambrian and Ordovician limestone and dolomite along an anticlinal axis underlie Jones Valley, in which Birmingham, Bessemer, and other steel centers are situated. The Silurian strata, with their iron ores, flank Jones Valley on the east and Opossum Valley on the west, and extensive deposits of coal in the overlying Pennsylvanian strata lie just beyond. The thickest parts of the iron ore beds crop out along Red Mountain, east of Jones Valley, and dip moderately to gently east; their weathered enriched soft ores (50–60 percent iron) were readily available for extraction by opencut in the early days, and the deeper hard ores have been followed about 3 miles downdip. The Big Seam has been mined almost continuously for about 12 miles from the vicinity of Bessemer to Birmingham and intermittently for another dozen miles or so northeast; in the latter stretch the Irondale seam also is of ore grade. To the southwest the ferruginous beds thin and have not been mined extensively (fig. 104, locs. 38, 39); they are covered by the Coastal Plain sediments about 40 miles from Birmingham. On the west side of Opossum Valley they are also thin and have been faulted out to a great extent; some are known from drilling to continue westward under the coal beds but are too deep to be of commercial interest.

The Birmingham district has produced about 275 million tons of ore and for many years had an annual output of some 4 million tons. Peak production was nearly 8 million tons in the 1940's (Thoenen and others, 1953, fig. 2), before importation of higher grade foreign ores, principally from Venezuela, began to supplant local ores in the blast furnaces.

Ample material remains in the Birmingham district to sustain a high rate of production for many decades. Thoenen and Reed (in Thoenen and others, 1953, table 2, p. 13) estimated that as of July 1, 1952, ferruginous material remaining to a distance of about 4 miles from the outcrop in Red Mountain was as follows (in round numbers): 550 million long tons of commercial ore averaging 39 percent iron, 580 million tons of marginal ore averaging 35 percent, and slightly over a billion tons of ferruginous sandstone averaging 25 percent iron.

Northeast of Birmingham, outcrops of the Red Mountain Formation may be traced almost continuously in a belt 20–40 miles wide across northeastern Alabama, northwestern Georgia, and eastern Tennessee; isolated remnants are present in a number of other places (fig. 104, locs. 18–25, 31, 35). Thicknesses of ore beds are in general only a few feet, but in a few places they are as much as 9 feet (Whitlow, 1962). The soft near-surface ores were mined along many miles of the outcrop by opencut, and relatively shallow underground operations extracted hard ores where grade and thickness permitted. The principal centers formerly supplied by these mines are Gadsden, Ala., and Rockwood, Tenn. Mining had ceased, however, by 1957, except for small, sporadic operations in a few places, and other sources now supply the ore for these plants. (See table 153 for details.)

In northeastern Alabama, northwestern Georgia, and eastern Tennessee, the geologic setting is similar to that at Birmingham. The red ores crop out along ridges and dip under younger rocks, which, in general, are coal-bearing. They are known to underlie several thousand square miles. A study by the U.S. Geological Survey and U.S. Bureau of Mines (1959) concluded, on the basis of available information, that a resource of 5 billion tons of material averaging 30 percent iron is present in beds having a minimum thickness of 2½ feet but that very little of it is of commercial interest. Similar tonnage figures were quoted by H. D. Pallister and E. F. Burchard (in Chapman and others, 1953, p. 50).

North of Tennessee the Clinton iron ores are generally thin and low grade, but the outcrop belts are extensive (fig. 104). A little ore has been mined (table 153), practically all in the 19th century for local furnaces that have long since been abandoned. The Silurian ores at Rose Run, Ky. (fig. 104, loc. 6), are oolitic and similar to the Clinton ores to the east. They are known to extend for about 12 miles in a northeasterly direction but are thin, very low in grade, and of no commercial importance today.

Ferruginous sandstone deposits of Clinton age in southwestern Virginia attain thicknesses of 20 to 45 feet. They average about 20 percent iron, far too low to be used without beneficiation, and have not been mined.

Ordovician red ores

Red ores similar to the Clinton ores occur in the Tellico Sandstone of Ordovician age in eastern Tennessee (Burchard, 1913, p. 49–73). Most beds are very thin, at best only a few feet thick, and seem to be highly lenticular, but thicker deposits of ferruginous sandstone have given rise to residual red and brown ores (included with brown ore deposits in fig. 104, loc. 26). Mining in the early years of this century yielded several tens of thousands of tons of residual red ore ranging to as much as 60 percent iron and locally containing a few percent manganese; some red ore in the underlying Athens Shale, also of Ordovician age, was mined in McMinn County, Tenn., in the 1950's. The ferruginous limestone of the Deaton Iron-Ore Series (Spencer, 1893) of Ordovician age in northwestern Georgia also contains similar red ore beds.

Iron carbonates

Thin beds and lenses of iron carbonate are widespread in the Appalachian Plateaus province, principally in rocks of Pennsylvanian age, although they also occur in other post-Silurian rocks. Because they are roughly contemporaneous with the coal measures, they tend to have about the same geographic distribution, being present in West Virginia, Maryland, Pennsylvania, Ohio, and Kentucky (fig. 104, loc. 1, 4, 5, 7, 10). Oolitic carbonate ore of Devonian age as well as the previously mentioned Silurian Clinton-type ores have been mined in the Rose Run area, Ky. (fig. 104, loc. 6).

The iron-carbonate ores in their unoxidized state range from 25 to 45 percent iron; commonly, however, they are more or less altered to limonite and thus may be enriched. Silica and clay are generally high, and the phosphorus content exceeds the Bessemer limit.

Several types of iron-carbonate deposits can be distinguished on the basis of appearance. Among them are blackband ores, concretionary ores, block ores, and so-called limestone ores. Blackband ores are associated with coal beds, grading into or interstratified with them. Some have provided almost enough carbon and calcium mixed with the iron ore to furnish both fuel and flux. Kidney-shaped nodular or concretionary ores generally occur in clay shale in rather discontinuous layers, are normally thin, and tend to grade into the blackband ores. Most contain the purest iron carbonate and upon weathering yield a correspondingly pure brown ore. Block ores are cut by intersecting joints and break into rectangular blocks. They are usually more persistent and uniform in thickness than the other varieties, with the thinnest beds containing the best ore. Limestone ores replace or lie immediately above limestone beds.

The iron-carbonate deposits in the Appalachian Plateaus province are extensively exposed and weathered to comparatively high-grade, readily minable oxidized ore which was utilized in the early furnaces. The iron-carbonate deposits have little or no economic value now because they are small, scattered, and low grade.

Metasedimentary (gray) iron ores

Bedded iron ores that occur in moderately metamorphosed lower Paleozoic rocks in eastern Alabama, Georgia, and Virginia contain specular hematite and (or) magnetite rather than the red earthy hematite of the Silurian ores farther west. The metasedimentary ores are low in lime but are siliceous, generally having large amounts of quartz in rounded grains. This relation of silica and lime is the reverse of that in much hard Clinton ore, and the metasedimentary ores were formerly considered as potentially useful for blending. The deposits are thin and lenticular, highly irregular in grade, and expensive to mine, so very little ore of this type was produced.

Near Talladega, Ala. (fig. 104, loc. 40), gray ore crops out intermittently in a zone about 12 miles long. The enclosing rocks are believed to be the Weisner Quartzite of Early Cambrian age. About 100,000 tons of ore was mined from opencuts and underground in the period 1904–07, but the deposits have not been worked since. Some test lots that were shipped to Bessemer, Ala., in 1909 averaged 49.43 percent iron and 19.21 percent SiO_2 (Reed, 1949, p. 4, 12–13). Trenching and drilling by the Bureau of Mines in 1943–44 showed that in most places the tested ore zones are 1–9 feet thick (averaging 3 feet) and generally contain 20–40 percent iron (p. 25–27).

In the Cartersville area, Bartow County, Ga. (fig. 104, loc. 33), a little high-grade ore was mined about 1890. Lenticular masses of specular hematite schist, probably equivalent to the Shady Dolomite, occur between the Weisner Quartzite and the overlying Rome Formation (Kesler, 1950, p. 1). Weathering is unusually deep. As the potential ore-bearing zone has a maximum thickness of about 30 feet and a length of at least 18 miles, considerable material may be present at depth. Most iron ore production of the Cartersville area after 1890 was from the surficial weathered zones of the Shady Dolomite and Rome Formation, however, and consisted of brown ore and associated ocherous and umberous residuum. Manganese and barite ores are also present. The ocher deposits have been extensively mined, almost to the point of depletion, for paint pigments; the umber deposits have been mined to a lesser extent.

In the Blue Ridge district, Botetourt County, Va. (fig. 104, loc. 13), moderate amounts of siliceous specular hematite were mined for local use from 1880 to 1930. The ore occurs in the Unicoi Formation of Early Cambrian (?) age in one or more beds that average only a few feet thick and are known to extend some 8–10 miles along the eastern border of Botetourt County. The ore averaged about 35–40 percent iron and 30–40 percent silica (Woodward, 1932, p. 106).

IGNEOUS ORES

Small iron deposits believed to have been formed by magmatic processes, either as segregations in igneous rocks or as lenses and veins in gneisses and schists, are fairly numerous in the Blue Ridge and Piedmont provinces of southern Appalachia. Because magnetite is the principal ore mineral, these deposits are commonly called magnetic iron ores. Hematite is also present in some deposits. Gangue minerals include pyroxene, hornblende, feldspar, garnet, epidote, quartz, and minor calcite. Phosphorus and sulfur are low. The ores are classified as nontitaniferous, containing less than 1 percent TiO_2, and titaniferous, containing 4–14 percent or more TiO_2 (Bayley, 1922, p. 211–213; 1923, p. 18–20). Titaniferous ores cannot be smelted economically in the blast furnace and have no present value as iron ores; however, they may be used as titanium ores if sufficiently rich in this element. Most of the deposits are in western North Carolina, easternmost Tennessee, and southern Virginia (fig. 104).

The best known and most important nontitaniferous ores occur along an arcuate zone extending from Avery County, N.C., into Carter County, Tenn. Deposits of coarse-grained magnetite form lenses in the Cranberry Gneiss; although narrow stringers of fine-grained lean ore connect some of these, most ore bodies are small and, because of their irregular shapes, difficult to explore and evaluate. The largest known are at Cranberry, N.C. (fig. 104, loc. 29), where nearly all production of magnetic ores in Appalachia took place (table 153). Opencut and underground mining from 1882 to 1930 yielded about 1,500,000 tons, which was shipped to a furnace at Johnson City, Tenn. (Kline and Ballard, 1948, p. 5). Mining extended more or less continuously for about one-half mile along a northwest-trending, southwest-dipping pinching and swelling zone that exceeds 200 feet in greatest thickness. Grade varied widely but probably averaged 20–25 percent. Selective mining, cobbing, and at times magnetic beneficiation yielded a product of about 40–45 percent iron (Bayley, 1922; and 1923, p. 52, 69). Smaller deposits were worked sporadically both southeast of Cranberry and northwest into Tennessee; nearly all were confined to surficial ore, however. In recent years, some ore was mined for use as heavy medium for coal-cleaning plants; the quantity is not believed to have been large.

Small lenses of nontitaniferous ore also occur in the Ballou belt, Ashe County, N.C. (fig. 104, loc. 28), and elsewhere. Moderate amounts of ore for local use were mined a century or more ago. Most are siliceous magnetites, but a few, the so-called marble magnetite ores, have calcite as the principal gangue mineral and might be useful for blending if present in quantity. Bayley (1922, p. 242–250; 1923, p. 183–197) described the few deposits of this type known, of which one at Lansing, Ashe County, produced a little ore in 1920 for shipment to Johnson City.

The titaniferous ores are segregations of magnetite and ilmenite, rutile, or other titanium minerals in gabbro or related basic igneous rocks. Like the nontitaniferous ores, they tend to occur in discontinuous belts. A special symbol on the map (fig. 104) distinguishes them; most occur in the Carroll-Grayson district, Virginia (fig. 104, loc. 16), and in Alleghany and Ashe Counties, N.C., to the south. Mining ceased long ago.

BROWN ORES

Iron ores formed by weathering processes at or near the present surface are known as brown ores because of the color of the limonite that is their predominant constituent. They are widely distributed in Appalachia and have been extensively worked from the earliest times to the present (fig. 104, table 153). As a general rule, individual deposits are irregular and of only small to moderate size, but their grade may be high. They are easily mined, and the ore smelts readily in both primitive charcoal furnaces and modern blast furnaces. Phosphorus and silica tend to be high, but lime is very low or absent. Hence these ores are well suited for blending, and this is their principal use today.

Most brown ores are mined in opencuts, although a few deposits extend deep enough to require underground mining. The ores have been shipped as mined, selectively sorted, or, very commonly, put through simple washing and screening plants to remove associated waste material. Heavy-media plants were introduced after World War II at Russellville, Ala. (fig. 104, loc. 34), to remove chert that could not be separated by washing. Andrew Brown (1948, p. 21–23) stated that in Alabama in 1943 the range of crude ore to concentrate was 3:1–10:1, with an average of about 5:1. Inasmuch as the better concentrates average 47–53 percent iron, a grade of only about 10 percent iron is indicated for the typical material extracted and sent to the washing plants. Total Appalachian production has been more than 50 million tons (table 153), but only a few areas in southwestern Appalachia have produced in recent years. The irregular nature of the deposits makes it difficult to evaluate them in advance of mining, so resource and reserve estimates are at best only guesses. Substantial quantities do remain, however, particularly in Alabama and Georgia (table 153).

The brown ores in the Valley and Ridge province have been categorized in various ways according to the local conditions of stratigraphy and topography under which they formed and were preserved. The terms "mountain" and "valley" ores applied to these deposits (fig. 104, loc. 2, 15, 26, 30, 32, 33, 37) refer, respectively, to their location on ridges held up by sandstone or quartzite or in valleys underlain by carbonate rocks of the lower Paleozoic stratigraphic section. The iron was derived from siderite, pyrite, or other ferruginous minerals in the sedimentary rocks. The deposits have the form of veins and replacements of limonite in partly weathered rock or of irregular concretions in clay residuum. They are generally elongate parallel to the strike of the bedrock formations. Depths are ordinarily only a few tens to a few scores of feet but may be 150 feet or more. Areas of individual deposits may consist of many acres and, in the southern States, hundreds of acres.

The most productive of the areas underlain by carbonate rocks, those at Woodstock (fig. 104, loc. 39) and Russellville (fig. 104, loc. 34), Ala., are at the edge of the Coastal Plain where iron, probably leached from unconsolidated glauconite-bearing beds of Cretaceous age, was concentrated in older Cretaceous sands and gravels lying unconformably on Paleozoic strata (Andrew Brown, 1948, p .15). At Russellville the deposits are in sand and gravel of the Tuscaloosa Group (Late Cretaceous) just above flat-lying Bangor Limestone of Mississippian age. Both the district and individual deposits are more nearly equidimensional in outline than those in the folded areas. Mining has extended over several square miles, principally in an area about 8 miles long and 2 miles wide, although the total district measures some 18 by 15 miles. Recent mining has required as much as 132 feet of stripping (H. D. Pallister, in Burchard, 1960), and the ore zone may be as much as several tens of feet thick.

The Woodstock and Russellville ores are similar to the Coastal Plain brown ores of southern Georgia and Alabama, which lie outside Appalachia but also supply part of the ore used in the Birmingham district.

Brown ores also occur on the metamorphosed Paleozoic and older rocks of the Blue Ridge and Piedmont provinces from Virginia to Alabama. Deposits tend to be small and have not been mined in recent years.

Oriskany ores

The Oriskany ores (fig. 104, loc. 8, 9, 11, 12) form a distinct type named for their close association with the Oriskany Sandstone of Devonian age. Tabular deposits more than half a mile long, several tens of feet thick, and extending as much as 900 feet downdip are in the Helderberg Group, which immediately underlies the Oriskany. They were formed by replacement of limestone in the Helderberg by iron derived from pyrite in shale beds higher in the section (Lesure, 1957, p. 98–100). Although ore occurs in the Helderberg at places from New York to Kentucky, its greatest development by far was in the Clifton Forge iron district (fig. 104, loc. 12) in Alleghany, Botetourt, and Craig Counties, Va., which has produced approximately half the total iron ore of that State. The Oriskany ores mined at Clifton Forge averaged 43 percent iron, 21 percent silica, 0.38 percent phosphorus, and 1.3 percent manganese (Morrison and Grosh, 1950, p. 7). Operations ended in 1925 for economic reasons rather than because of exhaustion of reserves.

Gossan ores

In two districts, Ducktown, Tenn. (fig. 104, loc. 27), and the Great Gossan Lead, Va. (loc. 17), the brown weathered gossan overlying massive deposits of pyrite and pyrrhotite was formerly mined as iron ore. Containing 40–50 percent iron and little phosphorus, it made good blending material. The ores extended only to the permanent water table and are now largely mined out.

The sulfide ores underlying the gossans contain various other metals (copper, lead, zinc, gold), as well as sulfur and iron, and they have been and continue to be mined. Considerable iron sinter, produced by the roasting of sulfides to recover the sulfur at Ducktown, is shipped to Birmingham. Iron produced in this way is economic only if other materials, such as sulfur and copper are also recovered.

RESOURCE POTENTIAL

Although improved transportation facilities and technologic improvements in steelmaking from raw materials to finished product caused the role of Appalachia's iron ores to decline for a long time, new developments conceivably could reverse this trend. All the principal ingredients for steelmaking are abundantly present; only the lower grade of the major ore resource and a generally unfavorable situation for low-cost mining has eroded its position in the industry. The ore is equal or superior in average grade to material now furnishing much of the nation's iron; and, if techniques for concentrating it prove feasible, the geographic proximity to steel centers, particularly in the south, might make it fully competitive with ore from distant sources. Furthermore, new methods for making iron and steel in moderate quantities do not require the huge capital expenditures entailed in the major steel-making centers, so it may become economically advantageous to establish new facilities using local materials to serve nearby markets.

It is too early to predict the future pattern of the iron and steel industry in light of recent rapid changes. If the trend of the last decade continues, Appalachia will virtually cease to be a source of iron ore; on the other hand, by use of newer technology, it may again furnish a significant part of the iron for local consumption.

SEDIMENTARY ORES

As is evident from table 153, the resource potential of Appalachia is principally in the Clinton ores. Reserves of nearly 2 billion tons refer, however, to material that is becoming increasingly uneconomic because of the technologic revolution in the iron and steel industry during the last few years, and the resource figure of 8.6 billion tons is even less realistic in terms of potential future production unless means can be developed to make Clinton ore competitive.

Tests at beneficiating Clinton ores by industry and by the Bureau of Mines at Tuscaloosa, Ala., summarized by Clemmons (Thoenen and others, 1953, p. 21–64), have shown that the yield of the ores could be improved substantially by flotation, magnetic separation, and gravity methods. Notwithstanding, the iron content of most concentrates made by the methods available at the time did not exceed 55 percent (Thoenen and others, 1953, p. 27). The principal reason for this comparatively poor result is because the Clinton ores were not metamorphosed as were the Precambrian iron formations. They are, therefore, more difficult and complex to beneficiate largely because of their nonmagnetic character, the amorphous form of hematite covering sand grains, their phosphorus and clay content, the fine grain size of their gangue, and the lack of uniformity in ore composition throughout the district. However, tests did suggest that costs of upgrading (by flotation) the thick ferruginous sandstone available for open-pit mining at Birmingham might make this material competitive with the local ores. Tests and cost calculations indicated that 2.1 tons of material containing 28.4 percent iron could yield 1 ton of 49.5 percent concentrate at a cost of $7.14, competitive with the ores then being used.

Perhaps the most hopeful possibility is the recent discovery by Bureau of Mines metallurgists that hematite can be reduced to magnetite by roasting it with scrap iron in a kiln (Fine and Melcher, 1964; Melcher, 1965; Fine and Prasky, 1966). This discovery may be the technologic breakthrough that will permit recovery of iron from naturally nonmagnetic materials and at the same time reduce the problem of unwanted light scrap that cannot be used satisfactorily in steel furnaces, particularly in the basic oxygen furnaces that are rapidly taking over from the open hearths.

Tests to date have been made in a relatively simple rotary kiln fired with natural gas. Nonmagnetic taconite crushed to pass a ¾-inch screen and automobile body scrap sheared into conveniently sized pieces is fed continuously into the kiln and heated to from 800° to 1,000°C. Exchange of oxygen from hematite to the scrap converts both the hematite and scrap to magnetite which can be recovered as a high-grade concentrate by conventional grinding and magnetic separation. Theoretically 1 pound of iron metal will reduce 11.5 pounds of hematite and itself be converted to 1.4 pounds of magnetite (Fine and Prasky, 1966, p. 3); in practice a slightly higher ratio of iron metal may be preferable (Melcher, 1965, p. 5). Pilot-plant studies will be undertaken in Minnesota (M. M. Fine, oral commun., 1966); whether the process would be successful on Clinton material is not known, but it should be tried.

In the event that this or some other process proves technically and commercially feasible for Clinton ores, it is pertinent to examine more closely the potential resources. Thoenen and Reed (in Thoenen and others, 1953, p. 17, table 3) estimated that as of July 1, 1952, the recoverable reserves of the Birmingham basin included 547 million tons of ore, 579 million tons of marginal ore, and 1,033 million tons of ferruginous sandstone. The ferruginous sandstone, which is present in two zones that range in thickness from 20 to 50 feet or more, averages about 25 percent iron; large amounts are available for open-pit mining (Thoenen and others, 1953, p. 9–10). If about 85 percent of the iron can be recovered, as seems possible from experience (Fine and Prasky, 1966, p. 19), about 3 tons of crude ore should yield 1 ton of concentrates that would be at least equal in grade to the imported ore used at Birmingham and perhaps at costs that are fully competitive. Earlier magnetic roasting and separation tests on the ferruginous sandstone (Thoenen and others, 1953, p. 30–34) did not achieve high-grade concentrates with good recovery because of the percentage of locked quartz particles at the 100- to 200-mesh grinding sizes used (Thoenen and others, 1953, p. 28). Normal practice now, however, is to grind to −325 mesh or finer in order to pelletize even when it is not necessary for the concentration step, so good recovery should be possible.

Ferruginous sandstones are widespread in the Silurian strata of Appalachia elsewhere than at Birmingham. Where they are thick enough and so situated that open-pit mining methods may be used, there is a possibility that beneficiation can make an economically usable product. One such area occupies approximately 250 square miles in Bland and Giles Counties, Va. The Minerals Development Corp. (formed by the Norfolk and Western Railway, Roanoke Electric Steel Corp., and E. L. Keesling of Bramwell, W. Va.) has carried out reconnaissance mapping, test pitting, and drilling at selected localities under the direction of Dr. Byron N. Cooper of Virginia Polytechnic Institute (Eng. and Mining Jour., 1961, p. 174). Two zones of ferruginous sandstone 20–45 feet thick are present on and near Wolf Creek Mountain and Pearis Mountain, some 15 miles north-northwest of the town of Pulaski. Grade ranges from about 15 to more than 30 percent iron and averages about 20 percent (S. D. Broadhurst, oral commun., 1966); the material is said to be very similar to that at Birmingham (Avery Reed, oral commun., 1966). The most favorable areas are on the ends of folds where dips are low and opencutting would be feasible. Estimates of reserves in the properties tested by the Minerals Development Corp. are more than 150 million tons. Other deposits also occur in the area (Cooper, 1958, p. 1713; 1960, p. 1–5).

OTHER ORES

Resources of brown ores in Appalachia are large enough, perhaps 50–75 million tons (table 153), to continue to furnish ore for blending purposes for many years. Only Alabama, Georgia, and Tennessee produced brown ore in recent years because areas more distant from the Birmingham and Gadsden centers cannot compete. The blast furnaces at Rockwood, Tenn., are not operating at present; hence the small reserves of eastern Tennessee brown ores have no nearby market. Byproduct sinter is shipped from Ducktown, Tenn., to Alabama; the Ducktown sulfide reserves are large, so a steady supply of sinter also should be assured for many years. (See section "Copper and Sulfur," p. 377).

Although known resources of magnetite ores in Appalachia are small and uneconomic (table 153), it is not beyond the bounds of possibility that large deposits do exist. Since the development of the airborne magnetometer two decades ago, large magnetite deposits have been found and brought into production in eastern Pennsylvania, Missouri, Ontario, and elsewhere. Their very existence had been unsuspected, and it would have been impossible to discover them except by magnetic methods. The Piedmont and Blue Ridge provinces of Appalachia are the most likely areas that could contain concealed magnetite deposits, and complete aeromagnetic coverage of the region is desirable.

Ground magnetic surveys by the Bureau of Mines at and near the Cranberry mine in North Carolina (Scharon and others, as reported in Kline and Ballard, 1948, p. 32–69) established the presence of many small magnetic anomalies along the belt extending into Carter County, Tenn. Drilling of some of the areas showing magnetic anomalies proved the presence of ore, but neither magnetic surveying nor drilling was exhaustive, and further work, probably preceded by aeromagnetic surveys, seems desirable.

The deposits of the Cranberry zone and other known magnetite bodies do not appear to be large enough to be mined cheaply, either by opencut or subsurface methods. Furthermore, they are far from present markets. Nevertheless, their magnetic character facilitates both the discovery and upgrading of this type of ore, and systematic search should be made for additional deposits.

MANGANESE

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THE NATIONAL INDUSTRY

Manganese (Mn) is an essential raw material in steelmaking and is widely used in batteries, alloys, chemicals, and in many industries. About 95 percent of the manganese consumed by American industry is used as a desulfurizer and deoxidizer in the production of steel, and no substitute that can fulfill this essential function at reasonable cost has yet been found.

In 1964, the United States consumed more than 2,100,000 short tons of manganese ore of metallurgical grade (35 percent Mn or higher); 2,064,990 short tons (U.S. Bur. Census, in DeHuff, 1965) of ore were imported in 1964, averaging about 47.5 percent Mn, and about 26,000 tons were produced from domestic deposits. Increasing amounts of ferromanganese are imported; in 1964 imports amounted to 215,937 tons (U.S. Bur. Census, in DeHuff, 1965), equivalent in terms of manganese content to more than 342,000 tons of 48-percent Mn ore. Industry stocks at the end of 1964 were about 1.6 million tons. Thus in that year about 1 percent of national needs were produced domestically.

Manganese ores are irregularly distributed throughout the world. The U.S.S.R. and mainland China possess important commercial-grade deposits; the United States does not. Manganese is highly strategic in times of war, and American government and industry have expended much effort and large sums of money investigating domestic manganiferous deposits as well as means of beneficiating ores of noncommercial grade into usable material. To meet possible emergency needs, the Government has accumulated from domestic and foreign sources a stockpile that at the end of 1965 contained about 9.8 million tons of strategic quality and 1.5 million tons of nonstrategic quality manganese ore.

Manganese ore is reduced to the alloy ferromanganese (about 74–76 percent manganese, 14 percent iron, the rest various impurities) for use in steelmaking. Spiegeleisen, an alloy containing about 16–23 percent manganese, can be substituted for certain applications. To make ferromanganese, ores with a manganese-iron ratio of not less than 7:1 are desired; lower grade ores are used in making spiegeleisen. Electrolytic manganese may be made from off-grade ore, although obviously the better the ore, the cheaper the processing.

Much of the ferromanganese and electrolytic manganese produced in the United States is made in the northern part of Appalachia near and in the steelmaking centers. Some is also produced in the area of low-cost TVA electricity. Nearly all is produced from imported ore.

Battery-grade ore contains a high percentage of manganese dioxide (MnO_2) and has certain specific physical and chemical characteristics. Although in the past most MnO_2 used in batteries came directly from naturally occurring material, in recent years use of artificial battery-grade MnO_2 has been increasing. More expensive substitutes are known, and substitutes for other uses of manganese also are available.

The reduction of imported high-grade manganese ore is an important industry in Appalachia and is essential to the national steel industry, but no manganese ore is being produced (1966) in Appalachia, and only small quantities are being produced elsewhere in the country.

HISTORY OF MANGANESE PRODUCTION IN APPALACHIA

Because the use of manganese is intimately related to the iron and steel industry, a close relation of manganese production to the vicissitudes of that industry is inevitable. The Appalachian Region has a long history of iron and steel production, beginning in colonial days. Iron was an article of export from the colonies to England. At one time England forbade the colonies to work iron ores into iron implements and also forbade the construction of new forges for producing iron (Singewald, 1911). In the 19th century, with the economic development of the Great Valley and the westward spread of the population, scores of small forges, blast furnaces, and bloomeries were set up in the valleys and coves in the mountain areas to take advantage of the abundant iron ores and charcoal. Certain areas (later found to contain manganese-bearing ores) were famous for iron and steel from which car wheels and rails of outstanding quality were fabricated. Later, manganese ore was mined and was exported to England.

With the coming of the Bessemer process for steelmaking and the demonstration by Mushet in 1856 of the need to add manganese to the charge, manganese was sought, and thenceforward there was a continuing demand for manganese ore. At first the demand was met from domestic deposits, which, although small, were adequate for the industry on the then existent scale. In the last decades of the 19th century, however, the great manganese deposits of India, Russia, central Brazil, and elsewhere were discovered and brought into production. As a measure of the disparity in scale between the Appalachian deposits and those abroad, a single one of the many mines in central Brazil has produced more than 12 times the known production of all the mines in Appalachia.

In the last half of the 19th century the steel industry expanded to form a few large productive units near concentrations of low-cost materials, with a consequent elimination of the small inefficient blast furnaces scattered through the mountains. The Appalachian manganese ores had to compete with imported ores moving by sea or by railroad to large consuming centers (Hewett, in Stose and others, 1919, p. 93). Development of high-grade iron ores that could be moved by water similarly eliminated many of the small-to-medium iron mines in Appalachia. Short railroads driven into the mountains to bring the iron ores to market then were removed, and local manganese ores were burdened with even higher costs of transportation.

The first recorded production of manganese ore from Appalachia was in 1837 (Harder, 1910), but detailed records of production go back only to 1889. Since that year, as shown in table 155, some 456,078 tons of concentrates containing more than 35 percent manganese have been produced.

Because of the highly irregular nature and the generally small size of individual manganese ore deposits in Appalachia, systematic and efficient extraction methods have been difficult to maintain except at a few of the larger deposits. As illustrated in table 155 and figure 105, production has been notably responsive to price fluctuations.

The price of manganese ore since 1889 has varied with the average grade of the ore, with distance to market, and with the world market price. From 1952 to 1959, an artificial price was set for domestic manganese ore at a level more than twice the world price (table 155). During World War I, the average value (1958 constant dollars) reached a maximum of nearly $73 per ton; Appalachian production increased to more than 18,000 tons in 1918, but diminished to a few hundred tons in 1921 and 1922 when the value dropped to less than $30 per ton. With the advent of low-cost electrical power from TVA and the installation of nearby electrometallurgical and chemical plants, prices and production again gradually increased during the 1930's, and reached a maximum during World War II. Maximum production was 19,456 tons in 1942, and value per ton reached more than $46 the following year. After the war, foreign ores again displaced Appalachian ores. During the 1950's, when the U.S. Government subsidized domestic manganese production, the value reached more than $90 per ton and bore little relation to commercial demand. Production peaked at more than 45,000 tons in 1955, falling rapidly thereafter and ceasing in 1960. The nominal world market price for metallurgical grade manganese ore (48 percent or more manganese) in January 1966 was about $38.00 per ton.

Mining during the 1950's probably extracted most of the remaining easily found ore. Even at artificially high prices, production fell sharply after 1955. The lower average value per ton toward the end of the subsidy period (fig. 105) reflects the lower grade of the ore marketed, not a lower price per unit of manganese, for this remained fixed until late in 1959. International consumption of manganese is being adequately met by world production, and world reserves of high-grade manganese ores are very large. It can be expected that Appalachian manganese deposits will continue to have difficulty in competing with deposits elsewhere and that future production will be small.

DEPOSITS IN APPALACHIA

The only commercial manganese minerals now in world commerce are the oxide minerals and, to a very limited extent, manganese carbonate which can either be calcined to produce manganese oxide or treated chemically to recover manganese. Manganese may be recovered from locally abundant silicate minerals but

TABLE 155.—*Production of manganese and manganiferous ores from the Appalachian Region, 1889–1964*

[Source: U.S. Bur. Mines, except column on average value, which was calculated by Dorr from foregoing data]

Year	Manganese ore, >35 percent Mn (short tons)	Value, in 1958 constant dollars (thousands)	Average value per short ton (1958 dollars)	Manganiferous ore, 5–35 percent Mn (short tons)	Value, in 1958 constant dollars (thousands)
1889	5,867	218	37.2	(1)	(1)
1890	839	21	25.0	(1)	(1)
1891	4,004	109	27.2	(1)	(1)
1892	925	26	28.1	(1)	(1)
1893	1,351	25	18.5	(1)	(1)
1894	2,463	43	17.5	(1)	(1)
1895	1,216	36	29.6	(1)	(1)
1896	3,849	123	32.0	(1)	(1)
1897	3,604	104	28.9	(1)	(1)
1898	6,747	204	30.2	(1)	(1)
1899	1,523	49	32.2	(1)	(1)
1900	2,808	86	30.6	(1)	(1)
1901	3,942	99	25.1	(1)	(1)
1902	3,108	32	10.3	(1)	(1)
1903	560	12	21.4	(1)	(1)
1904				(1)	(1)
1905				(1)	(1)
1906				(1)	(1)
1907	112	6	53.6	(1)	(1)
1908				(1)	(1)
1909	224	19	8.5	(1)	(1)
1910					
1911					
1912					
1913					
1914	158	1	6.3	595	5
1915	3,968	75	18.9	1,310	8
1916	2,293	102	44.5	44,919	315
1917	11,430	833	72.9	37,243	406
1918	18,387	1,191	64.8	20,022	286
1919	1,728	74	42.8	4,246	31
1920	1,351	52	38.5	6,972	25
1921	308	9	29.2	14,925	56
1922	127	3	23.6	1,157	5
1923	1,973	50	25.3	36,014	222
1924	3,640	111	30.5	23,684	167
1925	4,749	105	22.1	41,983	295
1926	8,325	180	21.6	33,479	331
1927	4,342	122	28.1	25,329	285
1928	9,015	263	29.2	6,222	89
1929	6,313	205	32.5	6,875	116
1930	22,970	651	28.3	13,974	306
1931	7,626	171	22.4	14,530	223
1932	831	21	25.3	15,954	132
1933	5,420	190	35.1	13,125	133
1934	8,364	277	33.1	11,507	132
1935	11,016	330	30.0	5,489	75
1936	10,120	295	29.2	4,853	53
1937	8,768	392	44.7	13,432	103
1938	10,049	330	32.8	5,135	59
1939	13,579	447	32.9	9,962	109
1940	15,011	506	33.7	16,294	231
1941	16,339	678	41.5	10,919	130
1942	19,456	631	32.4	12,673	189
1943	10,649	493	46.3	8,820	127
1944	8,932	310	34.7	9,853	105
1945	1,096	26	23.7	1,392	9
1946					
1947	39	2	51.3		
1948	37	2	54.1		
1949	175	8	45.7		
1950	327	10	30.6		
1951					
1952	1,138	19	16.7		
1953	9,537	759	79.6	168	3
1954	32,718	2,838	86.7		
1955	45,126	4,172	92.5	347	5
1956	36,363	3,358	92.3	3,086	21
1957	19,511	1,554	79.6	2,203	15
1958	8,078	603	74.6	1,838	31
1959	11,271	859	76.2	1,544	30

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[1] Data not available for years 1889–1909.

TABLE 155.—*Production of manganese and manganiferous ores from the Appalachian Region, 1889–1964*—Continued

Year	Manganese ore, >35 percent Mn (short tons)	Value, in 1958 constant dollars (thousands)	Average value per short ton (1958 dollars)	Manganiferous ore, 5–35 percent Mn (short tons)	Value, in 1958 constant dollars (thousands)
1960	283	15	53.0	2,610	41
1961	-----	-----	-----	943	13
1962	-----	-----	-----	493	5
1963	-----	-----	-----	-----	-----
1964	-----	-----	-----	-----	-----
Total	456,078	24,535	-----	486,119	4,922

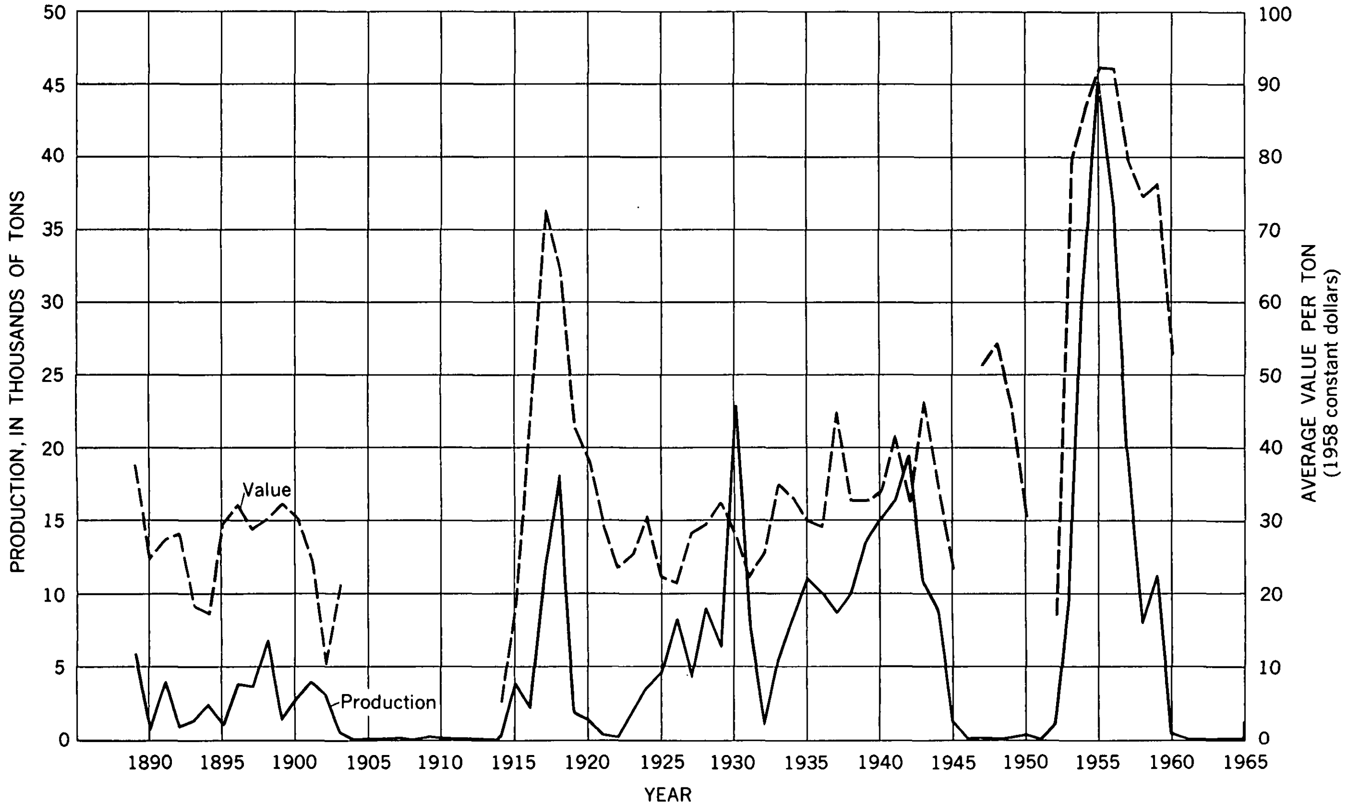

FIGURE 105.—Production and value of manganese concentrates in the Appalachian Region.

not economically at present prices. All three of these types of manganese minerals are known in Appalachia, but the oxides are the only ones that have been commercially exploited.

Hewett and Fleischer (1960, p. 7–20) cite many manganese minerals that have been found in deposits in Appalachia; the most common mineral is cryptomelane, followed by pyrolusite, psilomelane, hollandite, and lithiophorite. Manganite, reported from many deposits in the older literature, evidently does not occur. Wad, an amorphous manganiferous material of varying composition, is common. In this report, no attempt is made to distinguish the various manganese oxide minerals, most of which are virtually impossible to determine without the use of X-ray methods.

As illustrated in figure 106, manganese deposits in Appalachia are spread over a large area in Alabama, North Carolina, Georgia, Tennessee, Virginia, and West Virginia. Although perhaps 150 mines in 28 districts in the region have produced 50 tons or more, only a few mines were of appreciable size. Thus, during the period 1941–60, seven counties in the Appalachian part of Virginia produced 113,490 short tons of manganese ore; of these Smyth County produced 60 percent of the total production, and Bland County produced another 28 percent. The largest producing manganese mines in the east were in Augusta County, Va., but these are outside Appalachia, and their production is not included in the present statistics. In Tennessee, eight counties produced 84,830 tons of manganese ore

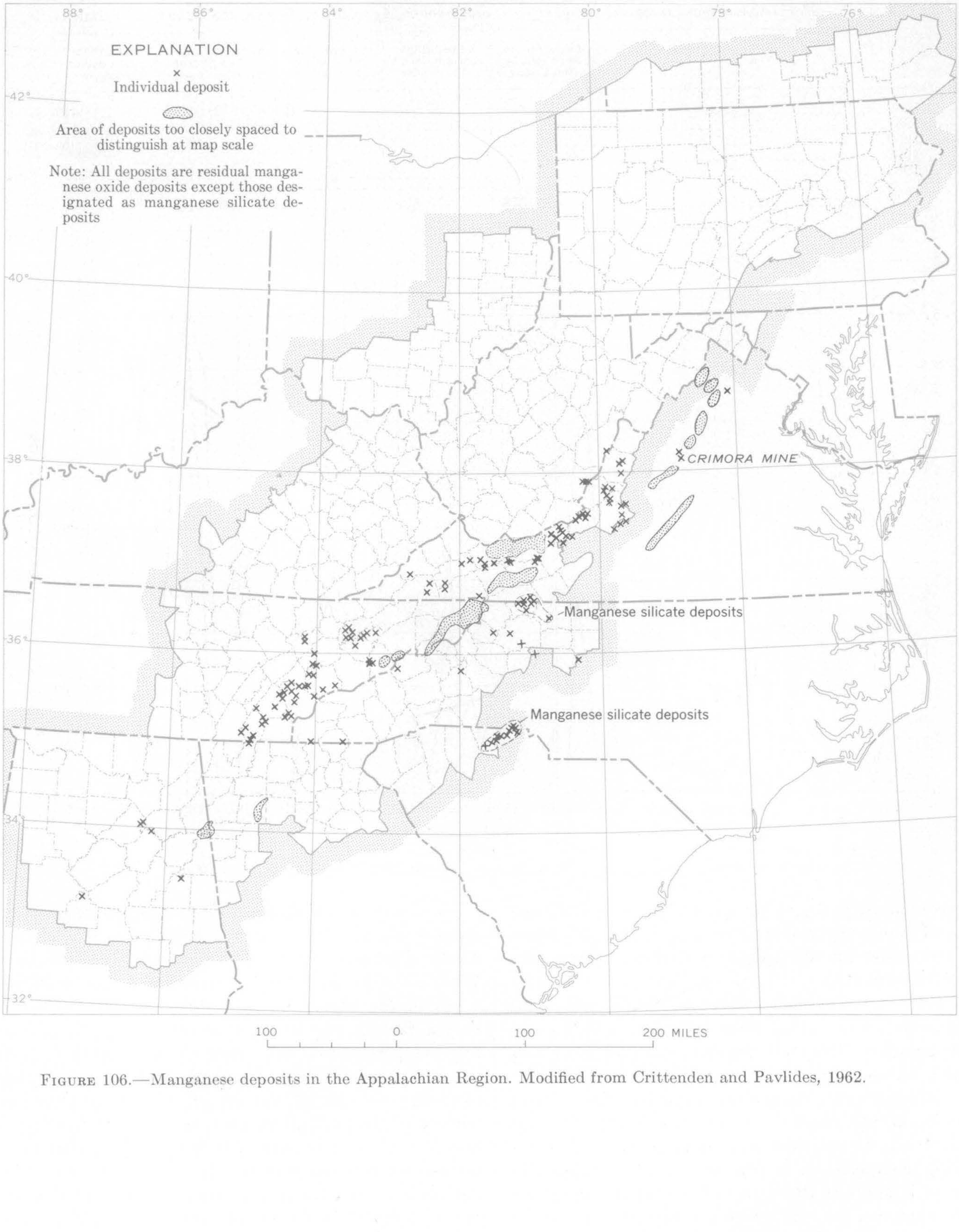

FIGURE 106.—Manganese deposits in the Appalachian Region. Modified from Crittenden and Pavlides, 1962.

during the same period; 51 percent of the total came from Johnson County and 36 percent came from Unicoi County. The only significant production from Georgia came from the Cartersville district (Kesler, 1950). North Carolina and Alabama have never produced significant quantities of manganese ore; 90 percent of the small West Virginia production came from Monroe County. Thus, although manganese production is widespread, the bulk of it came from few sources.

Manganese ore and manganiferous rock occur in three types of deposits in Appalachia: (1) as manganese carbonate in one or more veins or beds in the Sevierville area of eastern Tennessee; (2) as manganese oxide in residual clay and weathered Paleozoic sedimentary rocks in northeastern Alabama, northwestern Georgia, eastern Tennessee, and southwestern and western Virginia, and very locally, in southeastern West Virginia; and (3) as manganese silicate in schist in the Gaffney-Kings Mountain area of North and South Carolina. Economic or potentially economic deposits of manganese ore have not been found in the Appalachian parts of Maryland, Pennsylvania, or in other Appalachian States, although mineralogical occurrences are known.

Manganese silicate deposits in Surry County, N.C. (Ross and Kerr, 1932), and near Shooting Creek in Clay County, N.C., have attracted attention but have never been mined; they will not be discussed further.

MANGANESE CARBONATE DEPOSITS

Tabular bodies of manganese carbonate were explored in the East Fork district near Sevierville, Tenn., nearly half a century ago, and a small tonnage of manganese oxide derived by weathering from the carbonate was shipped (Reichert, 1942, p. 150–155). Efforts have been made to mine and calcine the manganiferous carbonate rock, which locally contains as much as 20 percent Mn, but the material has been too low grade and apparently the bodies are too small to support a continuing industry. If nearby phosphate zones in the wall rock prove to be economic, both manganese carbonate and phosphate perhaps can be mined simultaneously. (See "Phosphate in Appalachia" in the section on "Fertilizer Raw Materials" p. 281.) The carbonate might either be mixed with the phosphate rock as a fertilizer trace element, or its manganese content might be mechanically concentrated by standard methods. No significant quantity of the material is indicated by present exposures, but the deposit has not been thoroughly explored.

MANGANESE OXIDE DEPOSITS

Most manganese ore in Appalachia was produced from deposits resulting from concentration by weathering of small quantities of manganese originally present in certain sedimentary rocks. Two typical host rocks for such deposits are weathered quartzite or sandstone and a peculiar yellow and brown clay, locally known as buckfat clay, residual after carbonate rocks that were subjected to long-continued leaching and solution by meteoric waters. Of the two, residual clay is by far the more important as a source of manganese ore.

Although residual clay is a common weathering product of all carbonate rocks in the region, manganese ore occurs in minable quantities only in clay derived from a few formations, principally the Shady Dolomite, Tomstown Dolomite, and Rome Formation of Early Cambrian age (pl. 2, unit Ꞓml). By far the most productive has been the residuum derived from the Shady and Tomstown Dolomites.

The geology, occurrence, and environment of the manganese deposits and details of individual mines or mining districts are given in a series of reports on the manganese deposits of the eastern United States published during and shortly after World War II by the U.S. Geological Survey. These papers include: Stead and Stose (1943), Ladd (1944), Ladd and Stead (1944), and Miller (1944) on the manganese districts in the Virginia part of Appalachia; Reichert (1942) and King and others (1944) on the manganese deposits in Tennessee; Kesler (1950) on those in Georgia; and Pierce (1944) and Burchard and Andrews (1947) on those in Alabama.

Because the Shady and Tomstown Dolomites and the carbonate lenses in the Rome and other manganiferous carbonate formations are poorly exposed, cropping out only at widely spaced and erratic intervals, systematic sampling of the rocks is most difficult, and much remains to be learned of their composition. Several geologists, notably King (in King and others, 1944, p. 58) and Rodgers (1948, p. 39), have established that in many localities some of these carbonate rocks contain a small but significant percentage of manganese, very probably isomorphously substituting for calcium or magnesium in the calcite or dolomite molecule of the rock. This manganese is probably syngenetic, that is, was deposited as an original constituent of the rock rather than introduced from extraneous sources after the rock was consolidated. Whereas most carbonate rocks contain about 0.05 percent manganese or less, parts of the Shady have been shown to contain from 0.2 to more than 1.2 percent manganese. Concentration of such small quantities of manganese into higher grade bodies was first suggested by Weeks (1887) as the origin of the manganese ores found in the residuum of the Shady Dolomite.

Whether the small but abnormal percentage of manganese in these dolomites is relatively constant along strike is a question of much economic interest. If constant, the possibility of the existence of undiscovered manganese deposits in clay deposits hidden by talus or other surface debris is greatly enhanced, whereas, if the manganese content is sporadic along strike, the possibility would be reduced.

Residual clay deposits derived from the Shady and Tomstown Dolomites and the occurrence of the manganese oxides that have been commercially extracted from them are so similar throughout the region that they may be described collectively. Almost all the manganese oxide deposits in residual clay in Appalachia are found in the zone of complexly folded Paleozoic rocks of the Valley and Ridge province, or in windows in the Blue Ridge province. In the Valley and Ridge province, the valleys are in large part excavated in relatively nonresistant carbonate rock or shale; the ridges are formed of resistant quartzite, sandstone, or indurated siltstone. The most productive manganese deposits are in clay immediately above the resistant formations or, in part, the basal clastic rocks of the Lower Cambrian.

The manganiferous residual clay derived from the Shady or Tomstown Dolomites is found on the middle slopes of ridges of resistant basal clastic rocks. In any one district, the deposits are found within a rather narrow range of elevation, perhaps 200–400 feet; the range in elevation from district to district is much greater. The deposits commonly are at or near abrupt changes in slope where erosion stripped off the softer rocks from the upper and steeper parts of the linear ridges. King and others (1944, fig. 7) illustrate such typical valley profiles in eastern Tennessee.

The residual clay bodies at the break in slope range in thickness from a few tens of feet to as much as 250 feet. They are underlain by dolomite or quartzite and are overlain by younger talus and fanglomerate derived from the ridge above or by soil. In most places the talus and fanglomerate does not contain fragments of manganese oxide and thus definitely hinders ore discovery. On the other hand, soil derived from the clay commonly does contain fragments and nodules of manganese oxide, which are excellent guides for prospecting.

Residual clay has been found by drilling to be deepest adjacent to the insoluble quartzose rocks (Rodgers, 1948, fig. 3) in most well-explored areas. Judging from excavations observed by the writer in 1965, most manganese ore was extracted from clay within 100 or so feet of the contact between the clay and the underlying quartzose rocks. The residual clay is yellow, tan, or light brown, containing streaks of white and dark-brown material. It is cut by many slip planes resulting from readjustment of the plastic mass to solution of underlying carbonate rocks. Locally traces of the original rock structures may be preserved in the clay, but commonly these structures have been obliterated by the widespread slumping, settling, and compaction of the residual material.

Several types of manganese oxide occur in the deposits in clay, and individual deposits may have several types or only one. The soft manganese oxide used for batteries and certain chemical uses has the highest value but is the most difficult type to recover. This type, which is no longer recovered, consists of irregular bodies of pure pulverulant manganese oxide which were carefully extracted by hand to prevent contamination by clay. Most of these masses were small, and commonly no attempt was made to recover them because the ore could not be washed or concentrated. Only the larger and purer masses, perhaps several hundred pounds or more each, were recovered.

Manganese oxide also occurs as hard pure concretions of various sizes of as much as several hundred pounds but mostly in the range of less than an ounce to about a pound. Both hard and soft manganese oxides are found in veinlets, in impure sheets, and in lenses that are several feet to many tens of feet long and a foot or so thick. Exceptionally, the lenses are as much as 25 feet thick. The main production of manganese oxide came from these harder types of ore.

Manganese oxide in very low concentration is disseminated throughout some clay; this clay has a dark-brown hue called umberous. This material is of no present economic interest.

A few relatively unimportant deposits of similar type have been opened in residual clay derived from carbonate rocks of the Knox Dolomite of Late Cambrian and Early Ordovician age, from the Beekmantown Dolomite of Ordovician age, from the Tonoloway Limestone of Silurian age, from the New Scotland Limestone of Devonian age, and from the Fort Payne Formation of Mississippian age. The production of manganese ore from these deposits is a small fraction of that from the Lower Cambrian rocks.

Thus the manganese ore in the residual clay bodies occurs in generally irregular masses, commonly roughly tabular in form, ranging in size from small pellets to lenses and shoots several hundred feet long. The larger lenses are mixtures of barren clay and manganese oxide and are not composed of solid salable ore but rather of material which must be concentrated to be of marketable grade. King and others (1944, p. 69–70) say of eastern Tennessee, one of the most productive areas: "The manganese deposits in the residual clay of the Shady dolomite at most of the mines have supplied a few hundred tons or less each of concentrates, few deposits have produced 1,000 tons each, and, except for Bumpass Cove, the maximum yield from any single ore body has been less than 4,000 tons. All the manganese deposits in the residuum of the Rome formation have produced less than 500 tons of concentrates. The West Ore Bank in Bumpass Cove has produced at least 13,000 tons of concentrates." Although specific information about later mining activity in the area is lacking, there is no reason to suppose that larger individual bodies were discovered. The cumulative production of certain mines in the area increased during the 1950's through mining of newly discovered lenses and working of large masses of clay containing small pellets, concretions, and plates of manganese oxide, the grade of which was too low to be mined except under a subsidized price.

Manganese oxide in weathered quartzite and sandstone occurs in a different manner from that in the residual clay derived from carbonate rocks. Although some manganese oxide is found filling joints and on the surface of blocks of Lower Cambrian quartzite, undoubtedly derived from the manganiferous dolomite of the immediately overlying Shady Dolomite, the larger deposits, such as the Flat Top Mountain deposit (Ladd and Stead, 1944) in Bland County, Va., are associated with the Clinton Formation of Silurian age, the Becraft Limestone of Devonian age, or with still younger quartzose rocks. On weathering, the cement between individual sand grains in such rocks is dissolved and to some extent replaced by manganese oxide. The sand grains themselves may be replaced by manganese oxide in the more heavily mineralized zones. Brittle quartzite and sandstone are closely jointed in structurally favorable areas, as along the axes of anticlines and near faults. Manganese oxide is deposited in the fissures and on the joint faces and, in nodular form, in sandy clay derived by weathering from these rocks. The closely fractured and more permeable rock provided easy access to supergene mineralizing solutions, and replacement of the rock itself was facilitated. The source of the manganese introduced by these solutions and deposited in such an environment is not clear; it may have been concentrated from the rock itself but more probably was introduced from nearby manganiferous carbonate rocks undergoing weathering.

Much of the manganese ore in quartzite and sandstone is highly siliceous, but locally the replacement process went far enough to form ore of excellent quality. Such ore tends to occur in plates, chips, and other tabular forms rather than in pods, but some good-grade nodular ore is found as replacements at intersections of fractures and in strongly brecciated zones.

Structural control of manganese deposits is clear in some environments but obscure or lacking in others. The presence of subsidiary synclines at angles to the major structures favors concentration of manganese in residual clay deposits, probably because the solutions carrying the manganese dissolved from the carbonate rocks were directed toward fold axes (Stose and others, 1919, p. 52). However, many deposits also occur where crossfolds are absent. Major thrust faults have been important in the Sweet Springs district, Virginia and West Virginia (Ladd, 1944), and possibly elsewhere, but many major deposits occur where such faulting is absent. Localization of the deposits in quartzite and sandstone at Flat Top Mountain was strongly influenced by fracturing along the axis of an anticline.

GRADE OF ORE

Appalachian manganese ores were upgraded before being sold; information on the grade of these ores as mined is therefore not easily determined from available records. The grade of concentrates sold depended upon the cost of mining, cost of concentration, relative values of different grades of concentrates, loss during concentration, acceptability of different grades of concentrates on the market, and other factors. At times a large volume of relatively low grade concentrates was most profitable, whereas at other times the sale of a smaller volume of higher grade concentrates brought the greatest net return.

Ores from many manganiferous residual clay deposits were beneficiated to more than 40 percent Mn. Much was concentrated to more than 44 percent Mn, and shipments running 50 percent Mn or higher are recorded. On the other hand, records show that many mines produced concentrates of 36–40 percent Mn, with a high iron and high silica content. Concentrates from deposits in quartzite commonly contained more than 10 percent SiO_2, whereas those from the residual clay commonly were high in iron. The concentrates contained 0.1–0.2 percent phosphorus and several percent moisture. A few producers calcined their product to bring it to marketable grade.

The Crimora-Old Dominion deposit, although outside Appalachia, is probably typical of the more productive highly mechanized mines that worked deposits in residual clay. During the period 1943–46, two grades of concentrates were made, one averaging more than 44 percent Mn, the other about 39 percent (Eilertsen and Feiss, 1946, p. 33). The concentrates were either sold separately or were blended, depending on the market. Average grade for the 12,934 short tons shipped in 1944 was 41.9 percent Mn, 3.8 percent Fe, 10.8 percent SiO_2, 0.159 percent P, and 4.17 percent moisture.

Eilertsen and Feiss (1946, p. 32) report that during the same period of mining, 88.7 percent of the clay moved was sterile waste. The balance of the clay, some 167,000 cubic yards, was manganiferous and was processed in the mill. Approximately 20,000 tons of manganese concentrates averaging more than 40 percent Mn were recovered, plus about 5,000 tons of tailings containing about 20 percent Mn, which also were sold. Thus, about 125 tons of clay was moved per ton of concentrate recovered and about 14 tons of manganiferous clay was processed per ton of concentrate. These figures are approximate because the production figures for concentrates are order-of-magnitude only (Eilertson, oral commun., 1965).

Until four decades ago and in some places more recently, ore high in both manganese and iron was marketed as ferruginous manganese ore or manganiferous iron ore (table 155). A market for such ore and for limonite nodules and lenses no longer exists because the steel industry now uses higher grade raw material. This ore was, however, the basis for the scores of primitive forges and blast furnaces in the region during the 19th century. As may be seen in table 155, the unit value of such ore was very low, being closer to that of iron ore than of manganese ore.

Certain manganese deposits in Appalachia contain minor quantities of cobalt or lithium, but these metals have not been recovered. They are briefly discussed in the sections "Cobalt and Nickel" and "Lithium and Beryllium Minerals."

PROSPECTING, MINING, AND CONCENTRATION

During the century that manganese mining was active in the region, modes of finding new ore did not greatly change. The basic method was to locate float of manganese oxide and to dig in search for more. The most probable environments for manganese ore deposits are now known, so unfavorable ground now can be bypassed. Most new geophysical techniques developed during the last three decades offer little hope as exploratory tools in Appalachia, because ore bodies are small, diffuse, and erratic. However, Bloss and Steiner (1960, p. 1065) reported that at one locality in northeastern Tennessee chemical determinations of nickel in the ash of twigs and leaves seemed to be a reliable guide to manganese accumulations.

Deforestation and burning off of large areas during the 19th and early 20th centuries exposed many areas of soil which contained abundant signs of manganese; these were explored at the time. Today reforestation and the reduction of agricultural acreage is making the task of finding new areas of manganese float ever more difficult. Successful prospecting in the future will probably depend on meticulous and imaginative geologic analysis of structure and stratigraphy and geomorphology to indicate favorable zones for accumulation of manganese oxide in clay, followed by core drilling using the new heavy equipment recently developed for successful core recovery in unconsolidated material. New deposits undoubtedly can be found, but whether they will be minable will depend on their size, grade, and on prevailing economic conditions.

Extraction of ore in the early days was largely by underground methods because costs of moving sterile clay by hand were too high to permit opencut mining. Shovel mining and hydraulicking were used during and before World War I, but since then bulldozers, draglines, scrapers, and large power shovels have been used.

RESOURCE POTENTIAL

The Appalachian Region has produced about 500,000 tons of manganese concentrates since 1889, yet it is doubtful if measured reserves of manganese ore at any one time ever exceeded a few tens of thousands of tons. No measured reserves are known in the region at present (1966). Most of the more easily discovered ore bodies probably have been found, but new deposits undoubtedly remain to be found under the cover of talus and residual debris that mantles so much of the region. Their discovery will require detailed mapping of the geologic formations favorable to ore deposition, particularly the Shady and Tomstown Dolomites, and scrutiny of the overlying residuum. Improved geochemical techniques should assist in pinpointing areas of manganese oxide concentration. It is likely that ore deposits discovered in the future will be comparable in tonnage and grade to those already mined. Whether such deposits may be mined profitably will depend on a number of factors, including the mining and processing costs and the prevailing world prices of manganese.

Early concentration methods consisted largely of hand cobbing. During World War I, log washers and jigs, supplemented by hand cobbing, were the basic tools for concentration and remained so until the 1950's, when sink-float techniques were introduced which permitted the recovery of much fine ore that previously had been lost.

NIOBIUM (COLUMBIUM) AND TANTALUM

By Raymond L. Parker, U.S. Geological Survey, and
Robert G. Hobbs, U.S. Bureau of Mines

Niobium (columbium) and tantalum are rare metals that have become increasingly important in modern technology; they are used in certain electronic, nuclear, chemical, and high-temperature metallurgical applications. Both metals are used for vacuum tube elements. superconductors, and corrosion-resistant equipment and laboratory ware, and as constituents in special steels and high-temperature nonferrous alloys. These metals in the form of ferrocolumbium or ferrotantalum-columbium are used in the manufacture of some austenitic stainless steels. Niobium and tantalum carbides are used in hot-forging dies, cutting tools, and jet engine turbine blades. Niobium is used for cladding nuclear fuels and as an alloying addition to steels, whereas tantalum is used for capacitors, rectifiers, and surgical implants (Miller, 1959; Barton, 1962; R. J. Stevens, in U.S. Bur. Mines, 1965a, p. 253–261, 929–934).

Various acceptable but less satisfactory substitutes for niobium are: vanadium in stainless steel; molybdenum, vanadium, tungsten alloys, ceramics and ceramic coatings for high-temperature applications; and certain alloys of technetium, vanadium, tin, and gadolinium in applications to control nuclear fusion reactions (Stevens, in U.S. Bur. Mines, 1965a, p. 253–261).

Alternate materials for tantalum include aluminum, silicon, germanium, and selenium in rectifier applications and zirconium, titanium, and misch metal in vacuum tubes; platinum, niobium, and zirconium are possible replacement materials in applications where resistance to corrosion is necessary (Stevens, in U.S. Bur. Mines, 1965a, p. 929–934).

The United States is the world's largest consumer of niobium and tantalum, but it never has been a large producer; it relies almost entirely on foreign sources, principally Nigeria, Congo, Brazil, and Canada, for its ore supply. Critical shortages of these metals, caused by expanded wartime use, resulted in government allocation controls during World War II and the Korean conflict. From 1952 to 1955, domestic and foreign ores were purchased at bonus prices by the U.S. Government for stockpiling. The program was extended to 1958 for domestic ores.

U.S. imports and production and world production are shown in figure 107. During the last 12 years, imports of niobium-tantalum concentrates have ranged from the all-time high of 11,520,262 pounds in 1955 which reflected stock-pile purchasing to a low of 3,591,530 pounds in 1958. In 1963, 6,853,971 pounds of concentrates were imported. The United States' niobium-tantalum production reached a peak of 428,347 pounds of concentrates in 1958, most of which came from Idaho placer deposits. No domestic production has been recorded since 1959 (U.S. Bur. Mines, Minerals Yearbooks, 1959–64).

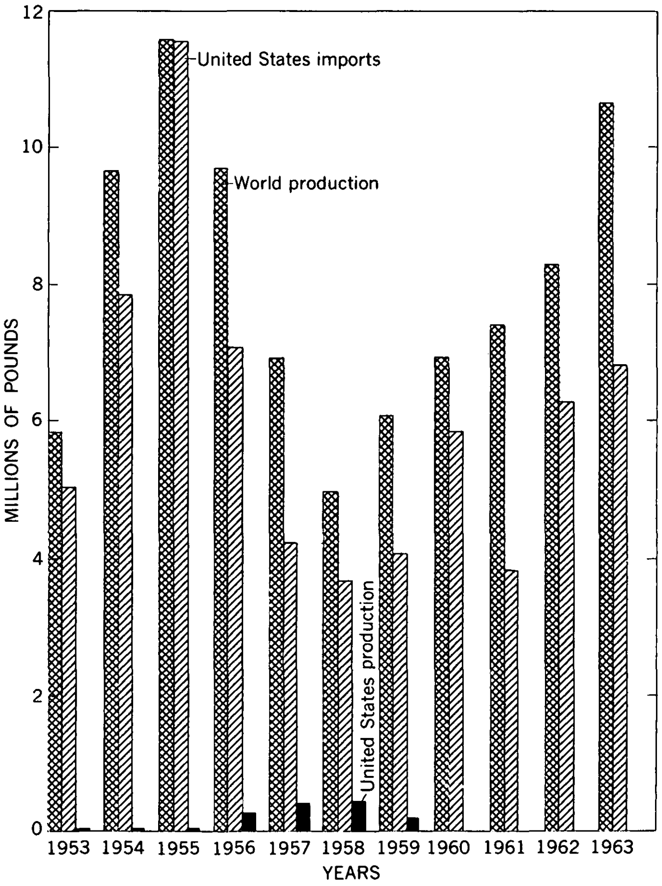

Figure 107.—World and U.S. production and U.S. imports of niobium and tantalum concentrates, 1953–63 from U.S. Bur. Mines, Minerals Yearbooks (1953–63).

Appalachia has yielded a small amount of niobium and tantalum in the form of columbite-tantalite and samarskite concentrates from pegmatites, principally in western North Carolina. Total recorded production of 15,627 pounds of concentrates (Barton, 1962, p. 83) came largely from the Spruce Pine and the Kings Mountain districts. The latter is a few miles outside Appalachia, in the tin-spodumene pegmatite belt.

Niobium and tantalum commonly occur together in nature as constituents of minerals that are compounds of niobium, tantalum, and oxygen with subordinate amounts of titanium, iron, manganese, rare-earth elements, uranium, thorium, and others. Important ore minerals are columbite-tantalite, $(Fe,Mn)(Nb,Ta)_2O_6$; pyrochlore, $NaCaNb_2O_5F$; microlite, $(Na,Ca)_2Ta_2O_6(O,OH,F)$; euxenite, $(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$; fergusonite, $(Y,Ce,U,Th)(Nb,Ta)O_4$; and samarskite, $(Fe,Y,U)(Nb,Ta,Ti)_2O_6$.

Niobium and tantalum minerals are found in granitic rocks and pegmatites, in alkalic rock complexes and associated carbonatites, and in placers derived from these rocks. Some granite masses contain disseminated columbite-tantalite, euxenite, or other niobium-tantalum-bearing minerals as primary rock constituents, and in some places in the world, weathering and fluvial processes have concentrated these minerals into commercial placer deposits. Pegmatites are well known for their concentrations of rare minerals, including those of niobium and tantalum; unusually rich deposits of this type in Africa and South America continue to be the principal source of the world's tantalum. Most pegmatites, however, contain only small to negligible amounts of niobium-tantalum minerals and do not constitute economic deposits.

Large low-grade deposits of niobium occur in alkalic rock complexes and carbonatites in many parts of the world. Niobium is contained in the mineral pyrochlore, which is disseminated in the carbonatites. Some multimillion-ton deposits are known in central Africa, southeastern Canada, Norway, and Brazil. Several of these deposits are being explored or developed and are expected to be the chief source of niobium in future years. At least five alkalic complexes with carbonatites have been found in the United States, none of which are yet known to contain pyrochlore in commercial concentrations.

Pegmatites are the only known source of niobium and tantalum in Appalachia. Those containing niobium and tantalum minerals are largely restricted to western North Carolina, principally in the Spruce Pine district (Brobst, 1962) and the tin-spodumene belt (Griffitts, 1954). Several other scattered occurrences are reported by J. F. Conley (1958). Geologic work (Griffitts and others, 1953) has not shown a widespread or generally abundant occurrence of niobium-tantalum minerals. Inasmuch as niobium-tantalum minerals are minor accessory constituents, they may have escaped detection in other pegmatites in the extensive pegmatite belt that extends along the east edge of Appalachia from Alabama to Virginia.

Several areas of alkalic intrusive rocks exist in Appalachia and adjacent regions; they range from peridotite to nepheline syenite in composition (Charles Milton, written commun., 1965; Bates and Bell, 1965). So far as known, however, neither concentrations of niobium of commercial interest nor carbonatites have yet been found associated with these rocks.

Columbite, fergusonite, and samarskite have been identified in the sands of Brindletown Creek in Burke County, N.C. (Conley, 1958, p. 16). Other local concentrations of niobium-tantalum minerals may be found in Appalachia in valley gravels.

The known niobium-tantalum-bearing pegmatites of Appalachia cannot be considered to be commercial deposits, and they do not constitute significant resources of these elements. Although small amounts of niobium-tantalum minerals conceivably could be produced as byproducts of the recovery of other pegmatite constituents, the small scale of most pegmatite mining and milling operations coupled with the low tenor of niobium and tantalum in pegmatites offers little promise for future exploitation.

It is possible that local concentrations of niobium-tantalum minerals can be found in the Appalachian Region in some placer deposits. Even though potential amounts are small, these minerals might be recovered as byproducts of mining for other heavy metals and minerals.

Experience in the years 1952–58 indicates that Appalachian pegmatites can furnish only a very small percentage of national needs, even when bonuses above market prices are offered.

SILVER

By Gwendolyn W. Luttrell, U.S. Geological Survey, and Robert G. Stansfield, U.S. Bureau of Mines

Silver, a gray-white lustrous metal, is the best metallic conductor of heat and electricity and is second only to gold in malleability. It has many industrial uses and long has been used in coinage. The principal industrial uses of silver are in the photographic and electrical industries and in manufacture of sterling silverware and electroplate, jewelry, silver solder and brazing alloys, and dental amalgams. Silver solders and brazing alloys are used extensively in the electric appliance, air-conditioning, automotive, and aircraft industries. These and other industries also consume substantial quantities of silver for electrical contacts.

A large and important substitution for silver was provided for by the Coinage Act of 1965, Public Law 89–91. This legislation provided for new U.S. subsidiary coinage; silver was eliminated from the dime and quarter, and a composite coin substituted with a cupronickel surface and a copper core. The act also reduced the silver in the half dollar from 90 to 40 percent.

The silver compounds used on photographic paper for office copy work have been replaced in large measure by an electrostatic duplicating process. Stainless steel has replaced quantities of silver in the manufacture of tableware. Tantalum can be used in place of silver in surgery for sutures, pins, and plates.

Appalachia has no ores mined primarily for silver, but silver has been recovered as a byproduct from ores of lead, copper, and gold. The silver content of these ores ranges from a trace to 3 ounces per ton in concentrates of base metals. In lead-zinc deposits, silver occurs in galena in the form of minute inclusions of argentite, tetrahedrite, tennantite, or other silver-containing minerals, or if the galena contains antimony as an impurity, replacing antimony in the galena crystal itself. In zinc deposits carrying very little galena, silver has been found associated with sphalerite, possibly as inclusions of silver-bearing tetrahedrite or tennantite (A. V. Heyl, Jr., written commun., 1965). The silver in copper deposits is thought to be incorporated in chalcopyrite, bornite, enargite, or chalcocite. Minor quantities of copper-silver minerals in the deposits, such as tetrahedrite, tennantite, or stromeyerite, contribute some silver. A small amount of silver is naturally alloyed with gold. Pardee and Park (1948, p. 29) stated that the amount of silver in Appalachian gold is commonly about 10 percent, and rarely is more than 20 percent by weight. Unalloyed native silver was recovered at places in lode gold mines of Appalachia.

Deposits of lead-zinc, copper, and gold which contain silver are shown on the accompanying map (fig. 108) and table (table 156). Silver has not been produced from every deposit shown, but all are known to carry at least traces of silver in the ore. The only mines listed that were operating in 1966 are those at Ducktown, Tenn., and Austinville, Va. However, no silver production has been recorded for Virginia since 1959 because the concentrates from this district have been shipped to smelters out of the State, where the silver is recovered.

Appalachian silver production has come almost entirely from Tennessee and North Carolina. Silver output in Appalachia in 1964 totaled 91,000 troy ounces, valued at $116,000 (1958 constant dollars), recovered as a byproduct of sulfide ores mined in the Ducktown district, Tennessee. The 4.38 million troy ounces mined in Appalachia from 1905 through 1964 (table 157) amounted to about 0.1 percent of the national output for the period. Of this Appalachian output, Tennessee produced 93.2 percent, North Carolina 6.2 percent, and the remaining 0.6 percent was divided among Virginia, Alabama, Georgia, and South Carolina. The Tennessee production of 4,100,000 troy ounces of silver, valued at $5.5 million (1958 constant dollars), from 1905 through 1964 was a byproduct of copper ores of the Ducktown district. From 1905 through 1962, the Appalachian counties of Ashe, Burke, Caldwell, Cherokee, Henderson, Jackson, Macon, Polk, Rutherford, Swain, and Yadkin, N.C., produced 270,000 troy ounces of silver valued at $267,000 (1958 constant dollars). Peak production from this area was 30,000 troy ounces in 1930, largely from copper sulfide ores mined in Swain County. This crude ore was shipped to a smelter in the Ducktown district, Tennessee, until production ceased in 1944. The Appalachian counties of Wythe and Floyd, Va., produced 16,000 troy ounces of silver from 1911 through 1959. Production of silver from Chilton, Clay, Cleburne, Randolph, Talladega, and Tallapoosa Counties in Alabama amounted to 5,000 troy ounces from 1905 through 1941; only 11 ounces was produced after 1937. In this same period, Georgia produced less than 2,000 troy ounces from Bartow, Carroll, Cherokee, Dawson, Douglas, Forsyth, Habersham, Haralson, Lumpkin, Paulding, Rabun, and White Counties; only 20 ounces has been produced since 1941.

Lead-zinc deposits occur in the Valley and Ridge province in folded and faulted dolomite and limestone of early Paleozoic age as described in the section on "Zinc and Lead." The silver content of galena in these lead-zinc ores is low but variable, ranging from traces to several ounces per ton in galena concentrates. Silver has been produced as a byproduct of the lead-zinc ores of the Austinville-Ivanhoe district in Wythe County, Va. There the ores occur along the limb of an anticline in brecciated dolomite of Cambrian age. Small amounts of silver have been reported in lead-zinc ores of Tennessee and Pennsylvania, but silver has not been recovered from these ores.

Copper deposits in Appalachia that carry byproduct silver include copper-bearing, massive pyrrhotite-pyrite ores and copper and gold ores in mineralized shear zones. These deposits are described in the section on "Copper and Sulfur." The copper-bearing pyrrhotite-pyrite ores in Appalachia lie in a narrow belt in the southern part of the Blue Ridge province. Another belt of massive sulfide deposits lies in the Piedmont province east of Appalachia (fig. 98). Silver content of massive sulfide ores ranges from traces in the ore of the Gossan Lead (Corriveau, 1956, p. 13) to as much as 2.49 ounces per ton in ore of the Stone Hill mine, Alabama (Espenshade, 1963, p. 44).

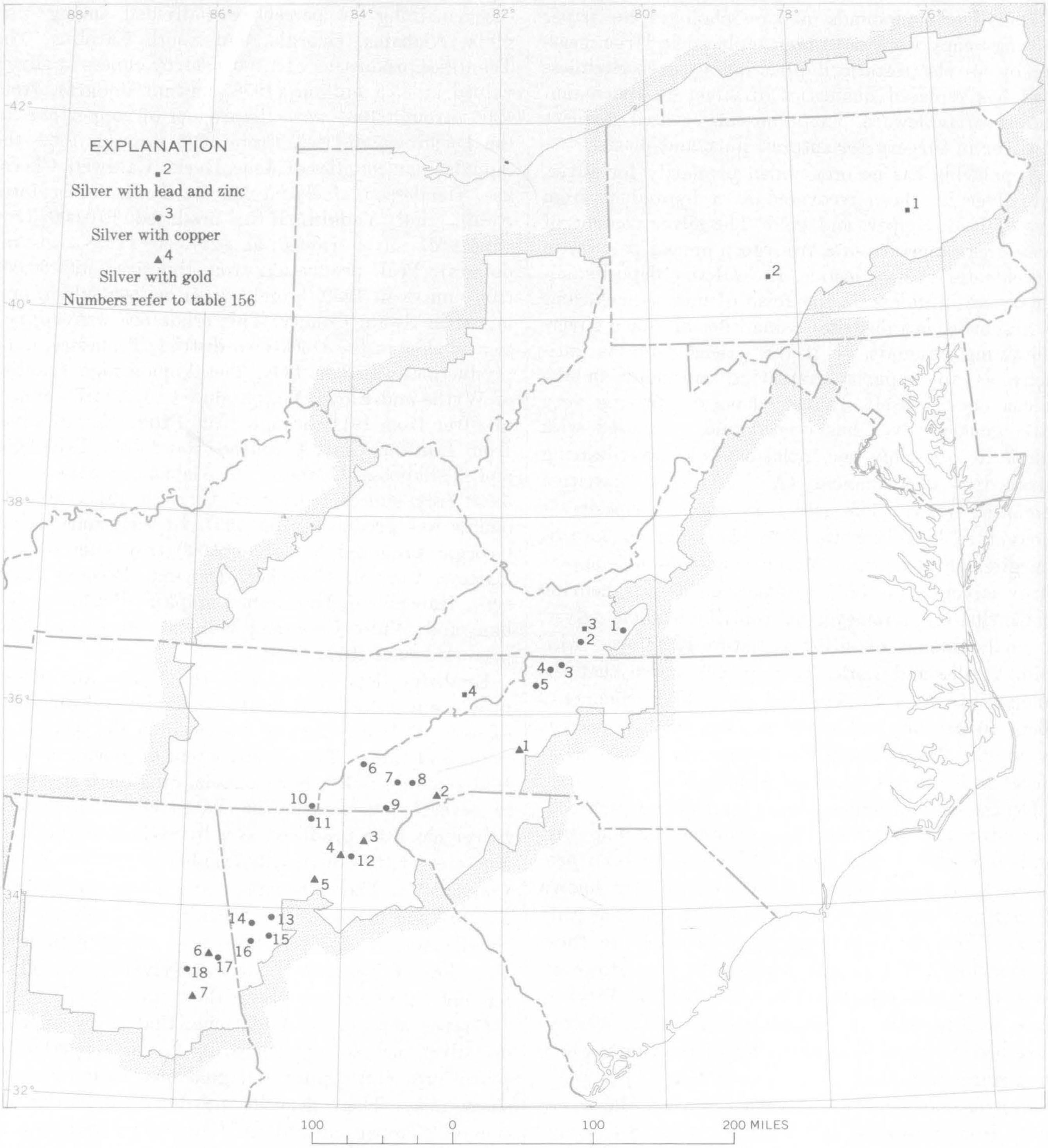

FIGURE 108.—Silver occurrences in the Appalachian Region.

TABLE 156.—*Silver-bearing lead-zinc, copper, and gold deposits in the Appalachia Region*

No. (fig. 108)	Mine; county, State	Grade of silver (if known) and source of information
	Lead-zinc deposits	
1	Almedia; Columbia, Pa.	
2	Sinking Valley; Blair, Pa.	1.5 oz per ton in a sample of galena (A. V. Heyl, written commun., 1965).
3	Austinville; Wythe, Va.	As much as 3 oz per ton in galena concentrate. (Currier, 1935, p. 76.) Recovered commercially.
4	Embreeville; Washington, Tenn.	3 oz per ton in a sample of galena (A. V. Heyl, written commun., 1965).
	Copper deposits	
1	Sutherland and Toncrae-Howard; Floyd, Va.	
2	Gossan Lead; Carroll, Va.	Trace (Corriveau, 1956, p. 13).
3	Peachbottom; Alleghany, N.C.	Silver in galena (Ross, 1935, p. 86).
4	Ore Knob; Ashe, N.C.	0.09 oz per ton of ore (Kinkel, 1962, p. 1116). Recovered commercially.
5	Gap Creek; Ashe, N.C.	
6	Hazel Creek and Fontana; Swain, N.C.	1.37 oz per ton of enriched supergene ore, and 0.385 oz per ton of ore (Espenshade, 1963, p. 24). Recovered commercially.
7	Savannah; Jackson, N.C.	
8	Cullowhee; Jackson, N.C.	0.4 oz per ton of ore (H. F. Kendall, 1953, p. 121). Recovered commercially.
9	Otto (Cabe); Macon, N.C.	
10	Ducktown; Polk, Tenn.	0.1 oz per ton of ore (R. A. Laurence, written commun., 1965). Recovered commercially.
11	No. 20; Fannin, Ga.	
12	Chestatee; Lumpkin, Ga.	
13	Little Bob; Paulding, Ga.	
14	Tallapoosa; Haralson, Ga.	0.97 oz per ton (Ballard and McIntosh, 1948, p. 5).
15	Villa Rica; Carroll, Ga.	
16	Reeds Mountain; Carroll, Ga.	
17	Stone Hill; Cleburne, Ala.	2.49 oz per ton in vein (Espenshade, 1963, p. 44). Recovered commercially.
18	Pyriton; Clay, Ala.	
	Gold deposits	
1	Brindletown; Burke, N.C.	
2	Fairfield Valley; Transylvania, N.C.	
3	Nacoochee: White, Ga.	
4	Dahlonega; Lumpkin, Ga.	
5	Creighton; Cherokee, Ga.	
6	Arbacoochee; Cleburne, Ala.	
7	Hog Mountain; Tallapoosa, Ala.	

TABLE 157.—*Production of silver, 1905–64*

[Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Troy ounces	Value, in 1958 constant dollars (thousands)	Troy ounces (thousands)	Value, in 1958 constant dollars (thousands)
1905	95,815	231	56,102	135,266
1906	25,767	66	56,518	146,016
1907	59,010	146	56,515	139,700
1908	61,476	224	52,441	102,375
1909	65,745	121	54,722	101,263
1910	70,352	132	57,138	107,131
1911	107,021	190	61,109	108,684
1912	90,671	178	66,034	129,748
1913	108,323	202	71,187	132,706
1914	97,610	156	69,623	111,602
1915	100,727	98	72,354	87,965
1916	94,881	149	78,857	124,433
1917	100,027	173	70,662	122,319
1918	95,449	173	68,059	123,520
1919	98,315	177	51,897	93,451
1920	110,728	165	56,539	84,303
1921	98,766	135	46,333	63,384
1922	78,355	126	61,208	98,722
1923	105,715	144	70,356	95,832
1924	94,785	110	64,071	74,139
1925	102,964	122	66,710	79,140
1926	104,009	119	62,487	71,285
1927	81,467	84	59,626	61,470
1928	94,602	100	57,872	61,332
1929	102,392	97	60,860	57,513
1930	113,671	79	47,725	33,226
1931	61,325	36	29,857	17,634
1932	29,345	19	22,740	14,845
1933	51,337	43	23,131	19,322
1934	71,276	103	32,782	47,411
1935	55,496	91	48,519	79,800
1936	55,648	99	61,153	108,632
1937	54,874	93	71,409	120,600
1938	45,255	62	61,706	85,419
1939	37,257	55	64,373	94,991
1940	43,915	67	70,436	107,714
1941	44,246	62	67,048	94,594
1942	40,393	48	54,091	64,864
1943	59,211	66	41,461	45,923
1944	48,323	48	34,474	34,287
1945	35,785	33	29,024	27,192
1946	18,016	19	22,915	24,108
1947	79,160	87	35,824	39,202
1948	39,695	42	38,096	39,951
1949	41,833	44	34,675	36,156
1950	39,958	41	42,459	43,769
1951	24,960	24	39,767	38,208
1952	57,569	55	39,452	37,427
1953	70,104	67	37,571	36,058
1954	62,532	61	36,941	35,988
1955	68,469	68	37,198	36,632
1956	66,752	64	38,722	36,926
1957	67,913	65	38,165	35,104
1958	61,772	57	34,111	30,872
1959	76,924	70	31,194	27,843
1960	87,296	78	30,766	27,598
1961	108,730	100	34,794	31,973
1962	118,145	127	36,798	39,656
1963	107,913	137	35,243	44,896
1964	90,539	116	36,334	46,745
Total	4,380,609	5,944	2,990,234	4,198,865

The copper-bearing shear zones occur mostly in the Piedmont province, only the southern part of which is included in Appalachia. These deposits consist of stringers and lenses of quartz containing copper sulfides and gold, and minor amounts of lead and zinc sulfides, along shear zones in silicified schist. Silver may be present as argentiferous galena as well as alloyed with gold.

Silver production has been reported from copper ores from the Ore Knob, Cullowhee, Peachbottom, Fontana, and Hazel Creek mines in North Carolina, the Stone Hill mine, Alabama, and from the Ducktown district, Tennessee.

Silver-bearing gold deposits in the Piedmont province lie in a belt 10–100 miles wide, partly in the Appalachia area in Alabama, Georgia, and North Carolina, and partly east of Appalachia (fig. 99). The deposits are described in the section on "Gold." The gold deposits occur in quartz veins, in decomposed residual rock material termed saprolite, and in stream placers.

Byproduct silver has been reported from the southeastern gold ores since the 1880's. Pardee and Park (1948, p. 30) estimated that gold bullion produced in Georgia contained about 105 parts of silver per 1,000 and gold from Alabama contained about 140 parts of silver per 1,000.

Because silver has been a byproduct of the recovery of other metals in Appalachia, its future is closely tied to production of gold, lead-zinc, and copper. Careful but imaginative exploration should result in discovery of additional deposits similar to those now known.

THORIUM AND RARE-EARTH METALS

By JOHN W. ADAMS, U.S. Geological Survey, and GEORGE E. FISH, Jr., U.S. Bureau of Mines

INTRODUCTION

Thorium and the rare-earth metals are treated together in this report because they are commonly associated in nature and are closely related economically. They are found in a large number of minerals, only a few of which, however, are at all common or have been found in sufficiently large concentrations to be considered as ore. The most widely used source material is monazite, a rare-earth phosphate that is also the principal ore mineral of thorium. Bastnaesite, a rare-earth fluo-carbonate, less common than monazite, is another important source of rare earths. Both monazite and bastnaesite contain predominantly cerium-group rare earths. Minerals in which the yttrium group predominate are xenotime, a yttrium phosphate, and samarskite and fergusonite, both multiple oxides of yttrium, niobium, thorium, and other elements. (See section on "Niobium (columbium) and Tantalum.") Minable deposits of yttrium-rich minerals are uncommon, but xenotime has been obtained from monazite placers at Aiken, S.C., and euxenite (an oxide of rare earths) has been recovered on a large scale from placers at Bear Valley, Idaho. Less common ores of thorium include thorite (thorium silicate) and thorianite (thorium oxide).

Thorium is a silver-gray metal which, like uranium, is the parent of a series of radioactive-decay products ending in a stable isotope of lead. Its geochemical behavior, however, is quite different from that of uranium because thorium tends to be dispersed rather than concentrated in significant deposits and it is relatively stable during weathering. Thorium is obtained chiefly from the mineral monazite, and to a lesser extent as a byproduct of uranium production.

The most important uses of thorium are in magnesium alloys and thoria (ThO_2) gas mantles. Thoria is also used as a refractory, a catalyst, and in tungsten filaments (Kelly, 1962, p. 25–28). Thorium consumption for nonenergy purposes from 1951 through 1959 is presented in table 158.

Thorium may become an important nuclear fuel. The common naturally occurring isotope Th^{232} is not itself fissionable, but can be transmuted in atomic reactors into the fissionable uranium isotope U^{233} by neutron capture (Olson and Overstreet, 1964, p. 1; C. T. Baroch, in U.S. Bur. Mines, 1965a, p. 952). By this process, potential resources of nuclear energy can be greatly increased. Three power reactors that use thorium and have a total capacity of 315 megawatts have been built in the United States (Baroch, in U.S. Bur. Mines, 1965a, p. 952–953). The use of thorium

TABLE 158.—*Thorium consumption (pounds of contained ThO_2) for nonenergy purposes, 1951–59*

[Because thorium was classified as a source material under the Atomic Energy Act of 1954, AEC authorization was necessary for any purchase of thorium by industry. In 1956, AEC discontinued statistical compilations of reports of company purchases and sales of thorium and thorium compounds. Therefore, data represent authorization for purchase of thorium through 1955 and estimated use for 1956–59. Source: Kelly, 1962, p. 26]

Use	1951	1952	1953	1954	1955	1956	1957	1958	1959
Magnesium alloys	---	---	3, 600	4, 647	23, 944	50, 000	100, 000	120, 000	136, 000
Gas-mantle manufacture	31, 132	25, 427	8, 707	9, 765	44, 566	40, 000	40, 000	40, 000	45, 000
Refractories and polishing compounds	3, 382	1, 157	236	24	105	200	---	5, 000	5, 000
Chemical and medical products	6, 246	11, 064	5, 179	3, 738	3, 898	4, 000	4, 000	6, 000	5, 000
Electronic products	1, 457	277	1, 222	2, 016	926	1, 000	1, 000	1, 000	1, 000
Total	42, 217	37, 925	18, 944	20, 190	73, 439	95, 200	145, 000	172, 000	192, 000

for nuclear energy is, however, in the experimental stage and is in competition with relatively low-cost and abundant uranium (Kelly, 1962, p. 25). A summary of Atomic Energy Commission (AEC) activity in thorium for fiscal years 1959–64 is shown in the following table.

Thorium activity of AEC, fiscal years 1959–64, in thousands of pounds

[From C. T. Baroch, in U.S. Bur. Mines, 1965a]

	1959	1960	1961	1962	1963	1964
Procurement	124. 1	96. 1	31. 7	0. 6	0. 8	0. 7
Consumption	15. 4	25. 7	132. 2	50. 6	72. 9	135. 4
Disposal	4. 3	----------	4. 8	----------	5. 6	. 1
Material on hand at end of fiscal year	3, 793	3, 864	3, 758	3, 708	3, 630	3, 496

The rare-earths metals comprise the 15 elements having atomic numbers 57–71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). These elements are commonly called the lanthanide series in reference to the first number of the group. One of the lanthanides, promethium, had been known only as an artificially produced isotope until its recently reported discovery (Erämetsä, 1965) as a trace constituent of the rare earths recovered from apatite in a phosphate plant in Finland. Yttrium (Y), atomic number 39, although not a lanthanide, is classed with the rare earths because of its similar chemical behavior and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium subgroup of rare earths, so-called because cerium is their most abundant member. The remaining eight elements (Gd through Lu), together with yttrium, are called the yttrium subgroup. The two groups are also referred to respectively as the "light" and "heavy" rare earths. The properties of the members of the two subgroups are sufficiently distinct to cause one to predominate over the other in a given deposit, even though all or nearly all are ordinarily present.

THE NATIONAL INDUSTRY

The rare-earth industry is developed largely around the cerium subgroup elements obtained from the minerals monazite and bastnaesite. The major U.S. source of rare-earth metals is bastnaesite produced in California. Concentrates of monazite and bastnaesite containing more than 4,400 short tons of rare-earth oxides apparently were processed in the United States in 1965 (J. G. Parker, in U.S. Bur. Mines, 1965a, p. 753). The rare earths contained in concentrates are converted into a variety of products, including cerium oxide, salts of the elements in varying degrees of purity, and misch metal, which is a mixture of the rare-earth metals.

For most industrial uses, materials containing several of the rare earths in partly purified compounds are satisfactory. Products equivalent to about 1,800 tons of rare-earth oxides are used each year in these bulk applications (Chem. Eng. News, 1965, p. 79) which include glass-polishing powders, cores for arc-light carbons, cracking catalysts, and the manufacture of misch metal used for sparking alloys and in metallurgical applications.

The development of ion-exchange techniques for the separation of rare-earth elements has made high-purity metals and compounds available at greatly reduced cost and has thus stimulated research into applications where their individual properties may be useful. A small but growing part of the industry produces these purified materials, for research and for newly discovered uses, which so far have been largely in the fields of nuclear energy and electronics. Two of the largest applications are the manufacture of synthetic yttrium-iron garnets for electronic use, and the recently publicized development of new red phosphors employing europium-doped yttrium-vanadium compounds for use in color television tubes (Chem. Eng. News, 1965, p. 84–85).

The rare-earth industry is faced with many problems resulting from the complex relationship of the suite of rare-earth elements in raw materials and from involvement with the political and strategic policies in this and foreign countries on exploitation of monazite because of the potential nuclear applications of its contained thorium (Parker, in U.S. Bur. Mines, 1965a, p. 767).

THE INDUSTRY IN APPALACHIA

Although deposits of thorium and rare-earth-bearing materials are not being mined within Appalachia at present, they have been mined in the past, mainly in North Carolina and to a lesser extent in South Carolina. Monazite was discovered in the southern United States in 1879 in the headwater tributary of Silver Creek at Brindletown, Burke County, N.C. Placer mining began in the western counties of the Carolinas in 1886, and the first shipments were made in 1887. However, production was not recorded until 1893, which was also the first year of recorded monazite production in the United States. Tonnage mined in South Carolina is not known, although in 1907 about 15 percent of the combined production from the Carolinas came from this State (Thom, 1908, p. 16). The production from North Carolina, shown in table 159, came from 12 counties (Pratt, 1916, p. 50–53) of which 6 are within Appalachia. Production from South Carolina came from 7 counties (Pratt, 1916, p. 50) of which 5 are within Appalachia.

DEPOSITS IN APPALACHIA

Most thorium and rare-earth minerals are found in Appalachia in two distinct types of occurrences: (1) as accessory minerals in igneous and metamorphic rocks, and (2) in placer deposits. Veintype deposits are also known, but appear to have little possibility for exploitation.

Areas or localities where thorium or rare-earth minerals are found in igneous or metamorphic rocks (fig. 109) are listed in table 160 by number. Figure 109 also shows the region of placer deposits in the southeastern monazite belt.

Granites, pegmatites, gneisses, and schists, the chief host rocks for the rare-earth minerals, are found in Appalachia in the interior parts of the Carolinas and in northern Georgia and Alabama. In such rocks, monazite and allanite (a rare-earth-bearing mineral related to epidote) are the most common thorium- and rare-earth-bearing species, but lesser amounts of xenotime and various multiple oxide minerals may be present. According to Overstreet (1960, p. B56),

TABLE 159.—*Monazite production in North Carolina, 1893–1910*

[Source: Pratt, 1916, p. 53]

Year	Production (pounds)	Value, in 1958 constant dollars
1893	130, 000	35, 680
1894	546, 855	180, 965
1895	1, 573, 000	721, 848
1896	30, 000	8, 287
1897	44, 000	10, 939
1898	250, 776	71, 651
1899	350, 000	101, 522
1900	908, 000	234, 640
1901	748, 736	270, 602
1902	802, 000	280, 174
1903	773, 000	249, 761
1904	685, 999	328, 254
1905	894, 368	424, 209
1906	697, 275	479, 047
1907	456, 863	130, 426
1908	310, 196	135, 853
1909	391, 068	167, 003
1910	83, 454	35, 083
Total	9, 675, 590	3, 865, 944

TABLE 160.—*Thorium and rare-earth occurrences*

Occurrence (fig. 109)		Thorium and rare-earth minerals	Reference(s)
Map No.	Locality; county, State		
1	Jefferson area; Ashe, N.C.	Allanite and (or) gadolinite	Councill (1955); Stow (1955).
2	Pearson prospect; Johnson, Tenn.	Thorite, unidentified rare-earth minerals in radioactive zone in pegmatite.	
3	Walnut Mountain; Carter, Tenn.	Veins containing magnetite and zircon with thorium and rare-earth minerals.	Olson and Adams (1962).
4	Wilkesboro area; Wilkes, N.C.	Allanite in pegmatites and hornblendic rocks.	Councill (1955).
5	Spruce Pine district; Yancey, Mitchell, and Avery, N.C.	Allanite, monazite, samarskite, and euxenite in pegmatites.	Maurice (1940); Olson (1944); Parker (1952).
6	Hiddenite area; Alexander, N.C.	Monazite in pegmatites	Palache, Davidson, and Goranson (1930).
7	Lemon Gap and Max Patch areas; Madison, N.C.	Allanite in pegmatites	J. F. Conley, (1958).
8	Mars Hill; Madison, N.C.	Monazite in pegmatite	Schaller (1933).
9	Bryson City area; Swain, N.C.	Allanite in pegmatites	Councill (1955); J. F. Conley (1958).
10	Zirconia district; Henderson, N.C.	Xenotime, polycrase, cyrtolite, monazite, and auerlite.	Olson (1952); J. F. Conley (1958).
11	Cashiers district; Jackson and Transylvania, N.C.	Samarskite in pegmatites	Olson (1952).

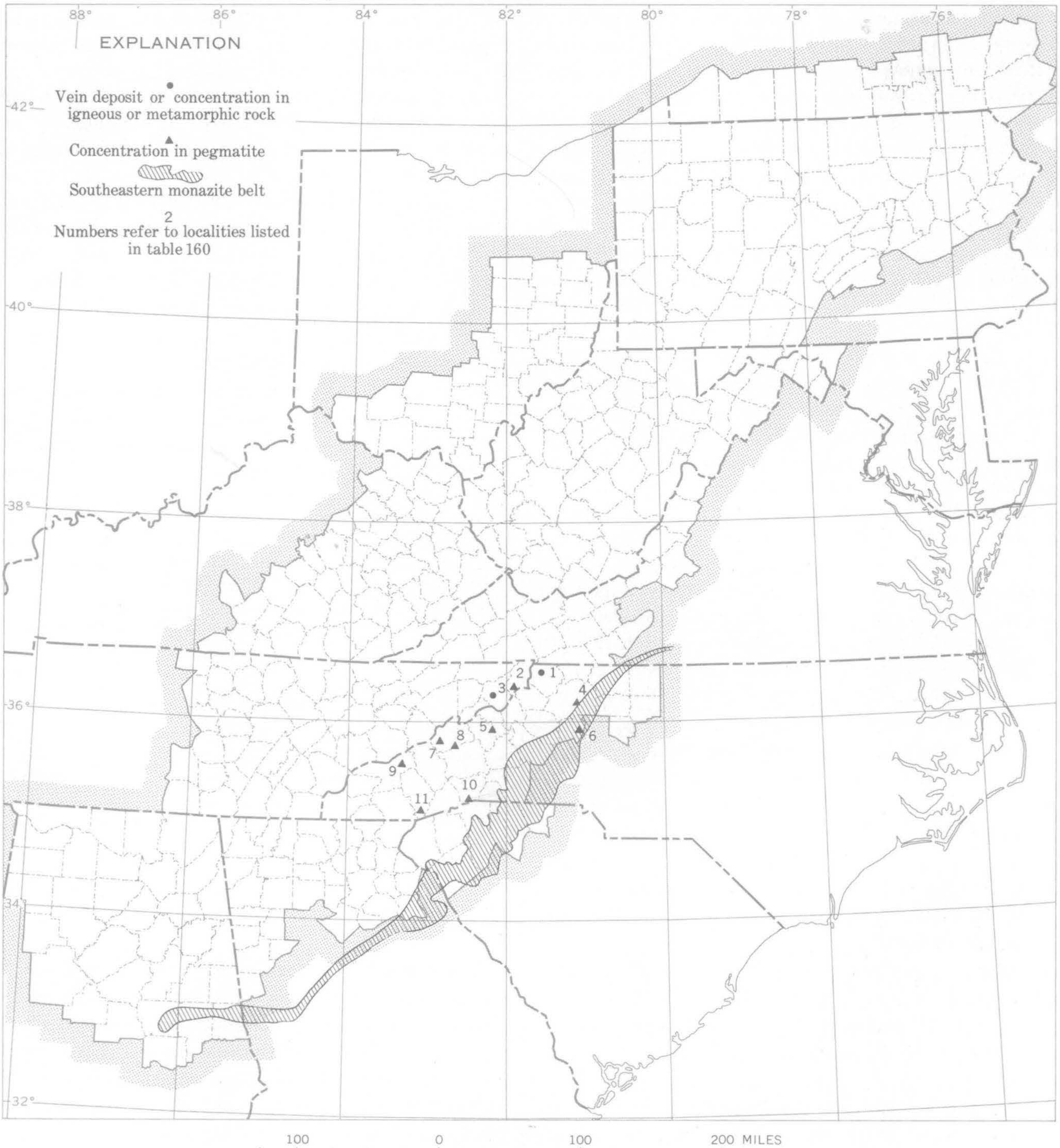

FIGURE 109.—Thorium and rare earths in the Appalachian Region. From Mertie (1953) and Overstreet, Theobald, and Whitlow (1959).

accessory monazite is more abundant in granites of deep rather than shallow origin, and in the more intensely metamorphosed rocks. Although these crystalline rocks contain only sparse and uneconomic concentrations of these minerals, they represent vast low-grade sources from which these minerals, after release by weathering, become available for concentration in placer deposits. An allanite-rich granite body near Elberton, Ga., which contains about 45 parts per million thorium, was investigated for the feasibility of extracting the thorium directly by chemical leaching methods (Olson and Overstreet, 1964, p. 16–17).

The thorium and rare-earth minerals are present as very small grains in most igneous and metamorphic rocks. They occur as much larger crystals in pegmatites, which consist largely of coarse-grained quartz, feldspar, and mica. Pegmatites (described in this report in the sections "Mica" and "Feldspar," p. 311, 277) are found in the crystalline rocks in the Piedmont and Blue Ridge provinces of southern Appalachia. They are particularly numerous in western North Carolina where they have been extensively mined for mica and feldspar, and where in certain districts (fig. 109; table 160) they contain thorium and rare-earth minerals. Some notable occurrences are Mars Hill in Madison County (No. 8), the Zirconia district (No. 10), and the Spruce Pine district (No. 5). Although thorium and rare-earth minerals may be abundant locally and in easily recoverable masses in the pegmatites, they are generally too sporadic in occurrence and not in sufficient quantity in any single deposit to constitute minable ore. They may, however, be recovered during mining operations for other commodities and are the sources of specimen material sold to collectors, schools, and museums.

Thorium, rare-earth elements, and niobium are present in anomalous amounts in veintype deposits at the Walnut Mountain prospect in Carter County, Tenn. (No. 3). The veins occur in a granitic host rock, seemingly along shear zones.

Accumulations of monazite in placers are the most important type of thorium and rare-earth deposit found in Appalachia. The deposits are largely restricted to beltlike areas, as described by Mertie (1953, 1957). The longest and most continuous belt is shown on figure 109. Within its wider part are the placer deposits that have been mined and the flood plains that were evaluated for monazite content by the U.S. Bureau of Mines and the U.S. Geological Survey.

The monazite placers are in locally derived alluvial sediments covering the floors of shallow narrow valleys underlain by deeply weathered monazite-bearing rocks. Generally, the alluvial sediments consist of a lower layer of quartz pebbles, gravel, and sandy clay, in which the monazite occurs, overlain by clay, silt, and sand. Monazite placers are highest in grade near the headwaters of streams and become larger but less rich downstream.

Overstreet and others (1959) examined hundreds of flood plains for possible placers of monazite in various drainage basins (table 161). The average thickness of alluvium in these flood plains is about 15 feet, and underlying gravels are about 1.5 feet thick. Few flood plains containing placers are more than 2–3 miles long and average about 7 million cubic yards in volume. The sediments contain from less than 0.1 to 50 pounds of monazite per cubic yard. In the 84 flood plains considered to be potential placers, the average tenor is 1.3 pounds of monazite per cubic yard (Overstreet and others, 1959, p. 712).

TABLE 161.—*Resources of thorium and rare-earth metals in explored alluvial monazite deposits between Savannah and Catawba Rivers, South Carolina-North Carolina*

[Modified from Overstreet and others, 1959]

River drainage basin	Monazite (includes traces of xenotime)			
	Short tons	ThO_2		Rare-earth oxides[1] (short tons)
		Percent	Short tons	
Savannah (in South Carolina)	59,000	4.21	2,000	32,450
Saluda	73,000	5.96	4,000	40,150
Enoree	44,000	5.56	2,000	24,200
Tyger	42,000	5.77	2,000	23,100
Pacolet	76,000	5.04	4,000	41,800
Broad	345,000	5.94	20,000	189,750
Catawba (southern tributaries in North Carolina)	145,000	4.39	6,000	79,750
Total	784,000		40,000	431,200

[1] Assumed 55 percent.

The heavy-mineral assemblage found in the monazite placers may include other thorium- or rare-earth-bearing minerals such as xenotime and the black multiple-oxide minerals. Xenotime makes up as much as 20 percent of the heavy minerals in some placers, but is less than 1 percent in most (Overstreet and others, 1959). Because of the increasing uses of heavy rare-earth metals, the xenotime content of placers may attract more interest than in the past. Xenotime and monazite may be recognized and distinguished in concentrates by the use of the hand spectroscope (Mertie, 1953, p. 5; J. W. Adams, 1965).

Multiple oxide minerals, chiefly fergusonite, samarskite, and euxenite, are found as brown to black radioactive grains in placers, but not in sufficient quantity to be of commercial interest.

RESOURCE POTENTIAL

Thorium and rare-earth minerals are in monazite-bearing placers of the Piedmont province. Although the total resources of monazite in Appalachia are large, the monazite-bearing deposits are widely dispersed and range from placers that are large and low in grade to others that are small and high in grade.

Placers in flood plains are estimated to contain 784,000 short tons of monazite. To this may be added an estimated 250,000 short tons of monazite present in small, but commonly rich, placers found at the heads of creeks (Overstreet and others, 1959, p. 714). The 1,034,000 tons of monazite is estimated to contain 53,000 short tons of thorium oxide and 568,700 tons of rare-earth oxides.

The deposits do not appear to be economically competitive with other sources of thorium and rare earths at present. They may, however, become minable in the future if other minerals such as gold, cassiterite, zircon, ilmenite, and rutile all can be recovered concurrently from these alluvial concentrations.

TIN

By C. L. SAINSBURY, U.S. Geological Survey, and
JOHN W. SWEENEY, U.S. Bureau of Mines

Tin is a silvery white metal with an unusual combination of properties—low fusibility, malleability, resistance to corrosion and fatigue, and ability to combine with other metals as an alloy. Uses of tin are as a protective coating for copper, steel, and other stronger metals; in soft solders and lead-tin coatings for steel sheet (terneplate); in making bronze and brass; and in die casting and producing babbitt, pewter, and type metal. Organo-tin compounds are used as stabilizers in plastics, wood preservatives, fungicides, insecticides, and similar materials (J. E. Shelton in U.S. Bur. Mines, 1965a, p. 961–970).

Total tin production in the United States has been insignificant, and the Nation is dependent upon foreign sources for nearly all its tin. More than one-third of the total free world tin production is consumed in the United States. In 1964, a small tonnage of tin concentrate was produced at the Meeke-Hogan mine, Kern County, Calif. Some tin concentrate was recovered as a byproduct of molybdenum mining at the Climax mine in Colorado, and a small tonnage was produced in Alaska. Production and value are withheld to avoid disclosing individual company data.

DEPOSITS IN APPALACHIA

Although tin deposits are known in several areas of Appalachia, there has been no output since 1942. Known deposits are either too small or too low in grade to permit profitable operation. Many attempts have been made to exploit them, but all have been unsuccessful (A. H. Reed, Jr., 1950a).

Cassiterite was discovered in Coosa County, Ala. (fig. 110), in 1880, but little or no prospecting was done until about 1930 when W. M. Hoyt, a prospector, located virtually all the known occurrences of tin in Coosa County. Prospecting continued between 1939 and 1943. In 1940, three corporations were formed to undertake the development and mining of tin deposits. Production is recorded for the years 1941 and 1942. In 1943, another company was formed and started operations at the old Coosa Cassiterite mine (F. R. Hunter, 1944, p. 61). Before the mill closed, about 5 tons of concentrate was shipped to Sewaren, N.J., for smelting.

In 1903, cassiterite was discovered near Gaffney, Cherokee County, S.C., and considerable prospecting was done. The Ross mine was developed and a small amount of tin concentrate was shipped in 1903 and 1904 (Pratt and Sterrett, 1904, p. 64) and in 1937. There has been no recorded production from this area since that time.

Small amounts of tin have been produced sporadically in North Carolina since 1903, mostly in the Kings Mountain area just east of Appalachia. Beginning in 1951, tin was produced in this district as a byproduct of spodumene concentration by the Foote Mineral Co., but the tonnage has been small (Broadhurst, 1955, p. 25).

A group of small tin deposits lie in a linear belt, mostly outside of Appalachia, along the east flank of the Blue Ridge from central Alabama to west-central Virginia. The total production has not exceeded a few hundred tons of tin metal, and no large reserves or resources are known. However, small placers containing tin might be mined profitably under conditions of high prices.

Most of the lode deposits can be classed as vein deposits of two main types: (1) quartz veins or quartz-pegmatite veins and (2) greisen veins. Of the first group, those deposits commonly referred to as being part of the "tin-spodumene belt" are most numerous and best known. Most of the deposits in this belt, however, are just outside the boundary of Appalachia (fig. 110). According to Kesler (1942), 91 deposits are known in an area 24.5 miles long and 1.8 miles wide. The bedrock of the area consists of early Paleozoic schists, gneisses, quartzites, and marble intruded by granitic stocks and batholiths. Within the belt are many pegmatites consisting principally of quartz and albite and lesser amounts of microcline and spodumene. Cassiterite occurs in small amounts in some of the quartz pegmatites, as well as in greisenized parts of

FIGURE 110.—Tin deposits in the Appalachian Region.

some. Beryl and columbite-tantalite also occur in some of the pegmatites. Kesler (1942, p. 254) pointed out that the spodumene is of greater commercial importance than the cassiterite, and Griffitts (1954) has shown that the pegmatites contain beryl which might be recovered as a byproduct of pegmatite mining. A small amount of byproduct tin concentrates was recovered from spodumene ores in 1951–53. Tin is not currently being recovered.

In Coosa County, Ala., a second belt of tin deposits in pegmatites and quartz-pegmatites or quartz veins, described by F. R. Hunter (1944) and several others, is commonly called the "Alabama tin belt." It is some 15 miles long and 2–3 miles wide. The belt is similar to the tin-spodumene belt of the Carolinas, for the bedrock consists of schists and gneisses that are intruded by granitic rocks. These rocks are cut by pegmatites and quartz veins, some of which contain cassiterite but not commercial amounts of spodumene. Cassiterite also occurs in the country rock adjacent to pegmatites or quartz veins, generally in a quartz-muscovite greisen that may also contain topaz and tourmaline. Only a small percentage of the pegmatites and quartz veins contain noticeable cassiterite, and although mining has been attempted on a few of these, no sustained activity has been recorded.

Elsewhere along the eastern border of Appalachia, tin-bearing greisens are known outside the main belts described, and small-scale mining has been attempted at Irish Creek, Va., and at the Ross mine in South Carolina. At the Brewer mine, cassiterite is associated with gold in pyritiferous veins (the veins cut altered slate) containing quartz and topaz.

Small placers are associated with many of the tin lode deposits, and a few have been mined to some extent. No large placer deposits have been found, although it is apparent from the literature that all placers have not been systematically evaluated. Some gravel deposits contain as much as 12–75 pounds of cassiterite per yard (Pratt and Sterrett, 1904, p. 23), but such deposits are of limited size and are restricted to small areas near outcropping lodes.

RESOURCE POTENTIAL

Lode and placer tin deposits occur in the Piedmont province, but the amount of tin that might be recovered from them is limited. It appears that few, if any, of the known lode deposits can be exploited, principally because the amount of tin in individual deposits is too low to permit the amortization of mills. The possibility for finding larger or higher grade lode deposits is poor. On the other hand, small placers containing several pounds of tin per yard could be mined, and present evidence indicates that such deposits do exist in Appalachia.

In discussing the grade of lode ores in the Alabama tin belt, Hunter (1944, p. 43) concluded:

> The overall grade of the tin ore can best be calculated from the amount of tin recovered at the Coosa Cassiterite Mill. Much of the ore had been sorted by hand, and therefore, was somewhat richer than that blasted from the deposits, but losses in milling somewhat compensated for the hand concentration and the recovery is probably a fair measure of the average grade of the ore. This ore was removed from three pegmatites. Figures supplied by Mr. Charles A. Dean (1942) of the Coosa Cassiterite Mine are here reproduced by his permission. During the six months of operation approximately 10,000 pounds of rather pure cassiterite concentrate were recovered from 888 tons of rock. Thus the ore carried approximately 0.56 per cent of SnO_2 by weight.

W. R. Griffitts (unpub. data, 1964) estimated that the pegmatites in the tin-spodumene belt in the Carolinas contain an average of 0.025 percent of tin, and that the belt as a whole may contain 15,000 tons of cassiterite in the spodumene pegmatites.

Kesler (1942, p. 261–262) estimated ores in 10 deposits of the tin-bearing spodumene belt to comprise 12,500 tons containing possibly 1.5 percent tin.

TITANIUM

By NORMAN HERZ, U.S. Geological Survey, and
NILS A. EILERTSEN, U.S. Bureau of Mines

PRODUCTION AND USE

The United States is the largest producer and processor of titanium mineral concentrates and slags in the world and the largest consumer of titanium products. In 1964, the gross weight of titanium mineral concentrates produced in the United States was in excess of 1 million short tons, about 36 percent of estimated total world production. United States consumption (including titanium-bearing slag from Canada) amounted to 1,188,075 tons of raw material (Stamper, 1965b, p. 1076–1077). The titanium industry is based on three principal source materials: ilmenite, rutile, and titanium slag.

Rutile (TiO_2) and ilmenite ($FeTiO_3$) are the most important commercial minerals of titanium. Anatase (TiO_2) and alteration products of ilmenite are also recovered from some placer deposits. Both rutile and ilmenite are found in primary or lode deposits in igneous or metamorphic rocks and in alluvial or eluvial deposits, including placers, beach sands, saprolite, and bauxite. United States ilmenite production is from anorthosite deposits in New York, saprolite deposits in Virginia, and heavy mineral sands in Florida and New Jersey. Rutile is produced from saprolite in Hanover County, Va., and from beach sands in Florida.

Titanium compounds and metal have many industrial uses, the greatest by far being the manufacture of titanium dioxide (TiO_2) to produce pigment. This pigment is largely used in the paint and paper industries, but also in such products as floor coverings, rubber, textiles, printing ink, roofing granules, ceramics, and fiberglass (Lavis, 1965, p. 13–14). Because of its stability, nontoxicity, and superior covering power in paints, the production of titanium pigment (TiO_2) in the United States has had phenomenal growth. In 1934, it was estimated to be 32,000 tons and in 1964 it had risen to 555,211 tons (Stamper, 1965b, p. 1078). Most titanium pigment is manufactured from ilmenite by the sulfate process in which both the iron and the titanium are dissolved by concentrated sulfuric acid and subsequently separated.

Since 1958, the chloride process for making titanium pigment from rutile has become commercially important. Titanium tetrachloride ($TiCl_4$) also is produced in this process and is used to manufacture titanium metal. Pure rutile is used in welding rod coatings.

Domestic production of rutile concentrates in 1964 amounted to only 8,062 short tons valued at $1,016,000, while imports were 110,981 short tons, up from 71,990 tons imported in 1963 (Stamper, 1965b, p. 1076). U.S. ilmenite production in 1964 was 1,001,132 tons, valued at $19,178,000, and imports were 119,819 tons (Stamper, 1965b, p. 1076–1077).

Titanium metal has many important uses because of its light weight, high melting point, high strength to weight ratio, toughness, resistance to creep and buckling, and better fatigue strength than either aluminum or steel; it also is nonmagnetic. Its principal uses either as a metal or in alloys are in air frames, jet engines, missiles, and space craft. Titanium is resistant to attack by salt water and marine atmosphere as well as by wet chlorine, nitric acid, and many organic solutions, which makes it useful in equipment subject to chemical corrosion, such as in salt-water desalinization plants, and in chemical processing plants.

Appalachia is both a consumer of titanium minerals and a manufacturer of titanium products (fig. 111). However, titanium minerals are not currently (1966) being produced in Appalachia and therefore are imported.

DEPOSITS IN APPALACHIA

Titanium minerals are not now being produced in Appalachia, but a considerable quantity was produced during the period 1942–52, when the Yadkin Mica and Ilmenite Co., a subsidiary of the Glidden Co., operated an open-pit mine and mill at the Yadkin Valley ilmenite deposit near Richlands, Caldwell County, N.C. During that period the mill recovered 215,400 tons of mineral concentrate averaging 51 percent TiO_2 (Williams, Lloyd, 1964, p. 28) from crude ore containing 30–35 percent TiO_2 (Gillson, 1949, p. 1052). Although core drilling proved the deposit to extend downdip, no underground mining was attempted.

A rutile deposit at Shooting Creek, N.C., was prospected intermittently by various companies, most recently by the American Smelting & Refining Co. in 1955–56 (Stuckey, 1965, p. 339–340). Lloyd Williams (1964, p. 19) quoted an unpublished estimate that reserves would furnish 172,000 short tons of concentrate containing 40 percent recoverable TiO_2.

The titanium-mineral-producing areas nearest to Appalachia are in Amherst and Hanover Counties, Va. Weathered nelsonite, an apatite-ilmenite rock, was mined in Nelson County, Va., from 1930 to 1958, and a titanium pigment plant was built at Piney River to treat the ilmenite concentrate. The operation was acquired in 1944 by the American Cyanamid Co. The deposit was mined out by 1958, and the company started mining a large deposit of ilmenite-bearing saprolite nearby in Amherst County. M & T Chemicals, Inc., recovers ilmenite and rutile from a saprolite deposit at Beaver Dam, Hanover County. Rutile was also mined from 1900 until 1949 by the American Rutile Co., at Roseland, Nelson County.

Primary titanium deposits in bedrock are found in a belt that trends from Piney River, Nelson County, Va., to Shooting Creek, Clay County, N.C., a distance of about 340 miles (fig. 111). They consist of ilmenite and titaniferous magnetite associated with rutile in places. They occur with very little gangue in veins conformable to the structural trends of the country rock (Bayley, 1923, p. 250).

Although the geology of most of the primary titanium deposits of Appalachia is not well known, many are found in metamorphic rocks such as gneiss and schist, and fewer are in intrusive igneous rocks, such as syenite, gabbro, and pegmatite (table 162). This distribution is in contrast to that in other regions including the Piney River, Va., district where the most abundant and largest titanium deposits are in anorthosites and related gabbros.

Residual weathering of these primary deposits has resulted in the formation of saprolite deposits which are richer in titanium than the primary deposits. In the weathering process, silicate minerals are leached, with consequent enrichment in heavy minerals, including titanium oxides. All the important primary deposits in and near Appalachia have an enriched saprolite zone of this type.

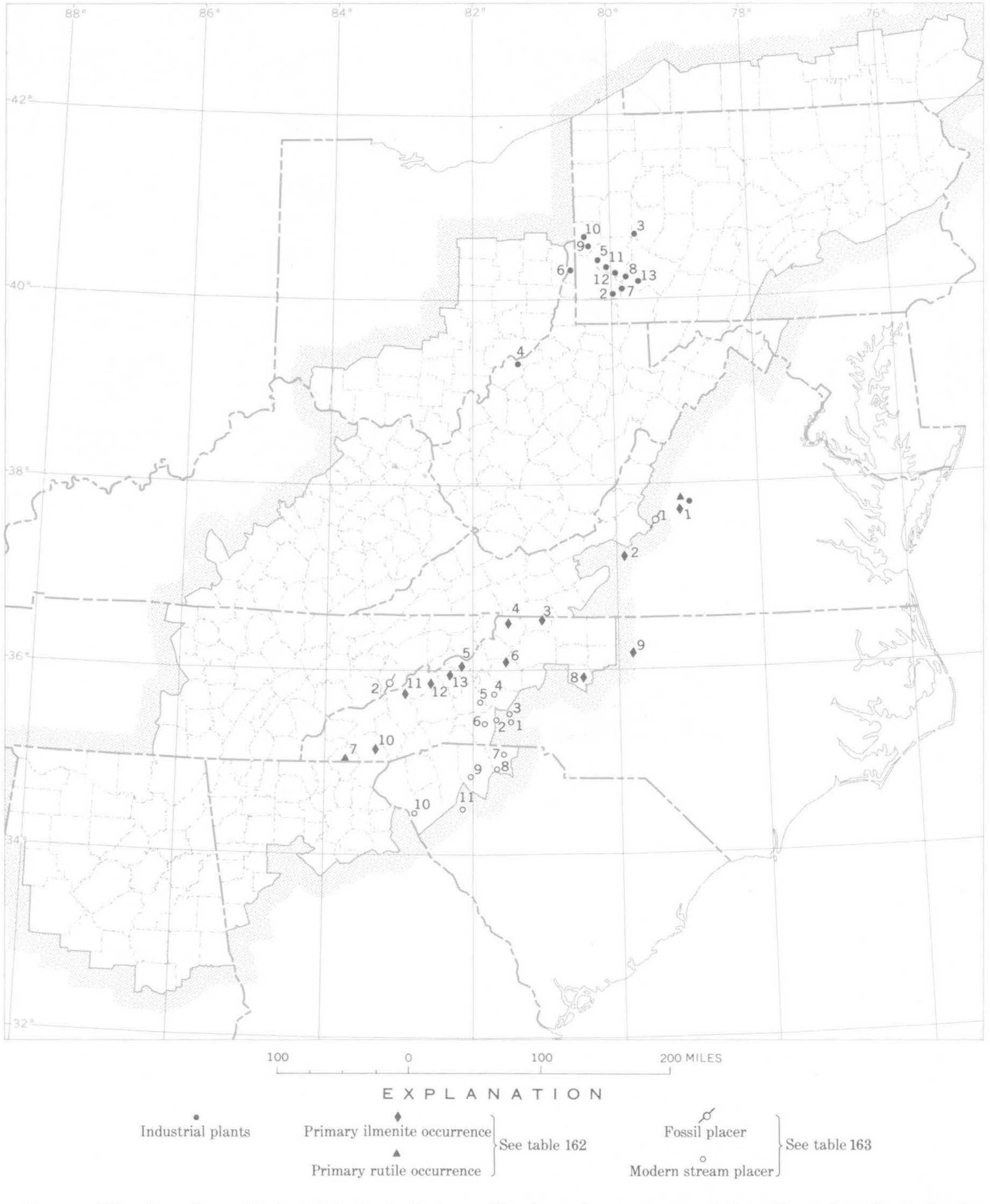

FIGURE 111.—Location of industrial plants that use titania, and occurrences of ilmenite and rutile in the Appalachian Region. 1. American Cyanamid Co., Piney River, Va.; 2. Corning Glass Co., Charleroi, Pa.; 3. Pittsburgh Plate Glass Co., Ford City, Pa.; 4. L. O. I. Glass Fiber Co., Parkersburg, W. Va.; 5. Federal Enameling & Stamping Co., McKees Rocks, Pa.; 6. Wheeling Tile Co., Wheeling, W. Va.; 7. American Chain & Cable Co., Monessen, Pa.; 8. Westinghouse Electric Co., Trafford, Pa.; 9. Crucible Steel Co. of America, Midland, Pa.; 10. Babock & Wilcox Co., Beaver Falls, Pa.; 11. U.S. Steel Co., Pittsburgh, Pa.; 12. Firth Sterling, Inc., McKeesport, Pa.; 13. Kennemetal, Inc., Latrobe, Pa.

TABLE 162.—*Primary titanium* (Ti) *deposits and their secondary accumulations in the Appalachian Region*

State, county	No. (fig. 111)	Deposit	Ore minerals	Description of deposit	References
Virginia:					
Amherst, Nelson [1].	1	Piney River and others.	Largely ilmenite, some rutile.	Saprolite derived from nelsonite dikes and mafic rocks. Reserves greater than 20 million tons.	Ross (1941); Fish (1962).
Roanoke [1]	2	Bush-Hutchins, Vinton.	Ilmenite	Nelsonite dikes, 8.4 percent TiO_2, with ilmenite-apatite-magnetite in syenite and greenstone.	Watson and Taber (1913, p. 235–247).
North Carolina:					
Alleghany, Grayson (Va.).	3	Carrico Pits, Alleghany County Ti-magnetite belt.	Ti-magnetite, ilmenite.	Ti-magnetite and ilmenite disseminations, mineralized zone 2,000 ft long, lenses about 25 by 100 ft in hornblende schists locally altered to steatite. Ore has 4.9 percent TiO_2.	Singewald (1913, p. 84).
Ashe	4	Ashe County titanium belt.	Ti-magnetite, ilmenite, rutile.	Lenses are wide as 25 ft in belt 2.5 miles long in hornblende schist partly altered to asbestos. Ore has 4.7–9.2 percent TiO_2.	Singewald (1913, p. 84); Broadhurst (1955, p. 26).
Avery, Mitchell, Carter (Tenn.).	5	Roan Mountain, Pumpkin Patch Mountain, Iron Mountain belts.	Ti-magnetite	Lenses as wide as 5.5 ft; about 12 deposits in hornblende gneiss, schist, and pegmatite; 4.5–6.8 percent TiO_2.	Singewald (1913, p. 92–93); Bayley (1923, p. 220–231).
Caldwell	6	Richlands Cove, Yadkin River Valley.	Ilmenite, minor rutile.	Ore zone, 1,000 ft long and 20–50 ft thick, of ilmenite in small masses in talcose rock conformable to mica schist, quartzite, gneiss. Drilling shows zone to be continuous for at least 500 ft down dip and to average 35 ft thick. 215,400 tons concentrate produced 1942–52, with average of 51 percent recoverable TiO_2.	Singewald (1913, p. 84–85); Lynd (1960, p. 859); Bryant and Reed (1966, p. 4–5).
Clay, Towns (Ga.).	7	Shooting Creek	Rutile, minor ilmenite.	Rutile associated with sugary quartz in garnet mica schist in 10-mile-long belt. Deposits are residual and small placers. 68,000 tons TiO_2 recoverable reserves.	E. C. Van Horn (unpub. data, 1945); Lloyd Williams (1964, p. 18–19).
Davie	8	Near Mocksville	Ti-magnetite	Veins in hornblende-rich syenite, also placers. Ore has 8.0–10.3 percent TiO_2.	Singewald (1913, p. 86).
Guilford, Rockingham, Davidson [1].	9	Tuscarora-Shaw belts.	Ti-magnetite, ilmenite, rutile.	Two parallel belts 30 miles long, 3 miles apart, lenses few inches to 8 ft thick as segregations in gabbrol. Ore has 12.0–14.5 percent TiO_2.	Singewald (1913, p. 86–91); Lloyd Williams, (1964, p. 40–42.)
Macon	10	Culasagee Creek	Ti-magnetite	Surficial residual float in a quartz and chlorite gangue. Ore 3.2–17.6 percent TiO_2.	Singewald (1913, p. 91).
Madison	11	New Found Mountain (Spring Creek).	do	Vein 5–6 ft wide. TiO_2 is 7.4 percent.	Singewald (1913, p. 92).
	12	Ivy Creek	Ti-magnetite, rutile.	In float and placers, concentration averages 37.9 percent ilmenite.	Singewald (1913, p. 92); Lloyd Williams (1964, p. 22).
Yancey	13	Hampton place and others.	Ti-magnetite, rutile or brookite.	Ore is in a vertical bed 6–10 ft thick; gangue is chlorite, quartz, feldspar; ore grade 11.9 percent TiO_2, nearby placers yield concentrates containing 14-20 percent ilmenite.	Singewald (1913, p. 93); Lloyd Williams (1964, p. 23).

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[1] Adjoins Appalachia.

The ilmenite deposits of Yadkin Valley (Richlands) and the rutile deposits of Shooting Creek, both in North Carolina, are in metamorphic rocks. The Yadkin Valley deposit is in the Wilson Creek Gneiss of Precambrian age and is unique in being the only exploitable primary ilmenite deposit in the world not in either gabbro or anorthosite (Lynd, 1960, p. 859). It also is the only ilmenite deposit that has been exploited in Appalachia. The ore body (Bryant and Reed, 1966, p. 4–5) consists of a series of narrow closely spaced lenses in a layered cataclastic gneiss, which form a nearly continuous vein about 1,000 feet long and about 200 feet deep, as shown by core drilling. The saprolite or weathered part of this body was mined from 1942 to 1952 when the saprolite ore was exhausted. The lenses consist of ilmenite and magnetite in a gangue of epidote, amphibole, chlorite, biotite, talc, and accessory pyrite. Foliation in the lenses is parallel to that in the enclosing country rock. Contacts between the lenses and the enclosing rock are sharp, but some ilmenite stringers found in the wallrock apparently replaced gneiss along a shear zone. A similar but lower grade ore body, consisting of ilmenite mixed with chlorite and serpentine, was reported three-quarters of a mile to the southeast (Hunter and Gildersleeve, 1946, p. 81).

The rutile deposits of Shooting Creek are restricted to a garnet mica schist of the Carolina Gneiss of former usage (E. C. Van Horn, unpub. data, 1945), in a belt approximately 10 miles long. Stringers of sugary-textured quartz associated with the rutile in many places suggest that the rutile was deposited by silicic solutions that pervaded the garnetiferous schist.

Small alluvial deposits are widespread (table 163). Modern placer deposits in the flood plains and gravels of streams in Appalachia consist of alluvial material having local concentrations of titanium minerals. Fossil placers, found in Cocke County, Tenn. (table 163), consist of ilmenite and rutile concentrates formed on ancient Precambrian beaches. These deposits are in the Snowbird Group of the Ocoee Series (Carpenter and others, 1966). They are described in the section "Zirconium."

Many modern stream placers are found in the western Piedmont of the Carolinas where heavy minerals were transported from a disintegrated source rock and concentrated in stream gravel. Much material was transported farther east to the beaches of the South Atlantic States to form exploitable deposits. The modern stream placers have moderately large reserves of heavy minerals, including the titanium minerals, monazite, zircon, and others which may be exploitable in the future.

RESOURCE POTENTIAL

Information about reserves of the primary titanium deposits is scanty, and published estimates should be considered as only "educated guesses." Matthews, Ralston, and Ross (1947) estimated the reserves of ilmenite and rutile ore in North Carolina at 778,000 short tons and those in Virginia at 10,850,000 short tons. Most of the Virginia reserves are in the Piney River district just outside Appalachia. Data published on individual small deposits in North and South Carolina indicate that the total reserves of ilmenite in placers are about 600,000 short tons and those of rutile are about 30,000 short tons. The primary deposits of ilmenite of Yadkin Valley and rutile at Shooting Creek probably have the largest reserves of titanium in Appalachia. However their actual size and grade

TABLE 163.—*Placer titanium deposits in the Appalachian Region*

State, county	Deposit		Ore minerals (reserves in short tons)	Description of deposit	References
	No. (fig. 111)	Name			
		Fossil placer deposits			
Virginia: Rockbridge.[1]	1	Buena Vista	Rutile, ilmenite	Lenticular titaniferous sandstone in bands 1/4–6 in. thick in lower 15 ft of Unicoi Formation. Rutile-ilmenite 50 percent of rock. Zircon also present.	Bloomer and deWitt (1941).
Tennessee: Cocke	2	Snowbird Mountain.	Ilmenite-rutile intergrowths.	Laminated bands, fraction of an inch of heavy minerals alternating with bands of quartz, feldspar, and muscovite. Ilmenite-rutile about 75 percent of heavies. In Snowbird Group of Ocoee Series. Zircon and magnetite also present.	Carpenter and others (1966).

See footnote at end of table.

TABLE 163.—*Placer titanium deposits in the Appalachian Region*—Continued

State, county	Deposit		Ore minerals (reserves in short tons)	Description of deposit	References
	No. (fig. 111)	Name			
Modern placer deposits					
North Carolina:					
Cleveland [1]	1	Buffalo Creek	Ilmenite (8,000), rutile (1,000).	Extends 6,000 ft up two streams, deposit 11.2 ft thick, 1.4 percent heavies with 20.8 percent Ti minerals.	Griffith and Overstreet (1953a); Lloyd Williams (1964, p. 34).
	2	First Broad	Ilmenite (50,000), rutile (3,200).	10.5 miles of flood-plain deposits sampled to average 22 ft depth, heavies 0.6 percent total and Ti minerals 34 percent of heavies.	Hansen and Cuppels (1954); Lloyd Williams (1964, p. 35–36).
	3	Knob Creek	Ilmenite (7,700)	0.9 miles of flood plain deposits sampled to average 18.5 ft depth with ilmenite 24.5 percent of heavy minerals.	Griffith and Overstreet (1953b); Lloyd Williams (1964, p. 35).
		Various		16 other placers sampled with heavies ranging from 0.1 to 1.8 percent of total alluvium.	Lloyd Williams (1964, p. 36–37).
Burke	4	Silver Creek	Ilmenite (38,000)	3.2 miles of flood plain deposits sampled, 19–23 ft depth, heavies 0.45 percent of alluvium, ilmenite 34 percent of heavies.	Hansen and White (1954).
		Various		Four other placers sampled with heavies ranging from 0.55 to 1.1 percent of total alluvium.	Lloyd Williams (1964, p. 37–39).
McDowell	5	South Muddy Creek.	Ilmenite (18,300)	5 miles of flood-plain deposits sampled to average depth of 18 ft, ilmenite 23 percent of heavy minerals.	Hansen and White (1954); Lloyd Williams (1964, p. 29).
		Two smaller deposits.		22 percent Ti-minerals in concentrate of first; 1.1 percent heavies in alluvium of second.	Lloyd Williams (1964, p. 28–29).
Rutherford	6	Sandy Run Creek	Ilmenite (5,600), rutile (880).	3 miles of flood-plain deposits sampled, average depth deposit 11.4 ft, 0.9 percent heavies in alluvium, Ti minerals 40 percent of heavies.	Griffith and Overstreet (1953c); Lloyd Williams (1964, p. 31).
		Various smaller deposits.		Eight other placers sampled with heavies ranging from 0.3 to 1.5 percent of alluvium; ilmenite 10 percent in one, 48 percent in another concentrate.	Lloyd Williams (1964, p. 30–32).
Various				Small placer deposits sampled in Alleghany, Alexander, Avery, Buncombe, Henderson, Jackson, Mitchell, and Transylvania Counties.	Lloyd Williams (1964).
South Carolina:					
Cherokee	7	Broad River	Ilmenite (47,000), rutile (3,500).	19.7 million cu yd alluvium to 22.3 ft depth with 0.44 percent heavy minerals.	Hansen and Theobald (1955).
	8	Thicketty Creek	Ilmenite (63,000), rutile (6,300).	20.8 million cu yd to average depths of 20.9 and 16.3 ft with 0.54 percent heavy minerals.	Do.
Spartanburg	9	Tyger River	Ilmenite (51,200), rutile (2,100.)	33.7 million cu yd alluvium to average depth of 20 ft with 0.35 percent heavy minerals.	Hansen and Cuppels (1954).
Anderson	10	Big Generostee Creek.	Ilmenite (167,000), rutile (6,600).	43 million cu yd alluvium to 16 ft depth with 0.44 percent black sand.	Hansen and Caldwell (1955).
Laurens [1]	11	Rabon Creek	Ilmenite (53,000), rutile (5,000).	52 million cu yd to 16 ft depth with 0.20 percent black sand.	Do.

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[1] Adjoins Appalachia.

are not known. Detailed geological work on these deposits, as well as reconnaissance in the whole titanium belt from Piney River, Va., to Shooting Creek, N.C., is needed to estimate the resource potential of titanium in Appalachia.

In 1952 and 1953, the U.S. Geological Survey and U.S. Bureau of Mines, in cooperation with the Atomic Energy Commission, studied many small placer deposits in North and South Carolina (table 163). The largest had reserves of 167,000 short tons of ilmenite, but most were much less than 50,000 tons. Although not minable at present, these placers may become so in the future as demand for ilmenite increases and if other heavy minerals can be recovered as byproducts or coproducts.

TUNGSTEN

By Robert A. Laurence, U.S. Geological Survey

Tungsten is extremely hard and has the highest melting point of any metal. It is used principally in alloys, chiefly alloy steels, in carbides, as a pure metal, and in chemical compounds (R. F. Stevens, in U.S. Bur. Mines, 1965a, p. 991, 998). In 1962, the United States produced ores containing 8.3 million pounds of tungsten, and consumed 13.7 million pounds (Stevens, in U.S. Bur. Mines, 1965a, p. 1001).

Tungsten alloys and chemicals are produced from domestic and foreign concentrates at six plants in Appalachia, all in Pennsylvania (Stevens, in U.S. Bur. Mines, 1965a, p. 993).

The only important tungsten deposits in the Appalachian States are in the Hamme district, Vance County, N.C., east of Appalachia, but tungsten minerals have been reported from 10 localities in Appalachia listed below. Deposits in the Hamme district were exploited from 1942 to 1958 and 1960 to 1963; concentrates produced contained about 16 million pounds of tungsten. From 1951 to 1958 the district was the largest single producer in the United States (Stuckey, 1965, p. 345). The 10 localities in Appalachia are gold and copper deposits of the Piedmont and nearby placers. The amounts of tungsten are very small, and there is no recorded production.

Tungsten occurrences in Appalachia

[After Espenshado (1950); Hurst and Crawford (1964); Hurst and Otwell (1964)]

Locality	*State, county*	*Tungsten minerals*
Campbell quarry	Cherokee, S.C	Scheelite.
Findley mine	Lumpkin, Ga	Do.
Creighton mine	Cherokee, Ga	Scheelite, wolframite.
Cherokee mine	do	Scheelite.
Hog Mountain mine.	Tallapoosa, Ala	Scheelite, wolframite.
Unnamed	Rutherford, N.C	Wolframite.
Do	Burke, N.C	Do.
Loud placer	White, Ga	Do.
Several streams	do	Scheelite.
Do	Habersham, Ga	Do.

URANIUM

By Arthur P. Butler, Jr., U.S. Geological Survey, and Robert G. Stansfield, U.S. Bureau of Mines

Uranium is a radioactive ductile heavy silver-gray metal. It is combined in nature with other elements in more than 150 minerals. The principal minerals in uranium ores are uraninite and pitchblende (uranium oxides), coffinite (a silicate), and carnotite (a uranium and vanadium oxide). Uranium also is a nonessential constituent in many other minerals, of which monazite and apatite, both phosphates, are the most common.

Deposits in continental sandstone and conglomerate are the principal present sources of uranium. Those in the United States are mainly bodies of mineralized sandstone in which the uranium minerals coat the grains of the rock or partly fill the interstices between grains. The mineralized rock forms crudely tabular and connected irregular elongate masses.

Veins containing pitchblende and other minerals were the principal world sources prior to the discovery and development of large deposits in sandstone. Veins have been the source of only about 5 percent of the uranium mined in this country.

Uranium also occurs in minerals sparsely distributed in some bodies of pegmatite, as an accessory constituent of some minerals in placer deposits, and as a widely dispersed trace constituent in marine phosphorites and some coal-bearing rocks and marine black shales. In the past, uranium minerals have been recovered as a byproduct in mining some pegmatites, and uranium has been recovered experimentally from phosphate mined in Florida. No coal-bearing rocks or marine black shale have been mined for uranium in this country.

All the types of deposits mentioned above, except marine phosphorite, are represented in Appalachia, but mining has been confined to a little underground exploration of one deposit in sandstone near Jim Thorpe, Pa. (McCauley, 1961, p. 9).

THE NATIONAL INDUSTRY

The Federal Government is the principal user of uranium, the chief use of which is in nuclear weapons. Much research and development work, led by the Atomic Energy Commission, has been directed toward using uranium as a fuel in nuclear reactors for generating electric power and for propulsion. Research is also proceeding on use of nuclear energy for desalting water. Radioisotopes of many elements are formed by irradiation and fissioning of uranium in reactors and are also recovered in processing spent nuclear fuel; they are widely applied in research and as substitutes for X-ray equipment.

The United States leads the free world in the production of uranium; New Mexico, Wyoming, Colorado, and Utah are the four leading producing States. In 1964, a total of 5.7 million tons of uranium ore was mined in 14 States; concentrate containing 11,847 tons of uranium oxide (U_3O_8) was milled from this ore and purchased by the Atomic Energy Commission (AEC) for $189 million (1958 constant dollars). In addition, concentrate containing 5,297 tons of U_3O_8 was imported under contracts which expired in 1966. For comparison, during the fiscal years 1943–47, only 1,440 tons of concentrate was produced domestically, and 10,150 tons was imported. Prior to 1942, uranium was produced in the United States only as a byproduct of ores mined for their vanadium or radium content.

Federal Government control of the uranium industry, effective since 1941, was somewhat lessened by legislation enacted in 1964. The new law amends the Atomic Energy Act of 1954 to permit private ownership of special nuclear materials and eliminates mandatory government ownership.

The current AEC contract price of $8.00 per pound of U_3O_8, in specified concentrate form, will be paid only through 1968, at which time the maximum AEC price will be reduced. Present AEC procurement contracts expire in 1970, and there are no plans to continue with a guaranteed price program after that date.

The military requirements for uranium have lessened in recent years, and the industry is in a planned transition stage from a government-financed program to one of supply and demand of private industry. Domestic sources of uranium are adequate for the next few years. The future demand will depend largely on the extent to which nuclear reactors are used for generating electricity and for propulsion. However, considerable growth is expected in these uses of uranium during the next two decades, and new sources will be needed to meet the demand, particularly after the late 1970's.

At the present time there is no substitute for uranium as a nuclear fuel, although thorium is considered to be a possible complement of uranium in the future.

THE INDUSTRY IN APPALACHIA

The only production of uranium ore in Appalachia consists of 300 tons taken from a deposit in sandstone in Pennsylvania (McCauley, 1961, p. 9). Most of the known deposits of this kind are small and of marginal grade, but some might be exploited if the price of U_3O_8 should rise above $10 per pound. Other types of deposits are either too small or, like the large resources in the Chattanooga Shale, too low in grade to be exploitable in the near future.

At Oak Ridge, Anderson and Roane Counties, Tenn., a gaseous diffusion plant owned by the AEC processes uranium hexafluoride to obtain a product enriched in the fissionable isotope, U^{235}. Reactor fuels are fabricated here. The Oak Ridge National Laboratory has been the source of more than 12,000 shipments annually of radioisotopes manufactured in special reactors or extracted in reprocessing nuclear fuels. It has discontinued supplying certain isotopes that have become available from private firms.

At Erwin, Unicoi County, Tenn., the private firm of Nuclear Fuel Services, Inc., converts uranium hexafluoride to uranium metal and manufactures uranium and thorium metal alloys. It also recovers uranium from unirradiated uranium scrap metal.

DEPOSITS IN APPALACHIA

CONTINENTAL SEDIMENTARY ROCKS

Uranium deposits in continental sandstone and mudstone consist of lenticular to tabular masses of mineralized rock, generally concordant with the bedding of the rocks, and of associated irregular masses which transect the bedding. With the exception of one poorly defined deposit in West Virginia, known only from a single sample, all the deposits in Appalachia are in Pennsylvania (fig. 112). The deposits in that State and their setting have been described by McCauley (1961) and Klemic (1962), whose reports are the principal sources for the descriptions presented herein.

Deposits are distributed through a stratigraphic interval of 10,000 feet. Most of them are in the Catskill Formation of Late Devonian and Early Mississippian age. They are most abundant in the lower part of the formation in the north-central part of the State (fig. 112). A few are in rocks of Mississippian age, the Pocono Sandstone, the Mauch Chunk Formation, and the Mauch Chunk-Pottsville transition zone (Klemic, 1962, p. 277–284). The largest deposits (fig. 112, Nos. 2–4) are in the upper part of the Catskill and the upper part of the Mauch Chunk in Carbon County. Two local minor occurrences in western Pennsylvania, which are not discussed further herein, are in coal and underclay of Pennsylvanian age (E. D. Patterson, 1954; Ferm, 1955).

The formations that contain uranium deposits consist of interfingering and interbedded stream-deposited sandstone and mudstone. Some beds contain carbonized remains of plants, which range from finely macerated material to identifiable fragments.

The Catskill Formation was deposited in the form of a delta, and the stream-laid beds pass transitionally

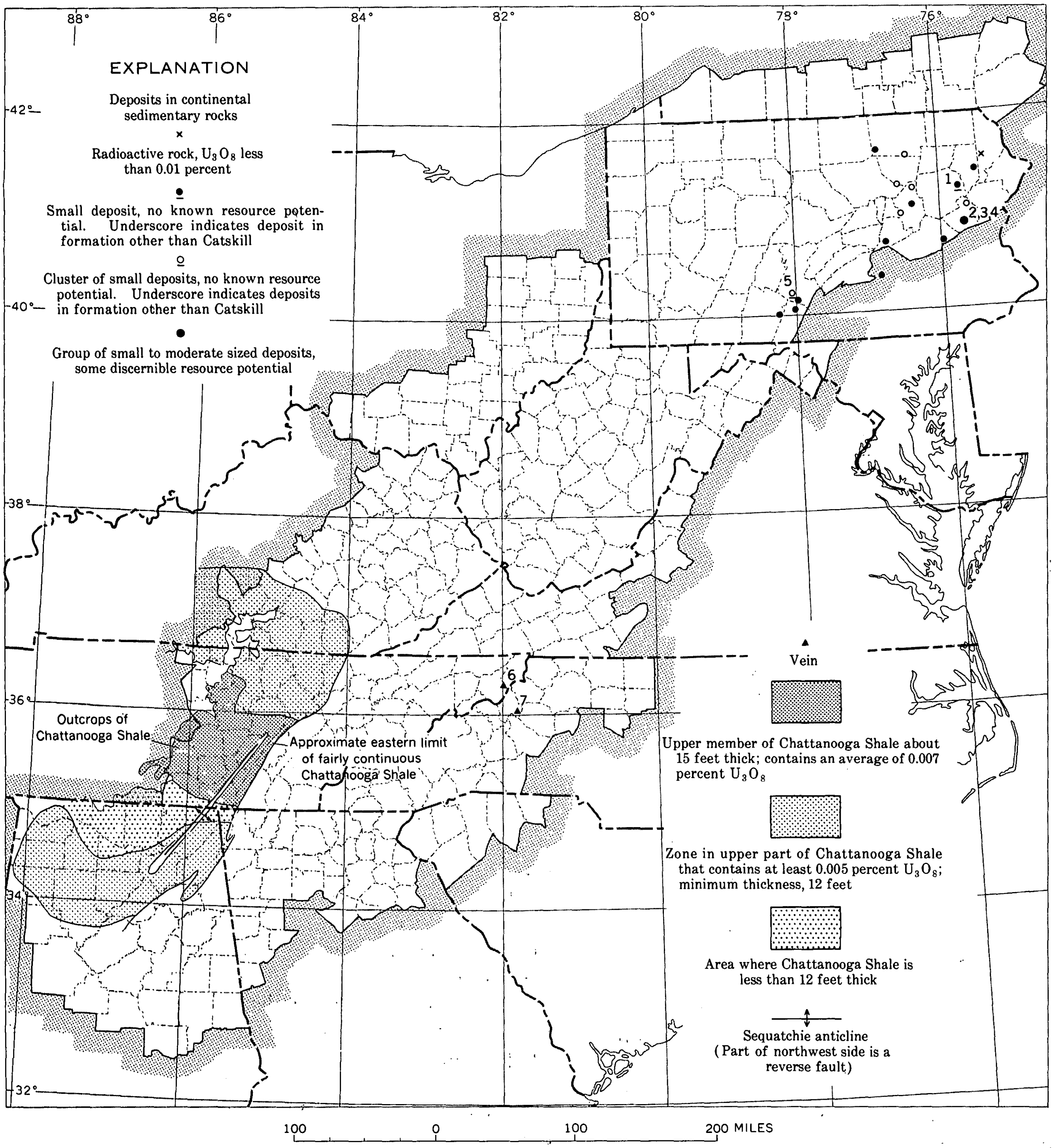


Figure 112.—Uranium in continental sedimentary rocks, in veins, and in marine black shale in the Appalachian Region. Numbers identify deposits specifically mentioned in text. Modified from McCauley (1961, figs. 1, 7) and Klemic (1962, pl. 2) for Pennsylvania; from Butler, Finch, and Twenhofel (1962) for veins; and from Conant and Swanson (1961, pls. 1, 15) and Andrew Brown (written commun., 1962) for marine black shale.

westward into beds that were deposited in estuarine and marine environments. The zone of transition may define a general lateral limit of ground favorable for deposits within the Catskill stratigraphic interval. The rocks of the Catskill are predominantly red, but about 25 percent of the total thickness is made up of a green or gray sandstone and shale. In part, beds of green and gray rock alternate with beds of red rock, and in part, the color changes laterally along the same bed from gray to red. The uranium deposits are within the gray beds (Klemic and others, 1963, pl. 2) or along the contact of gray rock with red rock (McCauley, 1961, p. 58, 61, 66).

The Pocono Formation overlies the Catskill and is a predominantly gray unit. One small deposit (fig. 112, No. 1) is near the top of the formation in Luzerne County, Pa.

The Mauch Chunk Formation at its type locality near Jim Thorpe (formerly Mauch Chunk), consists of a lower unit of predominantly red rocks about 1,700 feet thick and an upper unit about 500 feet thick, in which beds of gray sandstone and conglomerate alternate with red shale and mudstone (Klemic and others, 1963, p. 44–48). An interval of gray sandstone and conglomerate about 70 feet thick at the base of the upper unit contains one of the two largest uranium deposits in Pennsylvania (fig. 112, No. 4). Uranium also occurs in the upper 60 feet of the Mauch Chunk in Huntingdon County (fig. 112, No. 5).

The uranium deposits in sandstone and associated mudstone appear to fall into two groups, distinguished by differences in size and in complexity of shape. By far the larger number of deposits are small, lenticular to tabular masses of mineralized rock. Many of them, particularly in the northeast part of Pennsylvania (fig. 112), are copper-uranium deposits, which were once prospected for copper (McCauley, 1961, p. 17). They range from a single mineralized layer an inch in thickness to several such layers in a zone as much as 3 feet thick. Their lateral dimensions range from a few feet to a few tens of feet (McCauley, 1961, p. 26). In the area centered about Sullivan County many of the deposits occur in clusters that have a radius of 1–2 miles; elsewhere the small deposits are apparently isolated occurrences. Deposits in several of these clustered areas are distributed across a stratigraphic range of several hundred feet, and those in the same general stratigraphic interval are commonly separated from each other by hundreds to thousands of feet of barren rock.

Much of the uranium in unweathered parts of these small deposits is in unidentified form in gray or black material interstitial to the clastic grains of the rocks (Klemic, 1962, p. 262), in which carbonaceous material is relatively abundant (McCauley, 1961, p. 26, 39). In many deposits in the Catskill Formation bornite, chalcopyrite, and other copper sulfides are more abundant than uranium. Pyrite is generally present and fairly abundant. Yellow or green secondary uranium minerals are sparsely present in the weathered part of some deposits, and green and blue secondary copper minerals occur at many localities. The radioactivity of the rocks and the colored secondary minerals are aids in searching for outcropping deposits.

Most of the small deposits are in the gently deformed rocks of the Appalachian Plateaus province, but a few are in the folded rocks of the Valley and Ridge province.

Three moderate-sized deposits occur in the Valley and Ridge province in Carbon County. Two are in the Catskill Formation (fig. 112, Nos. 2,3), and one, from which about 300 tons of ore has been mined, is in the Mauch Chunk-Pottsville transition zone (fig. 112, No. 4).

One deposit in the Catskill Formation (fig. 112, No. 2) is exposed on both sides of the Lehigh River about 2,000 feet south of Penn Haven Junction. It consists of a fairly continuous but segmented lower layer of mineralized rock which ranges from a fraction of a foot to about 3 feet in thickness and a vaguely suggested upper layer very imperfectly defined by scattered masses of mineralized rock less than a foot thick and a few feet long. The layered parts of the deposit are nearly concordant with the bedding of the rock (fig. 113, section A). The upper and lower layers and the segments of the lower layer are connected by masses of mineralized rock of crescent-shaped cross section. These masses are 5–15 feet wide and about the same thickness. The distance between the upper and lower layers ranges from 5 to 25 feet. The length of the cross section of the deposit is about 300 feet on both sides of the river.

The general form of the deposit and the forms and dimensions of its component parts are similar to those displayed in large productive deposits in the Shirley Basin, Wyo., as shown by the cross section in figure 113.

The principal introduced minerals in the deposit are uraninite, pyrite, and clausthalite (lead selenide). The uranium content has not been determined systematically, but 14 analyzed samples contain 0.002–0.67 percent U_3O_8 (Klemic and Baker, 1954).

The other deposit comprising a few beds of radioactive gray sandstone in the Catskill Formation (fig. 112, No. 3) is on the north side of Mauch Chunk Ridge. The two most radioactive beds in this deposit

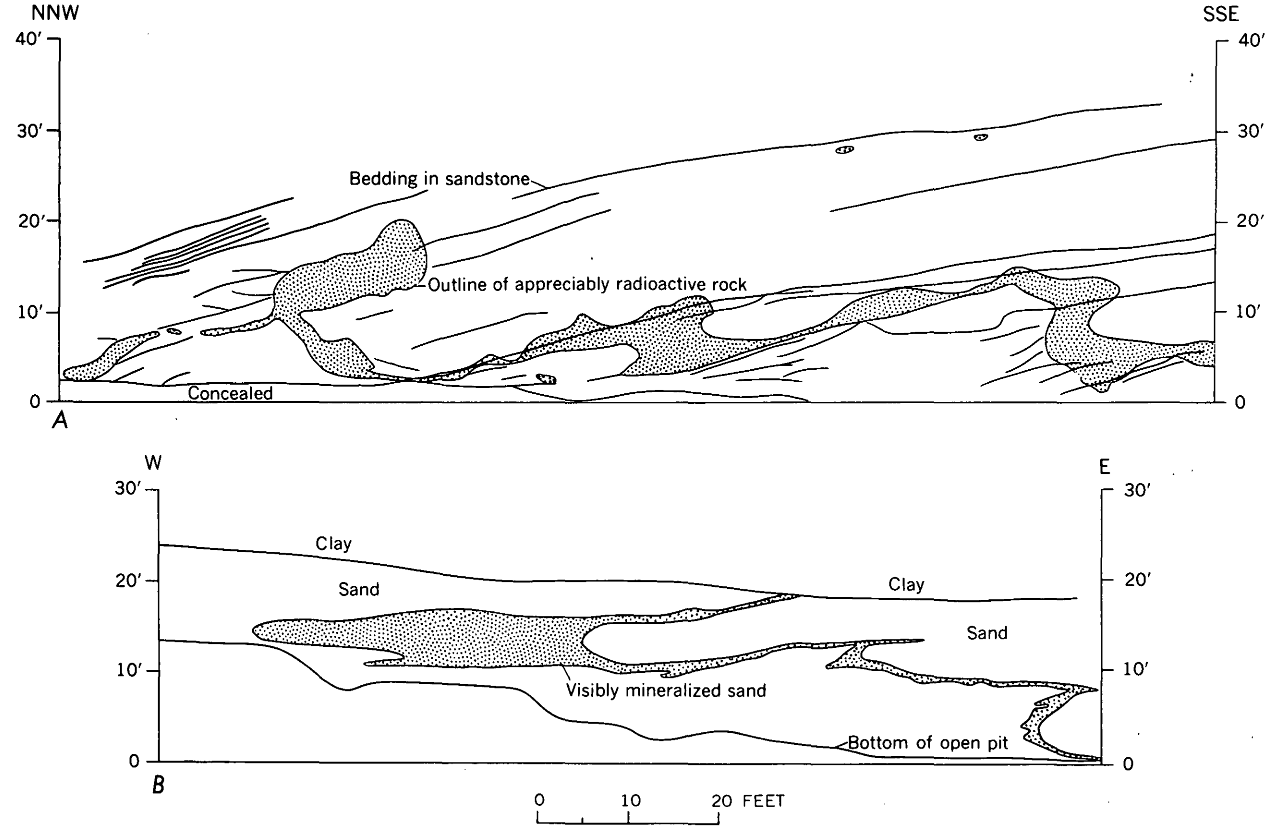


FIGURE 113.—Sections through parts of two uranium deposits showing general similarity of form. *A*, Part of deposit in Catskill Formation exposed on east side of Lehigh River, Carbon County, Pa.; datum is level of old railroad bed; modified from Klemic and others (1963, pl. 2.). *B*, Part of deposit in the Wind River Formation as exposed in July 1963 on north wall of Petrotomics' mine, Shirley Basin, Carbon County, Wyo. Arbitrary datum; modified from sketch by E. N. Harshman.

are about 25 feet apart, and each is 4–8 feet thick. Uranium occurs as dark specks in an unidentified mineral and in secondary minerals. The maximum uranium content reported in any sample is 0.13 percent (Klemic and others, 1963, p. 83). The deposit has been partly explored by drilling but has not been mined.

The deposit in the Mauch Chunk-Pottsville transition zone (fig. 112, No. 4), the third of the moderate-sized deposits, is on the northwest outskirts of Jim Thorpe. It consists of two main mineralized zones in gray conglomerate and sandstone that also contain carbonized fragments of plants. The zones extend discontinuously for about 2,000 feet along the south side of U.S. Highway 309, and are about 10 feet apart stratigraphically (McCauley, 1961; Klemic, 1962; Klemic and others, 1963). Uranium is partly in irregular tabular zones nearly concordant with the bedding and partly in poorly defined zones which transect bedding and are elongate in a southwesterly direction.

Parts of the outcrop of the deposit are brightly colored with secondary minerals, but the bulk of the uranium is in black particles interstitial to the grains of the rock. The deposit has been partly explored by drilling and experimental mining.

OTHER TYPES OF DEPOSITS

Vein

Uranium-bearing veinlets occur in crystalline rocks of Precambrian age in Carter County, Tenn., and Avery County, N.C. (fig. 112, Nos. 6, 7). Deposits in both areas have been partly explored by surface excavations and those in Avery County by about 3,000 feet of diamond drilling, but none have been mined.

In the vicinity of North Harper Creek and Shatley Fork, Avery County, N.C. (fig. 112, No. 7), lenticular masses of sheared pegmatite and phyllonite are cut by joints that trend northwest (Bryant and Reed, 1966). Locally these joints are partly filled with uraninite and other less-abundant uranium minerals. Some uraninite occurs as paper-thin veinlets on northeast-trending shear planes in the phyllonite. The rock units and the joints which cut them are discontinuous both vertically and horizontally. As a result the uranium-bearing veinlets lack continuity.

Although scattered samples taken from surface showings contain as much as about 1 percent U_3O_8 and radiometric readings suggest a uranium content of about 0.1 percent U_3O_8 in some drill holes, the veinlets are too scattered and discontinuous to be considered ore bodies under present economic conditions.

A few samples collected from the Tennessee occurrences by R. A. Laurence of the Geological Survey contained 0.021–0.13 percent uranium in undetermined mineral form. The deposits are exposed only in shallow surface workings, and little is known about them except that they are not large, continuous, or rich enough to have encouraged more than initial surface exploration.

Known uranium-bearing veins in Appalachia are in crystalline metamorphic and granitic rocks of Precambrian age. These and other similar crystalline rocks of Paleozoic age are present in much of the Appalachian Highlands from east-central Alabama to southwest Virginia. Other veins of uranium may be present in areas underlain by such rocks, but the restricted occurrence and small size of known veins suggest that the probability of finding an ore deposit is small.

Pegmatite

Pegmatite is a very coarse grained igneous rock commonly of granitic composition. Bodies of pegmatite are important sources of feldspar, mica, beryl, and of lithium-bearing minerals. Those in Appalachia are described in parts of this report dealing with those commodities.

Uranium-bearing pegmatites are sparse in Appalachia except in the Spruce Pine district, Mitchell and Yancey Counties, N.C. (fig. 85). In that district, uraninite and several other uranium-bearing minerals are common trace constituents in many bodies of pegmatite (Maurice, 1940; Brobst, 1962) but are not sufficiently abundant to encourage mining. As the possibilities for commercial production of uranium from pegmatites in this district are poor (Brobst, 1962), so are the possibilities in Appalachia as a whole.

Placer

Monazite in explored placer deposits in North and South Carolina contains 0.39–0.70 percent uranium (Overstreet and others, 1959, p. 712). The deposits are described in the section on "Thorium and rare-earth metals."

Uranium-bearing shale

The Chattanooga Shale contains tens of grams per ton of dispersed uranium which might become economically exploitable in the distant future. The shale is widespread in the southern part of Appalachia, and its uranium content is relatively uniform throughout large areas.

Extensive study and sampling of outcrop areas by the U.S. Geological Survey and exploratory drilling in cooperation with the U.S. Bureau of Mines on behalf of the U.S. Atomic Energy Commission show that uranium is most concentrated in the upper member, the Gassaway, in east-central Tennessee (Conant and Swanson, 1961, p. 70–76).

In an area of about 4,000 square miles in east-central Tennessee, as shown on the map (fig. 112), the upper member has an average thickness of about 15 feet and contains an average of 0.007 percent U_3O_8 (Conant and Swanson, 1961, p. 71, 76; Andrew Brown, written commun., 1962). Outside this area northward to central Casey and Pulaski Counties, Ky., and southward to near the southern limit of the Chattanooga in central Alabama, a 12-foot average thickness in the upper part of the shale contains about 0.005 percent U_3O_8 (V. E. Swanson, oral commun., 1961). More comprehensive information about the geology and uranium content of the Chattanooga Shale is given in reports by Kehn (1955), Glover (1959), and Conant and Swanson (1961).

PROSPECTING AND RESOURCE POTENTIAL

The most favorable places to search for uranium deposits are in continental rocks in the vicinity of known deposits, and more generally in the areas underlain by the formations which contain the known deposits. Thus, potentially favorable areas are those where the Catskill and Mauch Chunk Formations are present and possibly also those where the Pocono Formation and parts of the Pottsville Group are present. These areas form a band extending from southern New York southwestward across Pennsylvania and along the boundary between Virginia and West Virginia to southern West Virginia. The distribution of known deposits indicates that the segment of this band in Pennsylvania is most promising. More specific identification of potentially favorable areas will require intensive study to relate the distribution and habits of the deposits to the distribution and prevalence of other characteristics of the rocks in which they occur.

Within very generalized areas, the deposits are confined to rocks of shades of gray or green which contain carbonized remains of plants either as finely macerated material or fragments. Moreover, two of the moderate-sized deposits in Pennsylvania and large deposits in Western United States are in beds or aggregates of beds of sandstone not less than 20 feet thick which are parts of alternating sequences of sandstone and mudstone or claystone.

The thoroughness with which outcrops of potentially favorable host rocks may have been prospected and examined cannot be ascertained. Nevertheless, most of the potential resources are thought to be in concealed deposits. Finding such deposits will require detailed geologic study to determine the favorable areas not immediately adjacent to known deposits and exploration by drilling to depths of many hundred feet and possibly of 2,000 feet in some places.

Known recoverable and marginal resources of uranium in Appalachia are small, probably only a few hundred to a few thousand tons of material, all in the deposits in Carbon County, Pa. Potentially recoverable to marginal resources in deposits in continental sedimentary rocks may be appreciable but are not quantitatively definable with present knowledge. The deposit near Penn Haven Junction, Pa., is similar in form and habit to many deposits in Western United States, which are generally parts of mineralized areas whose lengths range from thousands of feet to several miles. Thus, it is possible that mineralized rock like that exposed at the outcrop of the Penn Haven Junction deposit may be extensive but concealed. If so, potential resources in ground contiguous with this deposit could be at least a few hundred thousand tons as in some of the smaller districts in the West. The Mount Pisgah, Pa., deposit also may have concealed extensions, although no other uranium occurrences have been found in rocks of this stratigraphic interval in nearby areas. The many widespread small deposits indicate that conditions favorable for introduction and deposition of uranium were widespread. As Klemic (1962, p. 276–277) has pointed out, the areas of favorable host rocks that are well exposed at the surface are only a minute fraction of the total area underlain by these rocks, and it is reasonable to expect that concealed parts of these contain uranium in amounts equivalent to those in the exposed parts.

Known resources contained in monazite in placer deposits in the Carolinas are 3,500 tons of U_3O_8 (Overstreet and others, 1959). This uranium could be recovered if the monazite were mined for its thorium and rare-earth contents, but the monazite is not sufficiently rich in uranium to encourage mining it for uranium alone.

The Chattanooga Shale in part of east-central Tennessee averages about 0.007 percent U_3O_8 (fig. 112) and contains about 6 million tons of metal. Many more millions of tons of uranium are contained in slightly leaner shale in adjoining areas. The highest grade material in the Chattanooga is not economically exploitable at present or in the near future, but may become exploitable in the more distant future, particularly if oil is also recovered from the shale. (See section on "Oil Shale," p. 133).

VANADIUM

By R. P. Fischer, U.S. Geological Survey, and Stanley A. Feitler, U.S. Bureau of Mines

For more than 20 years, the United States has been the largest producer and apparently the largest consumer of vanadium. The great bulk of production in recent years has been as a byproduct or coproduct of mining and processing of uranium-bearing sandstone of the Colorado Plateau. Currently, reduced demand for uranium has caused a shift in mining to those ores with higher vanadium content in the same geographic area. Consumption of vanadium has increased greatly over the last few years, and it may soon become necessary to augment production from the Colorado Plateau region by development of other domestic vanadium resources or by imports. Consumption of vanadium is closely related to the production of tool and other alloy steels, uses which constituted more than 70 percent of the total consumption in 1964.

During the period 1955–64, annual production has varied from a minimum of 3,030 to a maximum of 5,343 short tons of vanadium, mainly in the form of vanadium pentoxide, valued at approximately $11 million and $19 million (1958 constant dollars), respectively. Production exceeded consumption and exports exceeded imports in each of these years.

Vanadium is an important alloying element in steels and other metals, and is also used as a catalyst for various industrial processes. As an alloying agent for steel and iron, it is used to reduce and control grain size, to impart toughness, strength, and resistance to impact and abrasion, and to maintain hardness at increased temperatures. Vanadium is also used as an alloying agent in nonferrous alloys, chiefly those of aluminum and titanium, to control thermal expansion, grain size, and electrical resistivity, as well as to improve high-temperature strength. Compounds of vanadium are important to the chemical industry as catalysts for many industrial processes, including production of sulfuric acid, cracking petroleum, and for the preparation of numerous organic compounds. Other chemical applications include its use as a colorizer in glass and ceramic glazes, as a dryer in paints and varnishes, and in the processing of color film. Further details are given by G. L. DeHuff (in U.S. Bur. Mines, 1965a, p. 1039–1046).

Vanadium ore has not been mined in Appalachia, but plants processing vanadium are located in the area. A plant to prepare vanadium for use in alloys was established at Bridgeville, Allegheny County, Pa., in 1907, near the iron- and steel-producing center of Pittsburgh. From the 1920's until about 1960, most vanadium-alloying material was prepared in electric furnaces at Niagara Falls, N.Y., by Union Carbide Corp. and Vanadium Corp. of America. Production was resumed in Appalachia in 1960 when the Vanadium Corp. moved its metallurgical operations to Cambridge, Guernsey County, Ohio. In addition, Union Carbide now produces most of its vanadium-alloying materials at Alloy, Fayette County, W. Va., and Marietta, Washington County, Ohio.

Three types of vanadium-bearing deposits are known in Appalachia—deposits of uranium-bearing sandstone in Pennsylvania, deposits of titaniferous magnetite in North Carolina and Tennessee, and deposits of flake graphite in Alabama. These deposits are briefly described below, and their locations are shown on figure 114. They are also described in the sections "Uranium," "Titanium," and "Graphite." None have yielded vanadium, and none are judged to be of significant commercial potential for this metal. The known phosphate deposits of the eastern United States, unlike those in Idaho, contain virtually no vanadium.

The uranium-bearing sandstone deposits of Pennsylvania have been described by McCauley (1961), Klemic (1962), and Klemic and others (1963). Most of them are in beds of the Catskill (Devonian and Mississippian) and Mauch Chunk (Mississippian) Formations. Like those in Colorado, they consist of uranium minerals that impregnate the host rock and partly replace fossil plant material; the known deposits, however, are relatively small, and they contain only a little vanadium. In a few of these deposits, the uranium vanadate minerals, carnotite and tyuyamunite, have been recognized, but in most, the presence of vanadium has been detected only by spectrographic analyses of samples. The average vanadium content of probably a little less than 0.1 percent vanadium suggests that the average grade of the known occurrences in Pennsylvania is about one-tenth as much as the average grade of the vanadium-bearing sandstone mined in Colorado and the adjoining Western States. Thus the known occurrences of vanadium-bearing sandstone in Pennsylvania seem to offer no potential for commercial production of vanadium.

Deposits of titaniferous magnetite are common in northwestern North Carolina, and a few are in the adjoining part of Tennessee. They occur as veins in dark-colored gneiss and schist (Singewald, 1913; Bayley, 1922, 1923). Some were mined for iron ore many years ago, but none were extensively developed. (See section "Titanium.") Information regarding the vanadium content of these deposits is conflicting. Most titaniferous deposits contain about 0.5 percent V_2O_5, but Bayley (1922, p. 259–260) reported that three samples of ore from North Carolina were analyzed for vanadium and showed none. On the other hand, a few grab samples of titaniferous magnetite taken from deposits in North Carolina by the U.S. Geological Survey during World War II showed a few tenths percent V_2O_5. If these deposits are explored or exploited for iron or titanium, samples should also be tested for vanadium, because vanadium is being recovered from titaniferous magnetite deposits in Finland and the Republic of South Africa.

The flake graphite deposits of Alabama contain a vanadium-bearing green mica that might be recovered as a byproduct of graphite mining. As previously mentioned in the "Graphite" section, these deposits have been worked for graphite during major wars, but have been inactive at most other times when industry had ready access to foreign supplies. The deposits are in the Ashland Mica Schist of Precambrian age and form lenticular masses that vary considerably in size and in graphite content (p. 305). The vanadium content of the mica evidently varies considerably, as does the amount of mica in the rock. Mica concentrates of many graphite ore samples taken by the U.S. Bureau of Mines during World War II were found to range from about 2 to 30 percent of the sample and assayed from 0.07 to 0.67 percent V_2O_5 (Pallister and Thoenen, 1948). Although the total amount of vanadium in these deposits is probably large, it would seem that vanadium could only be recovered as a byproduct and only if an efficient and inexpensive metallurgical process were to be developed.

ZINC AND LEAD

By Helmuth Wedow, Jr., and Allen V. Heyl, U.S. Geological Survey, and John W. Sweeney, U.S. Bureau of Mines

THE NATIONAL INDUSTRIES

ZINC

Zinc is a bluish-white metal used principally for galvanizing iron and steel products, for zinc-base alloy die castings, and in the manufacture of the copper-zinc alloy, brass. The automobile, household appliance, and hardware industries are the major users of zinc. Thus, zinc is essential to modern living and stands fourth among metals with respect to new production (Am. Zinc Inst., 1958?). Additional details are given by H. J. Schroeder (in U.S. Bur. Mines, 1965a, p. 1091–1092).

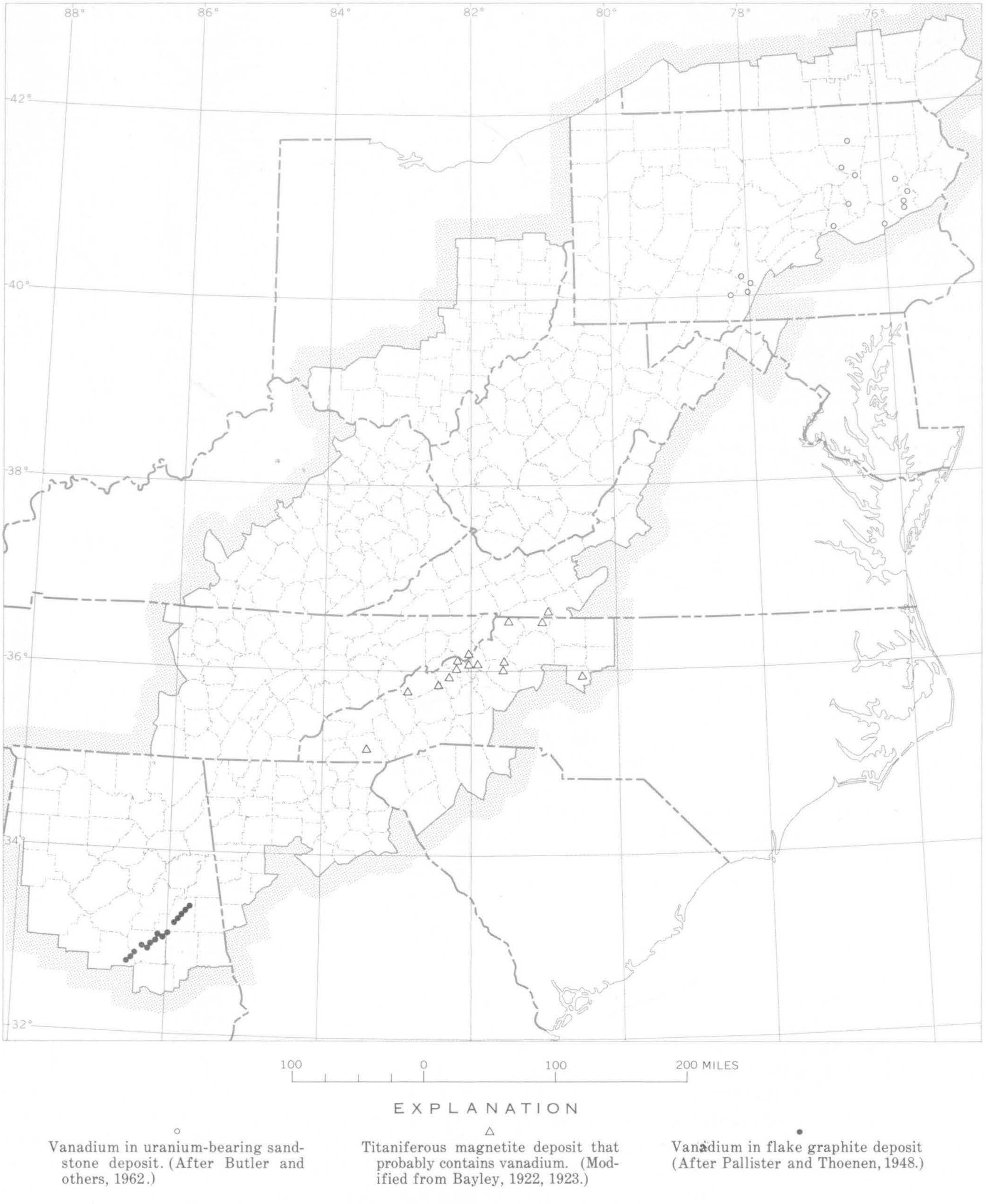


FIGURE 114.—Vanadium occurrences in the Appalachian Region.

The United States for nearly all of the past 50 years has been the world's leading producer of zinc ores, as well as the largest producer and consumer of zinc metal. Domestic mines range from small enterprises producing a few tons of crude ore a day to large mines producing several thousand tons daily. The major producing districts are the Mascot-Jefferson City in eastern Tennessee, Coeur d'Alene in Idaho; Balmat-Edwards in New York, and Red Cliff in Colorado. Other important districts producing zinc ore are West Mountain (Bingham) in Utah, Friedensville in Pennsylvania, Big Bug in Arizona, Austinville in Virginia, Pend Oreille and Metaline in Washington, Upper Mississippi Valley of southwestern Wisconsin and northwestern Illinois, and the Tri-State district of Missouri, Kansas, and Oklahoma (Schroeder, 1964).

In 1964, domestic mine production of recoverable zinc was 575,000 short tons valued at $155.5 million (1958 constant dollars). Table 164 shows production and value of zinc in the United States and in Appalachia, 1906–64.

In 1964, Tennessee was the leading zinc-producing State in the United States and Virginia ranked 13th. Eight of the 25 largest zinc-producing mines in the Nation are in these two States. In Tennessee, 1964 mine production of recoverable metallic zinc was 116,000 short tons valued at $31.3 million (in 1958 constant dollars) and was 20 percent of the U.S. production and value. Production in 1964 was 21 percent greater than in 1963, all coming from three main areas, Mascot-Jefferson City, Flat Gap, and Ducktown in eastern Tennessee. The Austinville district, Virginia, produced 21,000 short tons of recoverable metallic zinc in 1964, which was valued at $5.7 million (in 1958 constant dollars) and was 4 percent of the U.S. total zinc production.

LEAD

Lead is a soft, heavy, malleable metal that is used industrially in its metallic form and in compounds. Its principal uses are for storage batteries, tetraethyl lead, cable covering, paint pigments, construction, ammunition, and various alloys, chiefly solder, bearing metals, and type metal. About 55 percent of the lead is used for batteries and tetraethyl lead; the rest is distributed among the other uses. Additional details are given by D. E. Moulds (in U.S. Bur. Mines, 1965a, p. 494–496).

In 1964, total U.S. production of lead in ore was 286,000 short tons, approximately 10 percent of world production, and was valued at $75 million (1958 constant dollars).

The United States was the world's leading producer of lead ore from 1833 through 1956; thereafter Australia gained first place. Since 1957, Australia and the U.S.S.R. have each produced more lead ore than the United States.

TABLE 164.—*Production of zinc, 1906–64*

[W, Withheld to avoid disclosing individual company data. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1906	124	44	199,694	92,968
1907	109	48	253,017	84,228
1908	344	118	234,064	57,416
1909	596	229	302,373	85,669
1910	1,761	660	324,444	97,138
1911	2,124	813	331,515	132,080
1912	2,440	1,075	385,621	167,148
1913	8,302	2,870	413,824	144,626
1914	10,599	3,134	415,774	120,153
1915	17,728	8,504	588,060	257,394
1916	28,122	18,074	703,169	456,548
1917	29,839	12,788	713,556	305,719
1918	22,022	7,274	636,091	208,837
1919	23,247	5,457	548,846	136,896
1920	19,217	4,259	587,524	135,214
1921	9,692	1,326	256,640	40,238
1922	15,568	2,862	472,032	91,464
1923	15,900	3,592	610,690	139,991
1924	17,040	3,826	637,977	148,570
1925	18,988	4,934	710,847	186,909
1926	17,928	4,916	774,563	213,918
1927	18,725	4,358	718,541	170,334
1928	W	W	695,170	157,164
1929	W	W	724,478	172,249
1930	W	W	595,425	108,672
1931	W	W	410,318	70,667
1932	W	W	285,231	46,805
1933	32,770	6,570	384,280	81,720
1934	W	W	438,726	89,303
1935	48,832	9,833	517,903	108,552
1936	44,916	10,302	575,574	134,031
1937	55,255	15,684	626,362	178,395
1938	W	W	516,703	111,894
1939	56,225	12,712	583,807	136,949
1940	51,723	14,015	665,068	183,659
1941	59,064	17,578	749,125	224,515
1942	59,596	18,692	768,025	239,249
1943	58,667	19,738	744,196	244,445
1944	58,906	18,784	718,642	223,252
1945	49,625	15,038	614,358	180,341
1946	41,300	13,122	574,833	177,390
1947	47,871	14,008	637,608	185,150
1948	45,406	13,995	629,977	194,637
1949	42,950	12,680	593,203	171,563
1950	47,698	15,429	623,375	203,504
1951	45,971	17,764	681,189	264,690
1952	51,429	17,897	666,001	233,730
1953	55,141	13,448	547,430	132,890
1954	47,064	10,942	473,471	109,987
1955	58,545	15,671	514,671	137,763
1956	65,219	18,746	542,340	156,478
1957	77,334	18,156	531,735	125,244
1958	77,279	15,804	412,005	84,113
1959	104,382	23,662	425,303	96,438
1960	104,378	26,702	435,427	111,365
1961	104,320	23,868	464,390	106,207
1962	91,762	21,008	505,491	115,598
1963	116,711	26,943	529,254	122,043
1964	136,947	37,050	574,858	155,526
Total	2,500,504	661,459	31,794,812	9,049,636

Since 1875, about 60 percent of the lead ore of the United States has been produced in the Western States, chiefly Idaho, Utah, Colorado, Montana, Washington, Arizona, and California. In 1964, the principal lead-producing states were Missouri, Idaho, Utah, Montana, Washington, and Colorado. Seven companies accounted for more than 65 percent of the domestic mine output. Table 165 compares U.S. lead production and value with that of Appalachia for the years 1906–64.

The output of lead is strongly influenced by the production and use of automobiles, because the two major

TABLE 165.—*Production of lead, 1906–64*

[W, withheld to avoid disclosing individual company data. Source: U.S. Bur. Mines]

Year	Appalachia		United States	
	Short tons	Value, in 1958 constant dollars (thousands)	Short tons	Value, in 1958 constant dollars (thousands)
1906	415	185	350, 153	152, 355
1907	85	24	364, 715	144, 782
1908	-------	-------	330, 237	101, 223
1909	-------	-------	385, 113	117, 864
1910	99	30	382, 692	116, 933
1911	415	125	426, 585	128, 835
1912	235	67	442, 126	127, 128
1913	816	222	483, 113	131, 215
1914	127	6	504, 769	114, 123
1915	340	62	542, 098	98, 561
1916	602	199	601, 392	199, 023
1917	3, 221	1, 164	628, 464	227, 088
1918	2, 520	649	562, 402	144, 940
1919	2, 188	373	429, 589	73, 208
1920	1, 979	433	496, 814	108, 742
1921	-------	-------	414, 491	51, 032
1922	732	130	477, 633	84, 742
1923	1, 250	291	547, 217	127, 257
1924	2, 212	611	596, 068	164, 715
1925	2, 677	796	684, 439	203, 576
1926	3, 250	951	683, 917	200, 054
1927	2, 393	548	665, 489	152, 460
1928	W	W	632, 977	133, 017
1929	W	W	654, 331	146, 177
1930	W	W	558, 313	100, 959
1931	W	W	404, 622	60, 983
1932	W	W	292, 968	40, 690
1933	W	W	272, 677	48, 157
1934	W	W	287, 339	47, 567
1935	W	W	331, 103	60, 612
1936	W	W	372, 919	78, 691
1937	W	W	464, 892	119, 775
1938	W	W	369, 726	72, 836
1939	W	W	413, 979	84, 595
1940	2, 858	615	457, 392	98, 362
1941	3, 413	772	461, 426	104, 370
1942	2, 041	461	496, 239	112, 132
1943	2, 488	581	453, 313	105, 912
1944	4, 622	1, 034	416, 861	93, 284
1945	2, 297	974	390, 831	88, 566
1946	4, 506	1, 279	335, 475	95, 228
1947	3, 825	1, 332	384, 221	133, 805
1948	4, 703	1, 951	390, 476	161, 975
1949	3, 570	1, 300	409, 908	149, 233
1950	3, 367	1, 036	430, 827	132, 492
1951	1, 526	561	388, 164	142, 578
1952	3, 810	1, 286	390, 162	131, 687
1953	2, 797	777	342, 644	95, 195
1954	4, 320	1, 274	325, 419	95, 977
1955	2, 997	973	338, 025	109, 605
1956	3, 040	1, 006	352, 826	116, 736
1957	3, 143	914	338, 216	98, 307
1958	2, 934	687	267, 377	62, 566
1959	2, 770	628	255, 586	58, 974
1960	2, 152	499	246, 669	57, 208
1961	5, 733	764	261, 921	53, 632
1962	4, 110	751	236, 956	43, 297
1963	3, 500	753	253, 369	54, 508
1964	3, 857	1, 005	286, 010	74, 561
Total	161, 200	39, 854	24, 965, 675	6, 434, 105

uses of lead—storage batteries and gasoline additives—are directly related to the number of automobiles built and miles driven. For other uses, the rate of lead consumption depends upon not only the rate of industrial activity, but upon the competitive prices of substitutes such as aluminum and plastics. Total consumption has declined below historical peak levels on a per capita basis because of greater use of substitutes, but has been on an upward trend since 1960.

THE INDUSTRIES IN APPALACHIA

ZINC

From 1906 through 1964 the Appalachian Region produced more than 2½ million short tons of zinc, about 8 percent of the national production for this period (table 164). In 1964 the production of zinc in Appalachia was nearly 137,000 short tons, valued at $37 million (1958 constant dollars), which composed about 24 percent of the total United States production. All production since 1907 has come from Tennessee, Virginia, and North Carolina, chiefly from districts in eastern Tennessee and southwestern Virginia. Thus, the Appalachian Region, in the nearly six decades of recorded production, has come to the fore as the leading zinc-producing region of the country; it has the potential to maintain this position for some decades to come.

Cadmium is an important byproduct obtained in the smelting of zinc ores mined in Appalachia. The zinc industry of each State in Appalachia is discussed below.

The earliest known attempt to mine zinc in Appalachia was in Pennsylvania, where, in 1816–18, zinc-lead ore was produced from the Almedia mine near Webb's mine in Columbia County (Miller, 1924, p. 46). The operation was unsuccessful because zinc ore could not be smelted profitably at that time. The mine was reopened and operated in 1881–83 and again about 1900–1902 when $110,000 worth of concentrates was shipped to Germany. In 1949, the U.S. Bureau of Mines drilled the property and intersected good zinc-lead ore at depth (Earl, 1950, p. 3).

Zinc was discovered with lead ore in the bluff of the Susquehanna River between Sunbury and Selinsgrove, Pa., about 1845. The Doughty mine was first operated for lead, but in 1882 it was reopened and operated for lead-zinc ore for several years (Miller, 1924, p. 86).

In 1864 zinc and lead mining began in the Sinking Valley district of central Pennsylvania, near Tyrone, Blair County. The Keystone Zinc Co. was organized in that year (Miller, 1924, p. 14), and was in operation until 1870; it produced several thousand tons of oxidized zinc ore containing 31–47 percent zinc and 1–5 percent lead. Also in 1864 a large zinc oxide plant was built at Birmingham, Pa., and several other companies started prospecting in the district. These companies continued mining and prospecting until 1902.

Zinc prospects are known in several other parts of the Appalachian Region of Pennsylvania, but none of these deposits are known to have been productive (table 166). The Friedensville mine (fig. 115), Lehigh County, just east of Appalachia, is the only currently producing zinc district in Pennsylvania.

The first record of zinc production in the Appalachian part of Virginia was from near Austinville, Wythe County, in 1864, when the Union Lead Mine Co. sent zinc ore to Petersburg, Va., for trial smelting. Oxidized zinc ores were shipped from the area shortly after the Civil War. The Wythe Lead & Zinc Mining Co. acquired the property about 1874 and produced

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*

No. (fig. 115)	Location	Description	Host rock	Remarks	References
1	Walksville, Pa. Outcrops in roadcuts on Pennsylvania Turnpike, northeast extension. Located near highway survey point 401 about one-fourth mile south of Walksville, Carbon County.	Sphalerite, galena, chalcopyrite in thin fissure veins of quartz and dolomite. Veins are cross-cutting gash veins and along bedding plane partings in sandstone.	Trimmers Rock Sandstone of Late Devonian age.	The veins were found in excavating the turnpike. They are too small to be economic, but might be a guide for nearby prospecting. The deposits are notably similar to large veins near Wurtsboro, N.Y., in Silurian quartzite, and also to small veins of galena in Pennsylvanian clastic rocks near Nesquehoning, Pa.	Sims and Hotz (1951); Klemic and others (1963, p. 90–91, pl. 1).
2	Penn Haven Junction and Butcher Hollow occurrences in railroad cuts on both sides of the Lehigh River, 5 and 4 miles, respectively, north of Jim Thorpe, Carbon County, Pa.	Uraninite, clausthalite (lead selenide), and pyrite disseminated in gray sandstone along bedding planes and in roll structures.	Cherry Ridge Member of the Catskill Formation of Late Devonian age.	The uranium-lead-selenium deposits are similar in many respects to those of the Colorado Plateau. The lead content of the ore is as much as 0.5 percent.	Klemic and Baker (1954); McCauley (1961); Klemic (1962); Klemic and others (1963, p. 77–83).
3	Almedia mine, at Almedia, Columbia County, Pa.	Gash veins and breccia pipes in limestone on south flank of anticline contain sphalerite, galena, and cerussite.	Near contact of argillaceous limestone of Silurian age and overlying limestone of Early Devonian age.	The principal mines have produced considerable zinc-lead ore at intervals between 1816 when operated as Webb's mine and 1902 as the Almedia mine. Some ore found by U.S. Bureau of Mines drilling in 1949.	Miller (1924, p. 46); Earl (1950).
4	Doughty mine, on the east side of the Susquehanna River between Sunbury and Selinsgrove Junction near 135th mile post on the Pennsylvania Railroad, Northumberland County, Pa.	Sparse galena and oxidized zinc minerals in calcite-bearing gash veins and bedding plane partings in crests of anticlinal folds near the crest of the Selinsgrove anticline. Minerals are in limestone. Groups of veins are elongated S. 80° E. along axes of folds.	In upper strata of Tonoloway Limestone of Late Silurian age.	Mine had small production about 1882. Deposit is fairly large but probably not of commercial grade.	Miller (1924, p. 86).
5	Bellefonte prospect, on the east side of highway cutting through gap in Bald Eagle Mountain at north edge of Bellefonte, Centre County, Pa.	Galena, sphalerite, and quartz in veinlets in shattered quartzite.	Tuscarora Sandstone of Early Silurian age.	Deposit was prospected at intervals from 1915 through 1941. It is not commercial. Geologically it is similar to the Walksville, Pa. (No. 1), and Wurtsboro, N.Y., occurrences. A marked geochemical anomaly was found to the west across the valley in the same rocks (V. C. Kennedy, oral commun. to Heyl, 1950).	Miller (1924, p. 21).
6	Sinking Valley zinc-lead district including Birmingham zinc-lead mine, Birmingham, Blair County, Pa.	Fissure veins, bedded deposits, pipes and stockworks near major folded thrust fault. Ore is galena, sphalerite, and smithsonite associated with dolomite, barite, and pyrite in folded dolomitic limestone shattered by tight folding.	Upper Cambrian, Lower and Middle Ordovician limestones and dolomites.	A fairly large mineralized district that produced lead during the Revolutionary War and the 19th century, and zinc in some quantity between 1864 and 1876. Prospected in 1950's by The New Jersey Zinc Co.	Platt (1881, p. 247–273); Miller (1924, p. 13–16); Butts and others (1939).
7	Huntington County lead prospects, 1 mile northeast of McConnellstown, Huntington County, Pa.	Crystals of galena in calcite veinlets in limestone.	Helderberg Limestone of Early Devonian age.	Minor occurrences and prospects in small deposits very similar to that at the Doughty mine (No. 4).	Miller (1924, p. 47).
8	Siderite nodule occurrences in many localities in Allegheny, Westmoreland, Indiana, Armstrong, Clarion, and Butler Counties, Pa.	Siderite, barite, sphalerite, wurtzite, galena, and pyrite in diagenetic nodules in shales above Lower Freeport coal.	Shale below Lower Freeport coal, Freeport Formation of Allegheny Group of Pennsylvanian age.	Diagenetic nodules of this type are widespread at this horizon in western Pennsylvania and also in similar shales of Devonian, Mississippian and Pennsylvanian age. Throughout the Appalachian and Cumberland Plateaus.	Seaman and Hamilton (1950); Lapham and Geyer (1965, p. 29–32).
9	Uniontown lead-zinc prospect, Fayette County, Pa. In Victor Hollow a tributary of Georges Creek.	Galena, sphalerite, and calcite in thin veinlets in sandstone.	Pocono Formation of Early Mississippian age.	Small prospect, now filled in, was opened about 1877. The quantities of minerals were too small for economic mining, but their fairly widespread occurrence in the Pocono suggests an area worthy of some further study.	Miller (1924, p. 47).
10	Howell Farm prospect, Jefferson County, W. Va. Located on southeast bank of Shenandoah River in southeasternmost West Virginia.	Sphalerite, galena, pyrite, quartz, dolomite, and feldspar in westward-dipping breccia zone that approximately follows the bedding in dolomite beneath overthrust sandstone. Minerals are very fine grained and mostly replacements of the dolomite breccia.	Tomstown Dolomite near overthrust contact with overlying Antietam Quartzite of Early Cambrian age.	Old prospect on farm of Ulysses Howell, prospected by U.S. Bureau of Mines in 1953 and by Tri-State Zinc Co. with some success; fairly large deposit indicated. Other occurrences known for several miles along west base of Blue Ridge in the same rock sequence.	Ludlum (1955).
11	Serpent Mound occurrence, 2 miles east-northeast of Louden, Adams County, Ohio.	Sphalerite and smithsonite cement gray dolomite shatter breccia in the west-central part of the Serpent Mound cryptoexplosion structure. No galena is known.	Brecciated limestones and dolomites of Middle and Late Silurian age.	The known zinc occurrences are small but unprospected. They are distributed over 2–3 acres of exposed outcrop. The zinc may not be abundant enough to form a commercial grade deposit, but it should be a useful starting point to search for better deposits in the Serpent Mound structure and in the nearby region where other sphalerite occurrences are reported in Silurian carbonate rocks.	Heyl and Brock (1962, p. D95–D97).

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*—Continued

No. (fig. 115)	Location	Description	Host rock	Remarks	References
12	Central Kentucky district, Clark, Madison, Garrard, Lincoln, and Rockcastle Counties, Ky.	Barite, fluorite, sphalerite, and galena in fissure veins. Most venis are in nearly vertical strike-slip faults, that displace very low-dipping limestone and dolomite beds. Sphalerite contains notable trace-element quantities of cadmium and germanium, and in places, mercury.	Middle Ordovician limestones.	This southeast part of the district in Appalachia has produced only barite to date, but has been prospected for fluorite, sphalerite, and galena. Most promising strata for future prospecting are the Ordovician dolomites of Beekmantown age that lie at depth beneath the district and may contain disseminated deposits.	F. J. Fohs (1913, p. 441–588); Robinson (1931); Jolly and Heyl (1964).
13	Cumberland River area, Cumberland and Monroe Counties, Ky.	Sphalerite, galena, barite, and calcite fissure veins, similar to those in the Central Kentucky and Central Tennessee districts.	Middle and Upper Ordovician limestones.	Fissure veins, rich in lead and zinc, which are outlying to the Central Kentucky district. As in that district, the most favorable strata for future prospecting are at depth in the unprospected Lower Ordovician dolomites.	Jolly and Heyl (1964).
14	Central Tennessee district, Macon, Clay, Pickett, Overton, Jackson, Putnam. Smith, and De Kalb Counties, Tenn.	Barite, fluorite, sphalerite, galena, and calcite fissure veins in Middle Ordovician limestones. Some veins are known to extend into the upper part of the Lower Ordovician dolomites. Cadmium, germanium, and mercury are relatively abundant trace elements in sphalerite.	Middle and Lower Ordovician limestones and dolomites.	Fissure veins on the eastern periphery of the Central Tennessee vein district. Many small prospects but probably no lead-zinc production. Most promising strata for future prospecting are the lower Middle Ordovician and Lower Ordovician dolomites and limestones where disseminated deposits similar to those in East Tennessee might occur.	W. B. Jewell (1947).
15	Scattered drill holes and occurrences in south-central Tennessee.	Sphalerite disseminated in dolomite and breccias.	do	A large area of very minor amounts of sphalerite found mostly in deep drill holes. Deposits may be similar to those of the Mascot-Jefferson City district (see No. 29 below).	K. E. Born (unpub. data, Tenn. Div. Geology, 1942); S. W. Maher (oral commun., Tenn. Div. Geology, 1965).
16	Austinville district, Wythe, Smyth, and Pulaski Counties, Va.	Sphalerite, galena, pyrite and white dolomite cementing small to large bodies of dolomite breccia. Secondary lead and zinc minerals occur in residuum. Sulfides emplaced as open-space filling and replacement. District has many prospects, mines, and occurrences of Pb-Zn sulfides in an area roughly 5 miles wide and more than 50 miles long.	Lower Cambrian Shady Dolomite with a few outlying occurrences and prospects in the overlying Rome Formation.	This district is the largest zinc-lead producing district in Virginia. Current production is from the Austinville and Ivanhoe mines of The New Jersey Zinc Co. Currier describes more than 40 small mines, prospects, and occurrences in the district in addition to those in the immediate vicinity of the main producing mines.	Watson (1907, p. 520–541); Currier (1935a, p. 3–88); Brown (1935, p. 425–433).
17	Near Troutville, Botetourt County, Va.	Currier reported "galena and oxidized zinc mineral occur in a dolomite breccia cemented by white dolomite."	Middle and Upper Cambrian Elbrook Dolomite.		Currier (1935a, p. 94).
18	Near Bonsacks, Botetourt County, Va.	Pyrite, sphalerite, and traces of chalcopyrite in crackle breccia in dolomite veined by white dolomite.	Lower Cambrian Rome Formation.	Exposed by shallow shaft	Currier (1935a, p. 94–95).
19	Vicinity of Kimberling and No Business Creeks, Bland County, Va.	Sphalerite and galena associated with pyrite in limestone.	Age and name of host formation not given but location suggests it may be middle Paleozoic, probably Upper Silurian Tonoloway Limestone (Ladd and Stead, 1944, pl. 37).	One specimen of ZnS reported to contain more than 4 percent Fe.	Currier (1935a, p. 109).
20	Leckie-Moss manganese mine, near Garden Mountain, Bland County, Va.	Small amount of galena in limestone.	Upper Silurian Tonolway Limestone.		Stose and Miser (1922, p. 173).
21	Near Shannondale, Tazewell County, Va.	Sphalerite and galena impregnating float-block of Maryville-type limestone.			B. N. Cooper (1944a, p. 277).
22	Near Cedar Bluff, Tazewell County, Va.	Currier reported presence of a lead-zinc prospect in dense limestones.	Upper Cambrian Nolichucky Formation.		Currier (1935a, p. 109).
23	Rich Valley area between Saltville and Chatham Hill, Smyth County, Va.	Sphalerite and white gangue dolomite cementing dolomite fragments of breccias; some pyrite also occurs. Sphalerite locally oxidized in weathered zones.	Upper Cambrian Copper Ridge Dolomite.	Several areas explored by various mining companies by diamond drilling.	
24	Marion barite district, Smyth County, Va.	Local concentration of sphalerite in dolomite breccias cemented chiefly by barite and fluorite.	Lower Ordovician Beekmantown Dolomite (probably at Kingsport ore zone of Mascot-Jefferson City district of East Tennessee).	ZnS noted in three old barite mines in western part of district. One carload of copper ore reported to have been shipped from one barite mine at eastern end of district. Myers prospect at western end of district tested by diamond drilling with negative results.	Cooper (1936, p. 139); Edmundson (1938, p. 76–79); Young and Wedow (1961).
25	Osborn mine and adjacent prospects, Russell County, Va.	Sphalerite, galena, and white dolomite cementing dolomite country rock in a breccia or shear zone. Sulfide minerals largely altered to secondary minerals by weathering.	Middle Cambrian Maryville Limestone (just below contact with Nolichucky Shale).	Worked and prospected intermittently from about 1900 through World War II. Woodward reported an occurrence of calamine in the Middle Ordovician Holston Limestone, about 1½ miles north of the Osborn mine.	Watson (1907, p. 541); Currier (1935a, p. 109); Woodward (1938, p. 66–69).

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*—Continued

No. (fig. 115)	Location	Description	Host rock	Remarks	References
26	Pat Keith prospect, near head of Sinking Creek, Russell County, Va.	Small masses of resinous yellow-brown sphalerite and galena disseminated in dolomite.	Upper Cambrian Copper Ridge Dolomite.	Prospected about 1915 and again in 1930; no ore shipped.	Woodward (1938, p. 69).
27	Lane prospect, Scott County, Va.	Light-brown sphalerite and white dolomite filling fissures and replacing fractured medium-grained gray dolomite in a bed about 5 ft thick.	Lower Cambrian Rome Formation.	Mineralized area probably less than 200 ft in diameter.	J. Rodgers, C. H. Behre, and D. F. Kent (unpub. data U.S. Geol. Survey, 1943). Brent (1963, p. 42).
28	Arcadia prospects, Scott County, Va.	Dark-brown sphalerite with pyrite, calcite, dolomite, barite, and traces of chalcopyrite cementing and locally replacing fragments of a brecciated dolomite bed. "Vein" reported to range from 5 to 10 ft in thickness.	Middle Cambrian Honaker Dolomite (about 500 ft below base of Nolichucky Shale).	Early development consisted of several shafts and opencuts along 1800 ft of the bed. Workings reopened and extended in 1964 by American Steel Products Corp. of Cleveland, Ohio.	Secrist (1924, p. 33–37); Currier (1935a, p. 110); Gladstone and others (1945).
29	Mascot-Jefferson City district, Jefferson, Knox, Grainger, and Sevier Counties, Tenn.	Generally light-yellow sphalerite with minor amounts of pyrite and local traces of chalcopyrite with dolomite gangue in brecciated dolomite and limestone. Ore bodies are generally several tens of feet broad and high and ramiform in plan. Most of country rock in district has relatively shallow dip—generally less than 20°.	Lower Ordovician Longview, Kingsport, and Mascot Formations (about upper 1000 ft of Knox Group).Principal ore bodies occur in lower 200 ft of Kingsport Formation, particularly in zone where fine-grained dolomite overlies the first major limestone beneath the post-Knox unconformity.	This district is the leading zinc-producing district of the United States with eight active mines and one mine under development. Four relatively shallow underground sulfide mines have been abandoned as being worked out. Four mills process approximately 15,000 tons of crude ore daily. Signiffcant amounts of sulfide concentrates were first produced by the American Zinc Co. of Tennessee in 1912.	Secrist (1924, p. 104–128); Newman (1932); Currier (1935b, p. 264, 271–276); Oder and Miller (1945); Brokaw (1950); Oder and Hook (1950, p. 74–82); Bridge (1955); Oder and Ricketts (1961); Hoagland and others (1965).
30	Copper Ridge district, Hancock, Hawkins, Grainger, Union, and Knox Counties, Tenn.	Similar to Mascot-Jefferson City district, but ore locally contains minor amounts of galena and attitude of bedrock is steeper (25°–55°).	Same as Mascot-Jefferson City district (see No. 29 above), but some sphalerite has been noted in the Chepultepec Dolomite on Puncheon Camp Creek and in the Rome Formation on War Ridge.	Many sulfide occurrences prospected in early part of century; district has one active modern mine (New Jersey Zinc Co.'s Flat Gap mine at Treadway) and a potential for several other commercial deposits.	Secrist (1924, p. 64, 80–96); Rodgers (1943); Kent and Rodgers (1945); Hoagland (1962); Hoagland and others (1965).
31	Powell River district, Anderson, Campbell, Union, Claiborne, and Hancock Counties, Tenn.	Narrow replacement deposits along nearly vertical faults and fractures accompanied by some open-space filling in breccias and other fractures, and bedded replacement deposits apparently unrelated to faults and fractures. Sulfide minerals are chiefly brown sphalerite, galena, and pyrite.	Upper Cambrian Maynardville Formation and Copper Ridge Dolomite. A few prospects are also found in the Lower Ordovician Formations of the Knox Group.	Nearly 100 mines, prospects, and occurences of zinc and (or) lead minerals are reported. Principal production has come from the New Prospect, Bunch Hollow, and Kings Bend mines.	Secrist (1924, p. 37–47); Currier (1935b, p. 276–278); Kent and Rodgers (1945); Brokaw and others (1966b).
32	Straight Creek district, Claiborne County, Tenn.	Sphalerite, pyrite, and galena in replacement ore bodies, chiefly along intersections of fractures and faults.	Upper Cambrian Maynardville Formation and minor occurrences in overlying Copper Ridge Dolomite.	A small district southeast of and generally similar to the Powell River district. District contains one mine (inactive) and at least six additional prospects. The Straight Creek mine was reportedly opened about 1880 and worked or prospected intermittently since then; it is currently owned by The New Jersey Zinc Co.	Secrist (1924, p. 47–52); Currier (1935b, p. 278); Kent and Rodgers (1945); D. F. Kent and J. Rodgers (unpub. data, U.S. Geol. Survey, 1945).
33	Evanston district, Hancock County, Tenn.	Chiefly sphalerite with minor amounts of galena and pyrite disseminated in fine-grained dolomite; brecciation generally minor and local.	Lower Cambrian Rome Formation.	First discovered about 1916; district was actively prospected during World War I and for a few years following. Extensive beneficiation tests made by the U.S. Bureau of Mines in the early 1920's indicate ore is much finer grained, in general, than other East Tennessee zinc ores and will probably require different beneficiation methods.	Secrist (1924, p. 53–80); Currier (1935b, p. 278); R.M. Hutchinson (unpub. data, U.S. Geol. Survey, 1943).
34	Moore prospect, Anderson County, Tenn.	Yellow sphalerite and galena, traces of pyrite and chalcopyrite and a calcite gangue cementing fractured dolomite.	Lower Cambrian Rome Formation.	First examined by TVA in 1930's; additional prospecting in 1950's.	Maher and Finlayson (1965, p. 46).
35	Fall Branch barite district, Greene, Washington, and Sullivan Counties, Tenn.	Yellow to brown sphalerite with pyrite and a little chalcopyrite in a gangue of dolomite, calcite, and barite filling fractures and cementing breccias in dolomite country rock.	Lower Ordovician part of Knox Group, probably Kingsport and Mascot Formations.	Zinc content of barite ores first noted in 1890's. Zinc mining was begun in 1906 but shut down before the end of the decade. District consists of one small abandoned mine and numerous prospects.	Secrist (1924, p. 96–101); R. A. Laurence (unpub. data, U.S. Geol. Survey, 1934); J. Rodgers (unpub. data, U.S. Geol. Survey, 1943). I. Gladstone and V. Nelson (unpub. data, U.S. Geol. Survey, 1943); Maher and Finlayson (1965).
36	Butler district, Johnson and Carter Counties, Tenn.	Yellow-brown and red sphalerite with a little galena and pyrite in veinlets and small irregular masses cementing fractured dolomite; some quartz and barite have been noted. Country rock dips vertically or steeply southeast.	Lower Cambrian Shady Dolomite.	Includes Dugger, Wagner, and Dougherty prospects.	Safford (1869, p. 484); D. F. Kent, and J. Rodgers (unpub. data, U.S. Geol. Survey, 1943); C. L. Jones (unpub. data, U.S. Geol. Survey, 1945); King and others (1944, p. 172–173); King and Ferguson (1960, p. 86, 87).
37	Watauga Point and Carden prospects, Carter County, Tenn.	Small amounts of sphalerite and (or) galena locally replacing country rock and filling fractures; traces of pyrite and chalcopyrite also noted.	Middle Cambrian Honaker Dolomite.	Initial work done on Watauga Point prospect about 1900.	Secrist (1924, p. 140–141); Maher (1959, p. 142); King and Ferguson (1960, p. 86, 87).

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*—Continued

No. (fig. 115)	Location	Description	Host rock	Remarks	References
38	Embreeville district (Bumpass Cove), Unicoi and Washington Counties, Tenn.	Oxidized zinc and lead deposits in residuum overlying dolomite. Some sphalerite and galena occur disseminated in and along fractures cutting dolomite country rock.	Lower Cambrian Shady Dolomite.	First mined for lead about 1780; significant zinc mining began in 1913. Oxidized ores probably still have some reserve potential, although readily discovered deposits have been largely mined out. Potential for sulfide deposits probably limited by lack of large areas of favorable ore-bearing horizons.	Secrist (1924, p. 141–147); Rodgers (1948).
39	Prospects in Greene County, Tenn.	Local concentrations of sphalerite and (or) galena replacing dolomite or filling fractures in brecciated dolomite.	Cambrian and Ordovician Knox Group.	First prospected in early 1900's. Prospects include Naff and R. Johnson in the Mascot Dolomite; Brown-Tipton and Colvard in the Chepultepec Dolomite; and Nea in the Maynardville Formation.	Secrest (1924, p. 102, 104); Synder (1944); Kent and Dunlap (1945); Warner (1950); Brokaw and others (1966a).
40	Felknor mine, Jefferson County, Tenn.	Dark-yellow-green to light-yellow sphalerite with some galena, pyrite, and a little chalcopyrite in dolomite gangue cementing brecciated dolomite country rock.	Lower Ordovician Mascot Dolomite about 100 ft below post-Knox unconformity.	Mined for lead during the Civil War.	Secrist (1924, p. 147–151); Walthier (1944).
41	Trotter prospect, Sevier County, Tenn.	Yellow to green sphalerite in small irregular blebs and veinlets in dark coarse-grained dolomite. Original shaft completely caved and filled; sulfide minerals seen only on spoil dump.	Lower Ordovician Mascot Dolomite; main prospect shaft may be on post-Knox unconformity.	A few scattered grains of sphalerite were noted by H. Wedow and J. R. Marie in dark-gray medium-crystalline dolomitic breccia matrix in pinnacles of borrow pit several thousand feet upstream from left abutment of Douglas Dam; the stratigraphic position of these pinnacles is about 100 ft below post-Knox unconformity.	R. A. Laurence (unpub. data, U.S. Geol Survey, 1963); Marie (1963, p. 31, pl. 1); Maher (1964b, p. 106).
42	Fairgarden prospects, Sevier County, Tenn.	Sphalerite with dolomite, barite, and calcite gangue cementing brecciated dolomitic country rock.	Lower Ordovician Mascot Dolomite, probably in upper 200 ft.	First discovered in 1900; last prospected in 1957.	Secrist (1924, p. 151–152); Maher and Finlayson (1965, p. 44–45.)
43	Little River occurrences, Blount County, Tenn.	Four occurrences of light-yellow to yellow-brown sphalerite in dolomite.	Cambrian and Ordovician Knox Group (two occurrences in Lower Ordovician Kingsport Formation and two in Upper Cambrian Copper Ridge Dolomite).	Discovered by Frank Dakin in 1961–62.	Maher and Finlayson (1965, p. 46–47).
44	Maryville (Pistol Creek) prospect, Blunt County, Tenn.	Light-yellow sphalerite and dolomite cementing breccia of coarse crystalline dolomite.	Lower Ordovician Kingsport Formation.	Exposed in footing for bridge being built over Pistol Creek; recognized by R. L. Wilson while mapping in the Blockhouse quadrangle for the Tennessee Division of Geology. Geochemical survey shows anomalous amounts of zinc in soil for more than 1,000 ft of strike length in vicinity of bridge.	Maher (1959, p. 143–145); Neuman and Wilson (1960).
45	Friendsville prospect, Blount County, Tenn.	Barite, galena, and sphalerite with gangue of dolomite and calcite and a little pyrite and fluorite cementing breccia in dark fine-grained massive dolomite.	Lower Ordovician Mascot Dolomite about 250 ft below post-Knox unconformity.	First prospected about 1907-------	Secrist (1924, p. 128–130).
46	Eve Mills district, Monroe and Loudon Counties, Tenn.	Light-yellow to black sphalerite, pyrite, dolomite, calcite, and barite cementing fractured and brecciated dolomite; sulfides are believed to have replaced some of the carbonates. Exploration by the Federal Government during World War II indicated an ore body of more than 100,000 tons averaging about 3 percent Zn.	Lower Ordovician Kingsport Formation and overlying Mascot Dolomite.	Oxidized ore pockets found locally. Discovered in early part of 20th century; prospected by the American Zinc Co. in 1911–12 and again during World War II by the American Zinc Co. and the Federal Government. Also diamond drilled by the American Smelting & Refining Co. in the 1950's; cores available at the Tennessee Division of Geology.	Secrist (1924, p. 130–133); Dunlap (1947); Sayrs (1949). Geologic logs and assay data from 32 drill holes cored during World War II are on open-file at the U.S. Geological Survey.
47	Sweetwater barite district, Roane, Loudon, Monroe, McMinn, and Bradley Counties, Tenn.	Weathered brecciated dolomite pinnacles in barite pits show trace to minor amounts of sphalerite and (or) galena and their secondary weathering products in association with barite, fluorite (both green and purple to white) and pyrite (generally oxidized to limonite).	Lower Ordovician part of the Knox Group, chiefly the Kingsport Formation, but also the Mascot, Longview, and Chepultepec Dolomites.	Includes C. C. Patrick prospect northwest of Loudon and north of the Tennessee River which shows appreciable galena (Secrist, 1924, p. 134); and a lead prospect near Riceville, McMinn County (McCaskey, 1914, p. 191).	Secrist (1924, p. 133–134); Laurence (1939, 1960); J. C. Dunlap (unpub. data, U.S. Geol. Survey, 1945).
48	Hambright mine, Bradley County, Tenn.	Sphalerite, galena, pyrite, and white dolomite and possibly barite filling fractures and cementing breccias in fine-grained dolomite and limestone country rock.	Lower Ordovician Mascot Dolomite, about 300 ft below post-Knox unconformity.	First opened in 1851 and worked extensively by the Confederacy for lead during the Civil War.	Secrist (1924, p. 135–136); J. Rodgers, (unpub. data, U.S. Geol. Survey, 1943); Swingle (1959, p. 70–73).
49	Hardwick ("Dollie D") mine, Bradley County, Tenn.	Sphalerite, galena, dolomite, calcite and perhaps some barite filling fractures and cementing brecciated dolomite.	Upper Cambrian Maynardville Formation.	First opened in 1892; no work done since 1906 except exploration by various companies in 1925–26 and 1946.	Secrist (1924, p. 136, 138–140); Dunlap (1946); Swingle (1959, p. 73–75).
50	Cartersville district, Bartow County, Ga.	Traces of galena and sphalerite in barite.	Lower Cambrian Shady Dolomite.	Reported only from the Iron Hill and Tucker Hollow mines.	Kesler (1950a, p. 45–46).

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*—Continued

No. (fig. 115)	Location	Description	Host rock	Remarks	References
51	Near Jamestown, Cherokee County, Ala.	Galena associated with a little sphalerite (probably in dolomite).	Host rock not reported but probably is one of the Lower Ordovician Formations of the Knox Group.	Prospected in 1917	Adams and Jones (1940, p. 14).
52	Angel district, Calhoun County, Ala.	Galena, sphalerite, and barite filling fractures in brecciated dolomite; ore minerals show slickensides; some sphalerite altered to smithsonite by weathering.	Lower Ordovician Newala and Longview Formations; one prospect reported in Middle and Upper Cambrian Conasauga Formation.	Main prospect pit referred to as "Old Lead mine"; was worked for lead by the Confederacy during the Civil War.	Jones (1926, p. 177); Adams and Jones (1940, p. 14, 15, 34–35); Ehinger (1964).
53	Beaver Valley barite district, St. Clair and Etowah Counties, Ala.	Specks of galena reported in barite on the Pat Green property.	Cambrian and Ordovician Knox Group.		McCalley (1897, p. 262); Adams and Jones (1940, 32–34).
54	Sixmile Creek ("Sinks") barite district, Bibb County, Ala.	Disseminated yellow-brown sphalerite in detrital dolomitic matrix associated with barite masses in a breccia of fine-grained dolomite.	Lower Ordovician Newala Formation.	Found by T. L. Neathery of the Geological Survey of Alabama and H. Wedow of the U.S. Geological Survey in November 1965.	H. Wedow (unpub. data U.S. Geol. Survey, 1966).
55	North flank of Beech Mountain, Watauga County, N.C.	Minor occurrences of galena and sphalerite in phyllonite zones that usually also carry magnetite and hematite.	Cranberry Gneiss and Beech Granite (Precambrian).		Keith (1903, p. 8); Bryant (1962, p. 26–27).
56	North Cove prospect, McDowell County, N.C.	"Disseminated sphalerite with small amounts of cuprite, chalcopyrite, pyrite * * * associated with quartz, and calcite occur in veinlets and as irregular replacements in dolomite" (J. C. Reed, Jr., 1964b, p. 44).	Lower Cambrian Shady Dolomite (in Grandfather Mountain window).	Explored by several mining companies; diamond-drill cores from most recent exploration (1963) are on file with North Carolina State University at Raleigh.	Bryson and others (1937, p. 36–37); J. C. Reed, Jr., (1964b, p. 44).
57	Upper Creek prospect, Burke County, N.C.	Galena, in cubes as much as 5 mm across, and small amounts of sphalerite and chalcopyrite in 25–30-ft thick vein of granular quartz.	Precambrian or lower Paleozoic schist and gneiss.	Galena reportedly carries small amount of silver.	J. C. Reed, Jr. (1964b, p. 44–45).
58	Hot Springs-Del Rio barite district, Madison County, N.C., and Cocke County, Tenn. (includes adjacent Gulf Fork area in Tennessee).	Scattered occurrences of zinc and lead sulfides in vein barite deposits, and in quartz veins and shear zones.	Lower Cambrian basal clastic rocks and Precambrian Ocoee Series and basement complex.		Oriel (1950, p. 49); Ferguson and Jewell (1951, p. 52); Maher and Finlayson (1965, p. 45–46; Gulf Fork area).
59	Fletcher occurrence, Henderson County, N.C.	Galena filling fractures in and replacing mylonite of Brevard fault zone.	Brevard Schist (blastomylonite) (Lower Cambrian).		Davis and Hale (1966).
60	Pardo prospect, Henderson County, N.C.	Galena, sphalerite, chalcopyrite, arsenopyrite, bournonite, and tetrahedrite intergrown with quartz; believed to be either quartz vein or replacement of carbonate lens.	Hornblende gneiss and mica schist locally intruded by granite.	Galena is very argentiferous. Prospect is said to have been exploited for lead by Juan Pardo, a 16th century Spanish explorer.	C. E. Hunter and L. J. Hash (unpub. data, TVA, 1949); Davis and Hale (1966).
61	Redmon (Redmond) mine, Haywood County, N.C.	Irregular vein or series of disconnected lenses of sulfide-bearing quartz in shear zone along fault; sulfide minerals are galena, sphalerite, chalcopyrite, pyrite, and a trace of pyrrhotite in gangue of quartz, carbonate, fluorite, and chlorite.	Precambrian basement complex near contact with Precambrian Ocoee Series.	Discovered about 1905 and subsequently prospected by various mining companies.	Bryson and others (1937, p. 36); Espenshade and others (1947); Murdock ([1950?], p. 13); Hadley and Goldsmith (1963, p. B112–B114).
62	Regal occurrence, Cherokee County, N.C.	Minor amount of galena filling fractures in and locally replacing limestone.	Murphy Marble (Lower Cambrian).		Davis and Hale (1966).
63	Central Carolina barite district, Cherokee and York Counties, S.C. and Gaston County, N.C.	Galena and minor amounts of sphalerite and chalcopyrite occur with barite as veins and disseminated in a zone of calcareous(?) quartz-sericite schist ranging in width from a few feet to more than 1,000 ft.	At or near contact between Battleground Schist and Bessemer Granite (Ordovician to Mississippian).	One prospect in Cherokee County said to contain abundant galena.	Keith and Sterrett (1931, p. 9–10); Van Horn and others (1949); Kesler (1950b, p. 94–95); C. K. McCauley (1962).
64	Cameron mine, near Gaffney, Cherokee County, S.C.	Sulfide minerals in quartz-carbonate vein lying nearly parallel to schistosity of country rock. Chief vein minerals are siderite, quartz, galena, and chalcopyrite; pyrite, pyrrhotite, tetrahedrite, pyromorphite, cerrusite, and malachite are also reported.	Hornblende schist lens enclosed by granite.	Worked to a depth of about 140 ft during Civil War. Galena reported to be highly argentiferous.	Sloan (1900, p. 93, 94); Keith and Sterrett (1931, p. 12).
65	Kuhtman prospect, Oconee County, S.C.	Quartz vein carrying galena; vein 6–8 in. wide.	Gneiss	Worked briefly in 1860's.	Sloan, (1908, p. 93, 94).
66	Massive sulfide deposits in Virginia, North Carolina, Tennessee, Georgia, and Alabama.	Massive sulfide bodies chiefly of pyrite and pyrrhotite but with lesser amounts of base-metal sulfide contained local concentrations of sphalerite and galena. Many of these bodies will average more than 1 percent Zn with lesser amounts of Pb.	Precambrian or Paleozoic metamorphic rocks.	Sphalerite and galena concentrates are recovered as valuable byproducts in sulphuric acid manufacture and copper production. Examples of this type of deposit in Appalachia are in the Gossan Lead in Virginia (66A), the Ore Knob (66B) and Fontana (66C) mines in North Carolina, at Ducktown (66D) in Tennessee, the Little Bob mine (66E) in Georgia, and at Stone Hill (66F) in Alabama. Enough zinc is recovered at Ducktown (Copperhill), for example, to make it the 20th largest zinc mine in the United States in 1964 (Schroeder, 1965b, p. 1176).	Kinkel and others, "Copper and Sulfur" section, this report; Schroeder (1965b, p. 1176).

TABLE 166.—*Zinc and lead occurrences in the Appalachian Region*—Continued

No. (fig. 115)	Location	Description	Host rock	Remarks	References
67	Gold deposits of the southern Piedmont, North Carolina, South Carolina, Georgia, and Alabama.	Chiefly gold-bearing quartz veins and mineralized shear zones. Many of these deposits contain minor amounts of sphalerite and galena along with other metallic sulfides below the zone of oxidation, that is, below the zone of "free-milling" gold ores.	Precambrian and Paleozoic metamorphic and igneous rocks.	Sphalerite is widespread and common in this type of deposit except perhaps in northern Georgia (Pardee and Park, 1948, p. 37, 40). Galena occurs in many of the gold lodes in small amounts and is abundant in some, such as the Battle Branch mine (67A) in Lumpkin County, Ga. (Park and Wilson, 1936), and in the Cragford district (67B), Ala. (Jones, 1926, p. 15, 177). Just outside of Appalachia, sphalerite and silver-rich galena ores have been mined in Cabarrus (67D) and Davidson (67C) Counties, N.C., McCormick County (67E), S.C., and Lincoln County (67F), Ga. (Pardee and Park, 1948, p. 65–66, 72–73, 117–119, 131).	Bergendahl and Stansfield, "Gold" section, this report; Luttrell and Stansfield, "Silver" section, this report.

oxidized zinc ore from 1874 to 1900. In 1902 the property was sold to the Bertha Mineral Co. which subsequently became a subsidiary of The New Jersey Zinc Co. (Currier, 1935a). In the late decades of the 19th century the Bertha Zinc & Mineral Co. also produced oxidized ores.

When the oxidized zinc ores were depleted in the early part of the 20th century, attention was directed to the beneficiation of sulfide ores. Experimentation with flotation of zinc sulfides began in 1911, and in 1917 the first profitable production was achieved. Zinc sulfide was produced from 1910 through 1966 from the Austinville mine, with the exception of the years 1919–23.

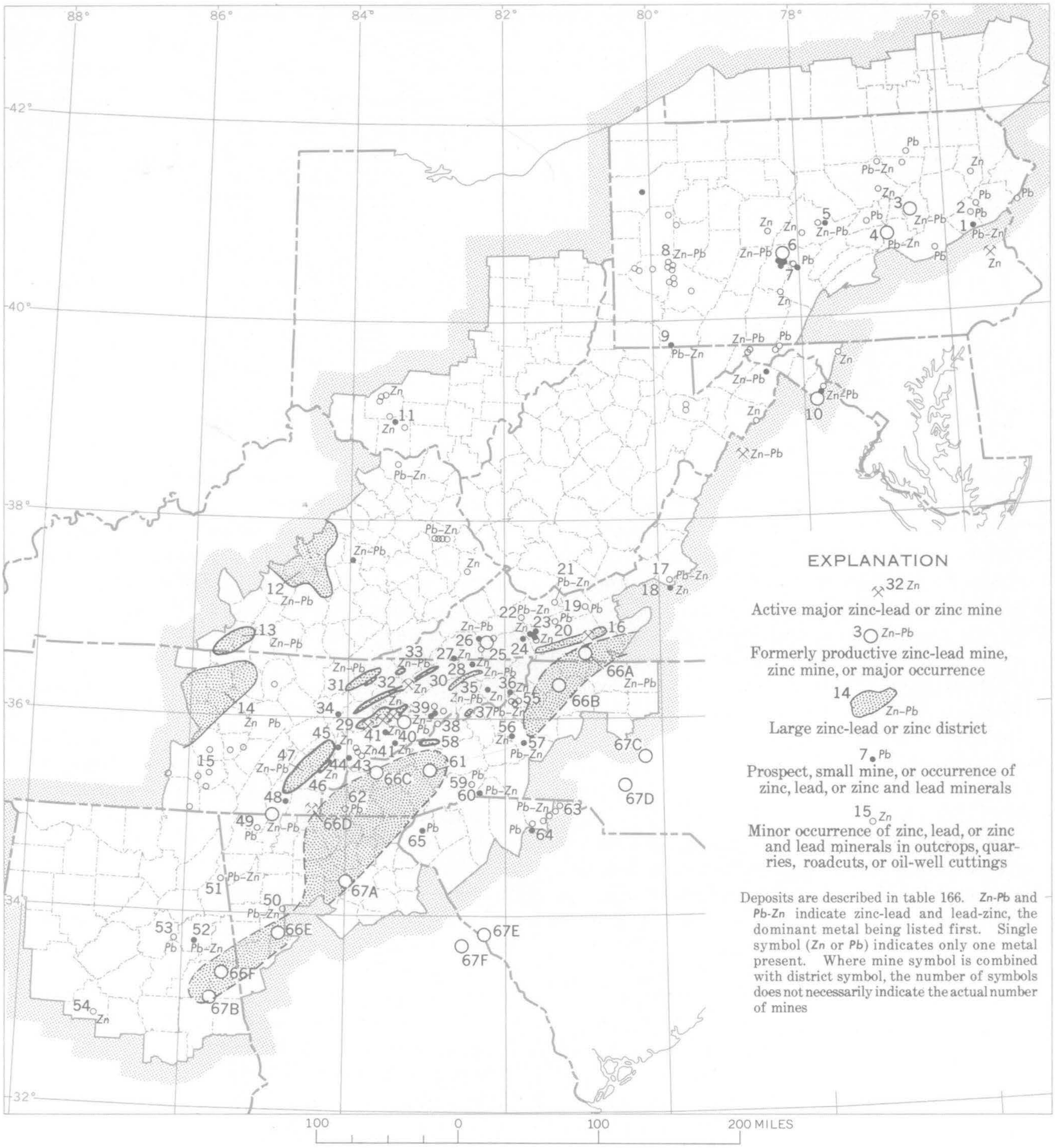
As early as 1864, oxidized zinc ores were mined as byproducts of iron mining in southwestern Virginia, especially near Ivanhoe, Pulaski, and Cedar Springs. This production continued until at least 1915. The Ivanhoe mine produced lead and zinc ores intermittently from 1915 to 1936. It was idle from 1937 until 1957 when it was acquired by The New Jersey Zinc Co. In recent years, particularly in the 1950's, several companies drilled in southwestern Virginia in the search for new deposits of zinc and lead.

About 1951, a large zinc ore body was found in the northern Shenandoah Valley near Timberville, Va., just outside Appalachia (fig. 115, unnumbered deposit in northwestern Virginia near the West Virginia boundary). Tri-State Zinc, Inc., mined this ore body from 1958 to 1963.

The first recorded production of zinc ore in Tennessee was in 1854 from oxidized deposits along Mossy Creek at the eastern end of the Mascot-Jefferson City district (fig. 115, No. 29). Similar ores were discovered in 1858 at Mascot and about 1892 near New Market. Recognition of the underlying sulfide ores at these mines and the depletion of the surficial oxidized ores after several decades of intermittent mining led to the gradual development of the modern large zinc mining industry of the Mascot-Jefferson City district. The first major company to enter the district was the American Zinc, Lead & Smelting Co. with the development of their mill and first mine at Mascot by 1913. In 1926, the Universal Exploration Co., a subsidiary of the United States Steel Corp., began shipping concentrates from its operations at the Davis mine southwest of Jefferson City. In 1947 the third major zinc operator, The New Jersey Zinc Co., acquired options to mineral rights and by 1953 was producing from its Jefferson City mine. During intensive exploration by all operating companies in the Mascot-Jefferson City district in the 1950's, large reserves were discovered in the West New Market area. In 1960, the American Zinc Co. of Tennessee entered into a joint venture with Tri-State Zinc, Inc., whereby Tri-State would develop part of this large mineralized area. This joint venture, known as the New Market Zinc Co., presently operates the New Market mine (Maher, 1958, p. 1–5; Boyle and Williams, 1965, p. 2–3).

Zinc sulfide ores were discovered in the Copper Ridge district, Tennessee (fig. 115, No. 30), about 1912. However, large-scale mining in this district did not begin until The New Jersey Zinc Co. developed its Flat Gap mine in the late 1950's after an intensive exploration campaign throughout the district. In 1966, this company began development of its Idol mine, about 10 miles southwest of the Flat Gap mine.

Although the Embreeville district in Washington and Unicoi Counties, Tenn. (fig. 115, No. 38), was long known for its iron and lead deposits, zinc pro-



Deposits are described in table 166. *Zn-Pb* and *Pb-Zn* indicate zinc-lead and lead-zinc, the dominant metal being listed first. Single symbol (*Zn* or *Pb*) indicates only one metal present. Where mine symbol is combined with district symbol, the number of symbols does not necessarily indicate the actual number of mines

FIGURE 115.—Zinc and lead in the Appalachian Region. Numbers refer to table 166 and are used in the discussion.

LIST OF DISTRICTS, MINES, PROSPECTS, AND OCCURRENCES

PENNSYLVANIA
1. Walksville (Pennsylvania Turnpike) occurrence
2. Penn Haven Junction occurrence
3. Almedia mine
4. Doughty mine
5. Bellefonte prospect
6. Birmingham zinc-lead mine and Sinking Valley lead mines
7. Huntington County prospects
8. Siderite nodule occurrences with sphalerite, wurtzite and/or galena in western Pennsylvania
9. Uniontown prospect

WEST VIRGINIA
10. Howell Farm prospect and Blue Ridge occurrences

OHIO
11. Serpent Mound occurrence

KENTUCKY
12. Central Kentucky fluorite-barite-lead-zinc district
13. Cumberland River area

VIRGINIA
16. Austinville zinc-lead district
17. Troutville occurrence
18. Bonsacks prospect
19. Kimberling and No Business Creeks occurrences
20. Leckie-Moss manganese mine occurrence
21. Shannondale occurrence
22. Cedar Bluff occurrence
23. Rich Valley area prospects and occurrences
24. Marion barite district
25. Osborn mine and adjacent prospects and occurrences
26. Pat Keith prospect
27. Lane prospect
28. Arcadia prospects and occurrences
66A. Gossan Lead district

TENNESSEE
14. Central Tennessee fluorite-barite-lead-zinc district
15. Surface and drill-hole occurrences in south-central Tennessee
29. Mascot-Jefferson City zinc district
30. Copper Ridge zinc district
31. Powell River zinc-lead district
32. Straight Creek zinc-lead district
33. Evanston zinc-lead district
34. Moore prospect
35. Fall Branch barite district
36. Butler district
37. Watauga Point and Carden prospects
38. Embreeville (Bumpass Cove) zinc-lead district
39. Greene County prospects
40. Felknor mine
41. Trotter prospect
42. Fairgarden prospects
43. Little River occurrences
44. Maryville (Pistol Creek) prospect
45. Friendsville prospect
46. Eve Mills zinc district
47. Sweetwater barite district
48. Hambright mine
49. Hardwick ("Dollie D") mine
58. Del Rio barite district
66D. Ducktown copper-zinc district

NORTH CAROLINA
55. Beech Mountain occurrences
56. North Cove prospect
57. Upper Creek prospect
58. Hot Springs barite district
59. Fletcher occurrence
60. Pardo prospect
61. Redmon (Redmond) mine
62. Regal occurrence
66B. Ore Knob mine
66C. Fontana mine
67C. Davidson County mines and occurrences
67D. Cabarrus County mines and occurrences

ALABAMA
51. Jamestown occurrence
52. Angel district
53. Beaver Valley barite district
54. Sixmile ("Sinks") barite district
66F. Stone Hill mine
67B. Cragford district

GEORGIA
50. Cartersville district
66E. Little Bob mine
67A. Battle Branch mine
67F. Lincoln County mines and occurrences

SOUTH CAROLINA
63. Central Carolina barite district
64. Cameron mine
65. Kuhtman prospect
67E. McCormick County mines and occurrences

duction did not begin until about 1910. According to Rodgers (1948, p. 46), more than 200,000 tons of oxidized zinc concentrates averaging about 40 percent zinc were shipped between 1913 and 1946.

Small-scale mining and milling in the Powell River and Straight Creek districts (fig. 115, Nos. 31, 32) began in the 1880's and continued intermittently through World War II. During early operations, zinc concentrates were shipped to a smelter at Clinton on the Clinch River (Maher, 1958, p. 2). Coproduct zinc concentrates have been produced since 1927 from the Tennessee Copper Co.'s operations (fig. 115, No. 66D) in Polk County, Tenn. (Maher, 1958, p. 5).

Zinc occurrences are also known in the Appalachian parts of middle Tennessee, Kentucky, Maryland, North and South Carolina, Georgia, and Alabama and in West Virginia. However, the only reported production of zinc from these States has been as a byproduct from some of the deposits in North Carolina.

LEAD

Lead ore has been produced in Appalachia since the 18th century. In 1964, lead produced from ores mined in Appalachia was 1.3 percent of total United States production and amounted to 3,857 tons valued at $1,005,000 (table 165). Virtually all lead from Appalachia came from the Austinville district in Wythe County, Va., although minor amounts were recovered in recent years from the zinc and zinc-copper ores of the Copper Ridge and Ducktown districts in Tennessee.

Lead ore was mined from veins in Sinking Valley, Pa., during the Revolutionary War, by General Roberdeau's soldiers and by local settlers; 1,000 pounds of lead were sold to the State of Pennsylvania at $6 per pound (Miller, 1924, p. 13–14). Total production is not known but the extent of old workings indicate that it may have been fairly substantial. From 1864 to 1870, several thousand tons of zinc-lead ore that contained 31–47 percent zinc and about 5½ percent lead was mined at the Birmingham mine. Elsewhere in the district, about 300 tons of lead-rich ore was mined from one of the Sinking Valley veins in 1876 (D. F. Reed, 1949a, p. 3). Some lead ore was produced in the Sunbury-Selinsgrove area about 1845 (Miller, 1924, p. 86). The mine was reopened about 1882 and was operated for several years. Lead ore was mined along with zinc ore from the Almedia mine in Columbia County, Pa., during the 19th century, and in 1901–02. Prospects for lead are known in several other places in the Appalachian part of Pennsylvania. The only other recorded production, however, was from a small mine in Mercer County, near Shenango where a small tonnage of lead ore was shipped in 1915 (Hill, 1917, p. 16).

Lead ore has been mined in several places in the Central Kentucky district outside Appalachia (Fohs, 1913; Robinson, 1931; Jolly and Heyl, 1964), but production has not been reported from the small part of the district that extends into Appalachia.

The lead-zinc deposits at Austinville, Wythe County, Va., have been exploited for lead from the time of their discovery in 1756 until the present. Prior to 1864, the time of the first shipments of zinc ore, only lead was recovered. Since 1870, more zinc has been produced than lead. From 1838 to 1864, it is estimated that about 10,000 tons of lead was produced from the Austinville mine. The New Jersey Zinc Co. has produced lead from the Austinville mine from 1901 through 1966. Lead was mined along with zinc ores at the Ivanhoe mine in Wythe County intermittently from 1915 to 1936, and from 1957 to 1966.

The only other lead production worthy of mention in the Appalachian part of Virginia was that of the Rye Valley Mining Co., which shipped 30 carloads of hand-sorted concentrate in the 1890's from its mine near Sugar Grove near the southwestern end of the Austinville district (Currier, 1935a, p. 107). Seven carloads of lead ore also were shipped from the Osborn mine in Russell County in 1900 (Woodward, 1938, p. 66–69).

Recorded production of lead from Tennessee totals 27,147 tons. Most came from the Embreeville or Bumpass Cove district in Washington and Unicoi Counties, which has yielded about two-thirds of the lead mined in Tennessee. The earliest mining was during the Revolutionary War. Intermittent and small production of lead continued until 1913 when the Embree Iron Co. discovered fairly large bodies of zinc silicate and lead carbonate ore. This discovery led to development of the Fowler and Peach Orchard mines which yielded lead ore from 1917–26. In 1927, a new drilling campaign was started and many small ore bodies were discovered. Mining was resumed in 1930 and continued to 1950.

Most of the remaining lead produced in east Tennessee came from the New Prospect, Straight Creek, Hardwick, Felknor, and Hambright mines in the years prior to 1918. Smaller quantities were obtained during World War II from operations at the New Prospect, Bunch Hollow, and Kings Bend mines in the Powell River district, and the Straight Creek mine, chiefly as a byproduct of zinc mining.

North Carolina, South Carolina, Georgia, and Alabama have produced little or no lead. In 1940, the Redmon mine in Haywood County, N.C., shipped about 45 tons of handpicked ore containing 12.1 percent lead and 6.5 percent zinc. As elsewhere in the southern Appalachian Region, lead was gleaned from many small deposits by the Confederacy during the Civil War, but little is known of the amounts produced.

DEPOSITS IN APPALACHIA

Sphalerite (ZnS) and galena (PbS) are the major zinc and lead minerals in Appalachia. Their alteration by weathering formed smithsonite ($ZnCO_3$), hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$), cerussite ($PbCO_3$), and rarer minerals. Galena and sphalerite generally occur together, but in most Appalachian deposits sphalerite is by far the most abundant. Pyrite and chalcopyrite are common associated sulfides, whereas pyrrhotite is found only in the more complex high-temperature deposits. The sphalerite usually contains appreciable cadmium and the galena traces of silver. The gangue of Appalachian zinc and lead ores consists of barite, fluorite, calcite, dolomite, and quartz, in addition to varying amounts of the country rock.

Although widespread in the Appalachian Region, most mineral deposits of zinc and lead are in the Valley and Ridge province, principally in southwestern Virginia and eastern Tennessee. Zinc and lead occurrences have been reported in the Appalachian parts of each of the States except New York. Even here, however, deposits are found in the Shawangunk district of Orange, Sullivan, and Ulster Counties, just east of Appalachia.

BLUE RIDGE AND PIEDMONT PROVINCES

Zinc and lead deposits of the Blue Ridge and Piedmont provinces occur in a variety of host rocks and structures and may have diverse origins. They occur as vein, disseminated, or massive replacement deposits as described in table 166 (Nos. 55, 57–67). The most important of these deposits are the massive copper-bearing sulfide bodies of the Ducktown district in southeastern Tennessee (fig. 115, No. 66D), described more fully in the section "Copper and Sulfur."

VALLEY AND RIDGE PROVINCE

In the Valley and Ridge province most zinc and lead sulfide ores are found in limestones and dolomites of Cambrian and Ordovician age as open-space filling and replacement bodies in breccias, gash veins, fissure veins, fault breccias, stockworks, or as bedded stratiform replacement bodies. Fissure and gash veins also are known in sandstone and other clastic rocks. Many deposits in carbonate rocks were capped by secondary concentrations of zinc and lead minerals formed during weathering. Many of the deposits are briefly described in table 166 (Nos. 3–7, 10, 16–54, 56). Additional information about some of the more significant districts and occurrences is given below.

The deposits in the Austinville district occur in the Lower Cambrian Shady Dolomite in breccia bodies that are restricted to certain favorable units along an anticline. Many ore bodies are associated with faults.

The Powell River and Straight Creek districts (table 166, Nos. 31, 32) in Tennessee produced small but significant quantities of zinc and lead. The chief host formations in these districts are the Upper Cambrian Maynardville Formation, in which the best deposits occur, and the Copper Ridge Dolomite. The ore bodies in these districts are replacement deposits along faults accompanied by some open-space breccia fillings, fracture filling, and bedded replacement deposits apparently unrelated to faults or fractures. Secondary zinc minerals occur in the surface exposures of most of the deposits of these two districts and accounted for most of the early production of this metal (Brokaw and others, 1966b).

The limestones and dolomites of Early Ordovician age are by far the most prevalent host rocks for zinc and zinc-lead deposits in the Valley and Ridge province. In the northern part of the province these rocks comprise the formations of the well-known Beekmantown Group, whereas in the southern part of the province they consist of the upper three formations (Longview, Kingsport, and Mascot—in ascending order) of the Knox Group. Of the deposits in these strata (table 166, Nos. 6, 24, 29, 30, 35, 38–48, 51–54), those in the Kingsport Formation are by far the most important economically and constitute the major reserves in the Mascot-Jefferson City (No. 29) and Copper Ridge (No. 30) districts of Tennessee. However, individual ore bodies in the upper part of the Longview Dolomite and in the Mascot Dolomite are mined or have significant reserves in some parts of these districts. In the east Tennessee districts, the most productive zone seems to be limited to the lower two-thirds of the Kingsport and about the uppermost 25 feet of the Longview—in all, a zone about 200 feet thick. The deposits consist chiefly of mineralized crackle and rubble breccias that are localized along the contact between a zone of fine-grained dolomite and an underlying zone of limestone. The grade of the ore is highly variable, ranging from less than 1 percent to as much as 20 percent zinc.

The Mascot-Jefferson City district is the principal zinc-producing district in the United States. It contains major ore reserves and is expected to continue as a large producer of zinc for several decades to come. Ore deposits of the district are described by Oder and Ricketts (1961). The origin of the deposits and of the host structures is a subject of considerable controversy among geologists familiar with the area. This subject is of more than academic interest in that opinions on it have guided exploration for new deposits. Most early workers, despite differing opinions on the source of zinc, favored the hypothesis that the breccias formed during tectonic activity in late Paleozoic time (Brokaw and Jones, 1946; Brokaw, 1950; and Bridge, 1956, p. 70–71). Although this hypothesis led to the discovery of significant tonnages of ore during earlier years, it has been largely superseded by the hypotheses that the breccias were formed by solution-collapse processes. This hypothesis was proposed by Ulrich (1931) and is discussed by J. W. Odell (in Oder and Hook, 1950, p. 78), Ohle (1959, p. 781–782), and Hoagland and others (1965). D. L. Kendall (1958, 1960) concluded that the breccias were formed and the ore minerals emplaced while the country rocks were still flat lying.

APPALACHIAN PLATEAUS AND INTERIOR LOW PLATEAUS PROVINCES

The known occurrences of zinc and lead minerals in the Appalachian Plateaus and Interior Low Plateaus provinces of the Appalachian Region are plotted on figure 115, and some of these are briefly described in table 166 (Nos. 1, 2, 8–15). Additional information about several of the more important or unusual occurrences is given below.

Many small veins containing sphalerite, galena, fluorite, and barite are widespread in the western part of the Appalachian Region in central and south-central Kentucky (Fohs, 1913; Robinson, 1931; Jolly and Heyl, 1964) and in central Tennessee (Jewell, 1947). Most veins are found in two major domal areas of the Cincinnati arch, the Lexington or Jessamine dome near Lexington, Ky., and the Nashville or Rutherford dome near Nashville, Tenn., (fig. 115, No. 12, 14). Fewer veins occur along the axis of the Cincinnati arch in Kentucky just north of the Cumberland River (fig. 115, No. 13). The veins are in nearly vertical faults, many of which have strike-slip displacement. Most veins are in limestone strata of Middle Ordovician age, but some extend up into younger rocks.

The veins in the central Kentucky and Tennessee areas are of two main types: (1) fissure fillings and (2) breccia replacement or cementation veins. Both types may be found in the same vein system. The limestone fragments of the fault breccias and, less commonly, the fractured vein walls are replaced by minerals to form replacement veins. In many deposits, part of the vein is a mineralized breccia, the other part an open-fissure filling. The veins pinch and swell along strike. A few veins in central Tennessee are nearly all sphalerite associated with very few other minerals, but most veins are a mixture of three or four minerals. In some mixed veins, barite, calcite, and fluorite are the main minerals; in others, sphalerite and galena are the main constituents. The barite commonly contains traces of strontium, and the sphalerite traces of germanium, cadium, gallium, and, in a few places, mercury (Jolly and Heyl, 1964, p. 613–614). The sphalerite is low in iron and the galena is notably low in silver.

These areas of central Kentucky and Tennessee contain other deposits of little or no economic value, but are of interest because they indicate wide distribution of lead and zinc. Geodes found at many places are filled with quartz, calcite, barite, and small quantities of galena, sphalerite, and celestite. In such occurrences, only the celestite and barite geodes may have any economic importance (see "Strontium" section). Geodes in Kentucky are found notably in the Lexington (Cynthiana) Limestone of Middle Ordovician age and in the Keokuk Limestone of Mississippian age. Disseminated galena and sphalerite in Mississippian limestone have been prospected at one locality in Estill County, Ky. Sphalerite occurs in a zone a few inches thick near the base of Pennsylvanian rocks in Hubbard Cove, Grundy County, Tenn. (Jewell, 1947, p. 104).

Sphalerite has been found in cuttings of deep oil and gas wells in dolomite of Early Ordovician age in Franklin, Warren, Grundy, and Van Buren Counties in south-central Tennessee (table 166, No. 15). It is generally honey yellow and closely resembles the sphalerite in the Mascot-Jefferson City district of eastern Tennessee.

Sphalerite occurs without galena in Highland, Adams, and Ross Counties, southern Ohio (fig. 115). The most unusual occurrence is in Silurian dolomite shatter breccia in the west-central part of the Serpent Mound cryptoexplosion structure (table 166; fig. 115, No. 11) near Louden, Ohio (Heyl and Brock, 1962). The sphalerite is coarse to medium grained, red brown and orange yellow, and is partly weathered to brown earthy smithsonite and hydrozincite. Loose fragments of rock estimated to contain 5–20 percent zinc and weighing several pounds are found at several places within an area of 2–3 acres. The other occurrences of sphalerite in these Ohio counties (J. K. Rogers, 1936, p. 114) are also in Silurian dolomite and are scattered over an area of several tens of square miles (fig. 115).

RESOURCE POTENTIAL AND PROSPECTING

In general, the outlook for zinc in Appalachia is excellent. The region produced almost one-fourth of the national total in 1964, and in the last 15 years more than tripled its output relative to the national production (table 164). The outlook for lead, although good, is less promising, because in nearly all known occurrences of any size it accompanies zinc as a subordinate metal (table 166).

Although production and reserves of zinc and zinc-lead ores in Appalachia stand at an all-time high, an intensive search for additional ore continues. The major producing companies of the region are exploring for ore extensions in the vicinities of producing mines as well as developing new mines and are, along with other major mining companies, studying the potential of the region for new districts. Attempts are being made to find additional ore in old districts through the application of new exploration techniques or through utilization of new concepts on structural controls and genesis of the ore deposits.

The great increase in production since about 1950 has been the result of several factors, among which the distribution and character of the ores are most important. The individual deposits, though low grade when compared with many deposits in Western United States, are much larger in size and occur in bedded carbonate rocks. The large size permits large-scale mechanical mining at relatively low cost. Because the waste material from the mills is almost all carbonate rock, it can be disposed of at a profit for uses such as agricultural lime and aggregate material. The proximity of many deposits to main-line rail and modern highway facilities and high-density population areas is also a major factor in the growth of the industry.

As can be seen in figure 115 and table 166, most of the significant occurrences of zinc and lead in the Appalachian Region are in Cambrian and Ordovician carbonate rocks. In fact, except for deposits of the Austinville district that are in the Lower Cambrian Shady Dolomite, most of the zinc mined, as well as that found in many outlying prospects, occurs in carbonate rocks of the upper part of the Knox Group or in equivalent beds of Early Ordovician age. This particular sequence of rocks is thus one of the most notable zinc-bearing zones in the region, if not the country. It contains scattered occurrences, deposits, and mining districts throughout the Valley and Ridge province from Pennsylvania to Alabama and on westward through the interior lowlands of Tennessee to Missouri and Arkansas. Sphalerite has been found in the sequence in deep oil wells in western Kansas (Evans, 1962).

One of the major regional controls for zinc and lead in the southern part of the Valley and Ridge province appears to be the restriction of significant amounts of these metals to the beds beneath the regional disconformity at the top of Lower Ordovician strata. The development of the working hypothesis that ores in the upper dolomite formations of the Knox Group are localized by solution-collapse structures formed when the rocks were still flat lying has permitted distinct progress in locating ore extensions and new ore bodies in known district. The number of scattered small prospects and occurrences of zinc and lead minerals in this stratigraphic zone throughout the region lends credence to the belief that new districts remain to be discovered.

In part, the distribution of zinc and lead occurrences shown in figure 115 is suggestive of prospecting areas. The most immediate target areas for prospecting in the southern part of the Valley and Ridge province should be those where the strata of the Lower Ordovician formations dip at relatively low angles. Such low dips obviously keep the mineralized target zones at depths within current economic means for exploration and development, in contrast to deeper targets in more steeply dipping rocks. A few examples of such target areas are (1) the Powell Valley syncline northeast of Speedwell, Tenn., (2) the gently dipping southeastern limb of the Powell River anticline from Tazewell, Tenn., into southwestern Virginia, and (3) the broad homoclinal belt of the upper part of the Knox Group that includes the eastern belt of the Sweetwater barite district, the small Eve Mills zinc district, and the Friendsville prospect. Similar areas of low-dipping Lower Ordovician strata occur in central Pennsylvania, northeastern Alabama, and northwestern Georgia. Also worthy of mention are the broad Nashville and Lexington domes in central Tennessee and central Kentucky, respectively, where Lower Ordovician beds occur at shallow depths beneath a cover of Middle Ordovician strata.

Although the general principle in the selection of exploration targets is to hunt for elephants in elephant country, smaller game should not be overlooked, that is, smaller deposits, though not of commercial significance in themselves, may well be guides to larger and better deposits. In this light, the limestone belts in central Pennsylvania and western Maryland are excellent targets for long-range exploration programs. In addition, in Pennsylvania, both the Almedia and Sinking Valley districts are worthy of further study. In eastern West Virginia, the zinc-lead deposit on the Howell Farm is but one of several occurrences in the Shady Dolomite and Cambrian quartzites in an area 10–15 miles long at the western foot of the Blue Ridge. Exploration in this area might reveal deposits geologically similar to those of the Austinville district of Virginia (fig. 15, No. 16), or those of the Embreeville district of eastern Tennessee (fig. 115, No. 38). Zinc and lead deposits might well be sought also in the Shady Dolomite along the southeast side of the Valley and Ridge province through eastern Tennessee into Georgia and Alabama. Zinc and lead sulfides occur in the Cartersville district of Georgia (fig. 115, No. 50) within this area. The scattered occurrences and small deposits of zinc and lead minerals in Cambrian carbonate rocks other than the Shady Dolomite of the southern Great Valley should also be investigated, not only for their own economic potential, but also as guides to more extensive deposits in higher stratigraphic units.

Parts of the Central Tennessee district, Cumberland River area, and Central Kentucky district are worthy of more study. These districts include small but rich lead-zinc veins with potentially recoverable amounts of cadmium, germanium, and barite. It also is possible, as mentioned above, that the Lower Ordovician Kingsport Formation has, at greater depth, zinc and lead deposits similar to the commercially important deposits in eastern Tennessee.

The zinc occurrences near Serpent Mound, Ohio, are small, but they are distributed over a fairly wide area both within and without the brecciated cryptoexplosion structure. The known occurrences are too low in grade to be commercial, but they indicate widespread mineralization and are worthy of further study in the search for larger and better deposits.

The potential for zinc and lead in the crystalline rocks of the Blue Ridge and Piedmont provinces is largely dependent upon the potential for massive sulfide deposits of the Ducktown type. Sphalerite and galena also occur in numerous small auriferous vein deposits throughout these provinces. It is conceivable that modest amounts of byproduct lead and zinc could be obtained if these deposits were worked again for gold.

Because most of the major zinc and zinc-lead deposits in Appalachia are found in the carbonate rocks of the region (table 166), one of the major problems in prospecting is the depth of soil cover, particularly in the southern part of the region. Many of the sulfide deposits now being worked have been found in years past through the discovery or exploitation of the oxidized ores in the residual soils. Perhaps one of the most successful of the newer prospecting techniques to be used in the search for new but relatively shallow deposits in Appalachia, as well as elsewhere in the world, has been geochemical prospecting. Residual soils, especially of known ore-bearing formations, are tested for anomalous amounts of heavy metals, chiefly zinc, lead, and copper, and areas of high concentrations are drilled to locate ore bodies. The value of soil prospecting was first demonstrated in the Mascot-Jefferson City zinc district (table 166, No. 29), by testing the soil over a known but unmined ore body (Hawkes and Lakin, 1949). Geochemical prospecting was vitally important in the exploration of the Copper Ridge district (table 166, No. 30) of Tennessee (Hoagland, 1962). This method of prospecting will continue to be one of the major tools in the search for new zinc-lead deposits in Appalachia.

Although the search for new relatively shallow deposits has been aided immeasurably by geochemical prospecting, the discovery of new deposits at greater depth depends almost entirely on the interpretation of geologic data gained from drill holes. Drill-hole data can be evaluated in many ways and the interpretations portrayed on various kinds of maps and illustrations. A modern technique that offers promise in mineral exploration involves the application of mathematical and statistical methods and the use of computers. An example is a project being done by the U.S. Geological Survey on the application of statistical methods to the analysis of drilling data from eastern Tennessee. Results of this project confirm a previous qualitative evaluation that the abundance of sphalerite increases in the Kingsport Formation in areas where the lower limestone member has been thinned by solution activity and where the overlying less soluble dolomite has collapsed and thickened with development of ore-localizing breccia zones (Wedow and Marie, 1963, 1965). In widely spaced reconnaissance drilling, trend-surface analysis of drill-hole data by computer may point to areas that have a greater probability for containing favorable ore-bearing structures.

Standard geophysical methods, such as resistivity and self-potential surveys, are used routinely in the Appalachian Region in the search for massive sulfide and related deposits. Such methods have not been successful in finding zinc-lead deposits in the carbonate rocks of the region. Nevertheless, McMurry and Hoagland (1956) and Keller (1960) suggested that further geophysical studies in the Austinville and Mascot-Jefferson City districts might prove fruitful.

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