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DOMESTIC RESOURCES OF URANIUM AND THORIUM

A summary based upon investigations

by the U. S. Geological Survey

By

V. E. McKelvey, L. R. Page, R. P. Fischer and A. P. Butler, Jr.

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CONTENTS

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CONTENTS (continued)

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CONTENTS (continued)

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ILLUSTRATIONS

TABLES

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DOMESTIC RESOURCES OF URANIUM AND THORIUM

A Summary Based Upon Investigations by the U. S. Geological Survey

By

V. E. McKelvey, L. R. Page, R. P. Fischer and A. P. Butler, Jr.

ABSTRACT

This report summarizes our knowledge of the geology of radioactive raw materials and outlines the work done by the Geological Survey as well as that planned or recommended. An evaluation of uranium and thorium deposits is given in terms of known reserves and potential resources.

Known reserves include the material in deposits that have been sampled, and for which reasonably reliable tonnage and grade estimates can be made. Potential resources express predictions of the total amount of material contained in the untested parts of geologic structures or formations that in places are known to contain radioactive material. These predictions are reasonable on the basis of geologic interpretations, even though the position of individual deposits is not yet defined.

The domestic known reserves of uranium in ore containing more than 0.1 percent U are estimated to be 2,800 tons (excluding deposits at Marysvale, Temple Mountain, and White Canyon, Utah; Grants, N. Mex.; Sunshine Mine, Idaho; and that discovered by the Commission on the Colorado Plateau). Of this, 2,600 tons are in

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deposits of the carnotite-type on the Colorado Plateau; the remainder are in veins and related deposits. The total potential resources of more than 0.1 percent grade are believed to be of the order of 150,000 tons of uranium. Most of these are in carnotite deposits but minor amounts are in veins and placers. Less than half of these potential resources, however, can be found and mined profitably under existing economic conditions, and it is unlikely that they can be discovered at a rate greater than 2,000 tons a year, even under the most favorable conditons.

Known reserves in deposits averaging 0.008 to 0.1 percent uranium are 1,500,000. Of this, 1,200,000 tons are in black shales that contain about 0.008 percent uranium and 290,000 tons are in phosphate deposits that average 0.012 percent uranium. The remainder of the known reserves are in lignites, veins and related deposits, sandstones and limestones, and placer deposits. The potential resources of this low-grade rock in all types of deposits total more than 2,300,000 tons.

The known reserves and potential resources of thorium -- exclusive of deposits studied by the Atomic Energy Commission and the Bureau of Mines -- in ores containing 0.1 percent ThO_2 are 11,000 and more than 5,000 tons of ThO_2 respectively. The known thorium reserves in ore 0.01 to 0.1 percent grade are estimated to be 880 tons of ThO_2. The potential reserves of this grade are considered to be very large. The outlook for finding additional sources of thorium are good.

INTRODUCTION

Domestic production of uranium has increased at a rate that could hardly have been hoped for even as late as 1947. This increased production is partly the result of price incentives provided in the Atomic Energy Commission's ore-buying program, but it also reflects important discoveries made during the intensive post-war search for uranium. We confidently expect that continued search will lead to discoveries that will permit some additional expansion in domestic production in the near future, but it is likely that we will have to import most of our uranium supply as long as we depend wholly upon production from ores containing more than 0.1 percent uranium. Reserves of ores containing 0.01 to 0.1 percent uranium are ample for sustained, large-scale production if emergency conditions or technological advances warrant their exploitation.

Thorium is not now used as a source of fissionable material and has received little attention in the search for radioactive ores, but the meagre evidence at hand suggests that domestic reserves might support a significant annual production of thorium.

The Geological Survey has been engaged in the search for uranium and thorium since 1939, first under its own auspices, later (1944) in cooperation with the Manhattan District and, since the spring of 1947, as a contractor for the Raw Materials Operations of the Atomic Energy Commission. The chief emphasis in these investigations, particularly since 1948, has been on the exploration and appraisal of areas such as the Colorado Plateau, or deposits such as the phosphates, that are likely to yield uranium in the near future, as well as on reconnaissance for new,

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high-grade deposits of uranium. Only a fraction of the work has consisted of long-range studies or of investigation of thorium deposits. The appraisal of our sources of fissionable raw materials is far from complete, but the data available do permit an analysis of the resource problem that should be helpful in planning the future course of action.

The purpose of this report, therefore, is to summarize the domestic resources of uranium and thorium -- their mode of occurrence, the work already undertaken on individual deposits, and the results obtained, particularly with reference to reserves; and to indicate which areas and investigations are likely to be most fruitful in the future. Reserves and resource estimates are stated for individual deposits or districts and are also summarized in a table. All reserves estimates are given in short tons.

GEOLOGY OF URANIUM AND THORIUM

Geochemistry

The uranium and thorium contents of the earth's crust have been estimated as about 0.0004 and 0.001 percent, respectively, by V. M. Goldschmidt (1937). Both metals are much less abundant than the heavy metals of industry, such as chromium, copper, zinc, and nickel, but they are several times more abundant than the precious metals.

Both uranium and thorium are lithophile elements, which, like the alkali metals, the alkaline earths, the rare earths, aluminum, vanadium, and phosphorus, show a strong affinity for oxygen (rather than sulfur) and are enriched in the most siliceous portions of the earth's crust. Uranium has three valences (3, 4, and 6) and may be either a cation or an anion. It is rather active chemically, and is found in combination with a score of other elements in compounds that, with few exceptions, are soluble in acid solutions. Thorium, which has only one valence (4), combines with a much fewer number of elements to form compounds that are mostly refractory.

Mineralogy

Uranium forms more than 100 minerals -- more than 200, in fact, if all minerals are counted in which uranium occurs frequently but as a non-essential, minor constituent of the lattice. The most important uranium minerals are oxides, such as uraninite or its colloform equivalent pitchblende; phosphates, such as autunite and torbernite; and vanadates, such as carnotite and tyuyamunite.

Other uraniferous minerals include carbonates, such as schroeckingerite; sulfates, such as zippeite; silicates, such as uranophane; and columbates, such as euxenite and samarskite. Some hydrocarbons, like thucolite and asphaltite, contain uranium in uncertain form -- possibly a metallorganic compound or a dispersed oxide. Uranium is also found in a variety of materials, such as phosphate, monazite, zircon, and carbonaceous matter, where it proxies for another element of similar ionic radius, such as calcium, or is attached (chemically adsorbed) by valence bonds to ions on the lattice surface. A few of the uranium-bearing minerals, such as samarskite and pyrochlore, are refractory, but most are slowly decomposed, particularly in humid or tropical climates, by natural waters.

Thorium forms relatively few minerals, most of which are oxides, such as thorianite and uranothorianite, and silicates, such as thorite. The most important source of thorium is monazite, a rare-earth phosphate, in which thorium proxies for rare earths in varying amounts. In contrast to the uranium minerals, nearly all of the common and important thorium minerals resist decomposition in natural waters.

Classification and mode of occurrence of uranium and thorium deposits

Few, if any, elements are concentrated under a wider, more varied set of conditions than is uranium, for its ores include those formed under nearly all types of igneous, sedimentary, and weathering processes.

Uraniferous concentrations by igneous processes include primary deposits in granites and pegmatites as well as those in hydrothermal vein deposits. The vein deposits are the principal source of ore containing more than 0.5 percent uranium. No uranium is currently produced from the uraniferous granitic rocks, which contain as much as 0.02 percent uranium, and only insignificant quantities have been recovered from pegmatites, which are of similar grade.

The sedimentary uranium deposits include the uraniferous black shales, phosphates, and placers. Both the uraniferous shales and phosphates contain about 0.007 to 0.02 percent uranium. No uranium is being produced from them now, but because of the large tonnages of uranium they contain, they form our principal future reserve. Few placers contain uraniferous minerals other than monazite, of which uranium makes up 0.01 to 0.5 percent, and none yield any production of uranium now. The uraninite-bearing gold ores of the Rand are a notable exception if, as some believe, they are of placer origin.

Because most uranium minerals are relatively soluble, primary concentrations in igneous or sedimentary rocks or veins are easily oxidized and leached. The uranium may be redeposited, from either surface or ground-water solutions, in stockworks or veins near the lodes from which it was derived, as in the Portugese deposits, or in porous sandstones, as in the Colorado Plateau carnotite ores, or in chemical adsorbents such as bone, iron oxide, monazite, lignite, or asphaltite. The oxidized vein deposits, the sandstone ores, and asphaltites generally contain 0.05 to 0.5 percent uranium. The more uraniferous lignites contain from 0.01 to 0.04 percent uranium (0.01 to 0.3 percent in the ash).

Natural waters, particularly certain springs and the ocean, contain uranium derived during weathering in amounts that range, in the few samples tested, from 0.0001 to 0.01 parts per million.

Concentrations of thorium are also found in igneous rocks, pegmatites, and veins, but the most important deposits are the monazite placers. Thorium is not concentrated by secondary chemical processes and no important concentrations have yet been found in sedimentary rocks (other than placers) or natural waters.

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METHODS USED IN THE SEARCH FOR URANIUM AND THORIUM

The urgent nature of the search for sources of fissionable materials has demanded application of a variety of methods, some of which are uniquely suited to the search for radioactive ores. These methods will be summarized briefly, not only to show what has been and can be done, but also to point up those approaches that should be pursued or developed further.

Geologic prospecting

Geologic methods of prospecting include both simple observational ("gold is where you find it") and more complex analytical ("gold is where it ought to be") approaches. Both command respect; the first because nearly all productive occurrences of minerals of all types have been found by that approach in the past, and the second because it is the best approach to the discovery of concealed and low-grade deposits and is, therefore, the method of the future.

One of the simplest and at the same time effective approaches taken by the Survey is the examination and testing of samples solicited from mining companies, housed in museums, and submitted by the public. Perhaps 15,000 such samples have been tested thus far. About 90 percent of those tested are essentially non-uraniferous, but it is safe to say that most of the occurrences of uranium now known in this country (exclusive of the Colorado Plateau carnotites and the sedimentary deposits) have come to our attention in this manner.

Another simple approach has been a rather exhaustive study of the literature made by Union Mines and the Survey in the search for occurrences of uranium that were not of commercial interest at the time they were reported. Fruitful leads to some of the uraniferous black shales and other deposits were obtained in this way and the recovery of uraninite from the gold ores of the Rand is a direct result of a study of the literature by Union Mines.

Analytical geologic methods involve inductive and deductive reasoning or, more commonly, a combination of both. Inductive prospecting consists simply of examining those rocks, structures, or geologic associations that are similar to others known to contain uranium. For example, once it has been established that uranium occurs in certain types of black shales, phosphates, and lignites or is associated with certain base metals, fluorite, and other minerals in veins, it is possible to select and examine other deposits of the same type. This approach has led to the discovery of uranium in the Florida phosphate, the Dakota lignite, and several of the uraniferous fluorites.

Deductive prospecting is based upon the analysis of miscellaneous geologic evidence or clues that suggest the presence of uranium. It is most effective when all the factors controlling the origin, including source and manner of deposition, of the deposit are known, but it can be used if only the habits of the ore are understood and some guides to its presence are recognized. For example, it has been found that most of the large deposits of carnotite in the Colorado Plateau are confined to a geographic belt (TEIR 109) _/ and that within this belt car-

_/ TEIR and TEMR numbers refer to U. S. Geological Survey Trace Elements Investigations and Trace Elements Memorandum Reports prepared for the Manhattan Engineer District and the Atomic Energy Commission. The reports cited are listed at the back of this report, together with other references.

notite bodies are found in places where the ore-bearing sandstone is thicker than average, where its color has been altered from reddish brown to a spotted yellowish brown, where the color of associated mudstones has been altered to greenish-gray, and where radioactive carbonaceous matter is abundant (TEIR 119). The origin of these ore guides and their relation to carnotite deposition is not yet fully understood, but their mere recognition has revolutionized exploration on the Plateau. Geologic guides or controls have been recognized for several other types of deposits, including some of the vein deposits and the lignites, and we may expect that this approach will become more powerful in the future as geologic data are gathered, synthesized, and analyzed.

Geophysical methods

Several tools and techniques that take advantage of the radioactivity of uranium and thorium have been developed to aid in the search for their ores. These include several types of radiometric reconnaissance, gamma-ray well logging, and radon measurement and detection. One other geophysical technique, electrical resistivity surveying, is being tried in exploration for carnotite deposits of the Colorado Plateau.

Although most of the area prospected by the Geological Survey have been selected on the basis of reported occurrences of uranium or geologic criteria which indicate that the area is favorable for the occurrence of uranium, we have leaned heavily on Geiger counters for the actual detection of radioactive ores in the field. Most extensive use has been made of portable counters, but batteries of Geiger tubes and crystal detectors have also been mounted on cars (TEIR 65) and in the Survey's twin-engined plane (TEIR 83) for use in traversing promising areas. These techniques each have their appropriate place in prospecting and all have been used with some success. The airborne equipment, developed since 1949 in cooperation with the Oak Ridge National Laboratory, has until recently been in an experimental stage but promises to be an especially valuable tool in the search for favorable areas and new deposits, for it is capable of detecting anomalies representative of only 0.01 percent equivalent uranium at a distance of 1,200 feet; complete coverage of an area may be obtained, therefore, by flying lines spaced at $\frac{1}{4}$-mile intervals at a cost of roughly $15.00 per square mile. This technique is not suitable for surveying areas with more than 700 feet of relief.

The gamma-ray logging technique, developed some years ago by the oil companies for purposes of stratigraphic correlation, has been adapted by the Survey to the determination of the radioactivity of ores cut by drill holes on the Colorado Plateau and the Florida phosphate. The equipment, formerly called "Barnaby", developed by Union Mines and the Survey for this purpose has proved very satisfactory and its use on the Plateau has yielded an unexpected but important dividend in that it detects, in otherwise barren holes, small radioactive anomalies down dip from ore bodies which provide a clue to the presence of ore. Incidentally, the examination of several thousand gamma-ray logs of oil wells made by or for oil companies has led to the discovery of uraniferous black shales in Kansas and Wyoming.

None of the radiometric reconnaissance techniques, of course, can be used to detect radioactive deposits concealed by more than a foot or so of barren rock or soil unless the deposits are discharging radon. Where radon is being discharged, however, particularly in mines when the barometer is falling and the rocks are "exhaling", an ordinary counter will detect radon and hence the presence of a concealed radioactive source. The Survey has recently developed portable equipment for the quantitative measurement of radon particularly for use in the study of the source of radon found in the Amarillo helium field in 1949 (TEMR 239).

Experimental studies of the electrical resistivity of the ore-bearing sandstone of the Colorado Plateau suggest that areas of thick sandstone (which favor the presence of ore) have greater resistivity than areas where the sandstone is thin. If this is confirmed by studies now in progress, electrical resistivity surveying may considerably reduce the cost of exploring deep ground.

Geochemical and geobotanical prospecting

Geochemical and geobotanical prospecting are both in their infancy in the science of ore finding in general, but because of the relative solubility of many uranium minerals or of minerals of other elements, like nickel or selenium, which are associated with some types of uranium deposits, both show promise as tools in the search for uranium. Geobotanical prospecting, consisting of the uranium analysis of leaves of certain plants, and the areal mapping of selenium-indicator plants, has already won its spurs as an ore-finding tool in parts of the Colorado Plateau (TEMR 199) and also may prove applicable in other areas. Geochemical prospecting, consisting of search for dispersion halos of uraniferous minerals or salts in soil or run-off waters that may indicate the presence of an ore body, is now in a research stage.

Physical exploration

If the results of geologic studies indicate that a given area may contain ore, it is necessary to pursue the search underground, by one or another type of drilling, trenching, or underground development. The purpose of such exploration may be to find or expose ore, to test continuity at depth, to find favorable ground, or merely to obtain geologic information that may further guide the search. About two thirds of the Survey's effort since 1948 has been directly or indirectly connected with physical exploration, mostly in the Colorado Plateau but also to a limited extent in other areas. Physical exploration may be expected to become an even larger part of the Survey's work in the future, as other types of prospecting result in the definition of favorable areas.

Summary

All of the methods described have continued application to the search for ore, but none should be used independently of the others. Those which should be pressed particularly in the future are aerial radiometric, geochemical, geobotanical and particularly deductive geologic prospecting. The latter requires increased emphasis on compilation, synthesis, and analysis of geologic data and on fundamental research.

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DOMESTIC URANIUM DEPOSITS

Domestic uranium deposits include representatives of all known geologic types. They are summarized in the following pages under the headings of veins and related deposits, pegmatites, igneous rocks, uraniferous sandstone and limestone, uraniferous black shale, uraniferous phosphate, uraniferous coal and lignite, placers, and radioactive natural waters. Estimates of known reserves and potential resources are stated for individual or groups of deposits or districts and are summarized in a later section of the report as well.

Known reserves include reserves in the measured, indicated, or inferred classes. Their grade has been determined from sampling of natural outcrops, mines, or drill holes and the tonnage calculated by reasonable projection beyond such samples. Potential resources include uraniferous deposits believed to be present in geologic structures or formations known to be uraniferous. Their estimation is based upon knowledge of the geology and habits of the ore that justifies the prediction that undiscovered deposits are beyond points of exposure or sampling. By no means all or even a major portion of the potential resources can be found and mined profitably under present economic conditions.

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Vein Deposits

Domestic occurrences of vein deposits include pitchblende-bearing veins, uraniferous fluorite deposits, and secondary, oxidized vein deposits. Their distribution is shown on figure 1.

Pitchblende-bearing veins

General statement.--The domestic production of uranium from pitchblende-bearing veins in the United States has amounted to only about 50 tons of uranium (TEMR 215), only about 10 percent of which has been produced since 1919. Most of the world production of uranium, however, has been derived from high-grade pitchblende-bearing veins in Europe, Africa, and Canada.

Although some foreign deposits contain several percent uranium, the domestic pitchblende-bearing veins rarely contain as much as 0.5 percent. The pitchblende occurs as grains, nodules, or masses disseminated in or scattered along veins that may contain various combinations of quartz and other silicate minerals, carbonates, fluorite, and hydrocarbons as gangue, together with copper, zinc, lead, silver, gold, cobalt, and nickel minerals. The observed associations of pitchblende with the metal assemblages copper, lead, and silver or cobalt and nickel; with hematitic or beidellitic alteration; with smoky quartz; and with dark-purple fluorite, are valuable guides to new deposits.

Pitchblende, for the most part, is a primary hydrothermal mineral in both veins and pyrometasomatic deposits; minor amounts in some veins are of secondary origin (King, R. U., et al, 1951). Commonly pitchblende in the upper parts of the deposits has been altered to the secondary uranium oxides, silicates, phosphates, vanadates, arsenates, carbonates, or sulfates (Stugard, F., et al, 1951). It is probable that the outcrops of some veins have been entirely leached of uranium by ground water.

The total known reserves of pitchblende-bearing ore in the United States (exclusive of that at Marysvale, Utah and the Sunshine mine, Idaho) are about 240 tons of uranium in rock containing more than 0.1 percent uranium and 260 tons of uranium in rock containing 0.01 to 0.1 percent. The potential resources in these two grade classes in known deposits are believed to be in the order of 1,400 and 700 tons respectively. Very likely only about one tenth of the known inferred reserves of 0.1 percent grade can be mined under present economic conditions because of the small size of the ore bodies and the high cost of underground mining.

Colorado Front Range area.--Most of the recorded domestic production (1872-1919) of pitchblende-bearing ore has been from the Central City district, Gilpin County, in the Colorado Front Range area; about 3 percent was from the Lawson district, Clear Creek County, and the Caribou-Grand Island district, Boulder County, Colo. (TEMR 215). Minor, but unrecorded, production probably came from small mines in the adjacent area; a few deposits are known as far north as Larimer County and as far south as Gunnison County, Colo.

Four mines are being actively prospected in these areas now. They are the Hudson-Bellview mine (studied by the Atomic Energy Commission) and the Martha E. mine in the Lawson district, the Copper King shaft in Larimer County, and the Caribou mine in the Caribou-Grand Island district. Work in the Caribou mine is being carried out by the owners under a contract with the Atomic Energy Commission.

The pitchblende-bearing veins of the Colorado Front Range have been studied by the Geological Survey under the auspices of the Atomic Energy Commission (TEMR 5, 13, 215). All pitchblende veins exposed in mine workings, accessible since 1947, have been mapped and sampled; the dumps of inaccessible mines and other favorable places have been checked both radiometrically and chemically; available information from previous written reports has been compiled; and recommendations have been made for preliminary exploration by the Government. The genetic relationships between pitchblende-bearing veins and the associated bostonite porphyry dikes have been studied in detail in an attempt to determine the factors involved in localization of ore shoots. Plans have been made for continued detailed geologic study by the Survey, including large-scale mapping in the three main districts.

Some of the pitchblende-bearing veins in the Colorado Front Range area are as much as half a mile long and 5 feet thick; some have been mined to depths of over 2,000 feet. Mining in the past has been primarily for gold and silver, but some lead and zinc have been produced. The pitchblende is commonly in small, but very high-grade (as much as 70 percent uranium) nodules, pods, or shoots separated by larger masses of essentially barren vein material. The average uranium content of the veins, including the rich nodules, pods, and shoots, is rarely as much as 0.25 percent uranium.

In these districts most of the known and reported occurrences of pitchblende are in mines that are either caved or flooded. The available information indicates that the known reserves in the Front Range area are about 35 tons of uranium in ore containing 0.1 to 3 percent uranium. The potential resources of similar ore in the area, however, are believed to contain about 1,200 tons of uranium. Known reserves of material, mostly in old dumps, of 0.01 to 0.1 percent uranium are believed to be about 50 tons of uranium and the potential resources of this grade are probably about 200 tons of uranium.

The known reserves and potential resources of the Colorado Front Range are thus not large, but the numerous occurrences of pitchblende in the area together with the geologic setting make it one of the most favorable areas in the country for new discoveries of pitchblende-bearing veins.

Boulder batholith area.--Pitchblende-bearing quartz-sulfide veins were discovered in 1949 in the Boulder batholith area, Jefferson County, Mont. by a local prospector. Since then the production (Free Enterprise mine) has been about 100 tons of ore containing 0.25 percent uranium. Exploration by the Newmont Mining Company is currently in progress on the President group of claims near Clancey. Geological Survey field studies, consisting of radiometric reconnaissance and areal geologic mapping, have been underway since 1949 (TEMR 31,229). The Atomic Energy Commission also has studied the deposits and made a detailed study of the underground workings at the Free Enterprise mine.

The pitchblende-bearing veins of this area are as much as 10,000 feet long and 10 feet or more thick, but their depth extensions are unknown (TEMR 229). Pitchblende and secondary uranium minerals occur in thin, rich lenses, 2 to 18 feet long, widely disseminated in quartz gangue. These veins average about 0.15 percent uranium but small parts of the vein may contain as much as 1.0 percent.

The known reserves in the area are about 15 tons of uranium in deposits containing about 0.15 percent uranium. The potential resources in known deposits are believed to be about 120 tons of the same grade. The chances of discovering new veins are good.

Arizona.--Pitchblende-bearing metallic veins have been discovered during the past two years in Pima and Santa Cruz Counties, Ariz. Geologic mapping and sampling of all known deposits, carried out by the Geological Survey, indicate that few if any of these veins contain minable deposits or ore containing as much as 0.1 percent uranium. These properties, however, do have known reserves of about 210 tons of uranium and additional potential resources of about 300 tons that contain 0.01 to 0.1 percent uranium. The possibilities of finding higher-grade ore at depth in these deposits or new deposits in adjacent areas should not be discounted, but they are not promising.

Miscellaneous.--Pitchblende-bearing veins and pyrometasomatic deposits also are known in New Jersey, Michigan, Colorado, Idaho, New Mexico, Nevada, Washington, and California. The pyrometasomatic deposits in the Franklin limestone, Warren County, N. J., studied only in a quick reconnaissance in 1950, appear promising and will be investigated in detail by the Survey in 1951. Potential resources appear to be about 300 tons of uranium in deposits containing 0.2 percent uranium, as judged on the basis of the few samples available. Additional potential resources of about 150 tons of uranium are estimated in deposits containing 0.01 to 0.1 percent uranium.

None of the other deposits contain as much as 10 tons of known reserves, but those in Pershing County, Nev., and in San Miguel, Gunnison, and Custer Counties, Colo., deserve further study, which will be undertaken by the Survey in fiscal year 1952.

One of the most promising vein deposits of pitchblende is that at Marysvale, Utah which is being studied by the Atomic Energy Commission and is therefore, not discussed here.

Fluorite Deposits

General Statement.--Uraniferous fluorite ore has not been mined in the United States for uranium, but small quanitites of uranium have been extracted from ores of this type in Europe (Kohl, 1934, 1942). The domestic deposits are in veins, breccia zones, and replacement bodies in igneous rocks and limestones. Fluorite is the main constituent of the deposits and is associated with quartz and sulfide minerals. The uranium is present in minute grains of uraninite in the fluorite at the Jamestown district, Colo., (Goddard, 1946, TEMR 27, TEMR 173); as autunite and torbernite in the Staats deposit, Beaver County, Utah (TEIR 50); and in an unidentified form -- possibly an isomorphous substitution for calcium in the crystal lattice -- in the Thomas Range fluorite district, Juab County, Utah (TEIR 136).

Very minor quantities of secondary carnotite and torbernite are found in the Thomas Range and Jamestown deposits, respectively. The uraniferous fluorite deposits are tabular, irregular, or pipe-like and some contain as much as several hundred thousand tons.

The total calculated known reserves in uraniferous fluorite deposits of over 0.1 percent grade are 45 tons of uranium; those of 0.01 to 0.1 percent grade are 250 tons. The potential resources in ore of these categories are about 200 tons and 900 tons resepctively. Because not all fluorite districts of the United States have been studied in detail it seems likely that new uraniferous deposits may be found by continued search.

Thomas Range Fluorite district.--The uraniferous fluorite of the Thomas Range fluorite district, discovered by a prospector in 1949 is for the most part a white clayey to chalky, friable material that occurs as replacement bodies in rhyolite porphyry plugs or in dolomite. A few deposits are controlled by faults and all deposits in dolomite are believed to terminate at depth at the underlying quartzite. The fluorite, as mined, is shipped without beneficiation as metallurgical-grade fluorspar.

During 1950 the Geological Survey studied 19 separate deposits in this area and prepared detailed maps of the larger deposits (TEIR 136). On the basis of these studies exploration of the most promising deposits has been recommended and a more complete geologic study of the district is planned for 1951 in order to evaluate more adequately this area as a source of concealed uraniferous deposits.

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Two properties, the Bell Hill and Harrisite, contain ore averaging 0.25 and 0.14 percent uranium respectively; their known reserves total about 45 tons of uranium; the Eagle Rock property has ore of the same grade, but is very small. The potential resources of this grade at these properties is about 200 tons of uranium. The other 16 fluorite deposits contain 0.01 to 0.089 percent uranium. The known reserves of this grade are 250 tons of uranium; the potential resources of this grade in these deposits are about 900 tons. The potential resources of the district are probably much greater than the figures indicate because relatively little attempt has been made to find concealed deposits in this new mining district. It appears possible that the uranium might be recoverable under proper metallurgical treatment because fluorite is expected to be the sustaining product.

Jamestown district.--The fluorite in the Jamestown district is in veins and breccia zones that cut a monzonite stock. The deposits are as much as 350 feet long, 50 feet wide, and at least 600 feet deep (Wilmarth, V. R., et al, 1951). The most radioactive fluorite is deep purple and contains minute grains of uraninite. Uraninite also is associated with sulfide minerals between the fluorite grains.

In the Nations Treasure mine torbernite occurs on rocks and fractures that cut the fluorite ore. Much of the fluorite in this district must be milled and during this process, concentrates have been made that contain as much as 1.2 percent uranium.

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Investigations by the Survey for fluorite during World War II (Goddard,1946) were used as a basis for later studies made on behalf of the Atomic Energy Commission in 1944 (TEIR 4), 1949 (King, R. U., et al 1951), and 1950 (Wilmarth, V. R. et al).

The known reserves in six properties in this district contain 0.01 to 0.073 percent uranium and total 145 tons of uranium. The potential resources of this grade ore are 200 tons. Possibilities of finding higher-grade ore are not favorable.

Staats property.--The fluorite deposits at the Staats property, Beaver County, Utah are in a shear zone at the edge of a monzonite stock. This zone is 1,000 feet long and 10 feet wide and extends to a depth of at least 200 feet. The uraniferous fluorite ore occurs in pods and streaks irregularly scattered through this zone. Torbernite occurs in the fractured monzonite throughout the zone.

This deposit was mapped and sampled by the Geological Survey in 1945 (TEIR 24) and 1946 (TEIR 50). The known reserves were estimated to be 500 tons of rock containing 0.4 percent uranium; and 153,000 tons of rock containing 0.03 percent. The potential resources of uranium in the high-grade rock are believed to be about 25 tons and in the low-grade rock 120 tons.

Miscellaneous deposits.--No other fluorite deposits are known to be uraniferous but several important ones, such as those at Beatty, Nev., and the Poison Oak mine, Mont., remain to be tested.

Vein deposits of secondary uranium minerals

General statement.--The upper parts of many uranium-bearing veins are characterized by the yellow, secondary uranium silicate, phosphate, vanadate, arsenate, carbonate, and sulfate minerals. Of these the silicate, uranophane, and the phosphates, autunite and torbernite, are the most abundant. In a few deposits the uranium is in an unidentified form in iron oxides or as a "sooty" variety of pitchblende. Because these deposits represent the weathered parts of primary veins, such as the pitchblende deposits, they are found in structures of similar size and continuity. The secondary minerals, however, by virtue of their origin, may be widely disseminated outward from the primary structure and give the appearance of a blanket deposit. The grade of such secondary deposits may be either higher or lower than that of the primary deposit, depending on the chemical conditions existing at the time of their formation. Because of the possibility that low-grade deposits of this type may lead downward to secondary or primary deposits of higher grade, the presence of secondary minerals in persistent geologic structures should be considered as indicating favorable places for exploration.

A few secondary vein deposits, such as those in Portugal and at Marysvale, Utah, have furnished ore of minable grade in the recent past. One recently prospected carnotite-bearing deposit, the Leyden prospect, Jefferson County, Colo., will probably be mined in the near future; the Yellow Canary carnotite deposits in Daggett County, Utah, and the Green Monster kasolite (a uranium silicate) mine in Clark County, Nev., are being actively prospected.

The total known domestic reserves in secondary vein deposits are about 55 tons of uranium in more than 0.1 percent rock and 205 tons in 0.01 to 0.1 percent rock; the potential resources of these grades are in the order of 250 tons and 600 tons of uranium, respectively.

White Signal District.--Autunite and torbernite occur in small amounts at numerous places in the White Signal district, Grant County, N. M. The largest deposit in the district, known to contain ore of 0.1 grade, is at the Merry Widow mine where 520 tons of rock are estimated to average 0.37 percent uranium. In general the vein structures of the district are narrow, but some may be several thousand feet long.

The Geological Survey made a brief reconnaissance examination of the district in 1944 (TEIR 4) and in 1949 and 1950 (TEMR 116, 117, 121, 146) studied the more promising prospects in detail. The results of these studies, plus the wide distribution of small amounts of secondary uranium minerals, indicated a need for more general geologic study of the district to obtain more thorough understanding of the area before recommendations could be made for finding concealed and higher-grade deposits. Plans have been made for areal mapping of this district in 1951, together with similar studies in the adjacent Black Hawk district, from which pitchblende has been reported.

The inferred reserves of the White Signal district are estimated to be 2 tons of uranium in rock containing more than 0.1 percent uranium and about 15 tons of uranium in rock containing 0.01 to 0.1 percent; the potential resources of these grades are 20 tons and 100 tons of uranium respectively. The geology of the district suggests that new and higher-grade deposits might be found by continued search.

Silver Cliff deposit.--The Silver Cliff uranophane deposit, Niobrara County, Wyo., is on a fault zone that cuts Cambrian quartzite. Several carloads of ore containing 3.0 percent U_3O_8 was mined from this deposit in 1919. The fault is several miles long, and favorable, but concealed, ground is believed to exist and to deserve exploration. Detailed study of this deposit is in progress and exploration of this property probably will be recommended in the near future (TEMR, in preparation).

The known reserves are estimated to be about 20 tons of uranium in ore averaging 0.08 percent, but ore of 0.1 percent or higher uranium content could be recovered by sorting. The potential resources in the deposit are probably about 50 to 100 tons of uranium.

Majuba Hill.--The copper-tin deposits at Majuba Hill, Pershing County, Nev., contain autunite, torbernite, and zeunerite (a uranium arsenate) associated with secondary copper minerals and cassiterite. These deposits were mapped and studied by the Geological Survey in 1949 and 1950 (TEIR, in preparation). The known reserves are estimated to be about 4 tons of uranium in rock containing 0.15

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percent uranium and half a ton of uranium in rock containing 0.015 percent. The potential resources of each grade are believed to be in the order of 25 tons of uranium.

Other deposits.--Six properties in Utah, New Jersey, Colorado, Nevada and Arizona, listed below, contain more than 10 tons of uranium, either in known reserves or potential resources. These properties have a combined known reserve of 50 tons of uranium in ore of more than 0.1 percent grade and 170 tons in ore of 0.01 to 0.1 percent grade; the potential resources of these categories are about 200 and 350 tons respectively.

The Yellow Canary prospect, Daggett County, Utah, is a carnotite deposit in a shear zone that cuts quartzite. It has a known reserve of 1.5 tons of uranium in rock containing more than 0.1 percent; potential resources are considered to be about 100 tons of uranium. The uraniferous metallic veins of the Sheeprock Mountain district, Tooele County, Utah, contain a potential resource of about 25 tons of uranium in rock of 0.015 percent grade.

The Marble Mountain deposits, Warren County, N. J., are among the few secondary vein deposits in eastern United States. The deposits are in closely spaced fractures in gneiss. The known reserves are 120 tons of uranium in rock of 0.06 percent grade.

The Leyden carnotite deposit, Jefferson County, Colo., is on a fault that cuts Cretaceous coal. The known reserves are about 50 tons of uranium in ore of more than 0.1 percent grade; the potential resources may be as much as 100 tons of uranium.

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Two uraniferous opal deposits are known to contain low-grade ores. The opalized limestone on the Katherine and Michael claim, Mohave County, Ariz. are believed to have a potential resource of over 100 tons of uranium. Opalized tuff of the Virgin Valley district, Humboldt County, Nev., contains known reserves of about 45 tons of uranium in rock of 0.02 percent grade; the potential resources are probably over 100 tons.

Outlook

Because no large, high-grade vein deposits have been found during the course of the extensive prospecting and mining activity in this country, one might doubt that any such deposits are present. Several facts, however, support the belief that the search for vein deposits may become increasingly fruitful in the future. As mentioned previously, uranium is a lithophile element and its primary deposits are most abundant in areas characterized by rocks and mineral deposits formed by silicic igneous activities. The United States contains many such areas and deposits and may, therefore, be regarded as broadly favorable for the occurrence of uranium in primary deposits. The many scattered occurrences of pitchblende and other types of vein deposits are encouraging indications, as is the fact that many of these deposits have been discovered only recently. We may discount the likelihood that all high-grade vein deposits of uranium would have been found in the course of previous prospecting or mining because even though uranium is associated with deposits of other metals, it generally occurs in different parts of the veins and might have been overlooked. Because of the solubility of pitchblende in natural waters, we may expect that uranium at or near the surface has been largely leached away at many localities, leaving insufficient clues to the presence of deeper deposits to draw the attention of one not looking for uranium.

Thus there is justification for the belief that additional vein deposits may be found on further search, but success will not come easily or cheaply. For one thing, we must learn more than we know now about the geology and habits of these deposits, and for another we must expect to do an increasing amount of costly physical exploration, for most of the deposits are likely to be concealed.

It is believed that the most favorable districts for finding ore of minable grade and for increasing our reserves are in areas such as the Front Range and Central Mineral Belt of Colorado; the Thomas Range district of Utah; the Clark County area, Nev.; the Mojave Desert area, Calif.; the White Signal district, N. Mex.; the Boulder batholith area, Mont.; and the Franklin limestone area, N. J. Geologic mapping, radiometric reconnaissance, sampling, and mineralogic study of the most important vein deposits in these areas are planned by the Survey for fiscal year 1952 with the objectives of finding new deposits, or predicting the position of concealed high-grade parts of known deposits, that might be further tested by exploration. During this work basic data will be accumulated that will aid in evaluating other areas that might be potential sources of uranium and favorable for prospecting.

In southeastern Kansas (TEIR 121, in preparation) and the Panhandle area of Texas, the known quantity of radon and helium in natural gas is greater than can be assumed by normal geologic conditions. Mathematical analysis (TEMR 239) indicates that the larger concentrations of radon in the Panhandle area could not be derived from rocks of normal radioactivity, but may be derived from local concentrations of uranium such as might be found in vein deposits. Geologic, geophysical, and radiometric studies of the radon-bearing gas in the Texas fields are being continued by the Survey in an attempt to evaluate this potentially significant geologic relationship in terms of uranium deposits.

In Alaska five areas (fig. 5) --the Seward Peninsular, southeastern Alaska, the lower Yukon-Kuskokwin region, the Alaska Railroad region, and the Gulf of Alaska region appear to contain vein deposits favorable for the occurrence of uranium. These will be studied in a reconnaissance fashion in fiscal year 1952.

Pegmatites

Many of the pegmatite deposits of the United States contain uranium minerals, but none of these deposits contain rock of sufficient uranium content to be considered as a source of this metal. Pegmatite deposits in Madagascar have yielded about 100 tons of complex uranium ore, but careful investigation of all domestic pegmatite districts by the Geological Survey (from 1939 to date), as part of the Survey's beryl, mica, lithium, columbium, and tantalum studies, indicate that deposits similar to those in Madagascar are not likely to be found in the United States.

Igneous Rocks

Igneous rocks show considerable differences in radioactivity; the felsic rocks are generally more radioactive, averaging about 3×10^{-6} grams of uranium per gram of rock, the mafic rocks less radioactive, averaging about 0.96×10^{-6} grams of uranium per gram of rock (Evans and Goodman, 1941). Studies in the Geological Survey's laboratory indicate that the radioactivity generally is associated with the accessory minerals.

The Geological Survey has tested samples from 30 to 40 bodies of massive igneous rocks in the United States, including the porphyry copper deposits at Bingham, Utah, and Santa Rita, N. Mex., and from about 20 localities in Alaska. In addition the radioactivity of numerous outcrops of igneous rocks in New England has been measured by car-mounted equipment. This work has not revealed any rock containing 0.01 percent uranium from which appreciable tonnages of uranium could be derived. No rock has been found comparable to that in Nigeria where 0.017 percent uranium in riebeckite granite is largely concentrated in the mineral pyrochlore which makes up about 1 percent of the rock, (Mackay and Bennett, 1949) and can be concentrated by gravity methods. The Geological Survey work has suggested, however, that late-stage differentiation phases of igneous rocks are much more radioactive than the average granitic rocks, and are worthy of continued study. Some rocks of the White Mountain magma series in New Hampshire are petrologically similar to the riebeckite granites of Nigeria. The radioactivity of the riebeckite granite in New Hampshire (Billings and Keevil, 1946) is much less than that of the more radioactive parts of the Nigerian rocks. Nevertheless the petrologic affinities suggest the New Hampshire rock is worthy of closer scrutiny as a possible large low-grade source of uranium. Other possibilities deserving similar scrutiny are syenitic rocks of the Bear Paw Mountains and Crazy Mountains in Montana, intrusive rocks of the Spanish Peaks, Colo., molybdenum-bearing granitic rocks in Maine and North Carolina, and granitic or syenitic rocks in which columbium is reported. It is possible that further investigation of rocks of such types might find some masses where the uranium, although constituting as little as 0.01 percent of the rock occurs in a mineral form that might readily be concentrated by simple methods. The search for these deposits will be continued in the future by airborne radiometric reconnaissance.

Uranium-bearing sandstone and limestone

General statement

Secondary concentrations of uranium, vanadium, copper, silver, and other metals in sedimentary rocks are known in many areas. Carnotite, a potassium uranium vanadate, is the principal uranium-bearing mineral, but copper-uranium minerals, uraniferous asphaltite, uranium oxide (possibly pitchblende), and complex secondary minerals are locally dominant. The deposits range in average grade from 0.05

to 0.5 percent U_3O_8. The deposits are mainly in non-marine sandstones, though in places they are in limestone or mudstone. Characteristically these beds are lenticular and the deposits within them are relatively small and have a spotty distribution. Most of the deposits probably formed from ground-water solutions, and likely their localization was controlled by sedimentary features in the host rock.

The only known productive deposits of this type in foreign countries are in Turkestan. Little information is available regarding their production and reserves, but they are believed to be relatively small and unimportant.

Carnotite and related deposits are widely distributed in parts of Colorado, Utah, Arizona, and New Mexico (Colorado Plateau), an area of about 100,000 square miles. They have been mined since 1910 and have been the principal domestic source of uranium and vanadium. They contain the largest known reserves of commercial ore. Similar but as yet unproductive deposits are found outside the Plateau in Wyoming, Idaho, Nevada, Arizona, Texas, Oklahoma, Pennsylvania, and New Jersey.

Known minable reserves of uranium in sandstone and limestone deposits studied by the Geological Survey total only about 2,600 tons but potential resources are much larger.

Colorado Plateau

The largest and most productive deposits of the carnotite type on the Colorado Plateau are in the Morrison formation and Entrada sandstone of Jurassic age. In the same general area, similar deposits also are present in sandstone beds of Triassic age, in the Todilto limestone of Jurassic age, and in the Dakota sandstone of Cretaceous age. The most promising of these deposits are being intensively developed.

A comprehensive study of the carnotite deposits of the Colorado Plateau was carried on by the Geological Survey from 1939 through 1945 (Fischer, 1942). This work formed the background for the coordinated program of exploration and geologic studies that the Survey has been conducting for the Atomic Energy Commission since 1947 (Fischer, 1949, and TEIR 80 and 109). Most of the work since 1947 has been concentrated on the Morrison deposits, but future plans include work on the deposits in Triassic rocks. Since 1949 Raw Materials Operations of the Atomic Energy Commission also has been conducting a similar program of exploration and geologic studies in the Morrison and Triassic deposits.

Morrison formation.--The carnotite deposits in the Morrison formation consist of sandstone impregnated with uranium and vanadium minerals. Carnotite ($K_2O \cdot 2UO_3 \cdot 2H_2O$) is the principal uranium mineral whereas most of the vanadium occurs as a micaceous vanadium-bearing silicate.

The ore bodies are irregularly tabular layers, at most only a few feet thick. These layers lie nearly parallel to the sandstone beds but do not follow the beds in detail. They range in size from those only a few feet across, which contain only a few tons of ore, to those several hundred feet across that contain many thousand tons. Locally the deposits are restricted to a single stratigraphic zone or bed. Although the deposits appear to have a spotty distribution along this zone, actually they tend to be clustered in favorable areas that are 1,000 to several thousand feet across. These favorable areas are separated by several thousand feet of less favorable ground that contains few if any deposits. The favorable areas can be recognized by geologic relations that can be observed at the outcrop and in widely spaced drill holes, and these relations have been valuable in guiding the exploration work done by the Geological Survey (TEMR 170).

The carnotite deposits of the Morrison formation have yielded nearly a million tons of ore averaging about 0.25 percent U_3O_8 and 2 percent V_2O_5. They are being actively mined, and in 1951 they will yield 250,000 to 300,000 tons of ore. Known reserves of indicated and inferred ore, exclusive of those found by AEC exploration, total about 1,200,000 tons, containing about 0.25 percent U_3O_8 (2,500 tons of uranium). Most of these reserves have been found within the past 3 years, as a result of intensive exploration conducted by private enterprise and the Geological Survey. From November 10, 1947, to April 1, 1951, the Geological Survey drilled 4,728 holes, totaling

597,152 feet of drilling. Of the total reserves mentioned above, this drilling alone found 670,000 tons of ore averaging about 0.30 percent U_3O_8 (totaling 1,700 tons of contained uranium) and 1.8 percent V_2O_5. These reserves are all in layers 1 foot or more thick and have a grade cut-off of 0.10 percent U_3O_8 or 1.0 percent V_2O_5.

Continued exploration will yield additional reserves. The rate of future discovery is difficult to predict, but it will be essentially related to the intensity of exploration activities, decreasing gradually as more and more "wildcat" drilling is done in ground far away from known deposits.

Potential resources, predicted solely on the basis of geologic interpretation, are large -- probably at least 50,000,000 tons of ore containing about 0.25 percent U_3O_8 (100,000 tons of U). Considerably less than half of these resources can be found and mined profitably under the economic conditions prevailing in 1951.

A three-fold expansion of the Survey exploration program is in progress. About 600,000 feet of drilling is planned for fiscal 1952, and, tentatively, about 800,000 feet is planned for fiscal 1953. A similar amount of drilling is planned by the Commission group. In line with the general directive received from the Commission, the Survey will continue to explore ground away from known deposits, ground that probably will not be tested by private industry because of the high risk of a poor yield, searching for deposits that ultimately will be developed into new mines. The Survey has also strongly recommended that development-type drilling be undertaken near mine workings, in order to find extensions of the known deposits and sustain continued operations of these mines. This drilling would satisfy a critical need on the Colorado Plateau today.

The geologic studies being conducted by the Geological Survey are aimed at long-range results -- to appraise the carnotite resources of the region and to aid in determining the genesis of the deposits, conditions of localization, and guides to ore finding. The studies consist of regional geologic mapping, regional stratigraphic studies, a study of recent and past ground-water conditions in the ore-bearing beds, and mineralogic work on the ore and host rock (TEIR 110). In addition, geochemical and geophysical methods of prospecting are being tried in hope of finding useful guides for prospecting (TEMR 199 and TEMR 100).

Entrada sandstone.--About a million tons of vanadium ore, containing 0.05 to 0.08 percent U_3O_8 and about 2 percent V_2O_5, has been mined from the Entrada sandstone in western Colorado. The ore consists of sandstone impregnated with the micaceous vanadium silicate and carnotite. The ore bodies are similar in habit to those in the Morrison formation, though generally they are considerably larger.

Known reserves total about 500,000 tons of ore, containing about 300 tons of uranium. Potential resources are large, perhaps totaling 25,000,000 tons of ore containing 15,000 tons of uranium.

Because of the low uranium content, however, not much uranium has been extracted from the ore that has been mined, and under present economic conditions and metallurgical practices it is doubtful that much uranium will be recovered. These deposits must be considered an important potential source, nonetheless.

The Geological Survey has done no work on these deposits since 1944, and no work is planned in the next few years. Ultimately, however, geologic studies should be extended to these deposits to obtain a better appraisal of their uranium possibilities.

Deposits in Triassic sandstones.--Triassic sandstones in the area extending from central Utah to northern Arizona contain many uranium-bearing deposits. Some of these deposits are nearly identical with those in the Morrison formation, some consist of copper and uranium with little or no vanadium (White Canyon area, TEMR 7), and some consist of uranium- and vanadium-bearing asphaltic sandstones (San Rafael Swell). Deposits of silver-bearing sandstone with some uranium, vanadium, and copper are present in southwestern Utah (Silver Reef, TEMR 214).

A few of these deposits have been known for many years, but none of them were intensively mined until about 8 years ago. Several are being mined today, others are being developed, and much of the region, even though it is remote and difficult of access, is being actively prospected. On the basis of the reported occurrences and the successful development at a few places, potential resources are assumed to be large, perhaps of the order of 25,000,000 tons of rock averaging 0.2 to 0.3 percent U_3O_8 and containing about 50,000 tons of uranium.

As the Geological Survey has made detailed studies at only the Silver Reef district, no complete estimate of known reserves can be given. At Silver Reef, known reserves total 75 tons of uranium in rock averaging 0.4 percent uranium.

The Geological Survey will start a comprehensive program of geologic mapping and study of the Triassic deposits in southern Utah and northern Arizona in the summer of 1951. The work is planned to learn the geologic relations and guides to ore-finding that can be used to explore these rocks for new deposits and to appraise the total reserves. Exploration for concealed deposits will be started as soon as possible, perhaps in 1952.

Dakota sandstone.--Carnotite-type deposits have recently been found in the Cretaceous Dakota sandstone on the Bulloch claims in Kane County, Utah (TEMR 213). Known reserves contain less than 10 tons of uranium but the occurrence is of interest not only because further exploration may reveal minable reserves but because it represents a new carnotite province on the Plateau.

Other deposits

The carnotite-type deposits in sandstones outside the Colorado Plateau area are relatively small and low grade. Perhaps the more promising deposits include the asphaltic sandstone on the Uto claims, Pawnee County, Okla.; carnotite in the Garo prospect, Park County, Colo.; the Cooper-Sands prospect, Uintah County, Utah (TEMR 32); and the Mauch Chunk area, Carbon County, Pa. (TEMR 241). Potential resources of over 10 tons of uranium in rock 0.01 to 0.1 percent grade are present in the Snow claims, Uintah County, Utah, and the Mike Doyle prospect, El Paso County, Colo. (TEMR 133). The known reserves in all of these and other smaller deposits are less than 1 ton of uranium in ore of more than 0.1 percent grade and 250 tons in rock of 0.01 to 0.1 percent grade; the potential resources in these deposits are 20 and 725 tons respectively.

Schroeckingerite, a uranium carbonate, occurs in unconsolidated sands and clays in the Red Desert area, Sweetwater County, Wyo. (TEMR 10, 96, 183, 244, and TEIR 122). The known inferred reserves of rock containing more than 0.1 percent are 5 tons of uranium; potential resources of this grade are believed to be in the order of 50 to 100 tons of uranium and the quantity of lower-grade material is large.

Uranium-bearing limestones

Uranium occurs in limestone or dolomite in Vermont, Kansas, Arizona, New Mexico, Missouri, and Utah. To date none of these deposits have been mined but the higher-grade deposits near Grants, N. Mex., probably will come into production in the near future. The deposits at Grants are being studied and reported on by the Atomic Energy Commission.

The total known inferred reserves and potential resources of uranium in the Uintah limestone, near M ton, Utah; the Milton dolomite in northwestern Vermont (TEIR 67); and the Spergen limestone, Ste. Genevieve County, Mo. (TEMR 28), appear to be about 200 tons of uranium in rock of 0.01 to 0.02 percent grade. The uranium content of limestones cut by oil wells in Kansas is not well enough known to justify an estimate of reserves.

Outlook

Carnotite and related deposits on the Colorado Plateau probably will continue to be the principal domestic source of uranium. Although the total amount of uranium in these deposits is not as large as in the phosphates, black shales, and lignites, nevertheless, known reserves and potential resources of carnotite ore are substantial. They will sustain milling operations at the present level, or even at an increased level, if the necessary economic stimulus is provided, for years to come. The cost of exploration and mining will increase, however, as the more easily accessible deposits are exhausted.

Of the 100,000 tons of potential resources of uranium believed present in the Morrison, we expect that both the Survey and the Commission exploration groups will find about 25,000 tons, on the basis of our present understanding of the distribution and habits of the ore, at a rate that will be more or less directly proportional to the intensity of exploration. Because of the large amount of drilling required to find the ore, however, there are practical limits, established by the availability of geologists, drillers, and equipment, to the intensity of exploration possible. These will probably be reached in fiscal 1953 when both the Commission and Survey groups will be drilling at a combined rate of about 1,500,000 feet a year. Although the cream-skimming exploration already completed has yielded about 1 ton of uranium per 350 feet of drilling, the future yield may not be more than half as great. The discovery rate in fiscal 1953 and later years will thus likely not much exceed 2,000 tons a year.

Because our present understanding of the habits and geology of the ores in the Triassic rocks is limited, we could not quickly find more than a few scores or hundreds of tons of uranium but we expect that completion of geologic studies of the type already undertaken on the Morrison will enable us to find a significant portion, perhaps 10 to 25 percent of the potential resources. These geologic studies of the Triassic rocks are being started now and will be pressed during the coming years.

Exploration and geologic study in other places, particularly in Wyoming, Okalhoma, Texas, and New Mexico, may well yield significant discoveries of carnotite-type ores outside of the Colorado Plateau area.

It should be emphasized that continued geologic study is needed to obtain a better appraisal of potential resources, to focus attention on the more promising areas and geologic environments, and to reorganize geologic relations that can be used locally to guide exploration and development.

Uraniferous black shales

General statement

Uraniferous black shales are potential sources for large quantities of uranium but they contain less than 0.02 percent (TEMR 240). Most of the uraniferous shales are of marine deposition and have been formed by the slow accumulation of organic matter and clay in the absence of large quantities of coarse clastics and carbonates. Many are bituminous and pyritic. The mineralogy of the uranium in the shale is unknown but it seems likely that it is chemically adsorbed by carbonaceous matter and clay (McKelvey and Nelson, 1950).

The most richly uraniferous black shale known is the Cambrian alum shale of Sweden, which has a grade of 0.02 to 0.05 percent uranium and contains bituminous nodules, called kolm, that have a grade of as much as 0.5 percent. Other, less uraniferous shales are found in Russia and Estonia and are doubtless present in other countries as well. Domestic deposits include those of the Devonian-Mississippian Chattanooga shale of the east-central United States; the Woodford chert, a partial stratigraphic equivalent of the Chattanooga and Pennsylvanian shales in Oklahoma; the Pennsylvanian Hartville formation in Wyoming; and the Mississippian Calico Bluff formation of east-central Alaska. Only the Chattanooga shale in Tennessee has been studied sufficiently to permit estimates of large tonnages with reasonable continuity of uranium content (TEIR 8, 62, 63).

Known reserves of uranium in black shales total nearly 1,200,000 tons of uranium in beds averaging about 0.008 percent uranium.

Chattanooga shale in Tennessee

Preliminary studies of the radioactivity of the Chattanooga shale in 1944 and 1945 (TEIR 8, 22) indicated that the shale is most radioactive in an area in east-central Tennessee between the Nashville dome on the west and the area of folded rocks on the east. The shale in this area was mapped and extensively sampled between September 1947 and June 1949 as part of the Geological Survey's program for the Atomic Energy Commission, and related studies were continued under the auspices of the Atomic Energy Commission until June 1950. Study of other aspects of the shale have been continued by the Geological Survey since then.

The Chattanooga shale in the east-central part of Tennessee ranges in thickness from 4 to 37 feet. The formation consists chiefly, of alternating beds of black bituminous shale and gray claystone or siltstone, of which the most uraniferous are in the upper part. The black shale consists mainly of quartz, illite, organic matter, and pyrite (Scott, 1949, p. 6) and yields about 9.5 gallons of oil per ton (Scott 1949, p. 95). Although the uranium seems to be chemically adsorbed by organic matter and clay, the uranium content has a nearly constant ratio to the pyrite content.

The shale is generally flat-lying throughout much of the area but in the eastern part it is in open folds the limbs of which have a maximum dip of 25°.

The most uraniferous, upper part of the shale averages about 16.4 feet and 12.2 feet in thickness in the Eastern Highland Rim of the Nashville Dome and the Sequatchie Valley (folded belt) respectively. The uranium content of this zone in these areas is about 0.007 and 0.008 percent respectively. Known reserves in the Highland Rim area total 3 billion tons of rock containing 210,000 tons of uranium; those in the Sequatchie Valley area total 12 billion tons containing 960,000 tons of uranium. Very likely the estimated reserves represent only a part of the total amount of shale of similar grade in the general region, but especially in the Eastern Highland Rim area they represent the most accessible rock. Although the rock would have to be mined by underground methods, the shale in the Eastern Highland Rim area is nearly flat lying and would be amenable to relatively easy mining. The larger amount of reserves in the eastern area is in moderately folded rocks where mining would be more difficult.

Chattanooga shale equivalents

Several black shale formations in the United States are partial stratigraphic equivalents of the Chattanooga. These include the Woodford chert in Oklahoma, the New Albany in Kentucky and Indiana, the Ohio in Ohio, the Antrim in Michigan, the Geneseo, West River, Rhinestreet, and Dunkirk shales in New York, and the Chattanooga shale elsewhere than in Tennessee. These shales have been examined by the Geological Survey in the course of general reconnaissance examinations (TEIR 1, 43, 34, 64) at intervals between 1944 and 1950.

Black shales in the Woodford chert are the only shales in this group that have a uranium content comparable to the Chattanooga (TEIR 21). A study of gamma-ray logs of oil wells indicates that Chattanooga shale and shale in the Woodford chert in Oklahoma and Kansas is as radioactive as the Chattanooga in the southeastern United States (Gott, et at, 1951).

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The Woodford has been less well studied than the Chattanooga, but parts of the formation very likely contain reserves equivalent in grade and magnitude to those in the Chattanooga. Known reserves are estimated to be 40,000,000 tons of rock averaging 0.007 percent of uranium and containing about 2,800 tons of uranium. Potential resources of uranium can not be estimated from available data but are known to be much larger.

Although other black bituminous and carbonaceous shales, roughly equivalent stratigraphically to the Chattanooga, represent untold billions of tons of rock their lesser uranium content makes them less attractive as possible sources of uranium.

Hartville Shale, Wyoming

Some beds of uraniferous black shales encountered in the Hartville formation of middle Pennsylvanian age in two oil test wells 50 miles apart in Goshen and Niobrara Counties, Wyo., are potentially the most important found by the Geological Survey (TEMR, in preparation). The five samples available contain 0.005 to 0.019 and average about 0.015 percent uranium. These shale beds and the enclosing rocks crop out about 12 miles west of the southern well, but are at depths of about 2,300 feet at the southern well and 6,000 feet in the northern. Although the rocks enclosing the uraniferous shales have been mapped at their outcrop west of the wells, the presence of radioactive beds in the subsurface was not known at the time of mapping, and the radioactive shales were not looked for. Data on the character, thickness, grade, and extent of individual beds are too meagre to

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permit estimates of reserves at this time. They indicate, however, the presence of black shales somewhat richer than the Chattanooga, which deserve further study to determine more fully their characteristics and the habits of uraniferous black shales that may be applied in search for still other shales. Such investigations will be undertaken during the coming summer.

Other shales

The Geological Survey has tested between 70 and 80 shales in formations other than those mentioned in the immediately preceding pages. These formations are distributed in 25 states. The Stark, Bourbon, and Hushpuckney shales of Pennsylvanian age in Kansas and shales in the Fort Scott limestone in Oklahoma contain from 0.008 to 0.013 percent uranium (TEIR 18) and are thus comparable in grade to the Chattanooga. They are, however, thinner where tested and may be less persistent. Although the grade of a few of the other shales tested are closely comparable to the Chattanooga, the radioactive parts of the shales are clearly thinner and of small extent. Some of the remaining shales, including the Green River shale in Utah, the Deepkill, and Normanskill shales in New York, and the Nonesuch shale in Michigan are as thick or thicker than the Chattanooga and as extensive as the better parts of the Chattanooga, but they are less radioactive (TEMR 240). Their radioactivity ranges from nil to 0.010 percent equivalent uranium.

By far the larger part of the formations examined are in the area of flat-lying rocks between the Appalachian and Rocky Mountains. Although many shales have been tested in the Rocky Mountain region, the examination of shale-bearing formations there has not been as comprehensive as in the central United States, and none of the other shales have been as comprehensively studied as the Chattanooga.

Outlook

The uranium in Chattanooga shale can be extracted by processes developed by Carbide and Carbon Chemical Division (Grimes, et al, 1950) and Battelle Memorial Institute (Ewing, et al, 1949) at a cost in money and material that is apparently felt unreasonably large now. The cost of processing a shale containing two or three times the uranium found in the Chattanooga shale would of course be lower, perhaps proportionately so. It is therefore important to continue to search for more uraniferous black shales and this the Survey plans to do by examination of such formations as the Deseret limestone in Utah and the Hartville shale in Wyoming. Despite the fact that many of the black shales of the United States have been tested, it is not unreasonable to expect that some large deposits may yet be found that contain 0.015 or 0.02 percent uranium.

Uraniferous phosphates

General statement

All phosphatic formations--phosphorites-- of marine deposition are uraniferous. Richly phosphatic parts (containing 25 to 35 percent P_2O_5) generally contain 0.01 to 0.02 percent uranium. The uranium is in the mineral apatite, a calcium fluorophosphate, and is believed to proxy for calcium in the lattice (McKelvey and Nelson, 1950). The phosphorites are continuous in grade and thickness over areas of thousands or even tens of thousands of square miles. Important uraniferous phosphatic deposits of this type are found in this country in the northwest and in Florida. Similar deposits occur in North Africa and Russia. The residual phosphate deposits of Tennessee are weakly or non-uraniferous.

Because uranium in the phosphates cannot be separated except from acid solutions of the rock its recovery will be as a by-product in the manufacture of concentrated fertilizers and from those processes which involve an acid-solution stage.

Known reserves and potential resources of uranium in phosphate rock total about 2,400,000 tons.

Northwest phosphate

The Phosphoria formation of Permian age is found in an area of some 100,000 square miles in Idaho, Montana, Wyoming, and Utah. Uranium was discovered in the formation by the Survey in the course of its early Trace Elements studies in 1944 (TEIR 5). Extensive investigation of the uraniferous and phosphatic deposits was launched by the Survey in 1948. The immediate objectives of this study are the definition of areas likely to contain 200,000,000 tons of minable uraniferous phosphate rock and the determination of grade and tonnage of those deposits that may be mined in the next 10 years. The long range objectives are to appraise the reserves of uranium, phosphate, and other minor metals and establish their origin. The chief approach has been that of sampling the phosphatic member at widely spaced intervals; geologically mapping those areas that appear to contain the largest, richest, and most accessible deposits; and studying the mineralogy and geochemistry of the rocks (TEIR 142). These investigations are about 60 percent completed.

Although the phosphatic member of the formation is as much as 200 feet thick, only one or two minable layers, 4 to 8 feet thick, contain more than about 30 percent P_2O_5 and 0.01 percent uranium, and these are found only in southwestern Montana, eastern Idaho, and adjoining areas of Wyoming and Utah (TEIR 111).

The phosphatic layers, originally deposited as blanket-like deposits on the sea floor, have been extensively folded and broken by faults. They are now discontinuous and extend to depths of several thousand feet below the surface.

The reserves in the Phosphoria formation in beds 3 feet or more in thickness, containing more than 30 percent P_2O_5 and 0.01 percent uranium and lying at depths not greater than 1,000 feet below entry level total about 800,000,000 tons of phosphate rock containing about 90,000 tons of uranium. An additional 6,000,000,000 tons of the same type of rock, containing about 600,000 tons of uranium, is present at greater depths and a still larger tonnage is present in lower-grade rock.

Florida phosphate

Several types of phosphate deposits, termed land-pebble, river-pebble, and hard-rock, are found on the Florida Peninsula. The land-pebble and the river-pebble deposits contain 0.01 to 0.02 percent uranium but the hard-rock deposits are much less uraniferous.

Uranium in the Florida phosphates was discovered by the Survey in 1945 (TEIR 17). A long-range investigation of the land-pebble deposits, from which most of the production is currently obtained, was begun by the Survey in 1948, with the object of determining the distribution of uranium in the field, appraising the reserves, and determining the origin of the deposits. Most of the work thus far has consisted of sampling the deposits to be mined in the near future, estimating reserves, and determining the mineralogic composition of the rock. The investigation is about 40 percent completed.

The land-pebble deposits are mostly in the Bone Valley formation of Pliocene age (TEIR 79). The underlying Hawthorn formation also is phosphatic, although it contains few deposits of minable quality. Since the Bone Valley formation has been exposed tc weathering it has been extensively leached by surface waters and ground waters. Much of the phosphate has been removed from the leached zone and most of the remainder altered to wavellite or psuedowavellite, both aluminum phosphates (TEIR 102).

Most of the Bone Valley phosphate deposits are 10 to 20 feet in thickness, and contain only 15 to 20 percent P_2O_5. But the low quality is offset by the facts that the deposits lie close to the surface and are mostly unconsolidated. They can, therefore, be mined cheaply by stripping and concentrated by screening, washing, and flotation. The concentrates contain from 0.005 to 0.025 percent uranium and average about 0.011. The leached zone, at present discarded as overburden, averages about 3 feet in thickness and although it contains only about 10 percent P_2O_5, its uranium content is about the same as the phosphate rock (TEMR 157). The slime fraction contains about 0.018 percent uranium. The river pebble, which is derived from the erosion of the Bone Valley formation, is slightly less phosphatic than the land pebble but it is equally uraniferous.

The known reserves of the concentrates from the land-pebble field containing more than 30 percent P_2O_5, total about 1,700,000,000 tons containing 200,000 tons of uranium. Potential resources of less phosphatic but equally uraniferous material in the leached zone, river pebble and the Hawthorn formation may easily be as much as 15,000,000,000 tons containing 1,500,000 tons of uranium.

Miscellaneous deposits

Phosphatic nodules in a black shale in the Pennsylvanian Coffeyville formation near Tulsa, Okla., contain about 0.03 percent uranium (TEIR 18). Five million tons of such nodules, containing 1,500 tons of uranium, are estimated to be present in about 100 million tons of shale which lies under less than 25 feet of cover.

Uraniferous phosphate also is present in the Mississippian Brazer formation in Idaho and Utah but as the phosphate does not compare in quality or thickness with that in the Phosphoria formation the deposits have not been prospected and their reserves are unknown. Phosphate deposits in the Tertiary series of the South Carolina coastal plain, analogous to those in Florida, are similarly unexplored, but as two samples recently collected contain 0.033 and 0.042 percent uranium it is possible that these deposits are more uraniferous than those known elsewhere (TEMR 246). It is unlikely, however, that they are large enough to be profitably mined. Uraniferous phosphate rock is known at several other localities in New York, Tennessee, Texas, Oklahoma, California and elsewhere but none is of minable quality.

Outlook

The problem of uraniferous phosphates is plainly not one of discovery of reserves but one of metallurgy and economics. Consideration of these factors is beyond the scope of this report and of the field of our responsibility, but a few remarks may be appropriate to give perspective to the phosphate picture. Whereas the nation now produces about 9 million tons of rock containing about 900 tons of uranium, most of which comes from Florida, it has plant capacity for treating only about 1,200,000 tons of rock in the triple superphosphate process or its equivalent. Of each ton of rock consumed in this process only about 0.4 ton is made into phosphoric acid; the remainder is mixed with acid to make the solid fertilizer and therefore does not pass through a liquid state. Thus only about 480,000 tons of rock containing 48 tons of uranium now goes through a stage from which its uranium could be removed.

Total production of phosphate rock will very likely rise to something like 11 or 12 million tons within the next few years and fertilizer requirements may well justify an increase to 30 million tons within a few decades. Plans are afoot to expand the production of triple superphosphate or its equivalent in the near future, possibly to an amount that would consume 3 million tons of rock. But even this expansion is difficult because of the acute shortage of sulfuric acid. If the fertilizer industry could be encouraged to convert to the triple superphosphate process much of the acid now used in the manufacture of ordinary superphosphate (which now consumes about 7,500,000 tons of rock) would be available. This conversion would be costly but it would permit the recovery of perhaps 400 tons of uranium a year. Additional expansion will not be possible until important new sources of sulfuric acid are developed.

Uraniferous lignite and coal

General statement

Some, but by no means all, lignite and coal in the Dakotas, Wyoming, and Nevada (fig. 3) have been found to contain 0.01 to 0.04 percent uranium (0.03 to 0.34 percent in the ash). Recent studies of the Dakota deposits suggest that the uranium there was chemically adsorbed from downward percolating waters draining slightly uraniferous but relatively soluble rocks (TEMR 175). The uranium is somewhat irregular in distribution but nevertheless some lignites are uraniferous over large areas. Doubtless uraniferous lignites will be found in similar geologic settings in other countries and at other localities in the United States, although they have not been reported thus far.

North Dakota, South Dakota, and Montana lignites

Uraniferous lignites in the area in the vicinity of the juncture of North Dakota, South Dakota, and Montana were discovered in the course of Geological Survey reconnaissance in 1949 (TEIR 61) and studied in more detail in 1950. The work completed thus far has consisted of reconnaissance mapping and sampling in several areas mainly in Harding and Perkins Counties, S. Dak., and Bowman County, N. Dak., partly to determine the quality and extent of the uraniferous lignites but also to establish their origin and habits. Additional studies in the same general area will be undertaken to sample lignites not already studied and to test, by drilling, the continuity of the uranium in the lignite in some areas where it is concealed.

The uraniferous lignite beds of this area are found in the flat-lying or gently dipping Cretaceous Hell Creek formation, and in the Ludlow, Tongue River, and Sentinel Butte members of the Paleocene Fort Union formation. The distribution of the uranium in the lignite is apparently controlled by proximity of the lignite to the tuffaceous Oligocene White River formation, which unconformably overlies the Cretaceous and Paleocene formations, and by the permeability of the rocks overlying the lignite, whether this permeability is inherent, as in sandstones, or induced by fracturing or faulting. At almost all localities the first lignite bed below the White River formation is uraniferous, provided the rocks between it and the White River are pervious, regardless of which formation the lignite may be in. The

The uranium content decreases about to the vanishing point in succeeding lower beds. In beds more than 3 or 4 feet thick, the uranium content is higher at the top than at the base. The uranium content is likewise higher along through-going joints or fractures than away from them. The uranium content is thus somewhat irregular in distribution, but samples collected from exposures along the periphery of buttes and in auger holes a few scores or hundreds of feet back from the outcrop show that the beds are uraniferous over large areas.

Known reserves in the area studied in detail, in beds 2 to 20 feet thick, total 20 million tons of recoverable lignite containing 1,400 tons of uranium. At least half of these reserves can be mined by stripping. These reserve estimates are cautious, because until drill samples are available in concealed areas it is not known, for example, whether or not the uranium persists all the way from one side of a butte to the other. Depending upon the continuity of the uranium content potential resources might be as much as 200 million tons, containing 14,000 tons of uranium.

Other areas

Uraniferous lignite or coal has also been found in the Eocene Wasatch formation in the Red Desert area, Wyo.; in a Cretaceous formation near Sage in western Wyoming; and in the Tertiary Gamma lignite, Churchill County, Nev. None of these deposits have been investigated except in preliminary fashion but more closely spaced sampling and mapping similar to that already begun in the Dakotas, will be begun on the Red Desert and Gamma lignites this summer.

Potential resources in the lignite of the Red Desert area, which contains 0.004 to 0.01 percent uranium (0.013 to 0.03 percent in the ash) in the few samples analyzed, may be as much as 2 billion tons containing about 200,000 tons of uranium. The potential resources of the sub-bituminous coal at Sage and the Gamma lignite in Nevada which contain 0.001 to 0.005 (0.005 to 0.013 in ash) and 0.006 to 0.056 percent uranium respectively, cannot be estimated from available data but they may be presumed to be measureable in scores of millions of tons containing thousands of tons of uranium.

Outlook

Many other coals and lignites have been tested and found not appreciably radioactive -- in fact, prior to the discoveries described here, coal and lignite in general were regarded as among the least radioactive of all rocks. The geologic controls discovered in the study of the lignite in South Dakota now give direction to the search for uranium in coal and lignite and we may expect that additional deposits including some that may be more uraniferous than those already known will be found in the future.

Although reconnaissance studies of lignite and coal should be continued in order to determine roughly which areas contain the richest and most easily mined deposits, it is evident that the problem is again not one of supplies but of metallurgy and economics.

Analysis of this problem is beyond our competence, but it is safe to say that the feasibility of the recovery of uranium from lignite will depend upon 1) whether or not uranium can be leached cheaply from the ash and 2) whether or not the recovery of the uranium may be combined with the production of steam power or chemical utilization of lignite in a co-product operation that would be less costly and less wasteful than would be the consumption of lignite for its uranium content alone. Considering the shortage of power in the West and the Bureau of Reclamation's tentative plans for an integrated power system in the Mountain and Pacific states (in which power added at one point would contribute to the needs at the other end of the network), as well as current interest in lignite as a source of organic compounds, a co-product operation seems within the realm of possibility. Certainly both the metallurgy and economics seem to deserve further study.

Placers

General statement

Even though many uranium minerals are of high specific gravity, they are seldom concentrated in placers mainly because the common minerals are not refractory enough to resist weathering. The uraninite-bearing conglomerate of the South African Rand may be of placer origin but, if so, it is the only known uranium mineral placer of commercial importance.

Some zircon and monazite contain uranium, however, and both are found in rather extensive placers. Domestic zircon and monazite placers have been little studied by the Survey but the available information will be briefly summarized here.

Idaho

Monazite-bearing placers are found in a wide belt in central Idaho (fig. 5). The deposits in several districts were sampled in systematic but reconnaissance fashion by the Survey in 1944 (TEIR 19 and incomplete manuscript). Because some of these and other deposits have since been sampled more intensively by the Bureau of Mines the data given here are incomplete but are presented in such a way that they can be combined with or replaced by the Bureau figures when they are available.

The monazite in the Idaho placers is associated with several other heavy minerals, notably zircon and gold. The placers sampled in 1944 are estimated to contain about 800,000 tons of heavy-mineral concentrates containing about 0.02 percent uranium, distributed by districts as follows: Boise Basin, 120,000 tons; Orofino, 17,500; Dixie, 73,000; Elk City, 90,000; Florence, 5,000; Secesh-Warren, 500,000; and Stanley, 20,000. The total uranium content of these reserves is about 150 tons. No doubt additional reserves will be found on further search. The J. R. Simplot Company, for example,

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has informed us that placers near Cascade on the North Fork of the Payette River are even more promising sources of monazite than those listed.

Virginia

Zirconiferous sandstone near Ashland, Hanover County, Va. (fig. 5) contains about 0.01 percent uranium and 0.04 percent ThO_2. The sandstone layer is rather extensive but is only about one foot thick. Its reserves total about 250,000 tons containing 25 tons of uranium. It is of little interest as a source of uranium because of the small tonnage, the refractory nature of the zircon, and the thinness of the zirconiferous layer.

Southeastern States

Monazite-bearing placers in the southeastern states produced a total of 5,462 tons of monazite in the period from 1887 to 1911, mostly from North Carolina, at an average rate of 218 tons and a maximum rate, in 1905, of 676 tons. The field survived the competition of the Brazilian monazites but could not withstand that of the Indian production.

Reconnaissance sampling of the deposits, done by the Geological Survey in 1946 (TEIR 36), was resumed under Commission sponsorship in 1948 but was terminated in fiscal year 1949 when interest in

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thorium dropped. Field work has been continued by the Survey in connection with studies of the southeastern granites and the mapping of the Shelby quadrangle, N. C. According to present plans, the Survey is to resume the work on monazite in fiscal year 1952 under the auspices of the Commission. The immediate purpose of this work will be to select areas of alluvial ground large enough to warrant further exploration and appraisal, which will then be conducted in cooperation with the Bureau of Mines.

Monazite in the southeast placers is derived from the weathering and erosion of several types of granitic and gneissic rocks (TEMR 248). The monazite-bearing rocks have been found to be confined to two northeastward-trending belts (fig. 5). The western belt, which includes the area of previously known placers in North Carolina, extends a distance of about 425 miles from southern Virginia to La Grange, Ga.; its width ranges from 10 to 50 miles and averages about 20 miles. The eastern belt, previously entirely unknown, extends 200 miles from Fredericksburg, Va. to Raleigh, N. C. and may extend as far north as Rockville, Md. The eastern belt is only about 5 miles in width. The definition of these belts greatly will facilitate the search for placer ground in the future.

The monazite content of the placers in headwater stretches of the streams, judged from 52 samples panned from many places in the western belt, averages 8.6 pounds to the cubic yard and contains 5.7 percent ThO_2 and about 0.35 percent uranium. Most of

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the placers are small and although the volume of alluvium increases downstream, the monazite content decreases. In between the upper reaches, where the volume of alluvium is too small to permit mining, and the lower reaches, where the monazite content is too small, many streams contain alluvial stretches of 200,000 to 10,000,000 square feet in size. The aggregate area of such placer ground is believed to be large.

No data are available upon which to base reliable estimates of reserves. Early mining, however, was done by crude, primitive, methods in only a small fraction of the area known now to be monazite-bearing. In view of these facts, it is logical to suppose that modern methods used at several localities would permit an annual production at least 10 or 20 times larger than that achieved formerly, or a tonnage of perhaps 5,000 to 10,000 tons of monazite a year containing 17 to 35 tons of uranium. It is not unreasonable to suppose that potential resources of monazite are at least 20 times the tonnage already produced or at least 100,000 tons of monazite containing at least 350 tons of uranium.

Other areas

Monazite has been reported in placer deposits in several other areas particularly in beach sands of California, the gold-bearing alluvial deposits of the Central Valley of California, San Luis Valley and Routt County, Colo., in sands of the Columbia River and locally along the coast near the Columbia River, Washington (Bain,

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1950; Day and Richards, 1906). The Geological Survey has briefly examined beach sands on the Oregon coast, and some of the alluvial deposits in California (TEIR 24). Some chromiferous sands contain 0.005 to 0.007 percent equivalent uranium, and one zircon concentrate contained 0.024 percent uranium. Concentrates of heavy minerals from placers in the Klamath region of northern California are essentially non-radioactive. Concentrates from placer workings on four rivers draining west to the Central Valley contain from 0.009 to 0.021 percent equivalent uranium, probably mostly as monazite. The ilmentite placers of Florida also contain uraniferous zircon and monazite. Monazite made up from 1 to 2 percent of the heavy-mineral concentrates obtained by Humphrey's Gold Corporation from sand in raised beaches in Clay County, Fla. (TEIR 17). The 1945 production of 90,000 pounds of concentrates thus contained at least 900 tons of monazite in which the uranium content was 0.28 percent or about 2.5 tons.

It may be possible to concentrate and separate monazite in the course of gold or other placer operations at some of the deposits outside Florida, but the potential production from any of the known deposits seems small at best.

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Outlook

As a group, placers are not a promising source of uranium if mined for that metal alone. If this uranium can be recovered from monazite mined primarily for its rare-earth and thorium content, however, some of the placers, particularly those in the southeast can be expected to yield a small but continuing annual production.

Natural waters

A great deal of information on radioactivity of natural waters has accumulated in the geologic and other scientific literature, but most of the information probably applies to radon content, and little attention has been paid to uranium. From time to time since 1947, the Geological Survey has collected and analyzed samples of waters either known to be or suspected to be radioactive. Most of this work has been done incidental to other investigations and no attempt has been made to made a systematic survey of uranium content of natural waters.

These analyses made by the Survey indicate that Great Salt Lake contains 1 x 10^{-9}g U/g water (TEMR 49); the Salton Sea contains 1 x 10^{-8}g U/g water (TEMR 42); and spring and ground waters sampled, mostly small local sources, contain from 1 x 10^{-8}g U/g water to 4.4 x 10^{-7}g U/g water in a spring near schroeckingerite deposits in the Red Desert, Wyo.

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Recent studies at Oak Ridge National Laboratory (Bruce, F. R. and Ferguson, D. C., 1951) indicate that the more radioactive domestic fresh water contains about 4×10^{-9}g U/g water and that recovery of uranium from fresh water containing 1×10^{-8}g U/g water (1 part in 100,000,000) may be feasible. The few samples of fresh waters that the Geological Survey has analyzed for uranium are mostly from sources with small flows, but some contain more than the minimum quantity of uranium that is considered recoverable. Search should be made for other natural waters containing more than the minimum required concentrations of uranium and with large enough volume of flow to provide worthwhile quantities. A related aspect of such an investigation would be the application of the information obtained from sampling of water to definition of areas of potential uranium deposits, as suggested by the Geological Survey in 1947 (TEIR 36, p. 17).

DOMESTIC THORIUM DEPOSITS

Domestic thorium deposits include those in veins and related deposits, igneous rocks, pegmatites, and placers. In all its important occurrences, thorium is associated with rare earths in R_2O_3/ThO_2 ratio of from 10 to 20 to 1 in monazite and 10 to 100 to 1 in the bastnaesite deposits. As previously mentioned, monazite also contains as much as 0.4 percent uranium.

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Because the Geological Survey has done relatively little work on thorium this account of our domestic resources is necessarily incomplete and sketchy.

Vein deposits

General statement

Thorium in vein deposits is generally associated with barite, calcite, and rare-earth minerals, such as bastnaesite, rather than with base and precious metals, although lead and zinc minerals are found in some deposits. Thorium-bearing vein deposits of rare-earth minerals occur in California, Colorado, Montana, Wyoming, and Idaho and although none have yielded any production, those in California and Wyoming are being actively prospected.

The investigation of thorium in vein deposits has been incidental to the Survey's work on uranium-bearing veins, except in the Clark Mountain district, Calif., where the information on thorium was obtained during the Survey's study of rare-earth minerals.

Custer County, Colorado

Numerous shear zones as much as 10 feet wide, and 2 to 3 miles long, cut pre-Cambrian rocks in Custer County, Colo. These shear zones are highly radioactive, but samples of weathered surface material do not contain appreciable uranium. A detailed study of a part of these zones was made at Harpuda Ranch (TEMR, in preparation). Preliminary estimates indicate the presence of several million tons of rock containing about 0.4 percent ThO_2, or several thousand tons of ThO_2. The only thorium mineral yet identified is thorite.

Gunnison County, Colorado

A silicified zone in granite similar to the shear zones in Custer County, occurs on the Little Johnnie claim, Gunnison County, Colo. It is over 1,000 feet long and 1.5 feet wide. The known estimated reserves are 170 tons of ThO_2 in rock containing 0.28 percent. Other veins in the area as well as possible extensions of the Little Johnnie structure indicate that the potential resources of ThO_2 in this area are in the order of several hundred tons.

Beaverhead County, Montana

Four vein deposits in Beaverhead County contain ore averaging 0.24, 0.40, 0.45, and 0.99 percent ThO_2. The known reserves of these deposits total about 230 tons of ThO_2 and the potential resources of this district in rock of over 0.1 percent ThO_2 are believed to be several hundred tons.

Lemhi County, Idaho

Three veins in Lemhi County, Idaho have estimated inferred reserves of about 375 tons of ThO_2 and potential resources of several hundred tons in rock containing more than 0.1 percent ThO_2.

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Clark Mountain District, California

The newly discovered bastnaesite (a fluorocarbonate of the cerium metals) deposits of the Clark Mountain district, San Bernardino County, Calif. contain the largest known domestic reserves of ThO_2 in lode deposits. One body on the Sulphide Queen claims, explored thus far only to a depth of 50 feet, is estimated to contain about 1,060 tons of ThO_2 in rock of 0.1 percent grade above a depth of 100 feet. Additional deposits on the Birthday and Windy claims contain about 70 tons of ThO_2 in rock ranging from 0.3 to 0.9 percent ThO_2. The potential ThO_2 resources of this district are likely to be several thousand tons of ThO_2 in rock of more than 0.1 percent grade.

The mineralogy of the thorium is as yet unknown. It appears to be present as a minor constituent of the vein minerals rather than as an identifiable thorium mineral. As far as we are aware, no tests have been conducted to see whether or not the thorium can be recovered in the course of the extraction of rare earths.

The potentialities of the Clark Mountain deposits were first recognized by the Survey in the fall of 1949 and they are now being actively developed for rare earths. Many believe that this district will eventually supply most of our domestic requirements for rare earths and may upset the world market as well.

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Wyoming

The rare-earth deposits in the Bear Lodge Mountains, Wyoming, probably contain several million tons of rock in which thorium is a significant constituent, but data necessary to calculate reserves are not available. These deposits have been drilled and studied by the Bureau of Mines.

Other deposits

Two areas of thorium-bearing metamorphic rocks and pegmatite are known in Worcester County, Mass. (TEIR 69, in preparation). One deposit, the "Worcester locality", contains alternating bands of biotite-feldspar gneiss and pegmatite, separated by a band of iron-oxide-rich biotite schist. The entire deposit, about 30 feet wide and 5,000 feet long, is estimated to contain at least 420 tons of ThO_2 in rock averaging 0.03 percent. The other deposit, the "Southbridge locality", is also in Worcester County and it extends into Windham County, Conn. It consists of alternating bands of hornblende-feldspar gneiss and pegmatites. The deposit is about 1,500 feet long and 900 feet wide. Reserves are estimated to be at least 360 tons of ThO_2 in rock averaging 0.03 percent. The potential resources are very large.

Available data suggest that further geologic study and exploration likely will result in discovery of additional reserves of thorium, particularly in the lode deposits of Custer and Gunnison Counties, Colorado; Lemhi County, Idaho; Beaverhead County, Montana; and San Bernardino County, California.

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Pegmatites

Pegmatite deposits rarely contain appreciable quantities of thorium minerals and none of those known in the United States contain enough thorium to be considered as a source of this metal.

Igneous Rocks

Many igneous and metamorphic rocks, particularly biotite-rich granites and granite-gneisses, contain monazite. Such rocks, together with monazite-bearing pegmatites which not uncommonly occur in the same terrane, are the source of monazite in placers. Rough estimates from sketchy data suggest that the richer monazite-bearing rocks of the Carolinas contain about 0.02 percent heavy minerals (TEIR 32) of which from 1 to nearly 50 percent is monazite. The average amount of monazite in bedrock in the monazite belts is about 0.005 percent (TEMR 248) hence the content of ThO_2 in monazite is only about 0.0002 percent of the rock. Monazite in Archean biotitic gneiss in Los Angeles and San Bernadino Counties, California, contains 10 to 15 percent ThO_2, as visual estimates suggest that the rock in some areas contains 1 percent monazite it seems likely that large masses of rock containing 0.1 percent ThO_2 may be found. Monazite-bearing rocks occur also in New England and Idaho but none are known to be appreciably richer than the Carolina rocks.

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Placers

Nearly all the world production of thorium has come from placer deposits of monazite. The monazite in these placers contains some uranium as well as the thorium. The domestic placer deposits of thorium, therefore, correspond to the placer deposits of uranium described in a preceding part of the report, and the features mentioned there are equally applicable to the placer deposits of monazite, the principal source mineral of thorium. The description of placers given here is therefore largely a statement of known reserves and potential resources of thorium.

Southeastern states

As mentioned previously, the stream placers of the southeastern United States might yield from 5,000 to 10,000 tons of monazite a year and they may be expected to contain potential resources of 100,000 tons or more of monazite, containing 5.7 percent ThO_2. Potential production of thoria might therefore be about 250 to 500 tons a year and potential resources 5,000 tons or more.

Virginia

The zirconiferous sandstone near Ashland, Va., previously described, comprises 250,000 tons of ore averaging 0.04 percent ThO_2 and containing 100 tons of ThO_2. The deposit is of little significance as a source of thoria because of its small size and thickness as well as the refractory nature of the zircon.

Idaho

Most of the essential data on placers in Idaho have been presented in discussing uranium. Only older analyses are available of the thorium content of monazite from Idaho, which are not certainly representative. They suggest a mean ThO_2 content of 4 percent. The reserves of heavy minerals listed in this report are estimated from only partial mineralogic studies of samples to contain about 130,000 tons of monazite. The thoria content of this monazite is therefore estimated to be about 5,200 tons. More accurate and complete estimates have doubtless been made by the Bureau of Mines in the course of their more recent investigation.

Alaska

Monazite has been detected in placer concentrates at 15 to 20 localities in Alaska. In only four, and possibly five, does it make up 5 percent or more of the heavy-mineral concentrates. These areas are the Chandalar district, on south flank of Brooks Range, upper Yukon region; Julian Creek, Kuskokwim region; Yetna district, 30 miles south of Mt. McKinley; Hot Springs district, 100 miles west of Fairbanks, a tin placer area; and Cape Mountain area, Seward Peninsula, where it occurs in concentrates from tin placers. Data are inadequate for estimating either reserves or potential by-product recovery from placer operations. In general, the reported proportions are comparable to the leaner areas in Idaho and are much less than in the better parts of the Carolina area.

Other areas

Florida is probably the only area outside of the Carolinas and Idaho with potentially large reserves of monazite. Terraces of beach sand in Duval and Clay Counties, Fla., are worked for their content of the heavy minerals, ilmenite and rutile. Only the deposits in Clay County, about 8 miles east of Jacksonville, contain monazite. In addition, they contain radioactive zircon. In 1945 the Humphrey's Gold Corporation was producing about 90,000 tons of heavy-mineral concentrates from these sands (TEIR 17). Monazite forms from 1 to 2 percent of these concentrates and contains 0.28 percent uranium as well as thorium. At the 1945 rate, production of monazite would be about 900 tons per year. Analyses for ThO_2 are not available but presumably the content would not be materially different from that of the Carolina monazite or about 5.7 percent ThO_2. The annual production of ThO_2, therefore, would be between 45 and 50 tons.

Placer deposits in California, Oregon, and Washington might contribute a small by-product of monazite from operations for recovery of gold or other sand products. At best such products probably would be measured in tens of tons per year.

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Outlook

The outlook for new discoveries of thorium in placers, igneous rocks, and veins is promising indeed. Potential resources in deposits known to contain more than 0.1 percent thorium are not as large as potential resources of uranium of comparable grade but in view of the promising leads at hand it is entirely possible that our thorium resources in high grade deposits may prove larger than those of uranium in deposits of equivalent grade.

Thorium is a logical co-product in the recovery of rare earths and possibly uranium too but if the consumption of rare earths controls the production of thorium the latter necessarily will be small. Assuming that we consume about 5,000 tons of monazite annually, as we did prior to the war, we process only about 300 tons of thorium. If future needs for rare earths are met from bastnaesite deposits, as is possible, the amount of ThO_2 processed might drop to 50 tons or less. This might be somewhat affected by the increased consumption of rare earths that seems imminent but it seems plain that any large scale production of thorium could not be as a rare-earth co-product.

SUMMARY OF RESERVES AND RESOURCES

Available information regarding reserves and resources are summarized in the accompanying tables. "Known" reserves and "potential" resources are tabulated into deposits that average more than 0.1 percent U or ThO_2 and deposits that have an average content of 0.01 to 0.1 percent U or ThO_2.

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Known reserves include measured, indicated, and inferred reserves that are known from exposures in natural outcrops, mine openings, or drill holes. The grade is determined from sampling, and the tonnage of ore has been calculated by reasonable projection based on knowledge of the geologic character of the deposit. Estimates of potential resources are based solely on knowledge of the geologic habits of deposits and the prediction that undiscovered deposits are present beyond points of exposure or sampling.

Because the geology and habits of some deposits are more thoroughly understood than the habits of others, the estimates of potential resources are accordingly more complete and reliable for some types of deposits, such as the Colorado Plateau carnotites and the phosphates, than for others, such as the vein deposits.

Most of the deposits containing reserves of 0.1 percent uranium or better can be mined economically or are marginal today. Not all of these deposits are being mined, however, and certain individual deposits present peculiar economic or metallurgical problems that restrict the availability of the contained ore. Some uranium in deposits of this grade class may be recoverable as a by-product.

Deposits containing reserves of 0.01 to 0.1 percent uranium generally cannot be exploited profitably for uranium alone under present conditions. Deposits that can be cheaply mined or processed are exceptions, of course, as are those, such as the lignites and phosphates, from which uranium might be recovered as a by-product.

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Because there is little demand now for thorium and because it is nearly everywhere associated with either other valuable co-product elements, such as uranium or rare earths, the minimum thorium content minable under present conditions, either for thorium alone or as a co-product, is poorly defined. The classification of reserves by grade presented in the summary of thorium reserves is the same as that used in the summary of uranium reserves partly for reasons of simplicity but mainly to permit a direct comparison of reserves of the two sources of fissionable materials. The paucity of reserves containing 0.01 to 0.1 percent ThO_2 is, of course, apparent rather than real -- with the little interest in thorium deposits of high quality, there has been almost no interest in deposits of such low grade.

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CONCLUSIONS

Domestic reserves of ore minable under present conditions are short indeed. Known reserves in ores containing more than 0.1 percent uranium total only 2,800 tons of uranium, nearly all of which is in the carnotite deposits of the Colorado Plateau. _/

_/ This estimate does not include reserves in deposits studied by the Atomic Energy Commission at Marysvale, Temple Mountain, and White Canyon, Utah; Grants, N. Mex.; Sunshine Mine, Idaho; and several areas in the Colorado Plateau.

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Potential resources in ores of this grade class are much larger -- 150,000 tons of uranium, mostly in Plateau carnotite-type deposits -- but very likely less than half of these resources can be found and mined profitably under economic conditions similar to those prevailing now; the discovery rate, moreover, can hardly be expected to exceed 2,000 tons of uranium a year under the most favorable conditions. In fact, such a discovery rate likely will not be reached until fiscal 1953, when the combined Commission-Survey drilling on the Plateau will be in the neighborhood of 1,500,000 feet -- roughly four times that drilled in fiscal 1950.

The longer range outlook is more encouraging. We have by no means exhausted the possibilities of finding minable ores, both in vein deposits and in carnotite-type deposits in other areas besides the Colorado Plateau. We may reasonably expect, therefore, that additional geologic study and exploration will yield new discoveries in the future. In addition known reserves of uranium in deposits containing 0.007 percent or more are 1,500,000 tons and potential resources of the same quality are more than 2,300,000 tons. Most of these resources are in phosphates, black shales, and lignites. Additional large and perhaps more uraniferous deposits of black shale, lignite, and igneous rocks will probably be found on further search. In all probability a relatively small tonnage of uranium will soon be recovered from phosphate, but none of the other deposits will yield uranium profitably now. Nevertheless, they constitute a tremendous source of uranium that can be mined if emergency conditions or technologic advances so warrant.

Our thorium resources are less well known but the evidence at hand indicates a known reserve of 11,000 tons of ThO_2 in vein deposits and placer concentrates containing more than 0.1 percent and more than 5,000 tons of additional potential resources of the same quality. Additional large deposits likely will be found on further search.

The greatest part of our effort in the search for additional deposits must continue to be directed toward the Plateau, for without question our best chances of finding deposits minable under present conditions are in that field. But it is also desirable to continue the search in other areas for high-grade uraniferous vein deposits; for low-grade deposits more uraniferous than those now known, particularly those that are apt to yield uranium as a by-product or be amemable to low-cost beneficiation; and for thorium deposits, both in veins and placers. These investigations are perhaps not as pressing as those on the Plateau, but they are important, partly because they will eventually permit the overall resource appraisal which the nation requires for effective planning and because they may well lead to discoveries that will augment or supplant production from the Plateau.

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Both fundamental and applied research on the geology of fissionable materials have been slighted in the "rock-in-the-box" program of the past. Steps are being taken to correct this deficiency now, but it might be easy, under emergency conditions, to make the same mistake again. This must be prevented if at all possible. The search in the future will focus more and more on concealed deposits; it cannot be conducted economically or successfully unless it is guided by a better understanding of the geology and habits of uranium- and thorium-bearing ores than we possess now. Such an understanding can be achieved only through careful synthesis and analysis of field and laboratory observations and through fundamental research on all phases of the geology and geochemistry of uranium and thorium.

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This report is more the product of the entire Geological Survey Trace Elements staff than of the few who compiled it. The references to other Survey reports acknowledge the technical contributions of numerous other geologists but they do not reflect the direct assistance given during the preparation of this report by many of our co-workers. Particular thanks are due James B. Cathcart, Roger W. Swanson, M. R. Klepper, R. U. King, D. G. Wyant, W. C. Overstreet, V. R. Wilmarth, G. B. Gott, Frank B. Moore, E. P. Beroni, F. Stugard, Jr., J. C. Olson, W. N. Sharp, F. A. McKeown, J. W. Adams, A. F. Trites, Jr. and E. P. Kaiser for supplying up-to-date reserve estimates; and to Katharine Lutz, W. A. Guinan, P. F. Narten, R. H. Stewart, F. N. Houser, and John Eric for assistance in compiling the illustrations and editing the manuscript.

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APPENDIX

The Geological Survey's Trace Elements Investigations, 1948-1951

The product of the Geological Survey's investigations conducted on behalf of the Atomic Energy Commission, expressed in terms of information on sources of thorium and uranium, is summarized in the foregoing pages. A summary of specific investigations, including those of the laboratory, is beyond the scope of this report, but a summary of the Commission funds expended in the various investigations is shown in the attached table and will be discussed briefly here. In addition to those funds received from the Commission, the Survey has used several hundred thousand dollars of its own funds for investigations related to or supporting those sponsored by the Commission. The use of these funds will not be discussed further except to say that they were spent largely on phosphate, beryllium, rare-earth, fluorite, black-shale, regional-mapping, and laboratory investigations.

The funds received from the Atomic Energy Commission for the Geological Survey's Trace Elements investigations total $10,442,452, up to and including fiscal year 1951. As may be seen from the attached table, these funds have been allocated to various investigations largely in proportion to the promise they offer for immediate production or "rock-in-the-box". Thus, 46 percent of the total funds received has been spent on the Colorado Plateau carnotites, our only present source of production; 5.7 percent has been spent

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on phosphates, the most imminent source of additional production; 1.8 percent on black shales; and less than 1 percent on monazite and lignite in which little interest has been shown. The search for new deposits, which makes up nearly 10 percent of the total, has been similarly oriented toward the search for deposits of minable grade. The laboratory investigations are shown separately. Because they have consisted almost entirely of analytical work and other types of investigations servicing or supporting the field projects, these costs might well have been included as part of the cost of the respective projects.

Although the rate at which these investigations have been pursued has varied, the annual expenditure was about $2,500,000 in fiscal years 1948, 1949, and 1950. The allotment in fiscal year 1951 was stepped up in mid-year to nearly $3,200,000. The funds budgeted for fiscal year 1952 total $4,860,700, of which about 59 percent is to defray the cost of a much expanded exploration program on the Plateau. Some additional funds may be allocated in fiscal year 1952 to support basic research. Plans and estimated costs of the fiscal year 1952 program are presented in some detail in the Trace Elements Work Plan and Operating Budget, fiscal year 1952, presented to the Commission April 6, 1951.

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TABLE 1.--SUMMARY OF DOMESTIC RESOURCES OF URANIUM
(all estimates rounded off to two significant figures)

Type of deposit	Deposits containing more than 0.1 percent U				Deposits containing 0.01 to 0.1 percent uranium 1/			
	Known Reserves		Potential Resources		Known Reserves		Potential Resources	
	Uranium in ore or concentrates (percent)	Contained uranium (short tons)	Uranium in ore or concentrates (percent)	Contained uranium (short tons)	Uranium in ore or concentrates (percent)	Contained uranium (short tons)	Uranium in ore or concentrates (percent)	Contained uranium (short tons)
1. Veins and related deposits 2/	0.1 - 3.0	150	0.1 - 3.0	2,000	0.01 - 0.1	900	0.01 - 0.1	2,200
2. Igneous rocks	- - -	- - -	- - -	- - -	- - -	- - -	0.01 - 0.02	very large
3. Pegmatites	- - -	- - -	- - -	- - -	- - -	- - -	0.01 - 0.02	negligible
4. Sandstones and limestones 3/	0.25	2,600	0.25	150,000	0.01 - 0.1	550	0.01 - 0.1	16,000
5. Black shales	- - -	- - -	- - -	- - -	0.008	1,200,000	0.007 - 0.02	very large
6. Phosphates	- - -	- - -	- - -	- - -	0.012	290,000	0.01	2,100,000
7. Lignites	- - -	- - -	- - -	- - -	0.014	1,400	0.01	210,000
8. Placers 4/	- - -	- - -	0.35	300	0.01 - 0.02	180	0.01 - 0.02	- - -
Total		2,800		150,000		1,500,000		2,300,000

Total in deposits containing more than 0.1 percent U - 150,000 tons.
Total in deposits containing 0.01 to 0.1 percent U - 3,800,000 tons.

1/ Includes lower-grade rock in uraniferous black shales.
2/ Excludes all classes of ore in the Marysvale district and Sunshine mine, studied by the Commission.
3/ Excludes known reserves discovered by AEC drilling on the Colorado Plateau and all classes of ore in the Grants, New Mexico deposit, also studied by the Commission - grade expressed in U_3O_8.
4/ Does not take into account any estimates that may have been made by the Bureau of Mines.

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TABLE 2.--SUMMARY OF DOMESTIC RESOURCES OF THORIUM 1/
(all estimates rounded off to two significant figures)

Type of deposits	Deposits containing more than 0.1 percent ThO_2				Deposits containing 0.01 to 0.1 percent ThO_2			
	Known Reserves		Potential Resources		Known Reserves		Potential Resources	
	ThO_2 in ore or concentrates (percent)	Contained ThO_2 (short tons)	ThO_2 in ore or concentrates (percent)	Contained ThO_2 (short tons)	ThO_2 in ore or concentrates (percent)	Contained ThO_2 (short tons)	ThO_2 in ore or concentrates (percent)	Contained ThO_2 (short tons)
1. Veins and related deposits	0.1 - 1.6	5800	0.1 - 1.6	very large	0.03	780	- - -	very large
2. Placers	4	5200	5	5000	0.04	100	- - -	- - -
Total		11,000		5000+		880		very large

1/ Does not take into account any estimates that may have been by Atomic Energy Commission or U. S. Bureau of Mines.

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TABLE 3 -- Dispersal of funds received from the Atomic Energy Commission for Trace Elements Investigations fiscal years 1948 - 1951

	1948	1949	1950	1951	Sub-total	Total	Percentage of Grand Total
Colorado Plateau							
Exploration	$353,600	$1,105,700	$1,026,900	$1,572,626	$4,058,826		
Geologic Studies	-	69,200	114,700	122,000	305,900		
Topographic Mapping	121,500	122,100	4,000	-	247,600		
Resistivity Studies	-	-	16,900	65,355	82,255		
Gamma-ray logging	-	12,200	46,900	58,819	117,919		
						$4,812,500	46.09
Reconnaissance							
United States	37,100	92,100	84,900	307,800	521,900		
Alaska	11,600	96,400	96,400	53,300	257,700		
Airborne Detection	-	30,000	85,000	73,552	188,552		
Mill and Raw Materials	20,600	9,900	8,100	11,500	50,100	1,018,252	9.75
Phosphates							
Southeast	40,700	78,400	97,000	88,000	304,100		
Gamma-ray logging	-	-	-	10,100	10,100		
Northwest	47,400	85,900	85,700	61,000	280,000		5.69
						594,200	
Laboratory							
Analytical work	73,880	177,480	216,568	265,000	732,928		
Supporting mineralogic & chemical investigations	110,820	266,220	324,852	397,500	1,099,392		
Equipment & construction	1,181,600	195,700	97,080	45,000	1,519,380	3,351,700	32.10
Beryllium	69,900	187,700	114,300	27,500	399,400	399,400	3.82
Black Shale	77,200	76,700	36,700	-	190,600	190,600	1.83
SE Monazite	23,700	22,300	-	-	46,000	46,000	.44
Lignite Investigations	-	-	-	29,800	29,800	29,800	.28
TOTALS	$2,169,600	$2,028,000	$2,456,000	$3,188,[illegible]52	$10,442,452	$10,442,452	100.00

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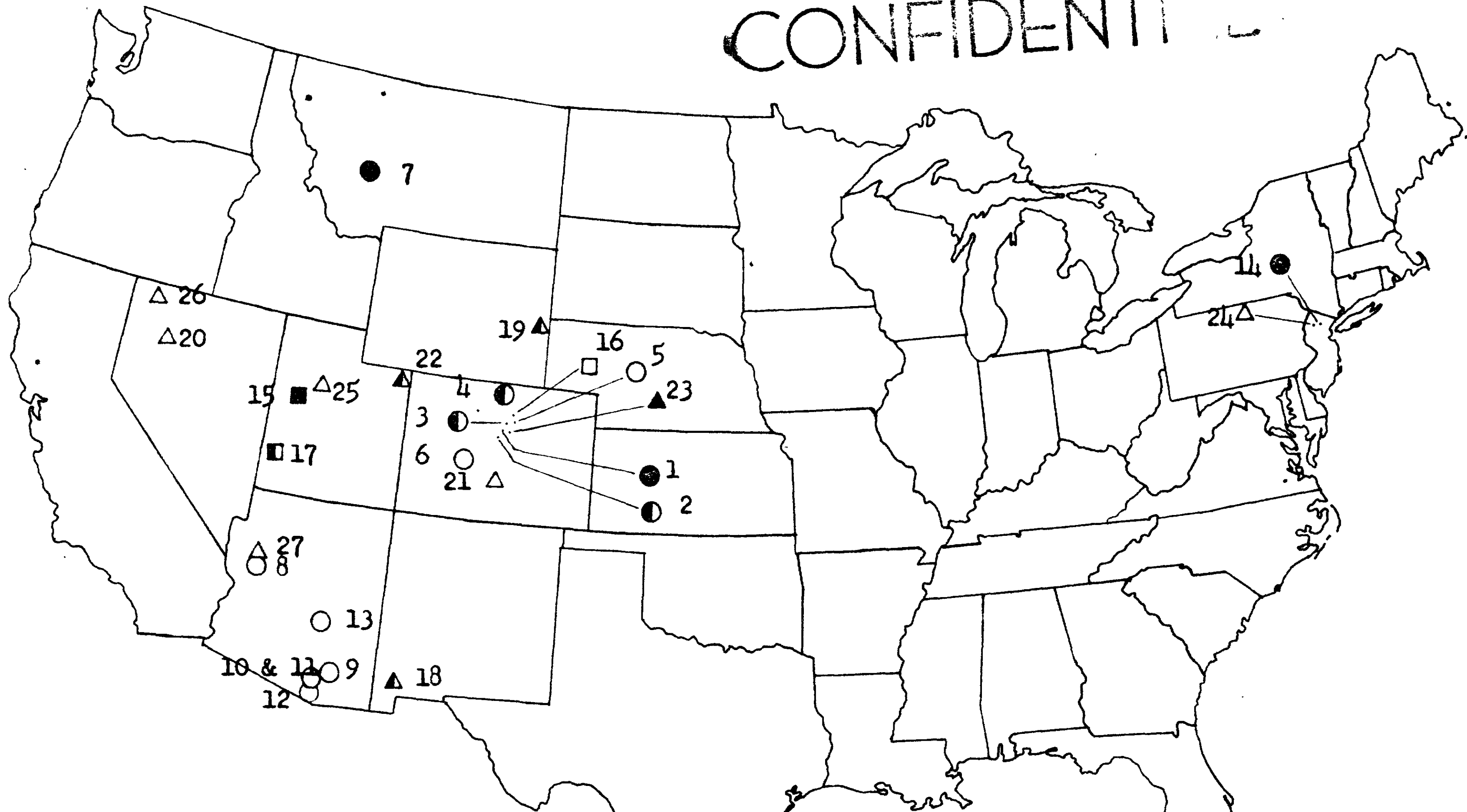

Reserves
(in tons of uranium)

● ▲ ■ More than 10 tons of known (measured, indicated, and inferred) reserves in rock containing more than 0.1 percent U.

◐ ◭ ◧ More than 10 tons of potential reserves in rock containing more than 0.1 percent U.

○ △ □ More than 10 tons of potential reserves in rock containing 0.01 to 0.1 percent U.

Deposits

○ Pitchblende-bearing
△ Secondary uranium
□ Fluorite

Number	Property or area
1	Central City district, Colo.
2	Lawson district, Colo.
3	Caribou - Grand Island district, Colo.
4	Copper King mine, Colo.
5	Black Cloud mine, Colo.
6	Domingo mine, Colo.

Number	Property or area
7	Boulder Batholith, Mont.
8	Hillside mine, Ariz.
9	Van Hill No. 7 and 8, Ariz.
10	Glen claims, Ariz.
11	Black Dike, Ariz.
12	Annie Laurie, Ariz.
13	Red Bluff, Ariz.
14	Edison quarry, N. J.
15	Thomas Range district, Utah
16	Jamestown district, Colo.
17	Staatz mine, Utah
18	White Signal district, N. Mex.
19	Silver Cliff mine, Wyo.
20	Majuba Hill mine, Nev.
21	Harpuda Ranch prospect, Colo.
22	Yellow Canary claims, Utah
23	Leyden mine, Colo.
24	Marble Mountain prospect, N. J.
25	Sheeprock Mountains, Utah
26	Virgin Valley opal district, Nev.
27	Katherine and Michael claims, Ariz.

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Figure 1.--DISTRIBUTION OF URANIFEROUS VEIN AND RELATED DEPOSITS.

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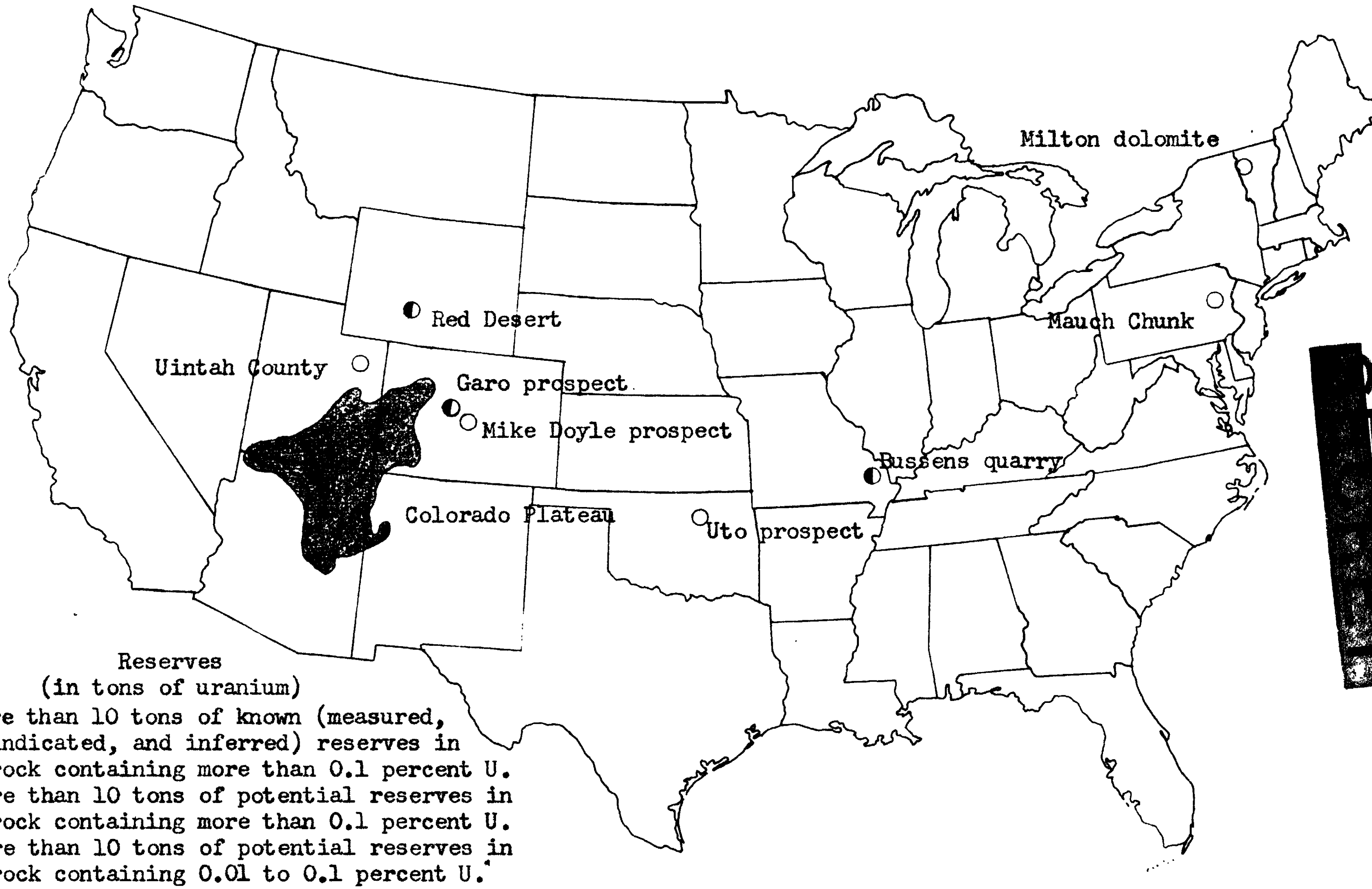

Figure 2.--DISTRIBUTION OF URANIFEROUS SANDSTONES, LIMESTONES, AND RELATED DEPOSITS.

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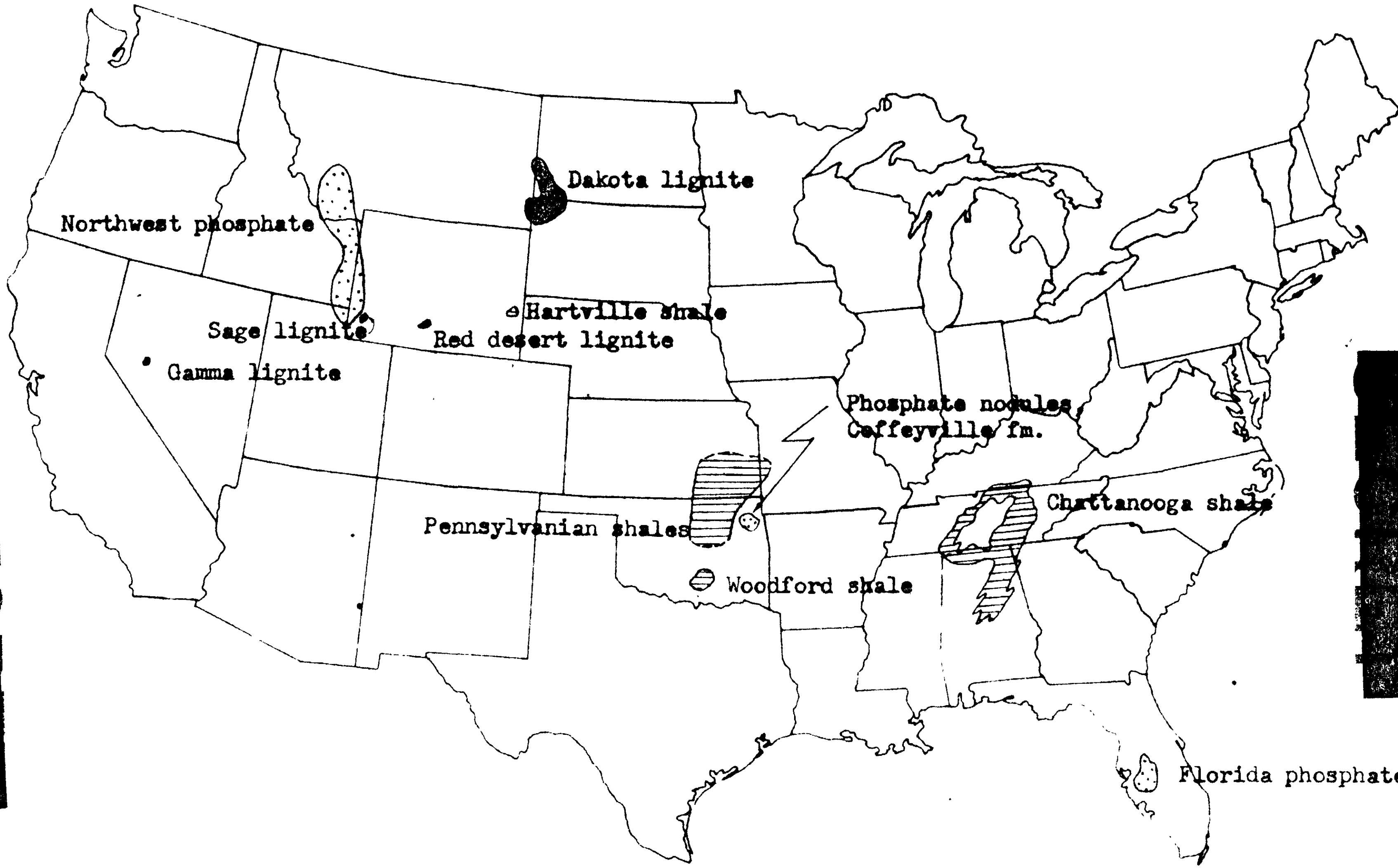

Figure 3.--AREAS CONTAINING DEPOSITS OF URANIFEROUS PHOSPHATE, SHALE, COAL AND LIGNITE.

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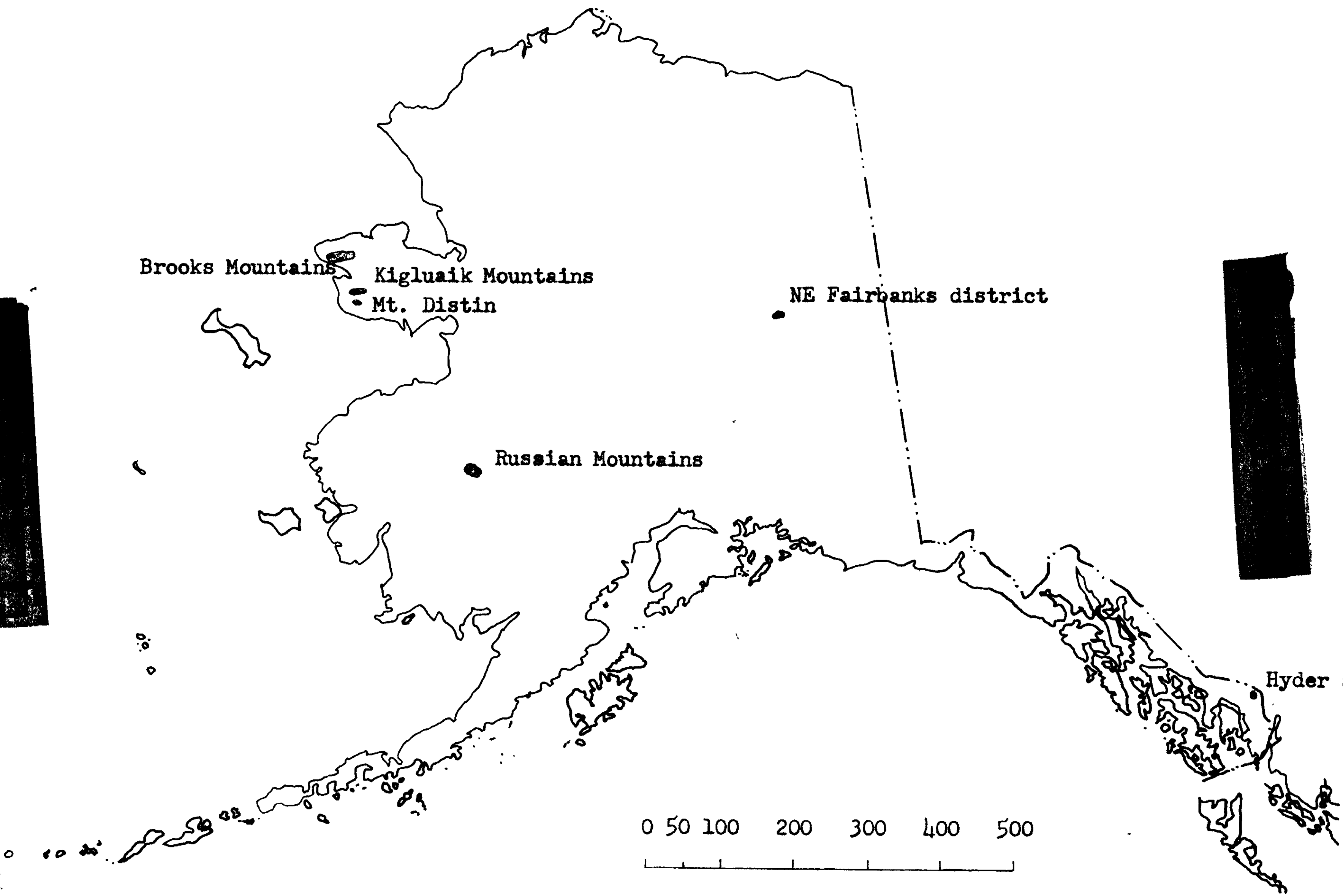

Figure 4.--ALASKAN MINING DISTRICTS MOST LIKELY TO CONTAIN URANIFEROUS VEIN AND RELATED DEPOSITS.

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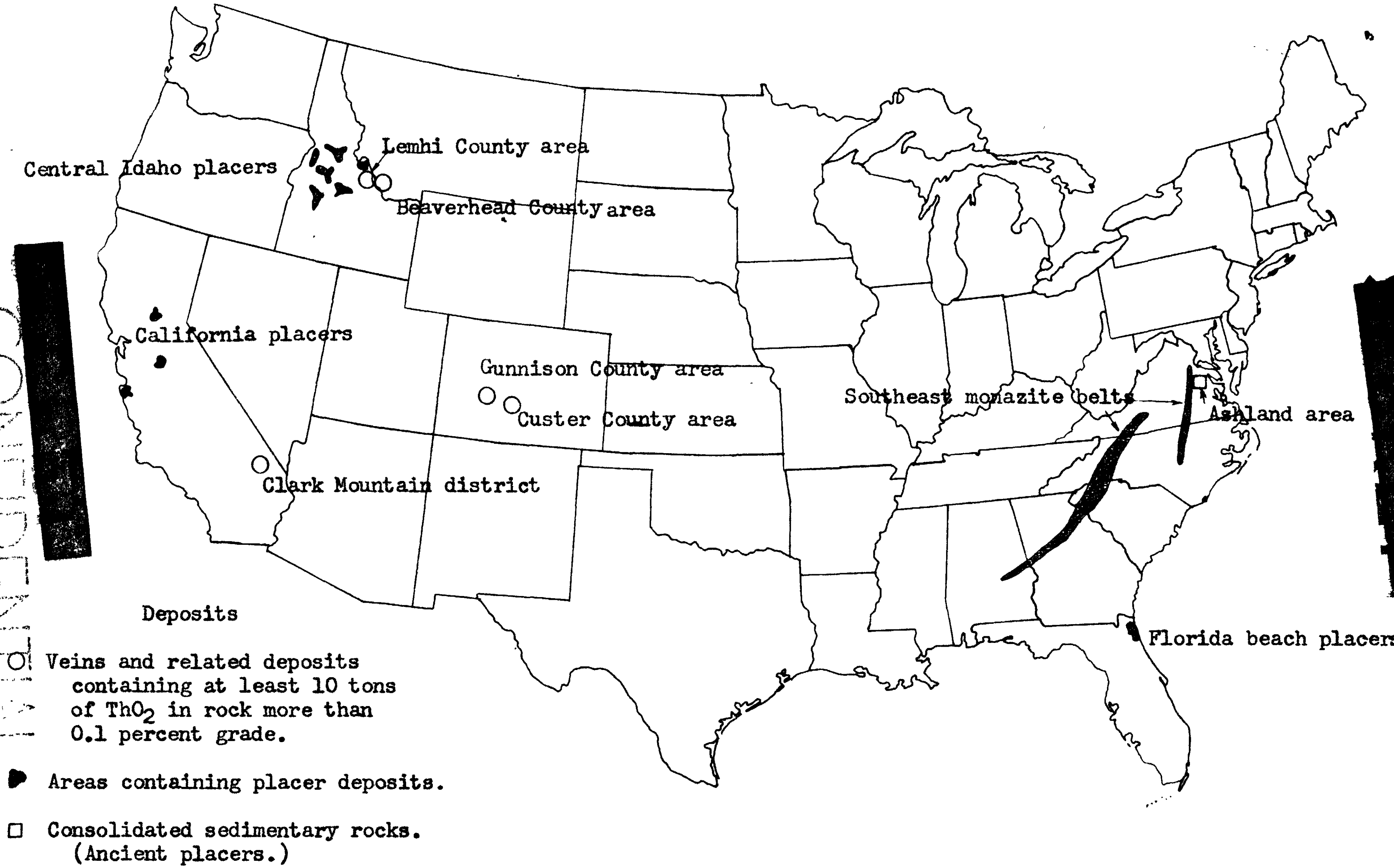

Figure 5.—DISTRIBUTION OF THORIUM DEPOSITS.

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