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COKING-COAL DEPOSITS OF THE WESTERN UNITED STATES

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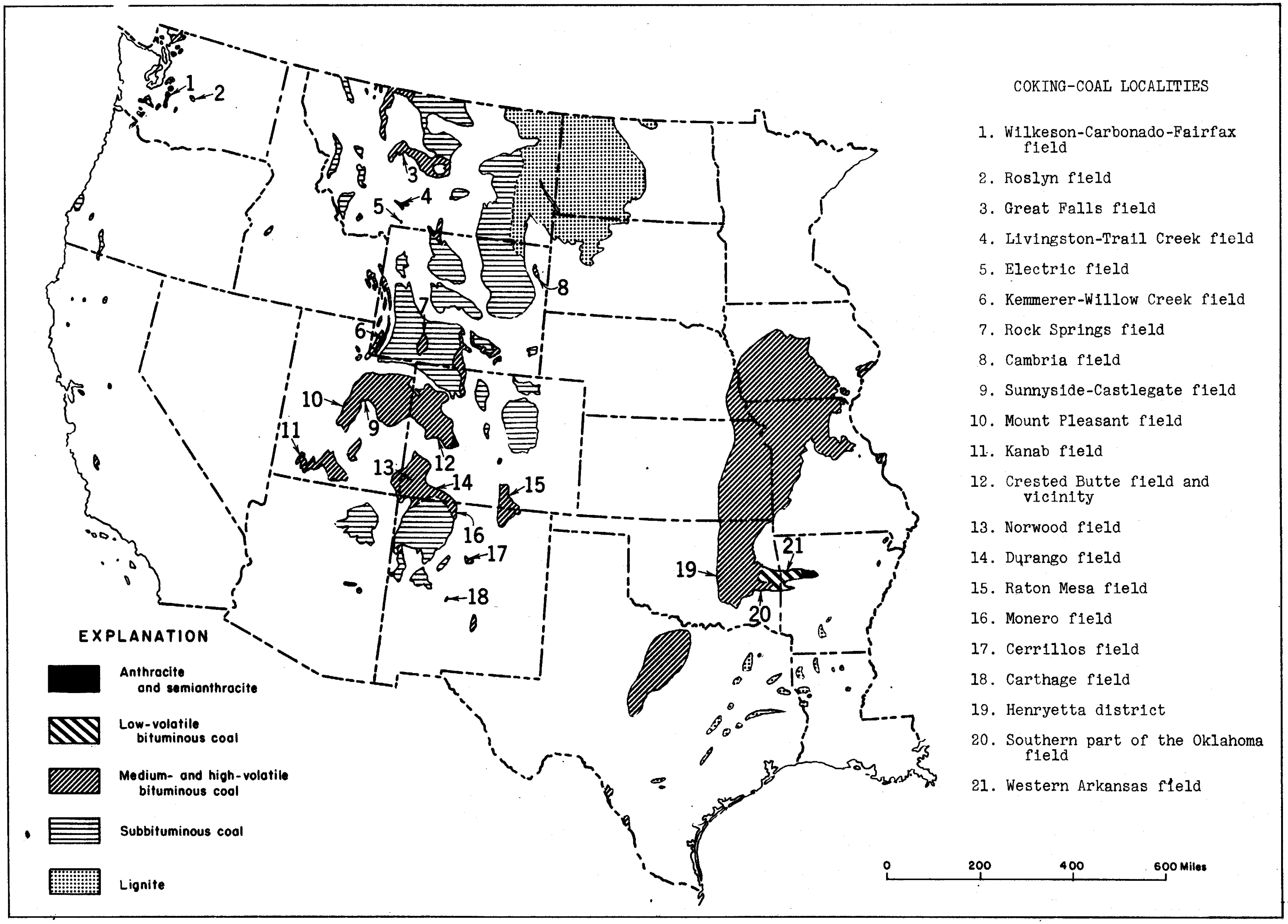

Figure 1.–Coal fields of the Western United States showing coking-coal localities.

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INTRODUCTION

The U. S. Geological Survey has been engaged in a study of the geology and coal resources of the western United States for many years, and the results of this work have been presented in numerous volumes of the regular series of Annual Reports, Bulletins, Professional Papers, and Folios of the Geologic Atlas of the United States. In 1942, in response to the needs of the expanding western steel industry, the U. S. Geological Survey began a program of mapping and re-examination of areas in the West believed to contain coal of coking quality, and at the same time the U. S. Bureau of Mines began a program of drilling, sampling, and testing the coal in these areas. As a result of this cooperative effort much new information has been obtained. Because many of the earlier geologic reports on the western coal fields are now out of print, and because some of the more recent geologic studies of the areas containing coking coal are still in manuscript or preliminary form, this circular has been prepared to summarize the information now available about the occurrence and reserves of coal in a number of selected localities in the western states where the coal has coking properties. Although emphasis is placed primarily on the geology of the coal deposits, references to publications concerned with the technological aspects of coking coal are cited where appropriate.

The analyses of coal and generalized statements of coking properties included in this circular are based chiefly on information contained in publications of the U. S. Bureau of Mines. Data included in the bulletins of the Washington Geological Survey and in the mineral reports of the Oklahoma Geological Survey have also been abstracted to provide a summary of the occurrences of coking coal in these states.

ORIGIN, CLASSIFICATION, AND DISTRIBUTION OF COAL

Coal is composed of ancient plants and plant fragments that accumulated slowly on the floors of former marshes and swamps. As this material increased in quantity year after year in the swampy environment, the lower layers were compacted under the weight of the upper layers and, in time, became peat, the initial stage in the development of coal. Later, the swamps were flooded by the sea and buried under vast accumulations of sand and silt washed in by streams flowing from nearby lands. The layers of peat thus became further compressed under the weight of these sediments. Pressure and heat from movements of the earth's crust aided locally in the process of compaction and coalification, which has been going on slowly and continuously for a long period of time.

During the process of compaction and coalification the beds of plant material undergo a series of physical and chemical changes, which, in general, result in a reduction of the amounts of moisture and volatile matter present, and a corresponding increase in the amounts of fixed carbon and heat value. The relative amount of change a coal has undergone, as measured by variations in these components, is the basis for the established classification of coal by rank. The terms lignite, subbituminous coal, bituminous coal, and anthracite, thus describe stages in the coal forming process. Each of these major ranks of coal is further subdivided on the basis of chemical properties, as shown in table 1, which is a reproduction of the standard classification used in the United States (Amer. Soc. Testing Materials, 1939, pp. 1-6). Figure 2 shows graphically the relation between the heat value, moisture, volatile matter, and fixed carbon for the various ranks of coal defined in table 1.

Considerably more than half of all coal used in the manufacture of coke is of high-volatile A bituminous rank, followed in order of abundance of use by low-volatile and medium-volatile bituminous ranks.

Coal-bearing rocks are widely distributed west of the Mississippi River, as shown by figure 1, which also shows the distribution by rank. On a simple tonnage basis this area contains 70 percent of the total reserves of the United States, of which the larger part is of lignite, subbituminous, and high-volatile C and B bituminous ranks, and is thus generally unsuitable for the manufacture of coke. By contrast, the area east of the Mississippi River contains 30 percent of the total United States reserves, all of which is of bituminous or anthracitic rank. A large part of the eastern bituminous coal reserves have coking properties. This geographic distribution of high- and low-rank coal is due in part to differences in age. Coal east of the Mississippi River, and in Iowa, Kansas, Missouri, Oklahoma, Arkansas, and parts of Texas, is of Pennsylvanian age. On the other hand, the coal in the Rocky Mountain and Pacific Coast regions is of Cretaceous or Tertiary age. Only in areas of mountain building and igneous activity, as locally in Montana, Wyoming, Colorado, New Mexico, Utah, and Washington, has the younger coal in the West reached bituminous or occasionally anthracitic rank.

The best metallurgical coke is made from high-volatile A or medium-volatile bituminous coal, or from blends of high- and low-volatile bituminous coal. Although the West possesses comparatively small reserves of coal of these ranks suitable for manufacturing coke, at least 21 localities in the West are known to contain coal that has coking properties. Several of these localities produce most of the coal used in the western steel industry. The growing industrialization of the West, and the accompanying

Table 1. Classification of coals by rank[a]

Legend: F.C. = Fixed Carbon. V.M. = Volatile Matter. Btu. = British thermal units.

Class	Group	Limits of Fixed Carbon or Btu. Mineral-Matter-Free Basis	Requisite Physical Properties
I. Anthracitic	1. Meta-anthracite	Dry F.C., 98 per cent or more (Dry V.M., 2 per cent or less)	
	2. Anthracite	Dry F.C., 92 per cent or more and less than 98 per cent (Dry V.M., 8 per cent or less and more than 2 per cent)	
	3. Semianthracite	Dry F.C., 86 per cent or more and less than 92 per cent (Dry V.M., 14 per cent or less and more than 8 per cent)	Nonagglomerating[b]
II. Bituminous[d]	1. Low volatile bituminous coal	Dry F.C., 78 per cent or more and less than 86 per cent (Dry V.M., 22 per cent or less and more than 14 per cent)	
	2. Medium volatile bituminous coal	Dry F.C., 69 per cent or more and less than 78 per cent (Dry V.M., 31 per cent or less and more than 22 per cent)	
	3. High volatile *A* bituminous coal	Dry F.C., less than 69 per cent (Dry V.M., more than 31 per cent); and moist[c] Btu., 14,000[e] or more	
	4. High volatile *B* bituminous coal	Moist[c] Btu., 13,000 or more and less than 14,000[e]	
	5. High volatile *C* bituminous coal	Moist Btu., 11,000 or more and less than 13,000[e]	Either agglomerating or nonweathering[f]
III. Subbituminous	1. Subbituminous *A* coal	Moist Btu., 11,000 or more and less than 13,000[e]	Both weathering and nonagglomerating
	2. Subbituminous *B* coal	Moist Btu., 9500 or more and less than 11,000[e]	
	3. Subbituminous *C* coal	Moist Btu., 8300 or more and less than 9500[e]	
IV. Lignitic	1. Lignite	Moist Btu., less than 8300	Consolidated
	2. Brown coal	Moist Btu., less than 8300	Unconsolidated

[a] This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu. of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

[b] If agglomerating, classify in low-volatile group of the bituminous class.

[c] Moist Btu. refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

[d] It is recognized that there may be noncaking varieties in each group of the bituminous class.

[e] Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

[f] There are three varieties of coal in the high-volatile C bituminous coal group, namely, Variety 1, agglomerating and nonweathering; Variety 2, agglomerating and weathering; Variety 3, nonagglomerating and nonweathering.

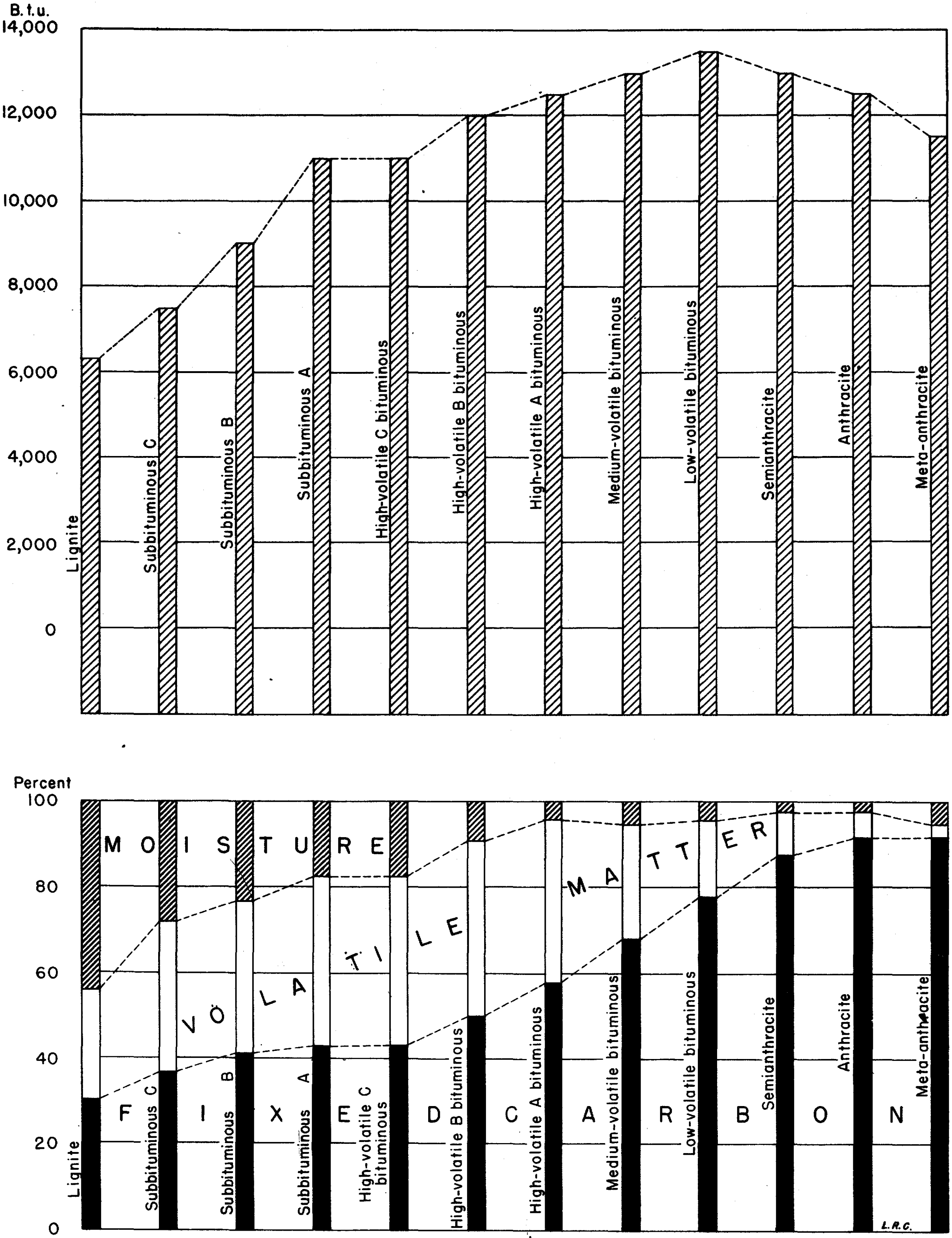

Figure 2. - Heat value of coal of different ranks compared to proximate analyses.

Upper diagram: Comparative heat value of typical samples of the several ranks of coal, computed on samples as received, on the ash-free basis. Lower diagram: Variation in the fixed carbon, volatile matter, and moisture of samples used in upper diagram, computed on samples as received, on the ash-free basis.

general increase in energy consumption thus place special emphasis on the desirability of more complete knowledge of western resources of coking coal.

PROPERTIES OF COKING COAL

Coke is a hard cellular mass of carbon and inert ingredients prepared from certain kinds of coal that fuse or become semi-liquid during destructive distillation. Once formed, coke is infusible, more or less friable, porous, and has a dark to metallic gray luster. Many bituminous coals will coke or fuse when heated in a closed furance, but only those coals that produce coke with a specific range of chemical and physical properties suitable for metallurgical and other industrial uses can be considered coking coals.

It has not been possible as yet to devise a set of standards for the identification of a good coking coal by its chemical composition or physical properties. Rank is not the only criterion, as many coals of apparently suitable rank have poor coking qualities. It must be concluded, therefore, that the original composition of the bed is an important factor in determining coking properties. Certain ingredients of coal are recognized as generally influencing coking properties. Most bituminous coals, for example, contain bright, vitreous bands that represent the coalified trunks and limbs of plants and are known as vitrain. The best coking ingredients occur within the vitrain bands, which are present in abundance in good coking coals. Fusain, the ingredient making up the dull, porous, and friable bands in coal, will not coke, and if present in large quantities renders a coal useless for the manufacture of coke.

Other factors being equal, coal having an oxygen content within certain known limits will coke, but if too high or too low a percentage of oxygen is present, the coal will not coke. The presence of hydrogen in excess also has been shown to decrease the coke yield of coal.

A good coking coal, when subjected to a uniformly increasing temperature, fuses or softens generally between 572° and 752° F. Gases of decomposition are formed at the fusing temperature, or slightly higher, causing the mass to become cellular and somewhat swollen. Viscosity increases until the mass becomes practically rigid before reaching a temperature of 842° F. Changes in structure continue to occur because of devolatilization, even after the coke has reached red heat, and the evolving of gases continues long after the mass has become rigid (Rose, 1927, pp. 601-602). Noncoking coals will not fuse or become pasty when heated. The fused cellular structure is a unique characteristic of coke that distinguishes it from charcoal or from chars formed from coals that do not fuse under coking conditions. The coking qualities of most coals can be improved by washing to remove ash and sulfur, or processing to remove noncoking components. An excellent coke may sometimes be obtained by blending two coals having somewhat different properties, although neither of the coals alone would produce a satisfactory coke. Similarly, blends employing a poorly coking coal as the base stock may include noncoking ingredients, such as anthracite fines, petroleum coke, or low-temperature char, which greatly improve the qualities of the resulting coke.

Under certain circumstances natural coke may be produced in coal beds penetrated or affected by igneous intrusions.

The standards that a coke must meet vary according to the purpose for which it is intended. Physical characteristics and the included impurities largely determine the value of coke as a fuel in particular industrial processes. On the basis of its principal uses coke may be classified as blast-furnace coke, foundry coke, water-gas coke, and domestic coke.

Specifications are most rigid for coke that is used in the blast furnace, where it must have strength adequate to support the charge, and must supply carbon monoxide for reducing the ore, as well as heat to melt the metal. Most blast-furnace coke is used in iron smelting, and for this industry the requirements are as follows (Rose, 1927, pp. 631-636):

	Maximum percentages
Ash (less than 10 percent desirable)	8-16
Sulfur	1.3
Phosphorus (for acid Bessemer iron)	0.01

In addition, a coke of medium density is usually preferred for use in blast furnaces, and the optimum size of the individual pieces of coke should range between 2 and 4 inches in diameter.

Standards of strength and ash content are somewhat lower for coke intended for nonferrous smelting in the blast furnace. An increasingly high proportion of nonferrous metal, however, comes to the smelter in the form of finely ground concentrates that are more easily handled in a reverberatory furnace, which requires no coke. Since 1910 the blast furnace, although still used to some extent in lead smelting, has been gradually replaced by the reverberatory furnace in copper smelting.

Foundry coke is used only to provide heat to melt the metal, and for this purpose the requirements are chiefly purity, large size, good strength, and a minimum reactivity with carbon dioxide gas.

Water-gas coke must have a maximum ash content of no more than 6 percent, because the clinker and its removal present serious operating problems in this industry. The fusing temperature of the ash should range between 2300° and 2500° F., and the sulfur content should be low. A strong coke of uniform size is desirable for use in manufacturing water gas.

Coke is an important source of fuel for smokeless domestic heating, as only a small proportion of the original volatile matter remains after destructive distillation. Coke used for domestic heating is, in general, not required to meet as exacting standards as that produced for industrial purposes. The coke should be dense and have an ash content that ranges between 8 and 10 percent. A fusing temperature of 2500° F. or more is desirable for the ash. Assuming optimum conditions such as an easily available supply of coal suitable for the production of a particular coke, the above standards are desirable for each type of coke. Necessity in wartime and in areas with limited coal reserves has shown, however, that by blending and by adopting special metallurgical processes, coke manufactured from coal of seemingly inferior quality can often be used satisfactorily for many purposes, even for the production of iron and steel. The selection of a coal for coking is, therefore, determined in part by economic considerations, and the demand for coke having certain physical properties is balanced against the availability of various coals that separately or in blends can be prepared to yield coke having these properties. In the western United States, the cost of shipping eastern coal is weighed against the cost of cleaning, blending, and using local coal. A decision based in part upon freight rates becomes one that the individual user of coking coal must make, depending upon his location and needs, and the characteristics of nearby coal deposits.

COKING-COAL DEPOSITS

Until recently, the West has been remote from population centers and the consequent industrial and domestic demands for coke. In addition, the limited reserves of low- and medium-volatile bituminous coal throughout the West have restricted the development of a large coking industry. The expansion of manufacturing and industry in the West during World War II, however, and the desirability of the post-war continuation of these activities have emphasized the need for coal that will best serve the West for coking and allied purposes, such as the growing need in some urban areas for a smokeless domestic fuel.

At several localities the western high-volatile bituminous coal will form a coke that performs satisfactorily in blast furnaces and foundries. It is, however, somewhat inferior in porosity, size, and strength to the coke produced from eastern coal. At other localities in the West the coal has potential use in the manufacture of coke, depending in part upon improved processing and coking practices, or specially adapted metallurgical processes. A few other areas contain coal with coking properties, but are considered of little or no economic importance because of impurity of the coal, difficult mining conditions, or exhaustion of reserves.

The important localities in the West that produce coking coal are the Raton Mesa field, Colorado-New Mexico, the Sunnyside-Castlegate field, Utah, the Crested Butte field, Colorado, and the coal fields in southern Oklahoma and western Arkansas. The highest quality western coke, satisfactory for all metallurgical purposes, is made from the coal from the Raton Mesa field blended with low-volatile coal. As this field lies on the eastern side of the Rocky Mountains, it is relatively remote from the several main centers of western iron and steel production and consumption, and more general use of the coal is restricted by transportation costs.

The coal from the Sunnyside-Castlegate field, Utah, is notable because it produces a borderline coke that, in spite of being brittle and containing too high a percentage of small sizes, is used successfully in blast furnaces for ferrous smelting. As a result, it has become the standard by which the coking properties of high-volatile western coal are judged. The Sunnyside-Castlegate field supplies most of the industrial coking-coal needs of Utah, and by virtue of its position west of the Rocky Mountains, is the source of much of the coke used on the West Coast.

Most of the other areas in the West containing coking coal are no longer used as sources of metallurgical coke, though at various times in the past, coal from many of these areas has been coked in beehive ovens and used in nonferrous smelters and refineries. With more restrictive specifications, and with improvements in transportation, however, the superior cokes made from eastern coal and from the coal produced in the Raton Mesa, Sunnyside-Castlegate, and Crested Butte fields in the West were able to compete directly with the local products.

The growing western iron and steel industry would be greatly benefited, however, if coal from some of the more advantageously located coking-coal deposits, of which the Washington coal deposits are an excellent example, could be utilized for metallurgical purposes. Such use might entail both cleaning and blending of the local coal, but even with the added processing costs, the utilization of the local coal might eventually prove to be more economical than shipping and processing coal from distant sources.

As many economic and technologic factors are involved in the definition of a coking coal, no simple field or laboratory test will measure the coking quality of a coal in absolute terms. On the basis of available information, therefore, it is difficult to delimit adequately the areas of coking coal in the western states or to make completely satisfactory estimates of their reserves. The accompanying map (fig. 1), however, shows 21 localities in the West where coal having coking properties has been obtained, and the available information regarding the occurrence of coal at each locality, the properties of the coke produced, and the reserves of coal is summarized in the following paragraphs.

In discussing reserves of coal the terms, measured, indicated, and inferred, are used to distinguish three classes of coal according to the abundance and reliability of the data on which the reserve estimates are based. Measured reserves are those based on observations about one-half mile apart, or which lie within one-half mile of a well-established, continuous outcrop. Indicated reserves are those based on observations about 1 or $1\frac{1}{2}$ miles apart, or which lie no more than 2 miles from a well-established, continuous outcrop. Inferred reserves are based on broad knowledge of the geologic character of the coal beds, and may be supported by few observations. In general, coal classed as inferred lies more than 2 miles from the outcrop.

In reporting tonnages of coal reserves, the term original reserves refers to total reserves in the ground before mining began, and does not take into account past production and losses or future losses. Remaining reserves are unmined reserves in the ground as of the date of the appraisal. Where this term is used, past production and losses have been subtracted from the estimated original reserves, but no allowance has been made for future losses. Where allowance has been made for past production and losses and future losses, the term recoverable reserves is used.

Washington

The important deposits of coking coal in Washington are in the Wilkeson-Carbonado-Fairfax field in Pierce and King Counties on the western slope of the Cascade Mountains, and in the Roslyn field in Kittitas County on the eastern slope of the Cascade Mountains. Smaller deposits of coal that may be of coking quality extend along the western slope of the Cascade Mountains through Skagit and Whatcom Counties nearly to the northern boundary of the State.

The coking properties of the coal in Pierce, King, Skagit, and Whatcom Counties appear to be due to the physical and chemical changes that resulted from the close folding of the sedimentary rocks containing the coal beds. In the Roslyn field the coal-bearing rocks are less sharply folded, and coal that is suitable for coking occurs only in the northwestern part of the field. In this area the coal-bearing rocks have been somewhat more altered than the rocks in the northeastern part of the field, which contains noncoking coal. Alteration of the rocks alone, however, does not appear to be sufficient to account for the coking or noncoking properties of the coal in this field. Differences in the composition of the coal are indicated by the higher agglutinating value and lower ash content of the coal in the northwestern part of the field as compared with the coal in the southeastern part.

Wilkeson-Carbonado-Fairfax field, Pierce and King Counties, Washington (Loc. 1). --Most of the coking coal produced on the Pacific coast is obtained from the Wilkeson-Carbonado-Fairfax field in Pierce and King Counties, Washington (Daniels, 1914; Warren and others, 1945). The coal beds in this field are in the Puget group of Eocene age, which is a sequence of interbedded sandstone and shale, 10,000 to 15,000 feet thick. Many coal beds of varied extent and thickness are present, but only 17 are known to be workable. The Puget group is divided into three formations, the oldest of which, the Carbonado formation, contains most of the important coal beds. The Wilkeson formation, a sequence made up dominantly of sandstone overlying the Carbonado, is barren, and the Burnett formation, the youngest formation in the group, includes only a few beds of commercial value, which yield coal of lower quality than the coal from the Carbonado formation.

The workable coal beds in the Carbonado formation are individually from 3 to 15 feet thick, but are divided by partings into benches, each of which is usually 2 to 4 feet thick. The partings between the benches consist of shale, clay, and bone, and each parting is from a fraction of an inch to one foot thick.

The principal structure of the field is an asymmetrical, northward plunging anticline, having an average dip of 60° on the east limb and steeper dips ranging from 60° to 85° on the west. The strongly folded west limb contains a series of synclines, or basins, in which most of the coal mines are located. Faults are numerous, and both overthrust faults associated with the folding, and younger normal faults cut the coal-bearing rocks with displacements ranging from a few feet to nearly 2,000 feet. The structure of the coal field is further complicated by the presence of dikes and flows of igneous rock, the heat from which has altered the adjoining sedimentary rocks and coal beds.

The coal varies widely in rank according to the amount of deformation or alteration it has undergone, but analyses on an as-received basis range in general as follows (Daniels, 1941, p. 16):

	Percent
Moisture	4.0- 2.0
Volatile matter	33.0- 20.0
Fixed carbon	51.0- 63.0
Ash	12.0- 15.0
Sulfur	0.6- 0.8
Phosphorus	0.05- 0.1

The coal from this area can be used in byproduct ovens and will yield a coke that can be used for most purposes. Coke manufactured during the period 1915-1934 ranged between 12.7 and 26.6 percent in ash content, and 0.25 and 1.65 percent in sulfur content. The higher figures are extreme, however, and can be reduced by washing and selective blending of the coal. Tests conducted by the U. S. Bureau of Mines utilizing coal from the No. 2 bed near Wilkeson blended with 25 percent petroleum coke, yielded coke with the following properties (Yancey and others, 1943):

Apparent specific gravity	0.87
True specific gravity	1.94
Ash softening temperature	2,800° F. plus
B. t. u.	12,620

	Percent
Moisture	1.0
Volatile matter	0.8
Fixed carbon	87.0
Ash	11.2
Phosphorus	0.69
Sulfur	0.5
Cell space	55.2
Coke yield	72.1

Tumbler and shatter tests: satisfactory for electrochemical and electrometallurgical purposes; questionable for foundry and iron blast furnace.

The phosphorus content of coal from the Wilkeson-Carbonado-Fairfax area is too high to meet the requirements of specialized industries, such as ferro-alloy manufacturing, but blast-furnace and foundry operators might use some of the coke from this field by modifying their standard operating practices. Within certain limits, therefore, coke prepared from blends of Washington coal could be utilized successfully for purposes now served by coke from eastern states.

As estimated by the operating companies in the area in 1940, the recoverable reserves of coking coal in the Wilkeson-Carbonado-Fairfax field were believed to be between 60 and 125 million net tons (Daniels, 1941, p. 16).

Roslyn field, Kittitas County, Washington (loc. 2). --The Roslyn field in Kittitas County, Washington, which has been described by Saunders (1914), covers an area of about 40 square miles on the east slope of the Cascade Mountains, approximately 75 miles east of Tacoma. The coal beds are confined to the upper 1,000 to 1,200 feet of the Roslyn formation, a sequence of sandstone and shale of Eocene age. This upper zone includes 10 coal beds, each ranging in thickness from less than 2 feet to 15 feet, but only four of these beds have been mi

Of them, the Roslyn (No. 5) and the "Big Dirty" beds are the most important.

The Roslyn coal bed normally is 4 feet 6 inches thick, having an upper bench of coal 29 inches thick, a 4- to 6-inch parting of coal and shale, and a lower bench of coal 20 inches thick. The bed is relatively uniform in thickness and has been worked throughout the entire area of the field. The "Big Dirty" bed is 15 to 19 feet thick, but the workable coal is limited to a zone 5 to 6 feet thick in the lower part of the bed. This lower part is usually divided into two benches by a thin clay parting.

The coal-bearing sediments in the Roslyn field dip toward the center of a gentle, southeastward plunging syncline at angles of 10° to 30°. In general, the structure is simple, and the coal is mined with ease. Local variations in the dip and thickness of the beds, known as "faults" by the miners, are actually rolls or warpings that have thickened or thinned the coal, but for the most part, they do not interfere seriously with mining. The Roslyn formation is overlain and underlain by basalt, but no dikes are known to cut the sedimentary rocks, and the coal is unaffected by igneous activity.

The coal from the Roslyn field is of high-volatile A bituminous rank. An analysis on the as-received basis of a composite sample of coal from the Roslyn bed taken from three locations within the Roslyn No. 3 mine at Ronald, Kittitas County, is as follows (U. S. Bur. Mines, 1941, pp. 42-43):

	Percent
Moisture	3.5
Volatile matter	37.8
Fixed carbon	46.7
Ash	12.0
Sulfur	0.3
Air-drying loss	1.6
B. t. u.	12,630

The average phosphorus content of four samples of coal from the Roslyn bed as determined by tests of the U. S. Bureau of Mines is 0.66 percent (Yancey and others, 1943, p. 8).

The agglutinating value of the coal in the Roslyn bed increases from the southeastern part of the field to the northwest. In addition, the ash content is somewhat lower in the northwestern part. In general, therefore, the coal in the northwestern part of the field is considered more suitable for use in making coke. Tests by the U. S. Bureau of Mines (Yancey and others, 1943), indicated that coke made from 100 percent Roslyn coal is somewhat fingery as compared with coke manufactured from coal produced in the field in Pierce and King Counties, or from blends of the two coals with petroleum coke. Furthermore, it tends to be weak in shatter and tumbler tests and to have a high phosphorus content. Roslyn coal forms excellent coke for domestic use, however, and is satisfactory for use in coking-coal blends.

As estimated by Mr. Thomas Murphy, Manager of Coal Operations for the Northwestern Improvement Co., the recoverable reserves of coal in the Roslyn bed before mining were 64,068,000 tons. During the period from 1886 to January 1, 1949, production from the bed has totaled 52,324,000 tons, leaving on January 1, 1949, recoverable reserves of 11,744,000 tons. Only part of this total lies in the more favorable northwestern part of the field.

Montana

Although Montana has large coal reserves, only three areas, all located in the central part of the State, contain coal that has coking properties. In the Livingston-Trail Creek field, Gallatin and Park Counties, the sedimentary rocks have been tightly folded and faulted, and as a result, part of the coal has coking properties. Similarly, in the Electric field, in Park County, the coal has coking properties because of the deformation to which the coal-bearing rocks have been subjected. In the Great Falls field, Cascade, Fergus, and Chouteau Counties, the rocks have only gentle dips and no alteration of the coal by earth movements or igneous activity has taken place. The coal in this field occurs in rocks of Lower Cretaceous age, however, and is older than the coal in the Livingston-Trail Creek and Electric fields, which is of Upper Cretaceous age.

Coal from these three Montana fields formerly was used in the production of coke for local copper smelters. Coke is seldom used in copper refining today, however, and as coke made from Montana coal is not of sufficiently high quality for use in other metallurgical processes without the adoption of special methods, no coal was being mined for coking purposes in Montana in 1949.

Great Falls field, Cascade, Fergus, and Chouteau Counties, Montana (loc. 3).--The Great Falls coal field, in Cascade, Fergus, and Chouteau Counties, Montana, includes three adjacent areas of minable coal, which together cover a minimum of 334 square miles (Fisher, 1909). The coal occurs about 60 feet above the base of the Kootenai formation, which consists of interbedded massive sandstone and shale of Lower Cretaceous age. Local variations in the thickness of the coal are characteristic, but at least one bed, ranging from 2½ to 14 feet in thickness, is present throughout the field. Near Belt and Sand Coulee, where the coal has been mined extensively, it ranges typically between 4 and 9 feet in thickness, and is broken into two or three benches by shale and bone partings, which must be removed. The individual shale partings range in thickness from a fraction of an inch to 1 foot and usually they are easily separated from the coal above and below.

The coal-bearing rocks dip gently 3° to 5° NE., but may exhibit minor local undulations. In some places steeper dips present difficulties in mine haulage. Faults having displacements of 5 to 20 feet, and igneous rocks, principally basalt dikes, break the continuity of the coal-bearing rocks locally, but neither of these features causes any unusual mining problems. There is no report of coal having been altered or changed in rank by contact with the igneous rocks.

The coal in the Great Falls field is of high-volatile B and C bituminous ranks. An analysis on the as-received basis of a sample of coal from the Deep Creek mine in Cascade County, 22 miles southwest of the town of Great Falls, is as follows (U. S. Bur. Mines, 1932, pp. 42-43):

	Percent
Moisture	5.9
Volatile matter	32.8
Fixed carbon	49.3
Ash	12.0
Sulfur	4.0
Air-drying loss	2.4
B. t. u.	11,470

Sulfur is present principally in the form of pyrite nodules, which range from the size of a pinhead to about 4 inches in diameter, the average being about 1 inch. Some of these nodules, together with much of the ash, can be eliminated by washing and jigging the coal.

Only certain benches of the coal possess coking properties. The Anaconda Mining Co. formerly operated coke ovens at Belt, Montana, but abandoned them, in part because of the difficulty and expense of separating coking from noncoking coal, and in part because of the decline in importance of the blast furnace in nonferrous smelting.

In the Great Falls field the estimated original reserves of coal that can be classed as measured and indicated, according to the definitions on page 5, total 308,820,000 tons. This coal is contained in several beds, each at least 24 inches thick, beneath no more than 500 feet of overburden. Some of these estimated original reserves have been depleted by mining, and the amount of coal remaining that is of coking quality can be ascertained only by actual tests; but the reserves are believed to be sufficient to supply moderate industrial demands that have somewhat lower standards for industrial coke. Additional information about the reserves of coal in the Great Falls field and other fields in Montana is contained in reports by Combo and others (1949, 1950).

Livingston-Trail Creek field, Gallatin and Park Counties, Montana (loc. 4). --The Livingston-Trail Creek coal field, in Gallatin and Park Counties, Montana, forms a narrow Y-shaped belt extending across three townships for a distance of approximately 22 miles (Calvert, 1912, pp. 384-405). The coal-bearing formation, composed predominantly of sandstone beds totaling 750 to 900 feet in thickness, is at the base of the Montana group of Upper Cretaceous age. This unit is probably equivalent to the Eagle sandstone, which occurs in the lower part of the Montana group at other localities in the state. Coal of workable thickness occurs in three or four beds that individually range from 2 to 5 feet in thickness. Several partings of clay, shale, or bone separate the coal into benches, each of which usually contains 1 to 3 feet of coal.

The coal beds in this area are on the steeply dipping flanks of anticlinal folds and locally are broken by faults. Because the rocks normally dip between 40° and 65°, and in some places are vertical or overturned, the coal is too deep for mining a short distance from the outcrops. Locally the coal has been crushed by differential movements in the overlying and underlying beds.

The coal ranges in rank according to the amount of deformation it has undergone, but in general it is of high-volatile A, B, or C bituminous rank. An analysis on the as-received basis of a sample of coal from the Anaconda mine at Storrs, Gallatin County, is as follows (U. S. Bur. Mines, 1932, pp. 48-49):

	Percent
Moisture	6.3
Volatile matter	32.4
Fixed carbon	45.6
Ash	15.7
Sulfur	0.4
Air-drying loss	4.5
B. t. u.	11,460

In the past, coal mined from several parts of this field has been washed and used for the manufacture of coke, and at one time 100 beehive ovens were in operation at Cokedale. The original coal reserves in the main bed in T. 2 S., R. 8 E., Montana principal meridian, were inferred to be 442,500 tons, all presumab of coking quality. All of the easily accessible coking coal in the field, however, is now mined out.

Electric field, Park County, Montana (loc. 5). --The Electric field, Park County, Montana, includes two small coal-producing areas, which together cover less than 3 square miles. The coal-bearing rocks in this field lie in the lower part of the Montana group of Upper Cretaceous age and are believed to be equivalent to the Eagle sandstone. The coal occurs in a thick sequence of shale interbedded with sandstone in a stratigraphic interval of 300 feet. Three principal beds, which individually range in thickness from 3 to 5 feet and locally contain thin partings of clay and sandstone, are known to be present.

Mining conditions are difficult in the Electric field because of the complexity of the structure. The coal-bearing rocks occur in two synclinal areas within a fault block that has been downdropped several thousand feet in relation to the surrounding area, so that the coal-bearing rocks on the east side of the fault block are in contact with pre-Cambrian crystalline rocks. The fault block itself has been cut by numerous normal and thrust faults. The sedimentary rocks lie in positions ranging from nearly horizontal to vertical, but tight folding is common, and steep dips prevail throughout most of the field. Because of the faults and steep dips only a small part of the coal can be considered minable by present standards.

Igneous rocks are not uncommon, but few have been encountered in the mine workings. They will present a more serious problem, however, as operations are continued southward to the vicinity of Electric Peak, which is the center of a system of radiating dikes and sills.

The coal in this field is relatively high in rank because of the alteration and deformation to which it has been subjected. In general, the coal is of high-volatile A or medium-volatile bituminous rank, but locally it is semianthracite. An analysis on the as-received basis of a sample of coal from the Aldridge mine at Aldridge, Park County, is as follows (U. S. Bur. Mines, 1932, pp. 54-55):

	Percent
Moisture	4.0
Volatile matter	22.5
Fixed carbon	59.3
Ash	14.2
Sulfur	0.6
Air-drying loss	2.7
B. t. u.	12,760

Of the three coal beds in the Electric field, the uppermost has the strongest coking properties and is the only one that has been mined extensively. Locally, however, coal from the other two beds also is suitable for coking. Practically all the coal mined from this area in the past was used to manufacture coke, chiefly for the smelters at Anaconda and Butte. It is reported that the coke was of good quality, although the operators were unable to meet the requirements of those smelters for an ash content of less than 18 percent (Calvert, 1912, pp. 406-422).

The original coal reserves of the Electric field in beds at least 3 feet thick, having overburdens of no more than 1,000 feet, are inferred to have been 20,834,670 tons. Because of the great number of faults in the field, and because of the scarcity of information about the coal underlying the centers of the two synclinal areas, none of the reserves can be classified as measured or indicated. The reserve estimate includes the coal in all three minable beds, and as only one is predominantly of coking quality, probably no more than one-third of this figure should be considered as representing the inferred coking-coal reserves. Further allowance should be made for past production in the field and for losses in mining.

Wyoming

The coal beds in Wyoming, which are of Cretaceous and Tertiary age, were deposited chiefly in broad synclinal basins lying between the mountain ranges. Around the edges of these basins the coal-bearing rocks may dip steeply as a result of later uplift of the surrounding mountains, but in the central parts of the basins the rocks are essentially flat-lying. Because many of the coal beds have been subjected to little or no deformation, Wyoming, which has large coal reserves, contains mostly subbituminous coal and low-rank bituminous coal. Only in three areas in the State is the coal suitable for coke production.

In the Rock Springs field, Sweetwater County, where the coal-bearing formations have been affected by the Rock Springs uplift, the lowermost coal bed, which is of Upper Cretaceous age, has coking properties, but yields a product that is poor in quality. The Cambria field on the western flank of the Black Hills, contains a coal bed of Lower Cretaceous age that was mined formerly as a coking coal. The Willow Creek coal bed of Upper Cretaceous age in the Kemmerer-Willow Creek field, Lincoln County, has coking properties, probably as a result of the rather close folding of the rocks.

Kemmerer-Willow Creek field, Lincoln County, Wyoming (loc. 6). --The coal field near Kemmerer in southwestern Wyoming, which has been described by Schultz (1914), comprises several areas of coal-bearing rocks located in a long, narrow synclinal belt that extends northwestward into Idaho. During 1942-1943, a part of this belt 12 miles long, approximately 12 miles north of Kemmerer, was the subject of a cooperative survey by the U. S. Geological Survey and the U. S. Bureau of Mines to determine the quantity and quality of available coking coal (Andrews, 1944; Toenges and others, 1945).

Coal having coking properties in the Kemmerer-Willow Creek area occurs in the Willow Creek and Kemmerer coal zones in the Frontier formation of Upper Cretaceous age. Higher in the section, coal generally unsuitable for making coke occurs in the Adaville formation, also of Upper Cretaceous age. Both the Willow Creek and the Kemmerer zones contain several closely spaced coal beds, the most important of which is near the center of the Willow Creek zone and is known both as the Middle Main bed and as the Willow Creek (No. 5) bed. The thickness and character of this bed have been proved by drilling and sampling for a distance of $4\frac{1}{2}$ miles along the outcrop on the east side of the synclinal belt, and with the exception of two small areas of poor coal, the bed ranges in thickness from 4 feet 3 inches to 4 feet 10 inches. Two clay partings, each 1 to 2 inches thick, generally occur 7 to 14 inches below the top of the bed. These partings can be removed by washing, but only with a resulting loss of some coal. The bed is overlain in the proved area by a 2 foot clay zone, which in turn is overlain by a thin coal, generally 15 to 25 inches thick.

On the eastern limb of the syncline the rocks have an average dip to the west of 28° to 33°. The regularity of dip, together with an absence of faults, makes this location a favorable one for mining. The rocks on the western limb, on the other hand, dip at least 45° and locally may be vertical or overturned. Although mining conditions would be difficult on the western limb of the syncline, the Middle Main bed in this area ranges between 3 feet 2 inches and 6 feet 5 inches in thickness and has no partings.

The coal in the Middle Main bed is of high-volatile A bituminous rank. An analysis on the as-received basis of a sample of coal from a drill hole at the northeast corner of sec. 12, T. 23 N., R. 116 W., sixth principal meridian, is as follows (Toenges and others, 1945, pp. 44-45):

	Percent
Moisture	2.8
Volatile matter	36.9
Fixed carbon	51.4
Ash	8.9
Sulfur	0.6
B. t. u.	12,780

Coke manufactured from coal from this bed alone is unsuitable for use in the blast furnace. With the addition of 50 to 60 percent of coal from the Sunnyside region, Utah, however, it will provide a coke nearly comparable to coke made from 100 percent Sunnyside coal. It is believed that the percentage of Sunnyside coal needed in the blend can be reduced by washing coal from the Middle Main bed to remove the impurities. Details of the physical and chemical properties of cokes, derived during tests of various blends of Willow Creek and other coals, are contained in the report by the Bureau of Mines (Toenges and others, 1945, pp. 14-25).

In the area proved by drilling, which includes 1,710 acres, or nearly 3 square miles, the estimated original reserves of coking coal in the Middle Main bed are 15,345,000 tons. Assuming minimum mining losses, the recoverable coal totals 11,215,000 tons (Toenges and others, 1945, pp. 10-11). Making generous additional allowances for losses incurred in eliminating the impurities contained in the two clay partings, the recoverable clean marketable coal in the area proved by drilling totals at least 8,000,000 tons (Andrews, 1944).

South of the area of drilling, the coal in the Middle Main bed presumably has the same coking properties as the coal just described, and considerable mining of the bed has taken place. In the five townships where the Middle Main bed is 28 to 42 inches thick, the original measured reserves of coal under less than 2,000 feet of overburden total 37,940,000 tons, and the original indicated reserves total 58,700,000 tons. Additional measured reserves of 8,560,000 tons of coal and indicated reserves of 39,420,000 tons of coal are present at depths between 2,000 and 3,000 feet below the surface.

Additional information about the coal reserves of the Kemmerer-Willow Creek field and other fields in Wyoming is contained in reports by H. L. Berryhill and others (1950).

Rock Springs field, Sweetwater County, Wyoming (loc. 7). --The coal in the Rock Springs field occurs in four main zones: the Rock Springs and Almond coal zones in the Mesaverde formation of Upper Cretaceous age; the Black Butte coal zone in the Laramie formation, also of Upper Cretaceous age; and the Black Rock coal zone in the Wasatch formation of Tertiary age. The Rock Springs zone near the base of the Mesaverde formation comprises the thickest and best coal in the field. The zone contains at least 12 coal beds that are individually from 2 to 10 feet thick, and many other beds less than 2 feet thick. Partings of shale, bone, and sandstone occur in the coal beds. The thickness of each parting ranges, in general, from a fraction of an inch to 1 foot.

The principal structure of the Rock Springs field is a low dome, in which the coal beds are exposed almost continuously around the non-coal-bearing central portion. Normal faults break the continuity of the beds on the flanks of the dome, and in areas where these faults are numerous, they may greatly increase the difficulty and expense of mining. Intrusions and extrusions are numerous in the northern half of the dome, but no alteration of the coal by igneous activity has been observed (Schultz, 1909, pp. 256-282; 1910, pp. 214-281).

The coal of the Rock Springs zone is of high-volatile C bituminous rank, and the coal in the overlying zones is of subbituminous A, B, or C rank. An analysis on an as-received basis of a sample of coal from the Rock Springs No. 7 bed from the Superior A mine, three-quarters of a mile southeast of Superior, Sweetwater County, is as follows (U. S. Bur. Mines, 1931, pp. 74-75):

	Percent
Moisture	12.7
Volatile matter	32.8
Fixed carbon	50.0
Ash	4.5
Sulfur	0.8
Air-drying loss	5.6
B. t. u.	11,720

Coal from some of the beds in the Rock Springs zone, particularly the No. 7, will yield a poor grade of coke that is unsuitable for metallurgical purposes. The estimated original reserves of the No. 7 bed, where it is at least 28 inches thick and has an overburden of no more than 2,000 feet, total 899,440,000 tons. Of this amount the measured reserves were 335,160,000 tons, the indicated reserves 392,650,000 tons, and the inferred reserves 171,630,000 tons. At depths between 2,000 and 3,000 feet below the surface the No. 7 bed contains additional indicated coal reserves of 35,780,000 tons and inferred reserves of 205,710,000 tons. Approximately 107,580,000 tons of coal from the No. 7 bed was mined or lost in mining to January 1, 1950. All mining has taken place in parts of the bed included in measured original coal reserves.

Cambria field, Weston County, Wyoming (loc. 8). --The coal in the Cambria field is contained primarily in a single bed that occurs sporadically near the base of the Lakota sandstone of Lower Cretaceous age (Darton, 1904; 1905). Abrupt changes in composition and thickness of the bed are common, but usually the bed ranges between 3 and 10 feet in thickness. Near the town of Cambria, where most of the mining has been carried on, the coal is typically 7 feet thick and of good quality. The structure of the Cambria field is a monocline in which the coal-bearing rocks dip gently to the southwest.

The coal from this area is of high-volatile C bituminous rank, and an analysis on an as-received basis of a composite sample of coal taken from three locations within the Antelope No. 4 mine at Cambria is as follows (U. S. Bur. Mines, 1931, pp. 76-77):

	Percent
Moisture	10.8
Volatile matter	39.1
Fixed carbon	35.1
Ash	15.0
Sulfur	4.9
Air-drying loss	8.1
B. t. u.	10,340

Certain parts of this bed, presumably of greater purity than the remainder, have good coking qualities, and in the past were employed for manufacturing coke to supply the Black Hills smelters and refineries.

The Cambria field contained estimated original reserves of 21,920,000 tons of coal at least 28 inches thick covered by no more than 1,000 feet of overburden. The coal that was measured or indicated by geologic evidence accounted for 18,600,000 tons of the total reserves, and an additional 3,320,000 tons was inferred to be present from general geologic knowledge of the area. These reserves have been almost entirely mined or lost in mining. Certainly the readily accessible reserves of coking coal, which represented only a small percentage of the total reserves, are now depleted.

Utah

The Sunnyside-Castlegate field, Carbon County, is the only area in Utah that contains coal having the qualities necessary for the production of satisfactory metallurgical coke. The coal beds, which are of Upper Cretaceous age, crop out along the south side of the Uinta Basin. At the town of Sunnyside, where mining has been carried on most extensively, the coal beds dip about 12° NE. Northwest and southeast of Sunnyside, however, the dip of the rocks decreases to between 2° and 4°.

Two other coal-producing areas, the Mount Pleasant field, Sanpete County, and the Kanab field, Iron County, have formerly been thought to contain deposits of possible coking coal. Tests on the coal from the Mount Pleasant field and experience in using the coal from the Kanab field, however, have shown that the coal from these areas does not possess the qualities required in the formation of good blast-furnace coke.

Sunnyside-Castlegate field, Carbon County, Utah (loc. 9). --The Sunnyside-Castlegate field is the most important source of coking coal in the West. In 1947, approximately one-third of the coking coal mined in this field was shipped to California, and two-thirds remained in Utah (De Carlo, Corgan, and Otero, 1947). As described by Clark (1928), the coking-coal area in the field comprises a strip about 40 miles long at the western end of the large Book Cliffs field of Colorado and Utah. The coal in the Sunnyside-Castlegate area has fair to good coking qualities, and it has been mined extensively for this purpose at Sunnyside, Columbia, and Horse Canyon.

The coal in the Sunnyside-Castlegate area occurs as a zone about 500 feet thick near the base of the Mesaverde group of Upper Cretaceous age. This formation consists of massive beds of sandstone, which crop out conspicuously in the Book Cliffs, and alternating beds of shale and coal, which lie between the sandstones. As many as nine coal beds are known to occur locally in the coal-bearing zone, and it is believed that at least two are present throughout the area.

The coal beds are generally lenticular in shape, and are, therefore, of varied thickness. The Lower Sunnyside bed, which is mined extensively near Sunnyside for use in the manufacture of coke, crops out for a distance of about 25 miles. It ranges in thickness from 5 to 11 feet in the area of active mining, but thins somewhat both to the northwest and to the south. Locally it is separated into two benches by a parting of sandy shale 1 to 2 feet thick. Partings, however, are uncommon in this field, and the coal normally occurs as one bench.

The Sunnyside-Castlegate coal field has a simple monoclinal structure. The beds dip 6° to 12° N. and NE. under the Book Cliffs, and, except for a few minor faults concentrated mostly at the south end of the field, are undisturbed.

The coal in this field is of high-volatile A and B bituminous ranks, and an analysis on the as-received basis of a sample of coal from the Lower Sunnyside bed at Sunnyside is as follows (Reynolds and others, 1946, pp. 12-13):

	Percent
Moisture	4.5
Volatile matter	38.5
Fixed carbon	51.2
Ash	5.8
Sulfur	1.3
Air-drying loss	2.2
B. t. u. (moist, mineral-matter-free)	14,020

The Lower Sunnyside coal is a conspicuous example of a high-volatile bituminous coal being used successfully in byproduct ovens for the productión of satisfactory metallurgical coke. A typical analysis of coke produced from Lower Sunnyside coal from the Columbia mine shows the following physical and chemical properties (Reynolds, 1946, pp. 44-48):

Apparent specific gravity	0.78
True specific gravity	1.89
B. t. u.	12,790

	Percent
Volatile matter	1.7
Fixed carbon	87.4
Ash	10.9
Sulfur	0.9
Cell space	58.7

Tumbler and shatter tests: satisfactory for all purposes.

Coke produced from Sunnyside coal yields only about two-thirds of its weight in furnace-size pieces, which contain many lateral and transverse fractures, but it is hard and holds up well in the blast furnace.

At the town of Sunnyside more than 800 beehive ovens have been constructed, many of which were in use during World War II. Nearby at Columbia there are additional beehive ovens, but most of the coal is processed in a modern byproduct plant at Provo, Utah. Coke made from this coal is used in the Columbia Steel plant at Ironton, Utah, the Geneva Steel plant near Provo, Utah, the Fontana plant in southern California, and in local sugar refineries.

The coking qualities of the coal in this field decrease northwestward from the Sunnyside area to Castlegate, and the coal at Castlegate is no longer used for coking purposes, though prior to 1903 it was the main source of supply for the State. Similarly, the coal in the Huntington Canyon area south of Castlegate has coking properties, but the coke made from this coal is inferior to that produced at Sunnyside.

The total reserves of coking coal in the Lower Sunnyside bed are believed to be large enough to supply anticipated demands. Detailed calculations of the reserves in the Sunnyside-Castlegate field as measured along the outcrops and indicated by the geologic continuity of the bed are tabulated by township and by individual bed in U. S. Geological Survey Bulletin 793 (Clark, 1928, pp. 101-102, 161). These figures show that the Lower Sunnyside bed contains estimated original reserves ranging from 5,472,000 to 8,928,000 tons per square mile in a belt about 10 miles long, and averaging about 2 miles wide, lying northwest of the town of Sunnyside. The coal here lies under less than 2,000 feet of overburden. As commercial mining in the Lower Sunnyside bed is restricted for the most part to an area southeast of this belt, the entire tonnage in the belt, less normal expectable losses in mining, is available for future needs. Additional reserves are present in the Lower Sunnyside bed in the area of active mining, which extends from a point about 1 mile northwest of Sunnyside, southeastward to a point several miles south of Horse Canyon.

Mount Pleasant field, Sanpete County, Utah (loc. 10). --The Mount Pleasant coal field, which is on the western side of the Wasatch Plateau, is favorably located with respect to the western steel industry, and for this reason it has been carefully investigated as a source of coking coal. The area was mapped by the U. S. Geological Survey in 1942 (Duncan, 1944), and an exploratory diamond-drill hole was sunk by the U. S. Bureau of Mines to obtain samples for analysis (Toenges and Turnbull, 1943).

The six coal beds encountered in the drilling are in the lower 200 feet of the Blackhawk formation of Upper Cretaceous age and range in thickness between 18 inches and 5 feet 8 inches. On the western margin of the Wasatch Plateau, the rocks are broken by numerous faults, and west of the fault zone the coal beds have been dropped down to more than 2,000 feet below the surface, thus placing them beyond the present practical limit of mining. On the east side of the fault zone, however, the coal beds were found in the test hole at depths of only 955 to 1,151 feet below the surface.

An analysis on the as-received basis of a core sample of coal from one of the thicker beds in the Mount Pleasant field is as follows (Toenges and Turnbull, 1943, p. 14):

	Percent
Moisture	3.2
Volatile matter	42.9
Fixed carbon	45.3
Ash	8.6
Sulfur	0.6
Air-drying loss	1.4
B. t. u.	12,890

Coking tests made on six samples of this coal, which is of high-volatile A and B bituminous ranks, as is the coal from the Lower Sunnyside bed, revealed that the resulting coke was softer, considerably weaker, and more fingery than coke manufactured from Sunnyside coal. It was concluded, therefore, that coal from the Mount Pleasant area is not suitable for the production of blast-furnace coke to be used in smelting iron ore.

Kanab field, Iron County, Utah (loc. 11). --The Kanab field, which has been described in U. S. Geological Survey Bulletin 316 (Lee, 1907, pp. 359-374), is on the western edge of the Colob Plateau near Cedar City. The coal beds in this field crop out in the cliffs that border the Colob Plateau or in the canyons eroded in its margin. The coal occurs near the base of the Benton shale of Upper Cretaceous age in one minable bed 3 to 8 feet thick and in several additional thin beds. Partings of shale and clay between 1 and 4 inches thick split the coal into benches, which individually are usually 2 to 3 feet thick.

The Kanab coal field is located along the northern extension of the Hurricane fault, and the conspicuous elevation of the cliffs above the basin to the west is due to displacement along the line of this fault. The coal-bearing rocks are somewhat folded and broken by minor faults, although locally they may be nearly horizontal. At places where the plateau is capped by basalt, the underlying sedimentary rocks are cut by large dikes, but no visible alteration of the coal by the igneous rocks has been reported.

The coal of the Kanab field has a heat value ranging in general between 11,000 and 12,000 B. t. u. on a moist, mineral-matter-free basis. This is a borderline coal, therefore, and can be classified as either subbituminous A or high-volatile C bituminous in rank, depending upon the weathering and agglomerating indices.

An analysis on an as-received basis of a sample of coal from the Jones mine on Coal Creek, 7 miles southeast of Cedar City, Iron County, is as follows (U. S. Bur. Mines, 1925, p. 37):

	Percent
Moisture	10.4
Volatile matter	36.3
Fixed carbon	43.7
Ash	9.6
Sulfur	5.8
Air-drying loss	1.8
B. t. u.	10,870

The coke produced from this coal is high in sulfur and tends to be too friable for metallurgical use. Formerly, coke produced from coal obtained from the Kanab field near Cedar City was used to smelt the nearby Iron Springs iron ores. The results, however, were unsatisfactory, and the field, which contains large reserves of coal, is generally not considered as a source of coking coal.

Colorado

Two of the important centers of western coking coal production -- the Raton Mesa field and the Crested Butte field -- are in Colorado. In the Raton Mesa field, which extends from Huerfano County southward into New Mexico, the now extinct Spanish Peaks volcano has played an important part in the geologic history of the region. During the period of activity of this volcano, dikes and sills of igneous rock were intruded in radial arrangment into the surrounding coal-bearing sedimentary rocks, and the accompanying heat may have raised the rank of the coal, and thus may have improved the coking properties.

In the Crested Butte and adjacent fields of Delta, Gunnison, and Pitkin Counties, the geologic structure is very complex as a result of the uplift of the Rocky Mountains, and the coal-bearing rocks have been folded, faulted, and cut by large intrusions of igneous rock. Consequently, the coal beds have been altered extensively, and locally are suitable for coking purposes.

The Durango field, a third area in Colorado containing deposits of coking coal, is on the northern edge of the San Juan Basin, which lies mostly in New Mexico. In the vicinity of Durango, La Plata County, the coal beds dip to the south at angles ranging from 6° at places a few miles southwest of the town up to 40° at places a few miles to the northeast. In most of the San Juan Basin, the dips are lower and the coal is of lower rank than in the Durango field. The folding along the northern edge of the Basin, therefore, appears to have caused significant alteration of the coal, and to be partly responsible for the localization of the deposits of coking coal.

Crested Butte field and vicinity, Delta, Gunnison, and Pitkin Counties, Colorado (loc. 12). --The Crested Butte coal field, together with several adjacent fields in Gunnison, Delta, and Pitkin Counties, constitutes the second largest coke-producing area in the West, exceeded only by the Sunnyside-Castlegate field in Utah. The general geology of the region is described in two publications of the U. S. Geological Survey (Eldridge, 1894; Lee, 1912). In addition, an area containing coking coal in western Gunnison County near Somerset, known as the Coal Creek district, has been the subject of a recent cooperative investigation by the U. S. Geological Survey (Johnson, 1948) and the U. S. Bureau of Mines (Toenges and others, 1947).

The coal fields in the Crested Butte area are on the southeastern rim of the Uinta Basin, a large structural feature that extends into Utah. Igneous intrusions and the uplift associated with the formation of the Rocky Mountains have so disturbed the rocks in the Crested Butte area, however, that the relations of the structure to the Uinta Basin are not clearly defined.

The coal beds are in the Bowie shale member and the overlying Paonia shale member of the Mesaverde formation of Upper Cretaceous age. Several coal beds of minable thickness occur in each of the two members, and a total of eight beds have been observed in one locality. Correlation of the coal beds and accurate determinations of thickness are difficult because of the deformation in the area, but, in general, the thicker beds range between 4 and 12 feet in thickness.

The Mesaverde formation is extensively folded, faulted, and cut by igneous rocks in the Crested Butte area. As a result of the deformation and the effect of the intrusions, the coal ranges in rank from bituminous to anthracite. In general, the coal in the Bowie shale member is slightly higher in rank than the coal in the Paonia shale member, but this difference disappears where the coals have been altered. The variation in rank in this area is so great that no single analysis or group of analyses is adequate to show the character of the coal, but for the most part, the ash content is moderate and the sulfur content low.

Coal with coking properties occurs at Gibson Ridge, Floresta, Mount Carbon, Red Gap, and Placita, in addition to the Coal Creek district, but because of the range in rank and quality of the coal in this area, the coke produced from the coal also shows a considerable range in quality. Good metallurgical coke is produced, however, from coal obtained at several places in Gunnison County.

In the Coal Creek district, T. 13 S., R. 89 W., sixth principal meridian, the Mesaverde formation is divided from bottom to top into the Rollins sandstone member; the lower coal member, in general equivalent to the Bowie shale member; the upper coal member, in general equivalent to the Paonia shale member; and the barren member. Recent exploration in the Coal Creek district has shown that the lower coal member contains two principal beds. The lower bed, known as the Snowshoe, is between 9 and 15 feet thick in the central part of the township, but thins to the north and west and splits into two benches, each containing 1 to 7 feet of coal. The upper or Bear bed, although locally minable, is less than 3 feet thick throughout most of the Coal Creek district. The upper coal member of the Mesaverde formation includes one coal bed that within a limited area is 23 to 26 inches thick. In most of the Coal Creek district, however, the upper coal member contains only thin erratic coal beds each of which is usually less than 1 foot thick.

Tests conducted by the Bureau of Mines show that coal from the lower bench of the Snowshoe bed and from the Bear bed yields a stronger coke than does coal from the Sunnyside bed in Utah. The coal from the upper bench of the Snowshoe bed produces a coke slightly inferior to coke made from Sunnyside coal. All three of the cokes are satisfactory in chemical composition, having sulfur contents between 0.4 and 0.9 percent and ash contents between 6.3 and 10.9 percent. The lower Snowshoe bed and the Bear bed, therefore, can be considered suitable for use in the production of metallurgical coke.

In the area proved by drilling in T. 13 S., R. 89 W., the measured original reserves of coal total 100,000,000 tons, of which 65,000,000 tons is of coking quality. Assuming a 70 to 80 percent recovery in mining, which in this area is believed to be attainable, recoverable reserves of coking coal in the drilled area are between 45,500,000 and 52,000,000 tons. None of this coal is immediately accessible from the outcrop, and it all lies under moderate to heavy overburden. At the confluence of Anthracite and Coal Creeks, for example, the Bear bed was encountered in a drill hole at 658 feet, and the lower bench of the Snowshoe bed at 695 feet. East and northeast of this point the thickness of the overburden increases rapidly, and most of the coking coal lies from 1,000 to 2,000 feet beneath the surface.

In the entire area of T. 13 S., R. 89 W., the original reserves of coal contained in the lower coal member in beds at least 30 inches thick are estimated on the basis of geologic evidence to be 503,000,000 tons, of which one-half to two-thirds can be considered as coking coal. Again, an allowance must be made for mining losses.

With the exception of the arc of igneous rocks lying immediately southeast of T. 13 S., R. 89 W., the areas to the northeast and south of the township are believed to contain coal having coking properties. Although no reserve figures are available as yet for these additional areas of potential coking coal, their reserves should be comparable to those of the Coal Creek district. The reserves of coking coal in the entire Crested Butte area, therefore, are adequate to supply a large industrial demand.

Norwood field, Montrose and San Miguel Counties, Colorado (loc. 13). --Coke has been made locally from the coal in the Dakota sandstone near Norwood in Montrose and San Miguel Counties, Colo. The coal beds are thin and discontinuous, however, and the coking coal frequently is limited to separate zones within the beds. In general, the region is not considered as a source of coal for industrial coke.

Durango field, La Plata County, Colorado (loc. 14). --The Durango field, which lies on the northern side of the San Juan coal basin of Colorado and New Mexico, has been described by Taff (1907, pp. 321-337) and Zapp (1949). Coal in this field occurs in the Fruitland formation and in the Menefee formation of the Mesaverde group. The Fruitland formation, which is the younger, contains beds of coal of subbituminous rank that are not suitable for coking. The Menefee formation consists of inter-bedded sandstone and shale and has in its central part three, and in some places four, minable coal beds having coking properties. At least two of these beds have been extensively mined near Durango.

The minable coal beds in the Menefee formation range in thickness between 2 and 7 feet, but partings of shale and bone, each several inches thick, generally divide the beds into benches each containing 1 to 6 feet of coal.

All the coal-bearing rocks dip to the south or southeast at angles ranging from 6° or 8° near Hesperus, 8 miles west of Durango, to 40° in the area 6 miles northeast of Durango. A few faults are present in the field, but they are too small to interfere with mining operations.

Most of the coal in the Menefee formation is of high-volatile A bituminous rank. An analysis on the as-received basis of a sample of coal from the Hesperus mine is as follows (U. S. Bur. Mines, 1937, pp. 88-89):

	Percent
Moisture	5.6
Volatile matter	36.2
Fixed carbon	52.5
Ash	5.7
Sulfur	0.5
Air-drying loss	2.3
B. t. u.	13,120

Beehive ovens formerly were in operation at Durango and Porter, and the coke produced was used for smelting purposes. Recent tests by the Bureau of Mines of the agglutinating, swelling, and plastic properties of 19 samples of coal from this area indicated that most of the samples had good coking qualities, and that many were suitable for use in by-product ovens (Fieldner and others, 1945, p. 58). Although there are local variations in the coking quality of the coal in the Durango area, some of the coal in the Menefee formation probably could be treated by modern cleaning and processing methods and used to manufacture metallurgical coke.

The original measured reserves of thicker accessible coal in the Durango field, as estimated by Zapp, total 67,180,000 tons. All of this coal is in beds more than 42 inches thick at depths of less than 1,000 feet below the surface. Taking into consideration the coal that has been mined or lost in mining, the remaining measured reserves as of January 1, 1949, are 64,300,000 tons, of which 41,790,000 tons can be classified as recoverable reserves assuming 65-percent recovery of the coal. Larger indicated and inferred reserves of coal also are present in the field at depths between 1,000 and 3,000 feet below the surface (Zapp, 1949).

Raton Mesa field, Huerfano and Las Animas Counties, Colorado, and Colfax County, New Mexico (loc. 15). --The Raton Mesa field, which includes an area of about 2,000 square miles in Huerfano and Las Animas Counties, Colorado and Colfax County, New Mexico, is the third largest producer of coking coal in the West. Detailed descriptions of different parts of the field are contained in several publications of the U. S. Geological Survey (Hills, 1899, 1900, 1901; Lee and Knowlton, 1917; Lee, 1922), and the coal has been the subject of much technologic work by the U. S Bureau of Mines (Reynolds and others, 1946, pp. 75-78; Fieldner and others, 1945, pp. 58-59; Parry, 1943, p. 32).

The coal in this field occurs in three zones, the lower in the Vermejo formation of Upper Cretaceous age, and the middle and upper in the Raton formation of Cretaceous and Paleocene ages. In parts of the field as many as eight workable beds can be found, and at least one or two are present in all localities. The beds are generally discontinuous, however, and only a few are persistent over wide areas.

The beds in the lower zone are most persistent, and between one and eight beds, individually containing 2 to 14 feet of coal, are workable. Mining operations are extensive in this zone, which generally contains the highest grade bituminous coal in the field. In the middle zone, the workable beds, each of which averages 4 feet in thickness, are known only in Las Animas County, Colorado. In the upper zone, the beds thicken and thin within short distances, but those that are workable are between 2 and 6 feet thick.

Structurally, the Raton Mesa field is a northward trending syncline with steep dips on the west side and relatively gently dips on the east. In the northwestern part of the syncline lies the extinct Spanish Peaks volcano with numerous radiating dikes and sills of of igneous rock that have produced many local variations in the character of the coal and impose problems of mining in the vicinity.

Only by the examination of a large number of analyses can the range in rank of the coal in the Raton Mesa field be determined (U. S. Bur. Mines, 1936, pp. 44-51; 1937, pp. 76-84, 92-101). Where the coal is suitable for coking purposes, as at Trinidad, it is mined extensively to supply the byproduct ovens at Pueblo, Colo. The coal used to manufacture coke is generally washed to remove some of the impurities and blended with a small amount of noncoking coal or the char obtained by devolatilizing available low-rank coal. The resulting coke is much superior to any other commercial metallurgical coke produced from western coal. Where the coal is not suitable for coking, as at Walsenburg, it is mined for railroad and domestic use.

The reserves of coking coal in the Raton Mesa field have not yet been determined accurately because of the lack of adequate information concerning local variations in the quality of the coal and because of the discontinuity of the coal beds. The total estimated original reserves of coal of all classes in the field are quite large, however, and the reserves of coal of coking quality are believed to represent a considerable part of the total.

In 1949 and 1950 the U. S. Geological Survey was engaged in a detailed study of a part of the Raton Mesa field covering about 70 square miles between the towns of Stonewall, Tercio, and Weston in Las Animas County, Colorado, near Trinidad. The first report by Wood and others (1951) on the results of this work shows that the original reserves of coal in the area total 490,969,000 tons. The Raton formation contains 262,486,000 tons of coal, of which 151,266,000 tons is classed as measured and indicated reserves and 111,220,000 tons as inferred reserves. The Vermejo formation contains 228,483,000 tons of coal, of which 72,340,000 tons is classed as measured and indicated reserves and 156,143,000 tons as inferred reserves. Most of the measured, indicated, and inferred reserves of coal in the Stonewall-Tercio area lie under less than 1,000 feet of overburden.

A recent study of the coal reserves of New Mexico by Read and others (1950) indicates that in Colfax County the estimated original reserves of measured and indicated bituminous coal in beds 28 inches or more in thickness, under less than 2,000 feet of overburden, total 1,486,900,000 tons. An additional 1,445,200,000 tons of bituminous coal 28 or more inches in thickness is inferred to be present at depths of less than 2,000 feet below the surface, and 376,900,000 tons of bituminous coal at least 42 inches thick is inferred to be present at depths between 2,000 feet and 3,000 feet below the surface. As much of the coal in the Raton Mesa field is of coking quality, these figures give some indication of the probable reserves of coking coal in the part of the field that lies in Colfax County, New Mexico.

New Mexico

The most important coking coal area in New Mexico, the Raton Mesa field, lies partly in Colorado, and has already been described with the Colorado fields. The Monero field, Rio Arriba County, which lies southeast of Durango, is on the northeastern side of the San Juan Basin, and some of the coal beds, as at Durango, have coking properties. In the Cerrillos field, Santa Fe County, where the coal-bearing rocks have been intruded and upturned by igneous rocks, some coal has coking properties, but the reserves of such coal are small. Similarly, only a small amount of coking coal remains in the Carthage field where the geologic structure is very complex, and the coking properties of the coal are due in part to alteration accompanying the close folding and faulting of the sedimentary rocks.

Monero field, Rio Arriba County, New Mexico (loc. 16). --The Monero coal field has been described in a brief report by Gardner (1909, pp. 352-363), and the stratigraphy and structure of the area have been mapped more recently by Dane (1948). The coal field lies on the northeast side of the San Juan coal basin, immediately south of the Colorado line. The coal having coking properties occurs in the Gibson coal member of the Mesaverde formation as three minable beds which vary individually from 3 feet 7 inches to 4 feet in thickness. Partings of sandstone and shale from 7 to 9 inches thick split the beds into benches of coal that range in thickness between 1 foot 4 inches and 3 feet 4 inches.

In the vicinity of Monero and Lumberton, where most of the mining in this area is carried on, the rocks are broken by several normal faults, and about 2 miles west of Monero they are arched into a low dome. As a result, the beds dip at moderate angles to the southwest and the northwest and locally to the southeast.

The coal in this area is commonly of high-volatile A bituminous rank. An analysis on the as-received basis of a sample of coal from the Kutz mine, 1 mile south of Lumberton, Rio Arriba County, is as follows (U. S. Bur. Mines, 1936, pp. 56-57):

	Percent
Moisture	2.4
Volatile matter	38.0
Fixed carbon	52.3
Ash	7.3
Sulfur	1.5
Air-drying loss	1.2
B. t. u.	13,600

According to Read and others (1950), the original reserves of measured and indicated bituminous coal in Rio Arriba County in beds 28 inches or more in thickness, under less than 2,000 feet of overburden, total 4,500,000 tons. An additional 390,300,000 tons of bituminous coal 14 inches or more in thickness may be inferred to be present under overburdens of less than 3,000 feet. All of the coal mined in the Monero field is at present used for railroads and domestic purposes. Certain beds, however, are known to possess coking qualities in parts of the field, although the reserves of such coal have not been determined.

Cerrillos field, Santa Fe County, New Mexico (loc. 17). --The Cerrillos field, which is one of the oldest coal-producing areas in the West, lies 25 miles south of Santa Fe, near the town of Madrid on the main line of the Atchinson, Topeka, and Santa Fe Railroad.

As described in a report by Lee (1913, pp. 285-312), the coal in the Cerrillos field is in the Mesaverde formation of Upper Cretaceous age, which consists of a massive basal sandstone overlain by a sequence of interbedded coal-bearing sandstones and shales. Three zones of coal beds, known in ascending order as the Miller Gulch, Cook and White, and White Ash coal zones, are present. The upper two zones have been extensively mined. The main bed of the White Ash coal zone ranges from 33 to 66 inches in thickness, and the main bed of the Cook and White zone averages 52 inches in thickness. There has been little development of the Miller Gulch zone, but the main bed is known to be approximately 40 inches thick.

The coal-bearing rocks occupy the center of a small basin and dip gently toward the center on the east and west sides, but on the north and south they have been steeply upturned by large igneous intrusions. Dikes and sills of igneous rock cut the sedimentary rocks in the basin and locally have altered the coal so that it ranges in rank from bituminous to anthracite. Certain beds in the Cook and White, and Miller Gulch coal zones contain coal that can be coked and used satisfactorily in blast furnaces, but most of the minable coal has been too highly metamorphosed to have coking qualities. During 1942-1943 the U. S. Geological Survey and the U. S. Bureau of Mines jointly examined areas in the field where, on the basis of the distribution of the igneous rocks in relation to the coal beds, coking coal might be expected to occur. The results of this study showed that the reserves of coking coal were too small to warrant further exploration (Toenges, Turnbull, and Mould, 1943).

Carthage field, Socorro County, New Mexico (loc. 18). --The Carthage field, Socorro County, New Mexico is about 12 miles southeast of San Antonio. As described by Gardner (1910, pp. 452-460), the minable coal in the field occurs as a single bed that averages about 5 feet in thickness and lies just above the basal sandstone of the Mesaverde formation of Upper Cretaceous age. Partings of clay, shale, and bone that range in thickness from 2 to 15 inches split the coal so that the principal bench is between 2 and 4 feet thick. Several other coal beds are present in the Mesaverde formation above the minable bed.

The Carthage field is located on an uplifted fault block, which in turn has been broken by a system of north-south normal faults. Because of the faulting and numerous changes in dip, the complexity of the structure is such that mining operations can seldom follow the coal from one minor block to another.

The coal in the Carthage field is of high-volatile A bituminous rank. An analysis on an as-received basis of a sample of coal from the Government mine at Carthage is as follows (U. S. Bur. Mines, 1936, pp. 62-63):

	Percent
Moisture	3.7
Volatile matter	39.7
Fixed carbon	46.7
Ash	9.9
Sulfur	1.0
Air-drying loss	2.2
B. t. u.	12,860

The field has been mined more or less continuously since 1861, and prior to 1894 beehive coke ovens were operated. In 1942, the field was examined by the U. S. Geological Survey and the U. S. Bureau of Mines as a possible source of coking coal (Reynolds and others, 1946, pp. 10, 25, 35, 37-38, 41, 48, 62, 64, 67-68, 76). Tests showed that the coal yielded a fair coke inferior in quality to that produced at Sunnyside, Utah. Most of the Carthage field has been worked out, and the known areal extent of the coal bed at minable depth is no more than 2 square miles.

Oklahoma-Arkansas

The coal fields in southern Oklahoma and Arkansas together form a continuous area of coal-bearing rocks of Pennsylvanian age that crop out as a series of generally eastward trending anticlines and synclines cut by thrust faults having approximately the same strike as the folds. As a result of the folding and faulting, the coal has been somewhat altered and shows a marked increase in rank from west to east. In the southwestern part of the Oklahoma field where the rocks are only moderately folded, the coal is of high-volatile bituminous rank. In eastern Oklahoma and in western Arkansas, where the deformation was greater, the coal is of low-volatile bituminous rank. Some coal from the Oklahoma-Arkansas field can be used directly for coke making, and the remainder, particularly the low-volatile bituminous coal, is useful for blending with lower rank coal.

Henryetta district, Okmulgee County, Oklahoma (loc. 19). --The Henryetta district in Okmulgee County, although only 10 square miles in size, is one of the most extensively mined areas in the Oklahoma coal field. Coal is produced from one bed, the Henryetta, in the Senora formation of Pennsylvanian age. Usually this bed is 34 to 36 inches thick and contains clean coal, but locally 2 to 4 inches of impure or bony coal may form a parting in the center of the bed. The coal-bearing rocks in the Henryetta district dip gently to the west. The structure and the roof rock are favorable for mining, and the thinness of the coal bed is only a minor disadvantage. Exploratory drilling west of the mined area shows that the coal thickens in that direction to 39 inches and lies 580 to 630 feet below the surface.

Generally the coal in the Henryetta bed is of high-volatile B bituminous rank. An analysis on an as-received basis of a sample of coal from this bed from the Whitehead No. 2 mine at Henryetta is as follows (U. S. Bur. Mines, 1928, Tech. Paper 411, p. 21):

	Percent
Moisture	7.6
Volatile matter	34.7
Fixed carbon	52.7
Ash	5.0
Sulfur	0.7
Air-drying loss	3.8
B. t. u.	12,880

The U. S. Bureau of Mines in cooperation with the Oklahoma Geological Survey conducted experiments in 1941 to determine the coking properties of Henryetta coal both when used alone and when blended with Lower Hartshorne coal from Sebastian County, Arkansas.

Two analyses on a dry basis of the cokes that were produced are as follows (Davis and Reynolds, 1941):

	100% Henryetta coal	80% Henryetta coal 20% Hartshorne coal
	Percent	Percent
Volatile matter	10.5	1.8
Fixed carbon	82.4	89.7
Ash	7.1	8.5
Sulfur	1.6	1.8
B. t. u.	13,800	13,230

Henryetta coal does not form a coke as strong as that obtained from the eastern coal customarily used, but it is believed to be suitable for making blast-furnace coke. Blending with 20 percent low-volatile Hartshorne coal, however, produces a coke with greatly improved strength. The low softening temperature of the ash makes the coke unsuitable for use in a water-gas generator and probably for domestic heating because of clinkering, but this is no disadvantage in the blast furnace.

No estimates of the coal reserves of the Henryetta field are available, but according to a report of the Oklahoma Geological Survey in 1941, drilling has shown that beyond the area of active mining there are additional coal reserves that can be developed (Davis and Reynolds, 1941, p. 2).

The southern part of the Oklahoma coal field, Coal, Pittsburg, Atoka, Latimer, and Le Flore Counties (loc. 20). --Coal of coking quality is present in the southern part of the Oklahoma field in an east-west belt extending through Coal, Pittsburg, Atoka, Latimer, Haskell, and Le Flore Counties (Thom and Rose, 1935; Hendricks and others, 1939; Oakes and Knechtel, 1948; Knechtel, 1949). The coal-bearing rocks in the southern Oklahoma field are of Pennsylvanian age and locally contain at least seven workable coal beds, of which the most important are the Upper and Lower Hartshorne and the McAlester. Numerous other beds are present, but each is usually less than 12 inches thick.

The Lower Hartshorne coal bed lies near the central part of the Hartshorne sandstone, which includes interbedded shale and has a total thickness of 50 to 500 feet. The coal bed ranges from 2½ to 6 feet in thickness, averaging 4 feet in thickness where mined. Partings may be absent entirely in some places but as many as four are found locally. Generally these partings are composed of pyrite or mineral charcoal and individually are seldom more than a fraction of an inch thick.

The Upper Hartshorne coal bed is located near the base of the McAlester shale, which is 1,200 to 2,800 feet thick and composed predominantly of dark shale. The thickness of the coal is between 1 foot 8 inches and 5 feet 7 inches and averages about 3 feet. Usually the bed contains no partings, but from one to three, each a fraction of an inch thick, may be present locally.

The McAlester coal bed occurs just above the middle of the McAlester shale. It ranges from 1 foot 8 inches to 4 feet in thickness, and, where mined, it averages 3½ feet. Prospecting has shown, however, that the McAlester bed thins to less than 2½ feet throughout much of its area of occurrence. As many as seven partings may be present in the bed, but most of them are very thin bands of pyrite that can be easily removed.

The structure of the southern Oklahoma coal field consists principally of a series of eastward or northeastward trending folds. The synclines are broad and flat, but the anticlines are tightly folded, and the dip of the rocks, which varies from 5° to 90°, has to a great extent determined the areas where mining has taken place. Where the dips are less than 20°, mining operations have been extensive, but the more steeply dipping coal beds have been worked only locally.

Thrust faults having displacements that vary from a few feet to more than 1,000 feet also trend generally eastward or northeastward across the coal field and often can be traced for several miles. In addition, small normal faults are present in the area.

The coal in the southern Oklahoma field ranges from high-volatile C to low-volatile bituminous in rank. The difference in rank within the various parts of a single bed is often greater than the difference in rank of two separate beds, and the character of the coal can be shown only by many analyses (U. S. Bur. Mines, 1928, Tech. Paper 411, pp. 13-29). In general, the rank of the coal increases in an eastward direction. The coal is of high-volatile bituminous rank in the western part of the field and grades eastward into coal that is characteristically of low-volatile bituminous rank.

Between 1880 and 1908, coke was manufactured in the McAlester district, in the western part of the southern Oklahoma field, from high-volatile McAlester and Hartshorne coal. Only washed slack coal, however, could be used satisfactorily. An analysis of the coke that was produced from washed coal was as follows (Hendricks and others, 1939, pt. 1, p. 81):

	Percent
Volatile matter	2.590
Carbon	85.330
Ash	11.120
Phosphorus	0.043
Sulfur	1.750

Also, 40 ovens were used at Howe in the eastern part of the field from 1900 to 1905 for the production of coke from low-volatile Lower Hartshorne coal. The quality of the coke is said to have been good, and the lack of an adequate market is given as the principal reason for abandonment of the ovens. Low-volatile Lower Hartshorne coal cannot be coked alone at the present time, however, because it tends to expand and will ruin the walls of a modern byproduct oven.

Recently, coking experiments were conducted by the U. S. Bureau of Mines in cooperation with the Oklahoma Geological Survey on samples of McAlester coal from Pittsburg County and Lower Hartshorne coal from Le Flore County, Oklahoma (Davis and Reynolds, 1942). Analyses on a dry basis of the cokes that were produced are as follows:

	100% McAlester coal	70% McAlester coal 30% Hartshorne coal
Apparent specific gravity	.71	.82
True specific gravity	1.46	1.93
B. t. u.	13,940	13,440
	Percent	Percent
Volatile matter	12.0	1.8
Fixed carbon	81.8	91.1
Ash	6.2	7.1
Sulfur	.5	.8

The high-volatile McAlester coal alone yields a very weak coke, but blending with 20 percent low-volatile Lower Hartshorne coal produces a coke with increased specific gravity, size, and stability. The sulfur content is thereby increased, because of the high sulfur content of the Lower Hartshorne coal, but it is still within the limits set for blast-furnace coke. The low softening temperature of the ash from both coals prohibits the use of the coke in water-gas sets and in domestic heating, but will not affect its performance in a blast furnace.

With the recent expansion of the steel industry in the West, Oklahoma has again become a producer of coking coal. Since 1944, low-volatile coal from eastern Oklahoma has been used—principally in the coke ovens at Provo, Utah, Fontana, Calif., and Daingerfield, Texas—for blending with high-volatile coals to improve the physical properties of the metallurgical coke produced in the western states.

The reserves of low-volatile coal in eastern Oklahoma appear to be of the order of 2,000,000,000 tons, as determined by recent geologic mapping (Oakes and Knechtel, 1948; Knechtel, 1949). The total coal reserves of the Oklahoma field have not as yet been accurately calculated, but the reserves of coking coal appear to be adequate to maintain the present increased rate of production. In addition to the three principal coal beds in the field, at least four other beds, although somewhat thinner, are of minable thickness and can be developed as the Upper and Lower Hartshorne and McAlester beds are exhausted. It is believed that the coal from all of these seven beds can be used for coking or for coking blends.

Western Arkansas field, Sebastian, Crawford, Franklin, Logan, Scott, Johnson, Pope, and Yell Counties (loc. 21). --The western Arkansas field, which has been described in two reports of the U. S. Geological Survey (Collier, 1907; Hendricks and Parks, 1937), is an eastward extension of the Oklahoma field. In general, the same formations are present, although few of the coal beds can be correlated from one state to the other. The coal-bearing formations in Arkansas are the Hartshorne sandstone, the McAlester shale, and the Savanna sandstone. Each of these formations is equivalent to the formation of the same name in Oklahoma, except that the upper part of the Hartshorne sandstone between the Lower and Upper Hartshorne coal beds is absent throughout most of the Arkansas field. The contact between the Hartshorne sandstone and the overlying McAlester shale, therefore, is placed below the Lower Hartshorne coal bed in Arkansas, rather than at the base of the Upper Hartshorne coal bed, as in Oklahoma.

Three coal beds - the Lower Hartshorne, the Charleston, and the Paris - are of commercial importance in the Arkansas field, and numerous other beds, each less than 18 inches thick, are present. The Lower Hartshorne bed, which lies in the basal part of the McAlester shale, is generally correlated with the Lower Hartshorne bed in Oklahoma. Normally this bed is between 2 and 7 feet thick and is the most important coal in Arkansas. Partings are sometimes lacking but when they do occur, most of them are between 1 and 6 inches thick. Locally the individual partings increase to as much as 3 feet thick, and in such places only the upper bench of coal is mined.

Locally a coal bed correlated with the Upper Hartshorne of Oklahoma lies 40 to 90 feet above the Lower Hartshorne bed, but it is a thin, bony coal and has little or no commercial value.

The Savanna sandstone, overlying the McAlester shale, consists of alternating beds of sandstone and shale and contains the other two workable coal beds in the Arkansas field. The lower bed, the Charleston, generally has a thickness of 14 to 20 inches, and the upper bed, the Paris, has a thickness of 18 inches, increasing locally to 34 inches.

The Arkansas coal field extends east-west and lies between the Ouachita Mountains on the south and the Boston Mountains on the north. Different types of earth movements formed the two mountain areas, and the structure in different parts of the coal field varies according to position with respect to these two relatively uplifted areas. In the Ouachita Mountains horizontal pressures formed thrust faults and tight folds having limbs that are steeply dipping or overturned. On the south side of the Arkansas coal field, therefore, the rocks are folded and locally thrust-faulted, though not so intensely as in the Ouachita Mountains. In the Boston Mountains the rocks dip only slightly southward and are broken by high-angle normal faults. The northern side of the coal field has the same type of structure, although the degree of folding and amount of faulting are somewhat greater than in the Boston Mountains due to the additional pressure from the south.

All the coal in the western part of the Arkansas field is of low-volatile bituminous rank, but toward the eastern part of the field the coal increases in rank to semianthracite. An analysis on the as-received basis of a sample of low-volatile coal from the Central No. 10 mine at Hartford, Sebastian County, is as follows (U. S. Bur. Mines, 1928, Tech. Paper 416, pp. 12-13):

	Percent
Moisture	3.4
Volatile matter	19.4
Fixed carbon	66.3
Ash	10.9
Sulfur	1.1
Air-drying loss	2.8
B. t. u.	13,140

Low-volatile coal from the Arkansas field, when blended with high-volatile coal produces a coke with improved physical properties, particularly increased strength. Since 1944, therefore, this coal has been shipped to California, Utah, and Colorado for use in blends with western high-volatile coals.

The total original reserves of bituminous coal in the Arkansas field are inferred to be 1,396,000,000 tons, of which 82,785,000 tons of coal was produced through 1949. Assuming a loss in mining of 50 percent of the coal in the ground, a total of 165,570,000 tons of coal was mined or lost in mining through 1949. The remaining inferred reserves as of January, 1950, therefore, totaled 1,230,430,000 tons. As most of the bituminous coal in the Arkansas field is suitable for coking or for use in blends, this figure closely represents the remaining inferred reserves of coking coal.

CONCLUSION

Although the 21 localities in the West described above collectively contain large reserves of coal that has coking properties, only a few contain adequate reserves of the better quality coals necessary for the production of metallurgical coke. The Sunnyside-Castlegate field, Utah; the Raton Mesa field, Colorado-New Mexico; the Crested Butte field, Colorado; and the southeast Oklahoma and Arkansas fields, contain most of the reserves of the better quality coals, and account for most of the western production of coking coal. Several other fields, notably the Wilkeson-Carbonado-Fairfax, and Roslyn fields, Washington; and the Kemmerer-Willow Creek field, Wyoming, contain adequate reserves of coal that by washing and blending can be made to yield coke approaching in quality that made from coal obtained in the main producing fields listed above. The remaining fields, for the most part, either yield coal that is only feebly coking or contain only small reserves.

The practice of washing and blending coal to improve the quality of the resulting coke is employed at most coke-producing centers in the West. Materials typically added to the western coals to improve the quality of the blends include low-volatile bituminous coal, petroleum coke, and a char made by the low-temperature distillation of local coal. Of them, the low-volatile bituminous coal is most desirable. Unfortunately, the West contains insignificant reserves of suitable low-volatile bituminous coal, and the most convenient assured supply is from the southeastern Oklahoma and Arkansas fields, where there are large reserves of coal of this rank. Coke produced from blends of western coals does not equal the best eastern cokes in quality, but with a growing market for industrial products in the West, blends utilizing the better quality western coal as base stock continue to offer the best opportunity for reducing transportation and other costs below those required for eastern coke.

The development of the large reserves of western coking coal for use in iron and steel manufacturing is largely dependent, therefore, upon technological advances in washing and blending procedures, and in the design and operation of blast furnaces to utilize the available product effectively.

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