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THE GEOLOGICAL SURVEY'S WORK ON THE GEOLOGY OF URANIUM AND THORIUM DEPOSITS

By
Arthur P. Butler, Jr.

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GEOLOGY AND MINERALOGY

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THE GEOLOGICAL SURVEY'S WORK ON THE GEOLOGY OF URANIUM AND THORIUM DEPOSITS

By Arthur P. Butler, Jr.

(Modified from version read at Information Meeting on Raw Materials Research, University of Arkansas, Fayetteville, Arkansas, November 29, 1951)

ABSTRACT

The Geological Survey has been studying the geology of uranium and thorium continuously since 1939, when it began a comprehensive investigation of the vanadium-uranium deposits of the Colorado Plateau. Greatly increased demand for uranium arising from the advent of controlled fission in 1942 resulted in widening of the study in 1944 to include other possible sources and in further expansion on behalf of the U. S. Atomic Energy Commission since 1947.

The wide variety of materials investigated in this study are embraced by five somewhat arbitrary groups of related types of deposits as follows: (1) Igneous rocks, pegmatites, veins, and related deposits; (2) Deposits in sandstone of carnotite, copper-uranium, and other minerals; (3) Other consolidated sedimentary rocks; (4) Placers; and (5) Natural fluids.

Much of the Geological Survey's work has been concentrated in geologic study and exploration of the carnotite deposits in sandstone, but many hundreds of occurrences of uranium, or of materials that might possibly be uraniferous, have been examined since 1944.

Several bodies of igneous rock among at least 100 tested contain 0.005 to 0.01 percent equivalent uranium. Although none yet found offer a large volume of rock from which uranium might be concentrated by simple means, search is continuing. The small size and low average grade of numerous pegmatites examined suggest that pegmatites constitute only an inconsequential source of byproduct uranium or thorium.

The study of uraniferous vein deposits has included examination of scores of metalliferous veins and few fluorite veins, mainly in eight western states; detailed studies of some districts; and increasing attention to the association of uranium with other elements, of zonal arrangement of uranium in metalliferous districts, and of wall-rock alteration. These studies have resulted in discovery of new

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occurrences in Colorado, in better definition of the position of pitchblende shoots in metalliferous districts in the Colorado Front Range and of the assemblages of minerals that may be guides to new occurrences, and in a more satisfactory basis for appraising resources.

Similar investigations have been made of thorium-bearing veins in California, Colorado, Montana, and Idaho.

Concentrations of carnotite and other uranium minerals associated with vanadium or copper minerals in sandstones of the Colorado Plateau region are the principal domestic source of uranium. Comprehensive study of ore deposits in the Morrison formation in this region was greatly expanded in 1947 to include extensive exploration by drilling. Areal and detailed geologic mapping and regional and detailed study of the stratigraphy of the Morrison formation has contributed significantly to definition of habits and distribution of ore and to more effective exploration for ore. Similar studies of the Shinarump conglomerate, which is the host for less well-known but increasingly significant deposits of varied mineralogy, are in progress. Preliminary investigations have also been made of recently discovered deposits in the southern Black Hills, S. Dak. and near Pumpkin Buttes, Wyo.

Intensive study of uraniferous sedimentary rocks following earlier reconnaissance has served to determine the most uraniferous parts of the Chattanooga shale, of some Florida and western phosphatic rocks, and of some western lignites and to define some of the relevant geologic features of these potentially significant low-grade sources of uranium. Some other black shales as radioactive as the Chattanooga have been noted, but they are thinner or less persistent. Most of the numerous other sedimentary rocks tested are not appreciably radioactive.

Some placer deposits contain monazite, the principal source of thorium and rare earths. Monazite-bearing placers in Idaho have been studied in reconnaissance and those of the Carolinas are being studied to determine which are most likely to contain exploitable deposits. Belts of source rocks for monazite in the Carolinas have been partly outlined.

Search for natural fresh water that might be a source of uranium or a clue to the presence of uraniferous rocks is in progress; and the significance of radon in some natural gases and of radioactive scale on some oil-well pipes and of the relation between uranium and some oils and asphaltites are being studied.

Investigations for uranium and thorium in Alaska have consisted mainly of reconnaissance of areas containing types of rock or an assemblage of metals thought to be possibly favorable for uranium. Some granitic rocks on the Seward Peninsula contain sparse uranothorianite, thorianite, uranothorite, and thorite; and small amounts of radioactive minerals are associated with vein deposits of other metals at five scattered localities. A phosphate bed in the Lisburne limestone on the north flank of the Brooks Range and black shale near the base of the Calico Bluff formation are the only appreciably radioactive sedimentary rocks that have been noted. Small amounts of radioactive minerals found in some placers are useful mainly as a clue to possible bed rock occurrences.

Looking to the future, we believe that the sandstone-type deposits of the Colorado Plateau are an assured source of uranium for a number of years. Increased difficulty and expense of finding additional deposits in new, untested areas may be partly compensated by better definition of geologic controls and improved techniques of exploration.

Although most of the known vein-type deposits are small the numerous small deposits in western United States suggest that a few large deposits may yet be discovered. Finally the low-grade deposits, such as phosphates, shales, and lignites are potential sources of large amounts of uranium.

INTRODUCTION

The use of uranium for atomic explosives and the possibility of using uranium as a source of industrial energy arising from the successful development of controlled fission of uranium in December 1942 has greatly increased the need, or demand, for uranium. Prior to 1940 uranium was used mainly for coloring some ceramic products, and its ores were mined chiefly for their content of radium (Matthews, 1943). Veins of pitchblende in the Belgian Congo, Canada, and Czechoslovakia, and veins of secondary uranium minerals in Portugal were the principal ores mined. Although the carnotite ores of the Colorado Plateau had been a principal source of ore prior to the discovery of the Belgian Congo deposits and a little pitchblende had been produced from a few precious- and base-metal veins in the Colorado Front Range, only very high-grade pockets of carnotite in the deposits of the Colorado Plateau were mined domestically for uranium in the years immediately prior to 1940. Small amounts of uranium were known to occur in other rocks.

The sources of uranium known in 1940 were adequate to supply the increased demand for a time, but it was apparent that new sources would have to be found to supplement those already known, if the potentialities of the new uses were to be realized over an extended period of years. Moreover, new domestic sources would be imperatively needed if our access to foreign sources were ever cut off. An intensive search for uranium has, therefore, been in progress for nearly a decade. This search has modified considerably the picture of uranium and thorium resources as they were known in 1940.

Vein-type deposits are still the main sources of uranium ore, and beach sands the source of thorium ore, but carnotite is a much more important source of uranium than it was in 1940. In addition, large resources of uranium have been found in other rocks, including some, such as lignite, not then known to be uraniferous.

It is the purpose of this paper to outline the contribution made to this search by the Geological Survey's work on the geology of uranium and thorium deposits since 1944. The Geological Survey began a comprehensive investigation of the carnotite deposits of the Colorado Plateau in 1939, and cooperated in 1943 with the U. S. Bureau of Mines in a program of drilling to assist in production of vanadium from these deposits. In 1944, the Manhattan Engineer District, Corps of Engineers, U. S. Army asked the Geological Survey to widen the field of its investigations to include other possible sources. Since then, and particularly since 1947 when the program was greatly expanded on behalf of the U. S. Atomic Energy Commission, the scope of the Geological Survey's work on the geology of uranium and thorium has become so comprehensive and diverse that only its broader features and principal results can be reviewed in a summary paper.

This review is slightly modified for written presentation from the paper that was given orally before the Information Meeting on Raw Materials Research at the University of Arkansas, Fayetteville, Ark., on November 29, 1951. It is essentially a compilation based on Geological Survey reports about the geology of uranium and thorium that are listed by Vickers (1951). Many of these have been published and a list of the published reports has been compiled by Curtis and Houser (1953). In order to simplify the presentation, specific citations will not be made here and the reader should refer to these bibliographies for more detailed information on topics that are of interest to him. Vicker's paper is unpublished and available only to some of the groups engaged in work on behalf of the Atomic Energy Commission, but the compilation by Curtis and Houser is published and available to anyone. Credit for the information and ideas expressed here belongs to the authors listed in those bibliographies. Without their efforts and abilities this paper would be neither necessary nor possible. Errors of interpretation may creep into a summary of this sort, and for this, the author is solely responsible.

Esther J. Aberdeen and Robert E. Thaden ably assisted in compiling and summarizing information used in parts of this report, and together with Robert W. Schnabel and Maryclare Lingenfelter compiled the accompanying maps. The report also has benefited materially from ideas and suggestions contributed by V. E. McKelvey.

CLASSIFICATION OF DEPOSITS

Few, if any, elements are concentrated under a more varied set of conditions than is uranium. Its ores include those formed under nearly all types of igneous, sedimentary, and weathering processes. For simplicity in the present review the various types of deposits and environments in which uranium occurs as the result of the operation of these processes are grouped into five somewhat arbitrary classes as follows:

1) Igneous rocks, pegmatites, veins, and related deposits.
2) Deposits in sandstone of carnotite, copper-uranium, and other minerals.
3) Other consolidated sedimentary rocks.
4) Placers.
5) Natural fluids.

The foregoing grouping is inconsistent to the extent that it is based on the principal features of the environment of a deposit and some of the groups listed include deposits of diverse modes of origin.

All deposits related to structural features across the host rocks, whether veins in the strict sense, fractures coated with uranium minerals, or replacement bodies, and deposits disseminated in igneous and metamorphic rocks are combined in the first group listed above. Vein deposits of uranium, especially pitchblende-bearing veins, have been the principal source of ore containing more than 0.5 percent uranium. A few granitic rocks contain 0.02 percent uranium in minerals disseminated through the rock but generally the igneous rocks contain very much less. None are at present sources of uranium.

Deposits in sandstone of carnotite, copper–uranium and other minerals include: (a) vanadium–uranium deposits in which carnotite is the principal uranium mineral and the amount of vanadium generally exceeds the uranium by somewhat less than an order of magnitude; (b) the "roscoelite-type" vanadium deposits in which uranium is markedly subordinate to vanadium; (c) the copper–uranium deposits; (d) carnotite–asphaltite deposits; (e) carnotite–uranium oxide deposits; and (f) schroeckingerite deposits in mixed sandy and clayey rocks. Most of these deposits have no clear relation to cross-cutting structures or to possible igneous sources.

The vanadium–uranium carnotite deposits occur mainly in the Morrison formation of Jurrassic age of the Colorado Plateau. The ore presently mined usually contains from 0.1 to 0.5 percent uranium. These deposits have been the principal source of domestic uranium.

The "roscoelite-type" deposits occur mainly in the Entrada sandstone of Jurrassic age at Placerville and Rifle, Colo. They have been a significant source of domestic vanadium but contain much less uranium than the carnotite–type deposits.

Copper–uranium deposits, and carnotite–asphaltite deposits occur mainly in the pre-Morrison formations of the Colorado Plateau, principally in the Shinarump conglomerate, but some occur in other formations elsewhere. The uranium content is similar to that of the carnotite-type deposits. Few copper-uranium deposits have been mined in the past, because they are in relatively inaccessible places. Production from them has been small. Many new deposits, however, have been discovered in recent years and deposits of this kind are a potentially important source of uranium.

Deposits in the Todilto limestone near Grants, N. Mex., are examples of carnotite-uranium oxide deposits. Their uranium content is comparable to deposits of the carnotite type (Reyner and Sheridan, 1950). They were found in 1950 and are still being explored.

A deposit in the Red Desert north of Wamsutter, Wyo., is the only known deposit in which schroeckingerite is the predominant uranium mineral. It contains from 0.01 to 0.1 percent uranium. No uranium has been produced from it.

Marine phosphorites and black shales are the principal uraniferous sedimentary rocks other than sandstones. Uranium has been found, however, in a few limestones and in some nonmarine lignite and associated carbonaceous sedimentary rocks. The uranium content ranges from a few thousandths to about 0.02 percent in black shales and phosphates and locally to 0.25 percent in lignite at La Ventana Mesa, N. Mex. Most other sedimentary rocks do not contain appreciable concentrations of uranium. Uranium in the marine sedimentary rocks is generally distributed rather uniformly in relatively thin stratigraphic units that extend throughout areas ranging from a few to several thousand square miles in size. Probably it was deposited synchronously with the sediments. In the lignites and related rocks, however, the distribution of uranium is much more restricted. Although these rocks are of sedimentary origin, and the deposits in them are included with those in sedimentary rocks, some of the present evidence suggests that uranium may have been introduced by supergene processes.

Placers include stream and marine beach deposits of sands and gravel, mostly of relatively recent geologic age, although a few fossil placers are known. Placer deposits of uranium-bearing minerals are confined almost exclusively to accumulations of zircon and monazite, both of which generally contain from a few hundredths to a few tenths of a percent of uranium. They are primarily a source of thorium though it is possible that some uranium may be recovered as a byproduct of the treatment of thorium- or zircon-bearing minerals won from placers.

Natural fluids include water in springs, streams, lakes, and seas, oil-well brines; oil; asphalt; and natural gas. Some of these are radioactive, but the radioactivity in many of them arises from daughter products of uranium. None are at present a source of uranium. The source of the radioactive elements and their significance with respect to possible subsurface concentrations present some challenging geologic problems.

STUDIES OF DOMESTIC DEPOSITS

Introduction

A large part of Geological Survey's work on the geology of uranium and thorium deposits has been concentrated in exploration and geologic study of the vanadium-uranium (carnotite) deposits of the Colorado Plateau. Since 1944, however, the Geological Survey has examined hundreds of occurrences of uranium, or of materials that available evidence suggested might be uraniferous. A picture of the geographic scope and the variety of materials can be gained from the maps that accompany this report. (See pls. 1-6.)

Igneous rocks, pegmatites, veins and related deposits

Igneous rocks

Uranium and thorium occur in most igneous rocks but are more abundant in the granitic rocks. They are concentrated primarily in the accessory minerals of these rocks: allanite, zircon, sphene, apatite, monazite, and magnetite. Pyrochlore-bearing granite, richer in uranium than any known domestically, occurs in Nigeria (Davidson, 1951).

The Geological Survey has tested at least 100 bodies of igneous rocks. Many of these cannot be shown because of the scale of plate 1. Others are in areas of vein deposits and are not shown separately. In addition, the radioactivity of numerous outcrops of igneous rock in New England has been measured by carborne equipment. A few igneous rocks, representing late-stage magmatic differentiates have been found that contain 0.008 to 0.015 percent uranium. Granitic rocks containing 0.005 to 0.01 percent equivalent uranium are rather common, and many granites are more radioactive (See also Davidson 1951, p. 330.) than those generally reported in the literature (Evans and Goodman, 1941). No domestic igneous rock has been found, however, comparable to the Nigerian granite mentioned above.

Many of the more radioactive rocks contain thorium in excess of uranium. Incomplete data suggest, however, that only locally do granitic rocks contain as much as 0.1 percent thoria, for example, the biotitic Archean gneiss in Los Angeles and San Bernardino Counties, Calif. Generally, granitic rocks contain very much less.

Although no igneous rocks have yet been found that appear to be potential sources of uranium and thorium, the presence of granites more radioactive than those generally reported in the literature and of some late-stage differentiation phases of igneous rocks more radioactive than the average granite suggest that igneous rocks deserve continued scrutiny. Syenitic rocks in the Bear Paw Mountains and Crazy Mountains, Mont., intrusive rocks of the Spanish Peaks, Colo., and granitic rocks in which niobium or molybdenite have been reported are examples of rocks that may be worth examining. The mineralogy and distribution of uranium and thorium in igneous rocks deserve continued study to improve our understanding of the behavior and habits of those elements in igneous rocks and the processes by which they are concentrated. Continued examination of felsic rocks may also reveal masses of rock in which as little as 0.01 percent uranium may occur in a mineral form amenable to concentration by simple methods.

Pegmatites

Pegmatites have long been known as sources of specimens of uranium and thorium minerals, but they have not been an important source of those metals. Some pegmatites in South Dakota and in the southeastern states were examined during the early years of the program. In addition, information about uranium and thorium minerals in a vast number of pegmatites was accumulated in the course of the Geological Survey's strategic minerals investigations for mica and beryl during World War II (Page, 1950). The results of both investigations showed that the uranium content in uraniferous pegmatites approximates that of granitic rocks. Because they are relatively small bodies of low average grade they would be only insignificant sources of uranium or thorium.

Veins and related deposits

Vein deposits as possible sources of uranium in the United States capture the imagination because the spectacular bonanzas of uranium are veins in Canada and the Belgian Congo that have been the chief world source of uranium. Pitchblende veins in the United States, however, have contributed only about 50 tons of uranium or about 3 percent of Bain's (1950) estimate of total United States production up to 1940. Although domestic vein deposits are unlikely to be an adequate source of uranium over a long period, they may be a valuable supplementary source for medium- and high-grade ore amenable to treatment by developed processes. For this reason search for them is warranted. Moreover, as production of high-grade uranium ore in the United States was largely incidental to the mining of other ores, rather than a primary object of mining, little concentrated effort had been devoted to trying to understand the distribution of uranium in veins and to appraise the possibilities of finding uraniferous parts of veins already known or of finding new uranium-bearing structures.

The Geological Survey has examined scores of metalliferous and some nonmetalliferous vein and related deposits in about a dozen states, mainly in the west (pl. 1). The localities visited were selected either because of the recorded presence of uranium, favorable metal association; indication of radioactivity obtained in scanning many hundreds of mine, mill, and smelter products originally collected in a search for byproduct sources of other elements that were in short supply during the war; or the presence of uranium in samples submitted by the public.

The deposits include pitchblende-bearing gold-silver and base-metal veins in the Front Range, Colo.; copper and tin-bearing structures in the Majuba Hill mine, Nev.; veins of secondary uranium minerals in the White Signal district, N. Mex., and the Marysvale district, Utah; uranium-bearing silicified zones in the Boulder batholith in the Clancy district, Mont.; pitchblende in pyrometasomatic deposits in the Franklin limestone, Warren County, N. J.; uraniferous fluorite veins in the Jamestown district, Colo., and in the Thomas Range, Utah; thorium-bearing veins of rare-earth minerals in the Clark Mountain district, Calif. and thorite-bearing veins in Custer County, Colo. -- to name a few.

Pitchblende is the principal uranium mineral in many of the vein deposits studied by the Geological Survey. Brightly colored secondary uranium minerals, principally phosphates, silicates, vanadates, carbonates, and sulfates, are the principal uranium minerals in others.

Pitchblende occurs in many veins as grains, nodules, or disseminated masses forming high-grade pods or shoots separated by larger masses of essentially barren vein material. Many of the uraniferous shoots in deposits of the Front Range, Colo., are only small parts of extensive fractures containing deposits of other metalliferous minerals, principally those of gold, silver, lead, and zinc for which the veins were originally mined. Assemblages of these minerals, and of cobalt- and nickel-bearing minerals, smoky quartz, and dark-purple fluorite occur with much of the pitchblende and are valuable guides to new occurrences of uranium.

Many of the deposits of secondary uranium minerals are the result of weathering of deposits of primary uranium minerals. Their form and distribution are, therefore, analogous to those of the deposits of primary minerals from which they were derived. On the other hand, because the minerals are formed by supergene processes, their distribution is controlled in part by factors that were not present at the time of deposition of the primary minerals. As a result, the secondary minerals in some deposits represent an outward displacement of uranium into rocks surrounding the places where primary uranium oxide originally was deposited. Where such dispersal has occurred the deposits are showy but of lower-grade than the primary deposits from which they were derived. Some deposits of secondary minerals, therefore, are indicative of higher-grade deposits of primary uranium minerals beneath the zone of secondary minerals, or horizontally back from the outcrop of that zone in some of the sandstone-type deposits. Deposits of secondary minerals are known, however, in several places where primary uranium minerals have not yet been found, for example, the Yellow Canary claims, Daggett County, Utah, in the White Signal district, N. Mex., and at Majuba Hill, Nev.

The larger number of the deposits that we have examined were discovered by the general public. Much of the Survey's work on vein deposits has been reconnaissance examination and appraisal of deposits so discovered. At the same time we have carried on a search for new deposits. Examination of deposits discovered by others will be a necessary part of our work in the future, but the finding of obscure and concealed deposits of uranium demands application of geologic principles. In the study of vein deposits more attention is, therefore, being directed to the study of metal associations that may suggest favorable areas and to the study of known districts to define principles useful in exploration for ore and appraisal of resources. Studies of metal associations led to examinations in the Alma and St. Kevin districts, Colo., and in some mineralized districts of the northwestern part of the San Juan Mountains, Colo., during the summer of 1951. Uranium minerals were discovered in sulfide ore at the London mine, Alma district, at numerous places in the St. Kevin district, and at four places in the northwestern part of the San Juan Mountains. One of these deposits, in the Red Mountain district, in the San Juan Mountains, is a chimney-like body of ore rich in copper, silver, and lead. More detailed study of some of the deposits will be warranted.

Appreciation of the significance of radioactive purple fluorite led to investigation of the relatively new fluorite district in the Thomas Range, Utah. The investigations indicated that the geologic setting of the deposits was favorable enough to warrant some preliminary exploration to evaluate better the potentialities of the district. District studies with the aim of determining useful geologic guides to uranium distribution and a better appraisal of resources are being made in the White Signal district, N. Mex., the Lawson-Dumont and Central City districts, Colo., and the Boulder batholith area, Mont.

Studies of mineral associations in most of the mining districts in western United States, and evaluation of data already obtained on zonal arrangement and distribution of uranium and associated minerals, on gangue minerals, and on wall-rock alteration also are being continued as a means of selecting other possibly favorable districts for investigation.

Thorium-bearing deposits are being investigated concurrently with those of uranium, but less aggressively. D. F. Hewett of the Geological Survey recognized the potential importance of bastnaesite-bearing carbonate veins in the Clark Mountain district, San Bernardino County, Calif., when they were brought to his attention by a local prospector. These deposits may be a major domestic source of rare earths and may contain a large but low-grade reserve of thorium. The thorium may be present as a minor constituent of the vein minerals but it is also present as monazite. Thorium-bearing veins are also being studied in Beaverhead County, Mont., Lemhi County, Idaho, and Custer and Gunnison Counties, Colo.

Present data suggest that additional reserves of thorium will be found in some of these areas.

Sandstones

Deposits in sandstone have been the principal domestic source of vanadium and uranium. Production from these deposits has been the chief factor in lifting the United States into second place among the free nations as a producer of uranium (U. S. Atomic Energy Commission, 1951). Most of the deposits are concentrated in the Colorado Plateau in Colorado, Utah, Arizona, and New Mexico, but similar nonproductive deposits occur in Wyoming, Idaho, Nevada, Texas, Oklahoma, South Dakota, and Pennsylvania. (See pl. 2.)

Concentrations of vanadium, copper, silver, and other metals accompany the uranium at many places. Carnotite is the principal uranium mineral of these deposits, but copper-uranium minerals, uraniferous asphaltite, uranium oxide (possibly pitchblende), and complex secondary minerals are locally dominant.

The deposits are mainly in nonmarine sandstones, though some of them are in limestone or mudstone. Generally the beds are lenticular and the deposits within them are small and have a spotty distribution. The grade of the deposits being mined commonly ranges from 0.1 to 0.5 percent uranium.

Carnotite-type deposits in the Morrison formation and roscoelite-type deposits in the Entrada formation account for most of the known deposits of economic importance, but deposits of carnotite and uranium oxide in the Todilto formation and copper-uranium and uranium-asphaltite deposits in the Shinarump conglomerate are assuming greater importance as they become better known.

The Geological Survey began a comprehensive study of the deposits in the Morrison and Entrada formations in 1939, and cooperated with the Bureau of Mines in a program of drilling to assist production of vanadium in 1943. An expanded program of geologic study and exploration on behalf of the Atomic Energy Commission began in 1947. Much of the work has been done by or been carried out under the leadership of R. P. Fischer, and his ideas have contributed materially to the effectiveness of drilling, the results of which are summarized in a paper by V. E. McKelvey (1951 p. 10).

Geologic studies related to the carnotite-type deposits have included areal mapping of eighteen 7 1/2-minute quadrangles in Colorado and four 30-minute quadrangles in Arizona, detailed mapping of ore-bearing parts of the Morrison in areas near ore deposits, and comprehensive regional and detailed studies of the stratigraphy of the Morrison formation. These studies, together with data obtained from observation of drill cores and mine faces, are leading to definition of habits of the deposits and characteristics and composition of the enclosing and associated rocks, and to a concept of a large-scale pattern in the distribution of ore bodies that are proving useful in selecting areas for drilling and in the search for ore within favorable areas.

Deposits of copper-uranium ores in the Shinarump conglomerate of Triassic age have been known for years, but were not mined, chiefly because of their remoteness. Interest in them has been stimulated by the post-war demand for uranium and they are being actively prospected and mined.

The Geological Survey is engaged in regional geologic mapping and study of the geology in the areas where deposits occur. This work is aimed at acquiring an understanding of the habits of the ore and the factors that controlled its localization in order to develop guides useful in exploring for concealed deposits and a basis for appraising more satisfactorily the resources in deposits of this type. Comprehensive work by Smith, Witkind, Benson and others is underway in the Monument Valley Area, Ariz., and in the Capitol Reef National Monument and White Canyon areas in Utah. Parts of some of the areas have been selected for exploration.

Reconnaissance examination of similar deposits is also being carried out in other parts of Arizona, Utah, Colorado, New Mexico and Wyoming. Occurrences of uranophane, carnotite, and other uranium minerals were found near Pumpkin Butte, Wyo., by J. D. Love in the course of reconnaissance investigations during the summer and fall of 1951, and deposits of carnotite in the vicinity of Craven Canyon, S. Dak., have been examined by Page and others. The chances appear good that further search in areas outside as well as within the Colorado Plateau will reveal other promising deposits.

Other consolidated sedimentary rocks

The radioactivity of parts of the Phosphoria formation in Montana and the Chattanooga shale in Tennessee was discovered in 1944 during the scanning of samples of mine, mill, and smelter products for radioactivity as mentioned in the review of work on vein deposits.

Subsequent investigation of the Chattanooga shale by Nelson, Brill, Conant and others included reconnaissance measurement of radioactivity and sampling in Alabama, Tennessee, Virginia, Kentucky, and Indiana, and geologic mapping, more detailed sampling, and comprehensive study in an area of some 4,400 square miles in Tennessee where the shale is most radioactive. (See pl. 3.) These studies showed that three upper units of the shale are most uraniferous, defined the areas in which they are richest in uranium, and provided information for estimating reserves.

Reconnaissance investigation of the Phosphoria formation in Montana in 1944 showed that the phosphatic beds of the formation are uraniferous over a large area. (See pl. 4.) Comprehensive investigation of the formation in Idaho, Wyoming, and Utah was begun in 1947 by McKelvey, Swanson, Lowell, Kennedy, and others to appraise as completely as possible resources of phosphate in western United States. Study of the uranium content of the formation has been carried on jointly with the more comprehensive investigation. The work has included extensive sampling, study of stratigraphy and composition of the formation, and geologic mapping in selected areas. Distribution of phosphate and uranium, their relation to major stratigraphic features, the areas richest in phosphate and uranium, and structural features important in utilization of the deposits have been defined, and estimates of reserves have been made.

The results of the early work on the Phosphoria formation suggested that the land-pebble phosphate deposits and the so-called hard-rock phosphate deposits farther north in Florida should be investigated. The phosphate products derived from the Bone Valley formation in the land-pebble field proved to be about as uraniferous as the Phosphoria formation. These products account for the greater part of domestic phosphate production.

Comprehensive investigation of the Bone Valley deposits was begun in 1947. Although a major part of the effort has been devoted to determination of reserves of phosphate and uranium in areas that will be mined within the next few years, much data have been obtained on distribution, stratigraphy, and composition of the phosphatic rocks and their relation to overlying and underlying rocks. In the course of this work Cathcart and Altschuler have recognized a zone of partly leached, uranium-bearing phosphatic material overlying the workable phosphate deposits. The uranium content in parts of this zone is comparable to that in the phosphate products derived from the underlying rock. Much of the leached zone is quartz sand that may be readily separable from the uranium-bearing materials of the zone.

The work done thus far by the Geological Survey suggests that marine phosphates, in general are likely to be uraniferous, though the uranium is not uniformly distributed in the phosphatic rock. The reasons for the lack of uniformity and the factors causing greater or lesser concentration are still subjects of study.

A glance at plate 3 will show that the Geological Survey has examined many shales in addition to the Chattanooga. The uranium content of some, such as the Bourbon and Hushpuckney, is comparable to that of the Chattanooga shale; but their thickness and extent are less. Most shales, such as those of Devonian age in New York and parts of the Modelo formation in California, are at best only slightly radioactive, but many shales remain to be tested.

The results of investigations of shales by the Geological Survey and others, especially Beers (1945) and Russell (1945) shows that marine carbonaceous shales are more likely to be uraniferous than noncarbonaceous shales or nonmarine shales such as the Green River. Although some work has been done on the relation between uranium and other components of the shales and the relation between uranium and stratigraphy and environments of deposition, a great deal more work will be necessary before enough factors in the relationship are well enough understood so that those shales most likely to be uraniferous can be selected for investigation.

Coals and associated carbonaceous shales are generally among the least uraniferous rocks, but uranium was discovered in some lignites in the Red Desert area, Wyo. in 1945 and in some lignites in southwestern North Dakota in 1948 (pl. 3). Subsequent studies in South Dakota showed that the topmost lignite below an unconformable contact with the tuffaceous White River formation of Oligocene age is generally the most uraniferous bed in a sequence of beds. A working hypothesis was developed that uranium had been leached from the tuffaceous rock and fixed in the lignite. Examinations during the summer of 1951 of lignites or coals associated with tuffaceous rocks has led to the discovery of other uraniferous coaly rocks in Idaho, Wyoming, and New Mexico. On the other hand coals in areas of Tertiary volcanic rocks in the far northwest are not uraniferous.

Most other sedimentary rocks that have been tested by the Geological Survey are not appreciably radioactive, but all of them cannot be dismissed summarily from further consideration. Limestones, as Russell (1945) also has pointed out, are generally very weakly radioactive, but uranium comparable in amount to that in some shales has been found in a lenticular freshwater limestone in the Uinta formation in Utah and locally in a Cambrian dolomite near Milton, Vt.

The uraniferous sedimentary rocks as a group contain the largest reserves of uranium, but the relative amounts are so small that the possibility of effective recovery is still problematical. On the other hand, it is probable, as experience in 1951 demonstrates, that continued investigation will reveal sedimentary rocks more uraniferous than those now known.

Placers

Placer deposits of uranium-bearing minerals are confined almost exclusively to accumulations of relatively insoluble and abrasion-resistant minerals such as zircon and monazite. Most of the world's thorium has been won from placer deposits of monazite. This mineral occurs in extensive placers in Idaho, where it is associated with zircon and gold, and in placers in parts of North Carolina and South Carolina (pl. 5), from which it was formerly mined.

The Geological Survey has made a reconnaissance investigation of placers in Idaho and other areas shown in plate 5. In southeastern United States, two belts of monazite-bearing granitic and gneissic rocks have been discovered by J. B. Mertie and are being outlined in detail. These areas of bedrock are sources of monazite in beds of streams draining across or rising in them. Placers in the headwaters of streams draining the western belt contain from 1 to 50 pounds of monazite to the cubic yard, but the mean value is within the lower fifth of the range. These valley-head placers are small. Although downstream deposits of sand and gravel are larger, the concentration of monazite in them is less.

The Geological Survey is continuing examination of placer areas in the Carolinas to determine which are most likely to contain exploitable deposits. The most favorable areas are being explored in cooperation with the U. S. Bureau of Mines.

Placer deposits in most areas other than Idaho and the Carolinas appear to be unpromising sources of uranium or thorium, except as small quantities of monazite may be recovered as a byproduct of the mining of other minerals, such as ilmenite and rutile from old beach deposits in Florida.

Natural fluids

Some natural fluids, especially some waters, are radioactive. The radioactivity in them is caused mainly by radon and its daughter products. Usually large amounts of radon are present in some natural gases.

The Geological Survey has collected natural waters from time to time mainly in the course of other investigations, and analyzed them for uranium (pl. 6). During the summer and fall of 1951 about 50 samples of waters from springs, hot springs and streams, rising in different types of geologic terranes were collected for a joint project with the Oak Ridge National Laboratory. Waters of springs and seeps rising in or close to known uraniferous rocks, black shale in Tennessee, carnotite deposits on the Colorado Plateau, tuffaceous sandstone in South Dakota, and phosphate rock in Florida, are generally richest in uranium and contain from 16 parts of uranium per billion in a spring in a phosphate mine pit in Florida to 690 parts per billion in seepage water in a tunnel in the Chattanooga shale in Tennessee.

Most rivers and hot springs contain less than 10 parts uranium per billion, and generally less than 1 part.

Highly radioactive scale was found by Gott in some lead-off pipes from oil wells in the vicinity of the Nemaha Ridge in Kansas, although brines from some of these wells contain less than 1 part of uranium per million. Hill found that some of the natural gas in the Panhandle field, Tex., was radioactive, and further study showed that the gas contains a little radon. The significance and source of the daughter products of uranium in these places present some challenging geologic problems that are still being studied.

Fluid hydrocarbons, such as asphaltite and oil, that the Geological Survey has tested are not perceptibly radioactive. Some of the asphaltite in the Temple Mountain area is an exception, but is only one of several substances with which uranium minerals are associated in similar deposits throughout a much wider area.

STUDIES OF ALASKAN DEPOSITS

Work on the geology of uranium and thorium deposits in Alaska has consisted mainly of reconnaissance investigations and has closely paralleled similar work in the United States, but methods and the general scheme of work have been modified to suit conditions in the Territory. In general, the possible sources of uranium and thorium in Alaska are similar to those in the United States, although the presence of sandstone-type deposits has not been verified, and very little investigation has been made of fluid sources.

Igneous rocks in Alaska have been tested at about 20 localities. (See pl. 7.) Bedrock or float blocks nearly in place have been tested at the outcrop. Samples from some localities have been crushed and panned and some samples of gravel from streams with sources solely in areas of igneous rocks have been panned to concentrate the heavy minerals. The results obtained generally correspond with those obtained in the study of igneous rocks in the United States, but uranothorianite, thorianite, uranothorite, and thorite have been found among the accessory minerals of some granitic rocks, especially on the Seward Peninsula.

Numerous reported occurrences of uranium in vein and related deposits have been brought to the attention of the Geological Survey by the Territorial Department of Mines and individual prospectors. Many of these as well as other vein and related deposits believed to be possibly favorable for uranium, because of the metals that have been reported in them, have been investigated. The investigations have disclosed the presence of uranium-bearing minerals in a metalliferous vein in the Hyder district and radioactive hematite-carbonate veins in the Wales district, southeastern Alaska; radioactive materials, mainly thorium-bearing, associated with contact gold-copper deposits at Nixon Fork in the Kuskokwim region; and deposits of secondary copper-uranium minerals near Aniak in the Kuskokwim region and in tin-bearing parts of the York district on the Seward Peninsula.

The area of Alaska is great and the geology of much of it is little known so that information for making geologic deductions is very incomplete. Data are being collected and studied on the distribution and occurrence of metals and minerals with which uranium is associated in deposits in other parts of the world. The inferences drawn from this study together with data obtained from samples of vein deposits collected by Survey geologists not directly engaged in the investigations of uranium or furnished by prospectors will continue to be the principal guides for future work.

Samples of carnotite-bearing limestone from an undisclosed location in the Yetna district, south-central Alaska have been furnished to the Survey by prospectors. No other deposits possibly similar to the domestic carnotite deposits are known.

Several kinds of sedimentary rocks have been tested for radioactivity at numerous places mainly in east- and south-central Alaska. Only phosphate rock in the Lisburne limestone of Mississippian age on the north flank of Brooks Range and some black shales are perceptibly or appreciably radioactive. Some of the bedded phosphate rocks are similar to the Phosphoria formation and contain about the same amount of uranium. Most of the black shales are only weakly radioactive, but the radioactivity of some black shale beds on the upper Yukon River near the base of the Calico Bluff formation of upper Mississippian age is comparable to that of the Chattanooga shale.

Several hundred samples of placer concentrates in the Geological Survey's collection of Alaskan samples were scanned for radioactivity in 1944. The results suggested that several placer areas might be promising sources of radioactive materials. Field investigations in 1945 and 1946 showed, however, that the placers contain only small amounts of radioactive minerals although some of them contain a wide range of the more resistant uranium- and thorium-bearing minerals. Since 1947 placers have been tested mainly to determine whether or not they carried minerals that might be indicative of bed-rock sources of uranium or thorium in the drainage basin of the streams in which gravels occur.

THE FUTURE OF DIFFERENT KINDS OF DEPOSITS

Our appraisal of future possibilities of different kinds of deposits governs the direction our work takes and the emphasis placed on particular parts of it. This appraisal, of course, must be constantly reviewed as new information is developed and confirmed. It may be useful, however, to close this paper by such an appraisal.

First of all the sandstone-type deposits of the Colorado Plateau have assured potentialities as a source of uranium for some time to come, as the results of drilling and new discoveries in the last 2 or 3 years amply demonstrate. On the other hand, as exploration is pushed back into new untested areas, uranium ore will be more difficult and costly to find, and more costly to mine. We hope, however, that less favorable conditions for exploitation and discovery will be partly offset by the ability of geologists to improve the definition of favorable environments and to apply improved techniques developed by scientists in related fields. Furthermore, the discovery of carnotite deposits in South Dakota suggests that careful search in other areas where the geology is suitable may find still other deposits that will augment the supply of ore of this type.

Vein-type and related deposits are the next most promising source of ore for immediate use. Occurrences of this type of deposit, though mostly small, are so widespread in the United States west of the Great Plains that L. R. Page and other geologists of the Geological Survey interpret a large part of this region as a uraniferous metallogenic province. Nolan (1936) has observed that 85 percent of the ore of nonferrous metals produced from part of an area within one geologic province, the Basin and Range, has come from 10 out of 284 districts reported. If similar relationships hold within several geologic provinces, then the pattern would be the same in large regions such as western United States embracing several diverse provinces. It would seem likely, therefore, that the known presence of a large number of small deposits may be indicative of the existence of a few large undiscovered deposits. Such reasoning appears particularly valid with respect to uranium, because many of the vein and related deposits in which uranium is known are deposits in parts of structures that have been prospected mainly for metals other than uranium. The chances are favorable for the presence of a few large deposits awaiting the industrious prospector or the astute interpreter of the accumulating information about deposits of this type.

Lastly, low-grade deposits, especially those in which uranium is a byproduct, such as the phosphates, or those with coproduct possibilities such as the lignites are potential sources of large amounts of uranium. A fair share of our efforts will be devoted to searching for better deposits in carbonaceous rocks than we now know and for possible new sources in igneous rocks. We hope that research in geochemistry and geology as outlined in other papers presented at the Arkansas Information Meeting will contribute materially to this search.

Finally, although thorium is not of the same immediate interest as uranium, we plan to do relatively more work on its deposits than we have in the immediate past, so that if and when it is really in demand, the necessary information will be at hand.

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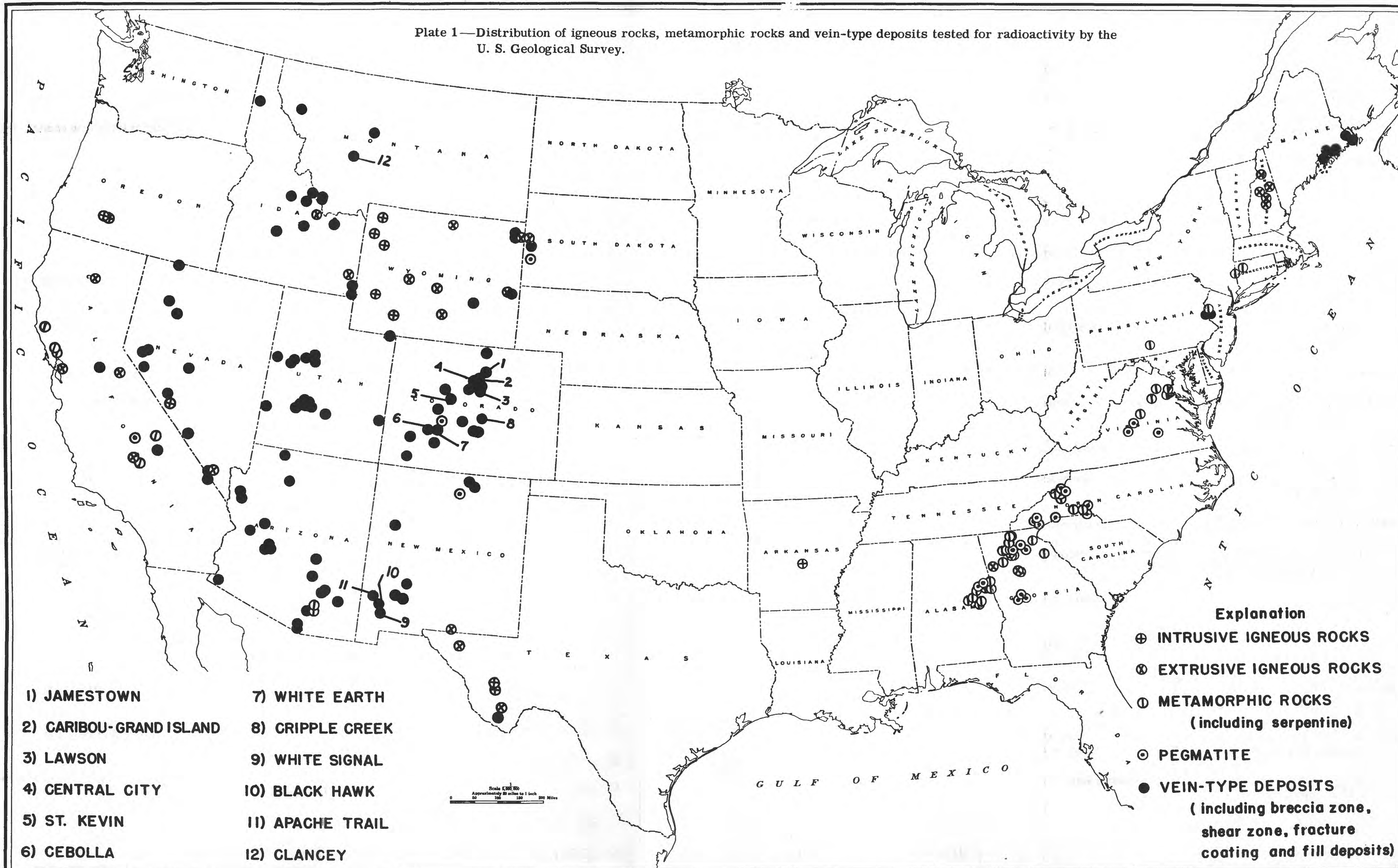


Plate 1—Distribution of igneous rocks, metamorphic rocks and vein-type deposits tested for radioactivity by the U. S. Geological Survey.

Plate 2—Distribution of sandstone tested for radioactivity by the U. S. Geological Survey.

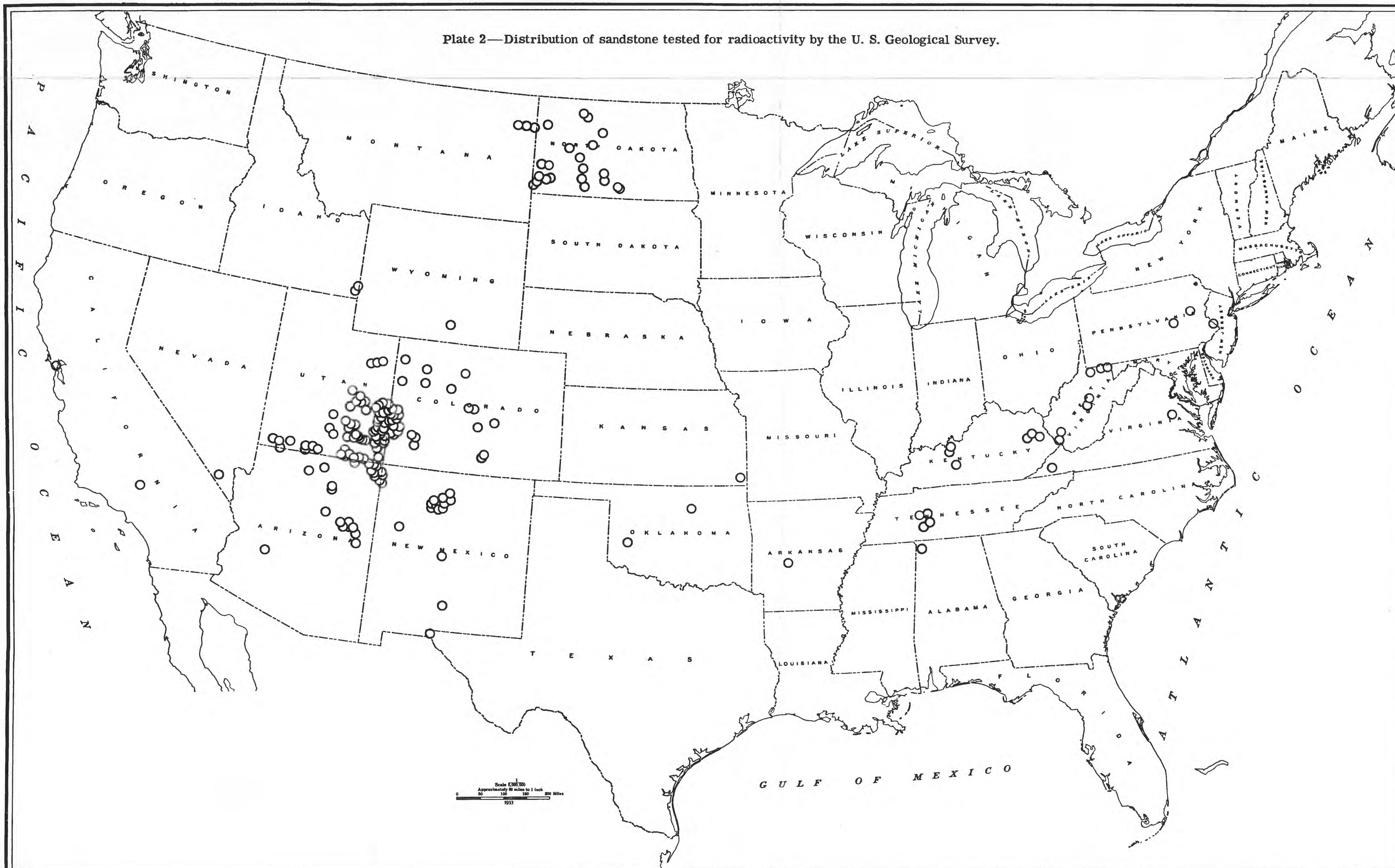
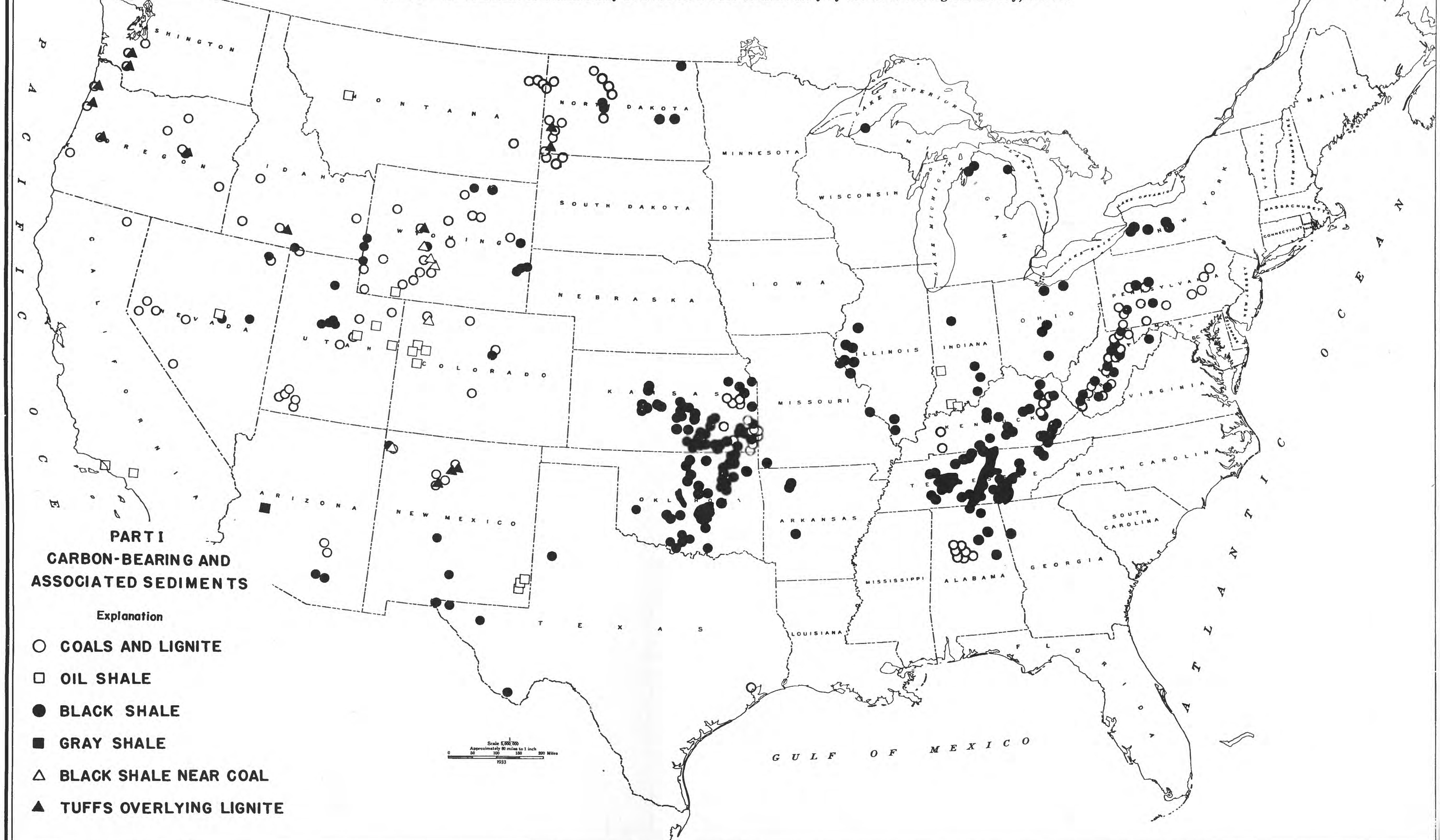


Plate 3—Distribution of sedimentary sources tested for radioactivity by the U. S. Geological Survey, Part I.



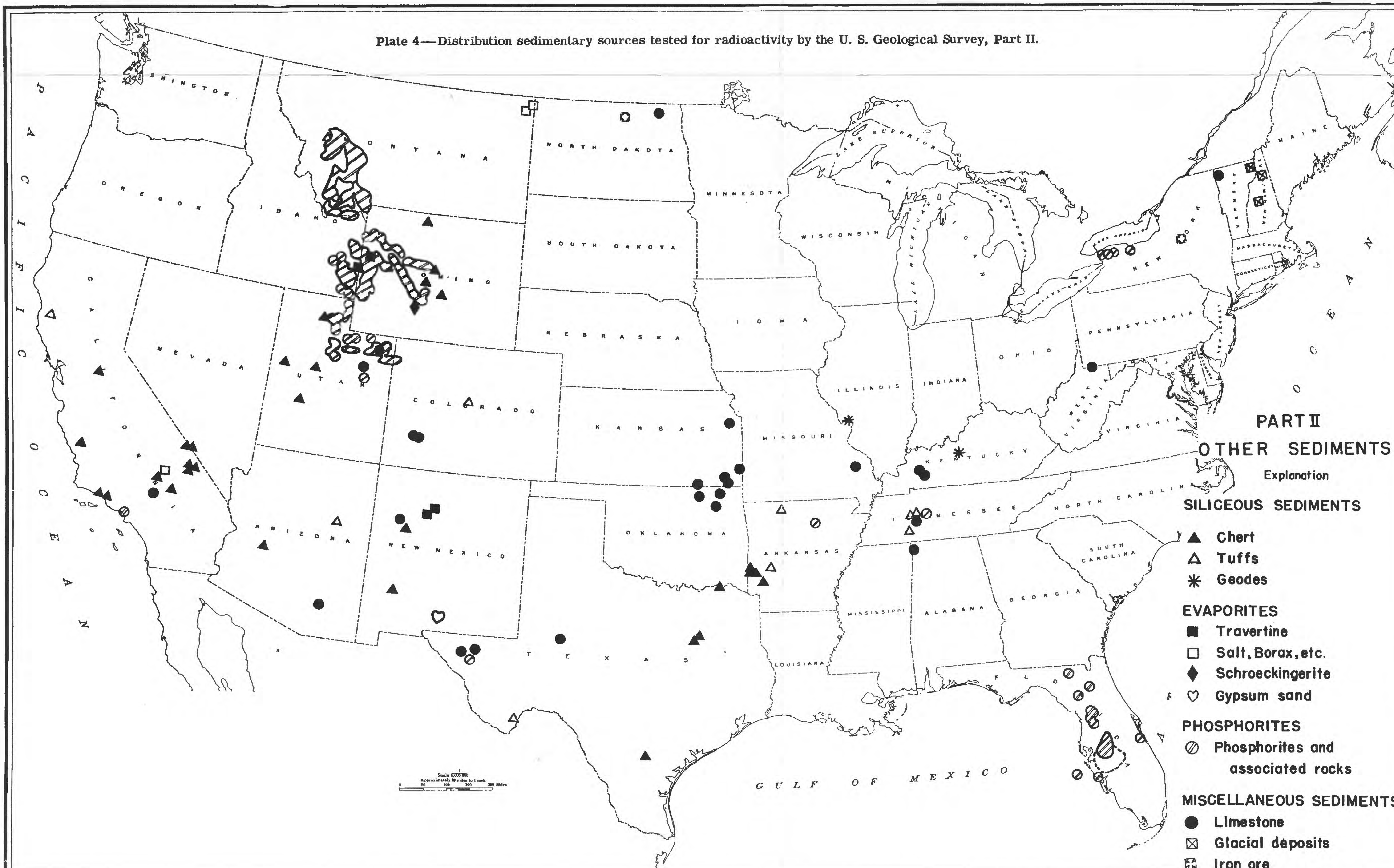
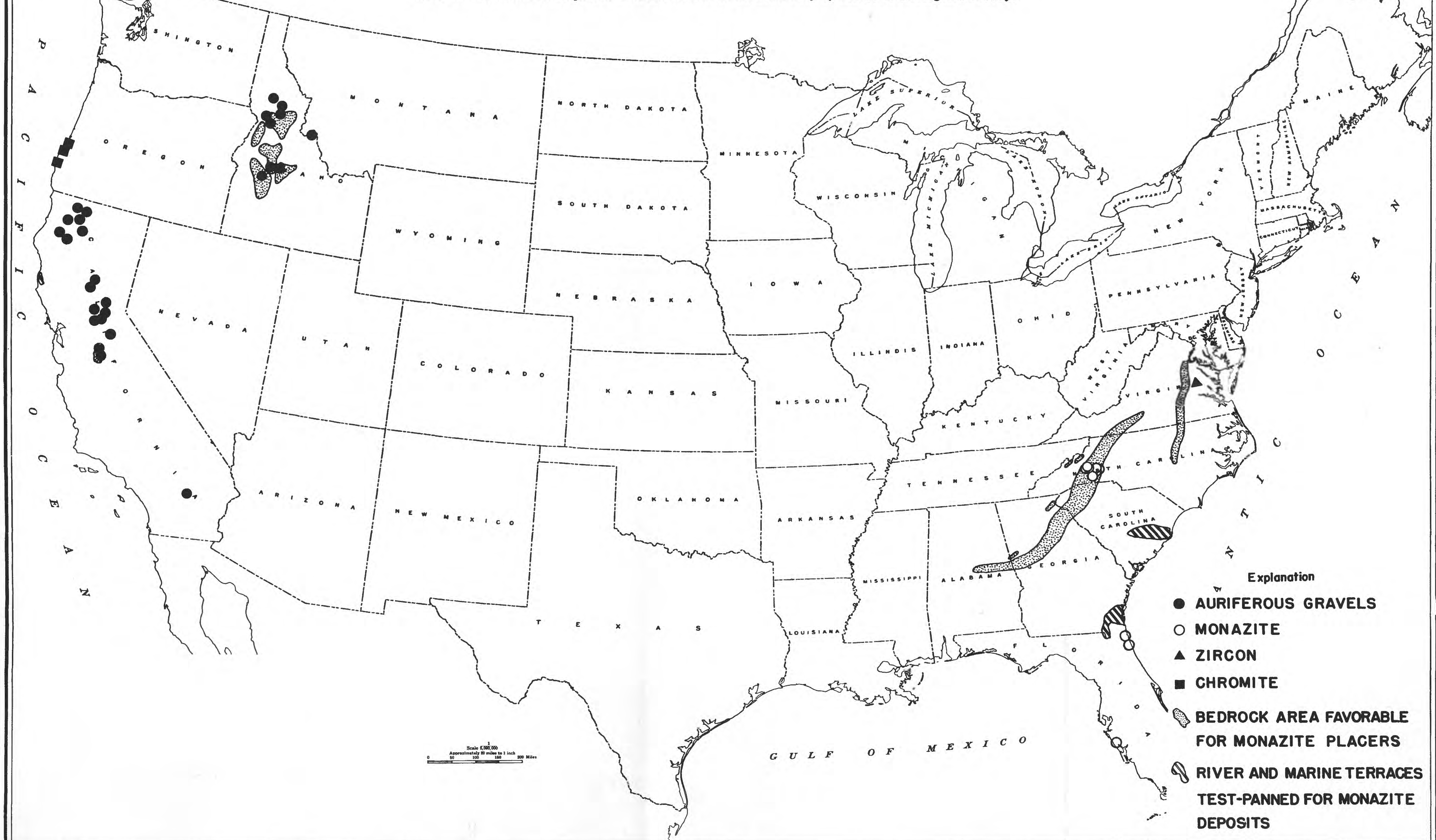


Plate 4—Distribution sedimentary sources tested for radioactivity by the U. S. Geological Survey, Part II.

Plate 5—Distribution of placer sources tested for radioactivity by the U. S. Geological Survey.



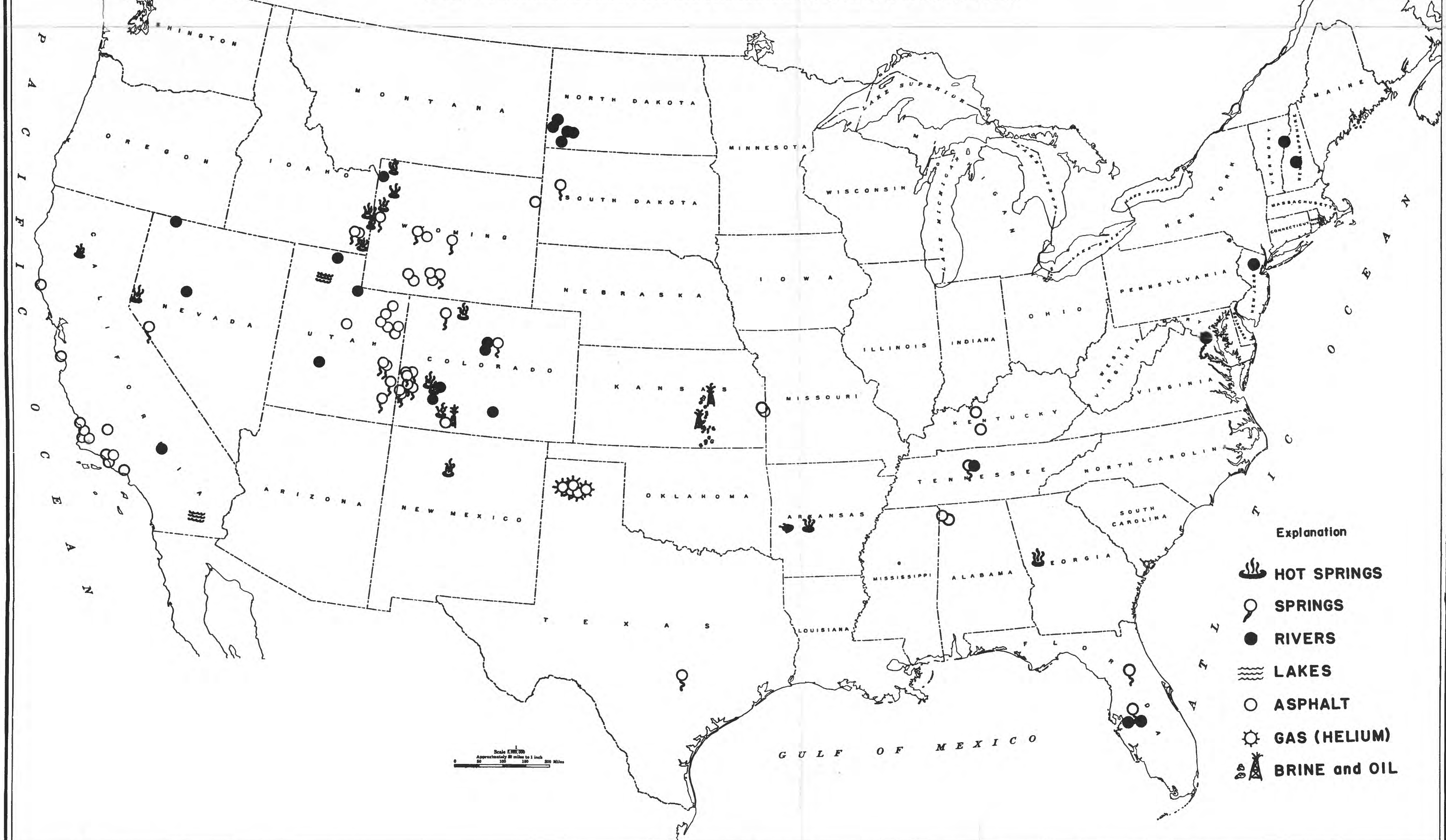


Plate 6—Distribution of fluid sources tested for radioactivity by the U. S. Geological Survey.