SEARCH FOR URANIUM IN WESTERN UNITED STATES

By V. E. McKelvey

Trace Elements Investigations Report 199

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Geology and Mineralogy

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ABSTRACT

The search for uranium in the United States is one of the most intensive ever made for any metal during our history. The number of prospectors and miners involved is difficult to estimate but some measure of the size of the effort is indicated by the fact that about 500 geologists are employed by government and industry in the work--more than the total number of geologists engaged in the study of all other minerals together except oil.

The largest part of the effort has been concentrated in the western states. No single deposit of major importance by world standards has been discovered but the search has led to the discovery of important minable deposits of carnotite and related minerals on the Colorado Plateau; of large, low grade deposits of uranium in phosphates in the northwestern states and in lignites in the Dakotas, Wyoming, Idaho and New Mexico; and of many new and some promising occurrences of uranium in carnotite-like deposits and in vein deposits. Despite the fact that a large number of the districts considered favorable for the occurrence of uranium have already been examined, the outlook for future discoveries is bright, particularly for uranium in vein and in carnotite-like deposits in the Rocky Mountain States.

INTRODUCTION

It is a pleasure to talk to you this evening about the search for and geology of uranium deposits in the Western States, partly because some of the most significant domestic discoveries have been made in Wyoming and also partly because uranium is more intimately involved in the fields with which petroleum geologists are most concerned than is any other metal. Because of the close relationship between petroleum geology and uranium geology, petroleum geologists have already made significant contributions to the geology of uranium and I believe we may expect to see uranium geologists contribute toward the solution of some important problems in petroleum geology in the future.

The search for uranium in the United States is one of the most intensive ever made for any metal during our history. In the 10 years since the search began, many thousands of man-years have been devoted to it, mostly in the Western States. Some indication of the size the effort now has attained is shown by the fact that about 500 geologists are employed by government and industry in uranium geology--more than the total number of geologists engaged in the study of all other minerals put together except oil. A detailed account of the subject, therefore, can't be given here, but I will attempt to tell you something about the common uranium minerals; the kinds of deposits in which uranium is found; the methods used in the search for uranium; the important deposits found thus far; the supporting research in progress; and the outlook for the future.

COMMON URANIUM MINERALS

Uranium forms a great variety of minerals--nearly 100 in all and, in fact, more than 200 if we count all the minerals in which uranium occurs frequently but is not an essential constituent. With the notable exception of pitchblende and a few other black uranium minerals, most uranium minerals are bright shades of green, yellow, and orange. The only sure way to identify them and to determine their uranium content is by mineralogical and chemical analyses in the laboratory but we may name two criteria that either singly or together aid in identifying uranium minerals in the field. First, some uranium minerals, particularly the colored ones, fluoresce under the ultraviolet lamp used also in prospecting for tungsten minerals; the precipitate formed by evaporating a sulfuric acid solution of uranium minerals also fluoresces. Secondly, along with thorium and some potassium minerals, uranium minerals are radioactive and hence discharge pulses of energy that can be detected by a geiger or scintillation counter. It may be worth noting too that quartz often becomes black and fluorite becomes dark purple or black after radioactive bombardment. The presence of black quartz and purple fluorite, therefore, may indicate the proximity of uraniferous minerals, though sometimes only in small quantities.

The minerals may be classified according to the other elements combined with them as oxides, vanadates, phosphates, carbonates, sulfates, silicates, columbates, titanates, and others in which uranium occurs as a minor constituent.

The common uranium oxides include uraninite or its colloform variety, pitchblende, and becquerelite. These oxides are two or three times heavier than common minerals like quartz or calcite. Pitchblende and uraninite are among the few primary uranium minerals formed through igneous processes. Most of the other uranium minerals are formed by weathering processes.

The common uranium phosphates are autunite and torbernite. Autunite is a brightly colored yellow mineral and torbernite is green. These minerals are generally formed by weathering and their presence suggests that primary uranium minerals may be found at depth.

Two uraniferous vanadates--carnotite and tyuyamunite--are important constituents of uranium deposits on the Colorado Plateau. Both are a bright, mustard or canary yellow.

Most uranium carbonates and sulfates are so soluble that they are not common in nature except as occasional efflorescences in dry regions. Schroeckingerite is one of the most important carbonates and zippeite is one of the most common sulfates. Of the uranium silicates, uranophane is the most common. The columbates, euxenite, samarskite, betafite, and fergusonite are black or brown minerals like pitchblende but are not found in large amounts. Brannerite and davidite are the uranium titanates. Both are black minerals but neither are common.

Of all these uranium minerals, only pitchblende, carnotite, tyuyamunite, autunite or torbernite generally form the principal uranium mineral of minable uranium ores. The others are often associated with uranium ores, of course, and are useful as clues to the presence of uranium.

Of the minerals that may or may not contain uranium we may list fluorapatite, fluorite, monazite, zircon, and certain carbonaceous materials. Fluorapatite generally contains no more than 0.02 percent uranium; fluorite, monazite, and zircon may contain as much as a few tenths of a percent of uranium, and certain carbonaceous materials, such as thucholite, may contain several percent of uranium or more.

TYPES OF URANIUM DEPOSITS

Before discussing the characteristics of the deposits in which these minerals are found, let me give you some economic yardsticks by which you may gauge their value. High grade uranium deposits over the world are those which contain about 0.5 percent uranium in the ore or in an easily formed mechanical concentrate. The Atomic Energy Commission will buy ores containing 0.1 percent uranium so that we may consider deposits of this grade minable in this country, if they are easily accessible. As with other ores, we might apply the rule of thumb that if a metal can be recovered as a byproduct of another constituent its concentration need only be one-tenth as much as it would need be otherwise. For practical purposes we may thus consider that deposits which might yield uranium as a byproduct need contain only about 0.01 percent uranium.

Uranium deposits may be classified as those formed by igneous, sedimentary, and weathering processes. One of the fascinating features of uranium geology is that uranium, to a greater degree than most metals, is concentrated by each of these processes. No geologist engaged in the study of uranium need be afraid that his interests or experience will be narrowed, for the geology of uranium has virtually the same breadth as geology itself.

Deposits formed through igneous processes include uraniferous igneous rocks, pegmatites, and hydrothermal veins. The uraniferous igneous rocks, mostly granite-like rocks or light colored siliceous volcanic ash or tuff, generally contain only 0.005 to 0.02 percent of uranium but of course they are apt to contain tremendous tonnages of uranium. Pegmatites, which are light colored, coarse-grained, vein-like igneous rocks, sometimes contain large crystals of uraninite and columbates but minable quantities of these rocks seldom contain more than 0.01 percent of uranium. Some of the hydrothermal vein deposits, on the other hand, contain large tonnages of ores containing more than 0.1 percent uranium and they form the only uranium ores that yield significant tonnages containing 0.5 percent of uranium or more. The uranium in vein deposits is nearly always in the form of pitchblende at depth, though near the surface it may be in secondary minerals formed during weathering, such as autunite or torbernite. Pyrite, quartz, and copper minerals are nearly always associated with the pitchblende; and silver, cobalt, nickel, and selenium may be present also. Fluorite is also a common constituent--in fact some fluorite veins contain uranium in the fluorite itself rather than in the form of pitchblende.

Sedimentary deposits of uranium are found mainly in marine phosphate rocks and bituminous black shales, in non-marine sedimentary deposits of volcanic ash, and in placers. The uranium content of the phosphate deposits and the black shales ranges from less than 0.01 percent to slightly more than 0.02 percent. Small as these concentrations may be, the total tonnage of uranium in these deposits is tremendous. Tuffaceous sediments, familiar radioactive materials to those of you acquainted with gamma-ray well logs, generally contain only 0.001 to 0.005 percent uranium. They have no direct economic value now but because uranium may be readily released from them during devitrification of the glass, they may constitute important source-beds of uranium concentrated in other rocks from percolating ground waters. Because the common uranium minerals are relatively soluble in the zone of weathering, most uranium minerals, unlike gold and tin, are not concentrated in placers. Known amounts of U mins in placers are not large and moreover the insolubility of these minerals makes it difficult to extract uranium from them.

This sounds contradictory. Should specify that the U-bearing placer mins that are found are very insoluble

Uranium deposits formed during weathering include a variety of types. I've already mentioned that pitchblende in the vein deposits may be oxidized to secondary minerals near the surface. These minerals may be dissolved, transported short distances from the primary lode, and redeposited along cracks or bedding planes in other rocks nearby. These deposits may contain 0.1 percent or more of uranium and, although their tonnages are generally small, their presence suggests the existence of primary ores nearby. The uranium in the uraniferous lignites also appears to have been introduced after the lignites were formed by percolating meteoric waters that picked up small quantities of uranium from the weathering of igneous rocks or volcanic ash. The uranium content of the lignites ranges from less than 0.01 to more than 0.02 percent but some of the deposits contain large tonnages of uranium nevertheless.

The sandstone ores, like those of the Colorado Plateau and the newly discovered deposits along the margin of the Black Hills in South Dakota and near the Pumpkin Buttes in Wyoming, are the most important producers in this country but they are difficult to classify geologically. They have been traditionally called carnotite deposits because of the brightly colored carnotite and other oxidized minerals that characterize them near the surface. But deeper mining and drilling during the past few years has shown that carnotite is only a shallow oxidation product of the weathering of pitchblende and other dark uranium and vanadium minerals and sulfides that characterize these deposits at depth. The ore in these deposits occurs as irregular, generally tabular masses in non-marine sandstone or, more rarely, in shale or limestone. These masses are nearly always found in one favorable zone or layer and their distribution within this zone seems to be related to the presence of fossil logs and other types of carbonaceous matter and to sedimentary structures such as changes in thickness, fossil stream channels, and the presence of shale partings. One important characteristic of these deposits is that they nearly always occur in clusters--if you find one you can be pretty sure that others will be found nearby. The volume of ore in individual deposits ranges from a few pounds to more than 100,000 tons but the uranium content is nearly always in the range of 0.1 to 0.5 percent. The origin of these deposits is still being debated. It is generally agreed now that the ore was deposited in the rocks by percolating ground water solutions after they were formed. But whether these solutions picked up the uranium from hydrothermal solutions rising from depths or leached it from adjacent sedimentary rocks is not yet known.

The association of uranium with carbonaceous materials deserves special notice, particularly because of its bearing on petroleum geology. Carbonaceous matter is found associated with each of the types of uranium deposits I've mentioned--even with some of the vein deposits--and it has been said, perhaps brashly, that every important uranium deposit in the world is associated with or contains some carbonaceous material. In addition to the deposits I've mentioned, uranium is found in many asphaltites; isolated carbonized fossil plants; many, possibly all, petroleums; and radioactive decay products of uranium are found in many natural gases and oilfield brines. The significance of this association is not completely known. It seems definite that some carbonaceous matter is in some way a precipitator of uranium and that some plants concentrate uranium, at least in small amounts. In addition, it is possible that radiation stemming from uranium in sediments generates petroleum from associated organic matter, that it also polymerizes migrant methane into the asphalt-like substances found in some pegmatite and vein deposits, and that petroleum fluids may sometimes transport uranium to sites of ore deposition.

METHODS OF PROSPECTING FOR URANIUM

The methods used to search for uranium deposits may be described as (1) geologic, (2) radiometric, (3) geobotanical, and (4) physical exploration.

Geologic prospecting is based on the recognition of uranium minerals or on the recognition of geologic features commonly associated with uranium deposits such as I have just described. This is the method that the complete amateur uses when he picks up a bright-yellow or green mineral and it is also the method that the geologist uses when he stops to examine a quartz-hematite vein or another rock that he knows is often associated with uranium. Success in geologic prospecting is proportional to the prospector's knowledge of ore habits and guides and, of course, on his luck and optimism. I think I am safe in saying that few if any mines, or oil fields either, have been found by pessimists.

As I mentioned a few minutes ago, the radioactive rays given off by uranium minerals may be detected by use of geiger and scintillation counters. Their use gives the prospector an unusual advantage, for these instruments can detect the presence of radioactive minerals even if they are concealed from sight by a few inches or so of soil or rock. Geiger counters and scintillation counters have been developed in a variety of shapes and sizes, suitable for use by the prospector on the ground, for carborne and airborne reconnaissance, and for drill-hole logging. Both small and large planes are used in airborne reconnaissance. The light planes, such as those operated by the Atomic Energy Commission, are used to search for specific deposits in broadly favorable areas. They fly at an altitude of about 50 feet and are equipped with scintillation counters that will detect almost anything that an ordinary field counter will detect on the ground. The DC-3 plane used by the Geological Survey is used for quick reconnaissance of large regions. It is flown at an elevation of about 500 feet along traverse lines about a quarter of a mile apart and it continuously records both radioactivity and magnetic measurements.

All of these instruments, of course, are used mainly in the direct search for ore, that is, the search for a hot spot or kick that represents an individual uranium deposit. But complications arise from the fact that most of the radioactivity we detect comes not directly from uranium itself, but rather from its radioactive decay products. These decay products, like radon and radium, sometimes get separated from the parent uranium but even then they may give a clue to the presence of uranium nearby. For example, K. G. Bell and A. S. Rogers of the Survey found on the Colorado Plateau that small pips are observable on the gamma-ray logs of barren holes drilled down dip from ore-bodies and can therefore be used in locating the ore itself. Similarly, the air in some mines is radioactive even though no radioactive minerals are observable in the mine walls and some natural gas is radioactive even though no uranium is known in the reservoir rocks. Such radioactivity is most likely due to the presence of radon, a highly radioactive gas formed as one of the disintegration products of uranium. Its presence indicates the nearby presence of uranium, though of course in unknown quantities.

The use of plants in prospecting for uranium was first pointed to by the research of Professor O. A. Beath of the University of Wyoming a few years ago and Mrs. Helen Cannon of the Survey has recently developed the methods to the point where they can be used in the search for some deposits. One method is based on the fact that certain plants, like juniper and saltbush, take up uranium from the soil if any appreciable amounts are present. Samples collected from these uranium absorbers show amounts of 2 or 3 parts per million or more of uranium in the vicinity of shallow ore deposits. The other principal method of geobotanical prospecting is based upon the fact that certain plants require for their growth large amounts of selenium and others require large amounts of sulfur. These plants are selenium and sulfur indicators and inasmuch as both selenium and sulfur are commonly associated with uranium, particularly in the ores of the Colorado Plateau, they indicate the presence of uranium too. Prospecting by this method consists first of mapping the distribution of the sulfur and selenium plants and then of drilling in the vicinity of the abundant indicators. It should be emphasized, of course, that geobotanical prospecting can be used only where the ore lies at depths of less than 50 feet or so below the surface and of course the indicator plant method can be used only where we are sure that sulfur or selenium is associated with uranium in the ore.

Most of the methods I have described thus far are all rather inexpensive to use--some require special equipment and knowledge but, with the exception of airborne reconnaissance, their cost is measured largely in terms of the time of the person applying them. If any of these methods or a combination of them does point to a local concentration of uranium, the lead is followed by physical exploration--that is drilling, trenching, test-pitting, or driving underground workings such as shafts or adits. In contrast to the methods already described, all methods of physical exploration are expensive. For this reason only promising prospects are probed by drilling or other means and when any of these methods are used they should be supported and guided by as full a knowledge of the geology of the district as can be had. On the other hand when prospecting has developed a promising lead, such as an outcrop of ore or a favorable geologic association or structure, there is no substitute for physical exploration of one type or another to determine the extent, grade, and tonnage of the ore.

The selection of areas in which to use these methods deserves some comment. We may distinguish two approaches, one the observational or, "gold is where you find it" approach, the other the analytical or "gold is where we knew it would be all along" approach. It will be no surprise to any mining men present to learn that most of the producing uranium districts in the world were found through the "gold is where you find it" approach, as were also some of the important recent discoveries in this country, such as the Grants, New Mexico; Marysvale, Utah; and Boulder batholith, Montana districts. Inasmuch as our understanding of the occurrence of uranium minerals or of the geology of this country is little more than skin deep the observational approach will continue to have an important place in modern prospecting for some time to come. Geologists of the Atomic Energy Commission and the Geological Survey have done a good deal of observational prospecting, not only by way of field reconnaissance but also by way of testing all the samples we can lay our hands on--museum collections; old drill cores; samples of all kinds of ores, concentrates, and tailings solicited from mining companies; samples submitted by the public; and so forth. We hope that others will continue also to look for uranium wherever and whenever they have opportunity, regardless of whether or not the specific area is supposed to contain uranium deposits.

The analytical or "gold is where we knew it would be all along" approach is the forte of the professional geologist. We geologists, you know, are notoriously poor prospectors, even though we are famous for our ability to tell a prospector why a given deposit contains or does not contain ore once he's found it. But we are rather proud of the record we're building in the search for uranium, based on the application of both inductive and deductive reasoning to the selection of areas favorable for the occurrence of uranium. Inductive prospecting is based upon the reasoning that if one phosphate rock is found to contain uranium, other similar phosphate rocks may contain it also. By examining rock associations similar to those already described, we have found several brand-new occurrences of uranium in this country, particularly in phosphate rocks, lignites, and black shales. Deductive prospecting is based on an understanding of ore habits and origin and its success is proportional to the degree to which we really understand these things. Accordingly, I am measuring our ignorance when I say that I can think of no new district found thus far by the application of this type of reasoning. I am pleased to report, however, that we have had almost spectacular success in the application of our understanding of ore habits and guides to the search for ore in previously known districts such as the Colorado Plateau. Discovery of ore in the future, particularly in concealed deposits, will depend more and more upon the application of deductive methods and I am confident that we will witness growing success in their application.

Nearly all of the prospecting methods I've described can be used with both the observational and analytical approaches. The most effective prospecting, of course, makes use of all knowledge and tools available and appropriate to the specific problem.

DISTRIBUTION OF IMPORTANT URANIUM DEPOSITS IN WESTERN UNITED STATES

Of the vein deposits known thus far, those at Marysvale, Utah; those near Boulder, Mont.; and those in the Colorado Front Range are the most promising. The deposits at Marysvale, found by a local prospector in 1948, are found in steeply dipping quartz veins, which cut quartz monzonite or granite. The walls are extensively pyritized and altered to clay minerals. The uranium occurs in brightly colored secondary uranium minerals near the surface but it is found as pitchblende at depth. Marysvale has been a rather consistent though small producer since its discovery and it promises continued yield in the future.

The Front Range of Colorado is the only area in the United States where pitchblende in hydrothermal veins was known and mined prior to the World war. II Very little uranium ore has been mined in recent years but many new occurrences of uranium have been found as a result of the activities of Survey geologists and prospectors. Exploration, largely sponsored by the Defense Minerals Exploration Administration, is now in progress at several localities and one high grade ore shoot that will probably come into production soon, was discovered as a result of this exploration in the East Calhoun mine in February. The pitchblende in most of the prospects in the Colorado Front Range occurs in small pods or shoots in quartz-pyrite veins that cut pre-Cambrian granite, gneiss, and schist. Some of the districts have a zonal distribution of minerals and B. F. Leonard of the Survey has recently found that pitchblende occurs in a zone intermediate between the central zone characterized by pyritic gold ores and the peripheral zone characterized by lead-zinc-silver ores. This relation may facilitate the search for uranium deposits there and in other districts as well.

The pitchblende-bearing veins in the Boulder, Jefferson County, Mont. area were discovered by a local prospector in 1949 and since then uranium has been found at several localities between Boulder and Clancey. Small quantities of ore have been mined at the Free Enterprise and Woodrow Wilson mines, and prospects for future discoveries elsewhere in the region seem good. The pitchblende occurs in quartz or chalcedony veins or silicified shear zones that cut quartz monzonite. Small amounts of precious and base metals are also found in the veins.

None of these districts have yielded important production and probably none of the many other districts now known to contain pitchblende contain any known minable ore. The significant thing, however, is that all of these districts except the Colorado Front Range have been found since the construction of the atomic bomb.

Deposits of secondary uranium minerals in veins and related deposits are found at many localities. Several of these deposits--such as those in the Boulder and Clancey areas, the Marysvale district, and the Lusk, Wyo. areas--represent the oxidized portion of pitchblende-bearing veins. It may be assumed, therefore, that pitchblende, possibly only in small quantities, may be found at depth in some of the other areas where none is known now. Examples of such districts are the White Signal and Blackhawk districts in New Mexico and Majuba Hill, Nev. Of all these deposits of secondary uranium minerals in veins, only those at Marysvale have furnished minable ore but the others constitute some of our best leads.

Of the sedimentary uranium deposits in the west, those in the Phosphoria formation, discovered by the Survey in 1944, are the most important. Although the Phosphoria formation contains some black shales, the uranium is almost wholly confined to the phosphatic rocks. The uranium in the phosphate rocks occurs in the fluorapatite mineral and the uranium content, which ranges from less than 0.005 percent to slightly more than 0.03 percent, therefore increases roughly as the phosphate content increases. In spite of the low uranium content of these rocks, extensive research sponsored by the

Atomic Energy Commission makes it possible now to recover uranium as a by-product of the manufacture of triple super phosphate fertilizer. Production from the Florida phosphates, in fact, began a few months ago. No important production is anticipated from the western deposits for some time simply because uranium production is tied to the phosphate production, which is still relatively small in the west, but it is plain that this formation contains a large reserve available for the future.

Although there are many marine black shales in the Western States that appear to resemble the Chattanooga shale of Tennessee and the alum shale of Sweden--both of which contain vast quantities of uranium--most of the black shales tested in the Western States are weakly uraniferous. A black shale in the Hartville formation in southeastern Wyoming, is of interest, however, because it contains as much as 0.019 percent uranium, more than any other yet known in the United States. This shale is thus far known to be appreciably uraniferous only in the subsurface where it has been penetrated by oil wells but we hope that further reconnaissance may disclose a locality at the surface where this shale is as uraniferous as it is in the subsurface.

Two uraniferous algal limestones have been found, one near Myton, Utah, the other at Miller Hill, Wyo. The Myton district is not well known but it appears to contain 0.01 to 0.02 percent uranium. The Miller Hill deposit, discovered last summer by airborne reconnaissance in an area selected by J. D. Love, has likewise not been explored but the few samples collected by Love indicate that several thin layers contain 0.01 to 0.15 percent uranium. Additional sampling and mapping will be undertaken in this area during the coming year.

Placer deposits have not been important sources of uranium anywhere, partly because the common uranium minerals are not resistant enough to be concentrated in placers and partly because those that are resistant to weathering are so refractory that it is difficult to extract uranium from them. Important placer deposits of monazite are found in central Idaho, however, and in addition promising concentrations of the radioactive blacks--that is samarskite, euxenite, and fergusonite--were discovered there, in the Bear Valley area, by a prospector a year or so ago. The monazite in these placers is of interest chiefly for its rare earth and thorium content and is not likely that the 0.1 percent uranium it contains will be recovered. The radioactive blacks, however, may yield a small tonnage of uranium as well as columbium if extraction problems can be solved. A number of these placers in central Idaho have been explored by the Bureau of Mines in recent years and there is much exploration activity now among private operators too.

Until a few years ago, uranium was not known to occur in coal and lignite at all--in fact coals and lignites were considered among the least uraniferous of all rocks. In 1945, however, Nelson and Slaughter of the Survey discovered weakly uraniferous lignites on the Red Desert in Wyoming during the course of radiometric car traversing and in 1948 D. G. Wyant discovered other uraniferous lignites in the Dakotas. Denson, Bachman, and Zeller found in their studies of the South Dakota lignites in 1950 that in most places only the first lignite bed immediately below the White River formation, which unconformably overlies the coal bearing series there, is uraniferous. Traced laterally, a given bed, uraniferous where it is the first bed below this surface, is found to be non-uraniferous down dip where it is overlain by another lignite higher in the section. From this and other evidence, they concluded that the uranium in the lignite was derived from the White River formation by percolating ground waters and since the

White River formation contains abundant volcanic ash, known to be slightly uraniferous in some other localities, they concluded that the uranium was derived from the decomposition of the volcanic ash. Application of this hypothesis to the search for other deposits the following season led to the discovery of uraniferous lignites in Fall Creek and Goose Creek areas of Idaho and the La Ventana Mesa areas of New Mexico.

Like the black shales and the phosphates, some of the lignites contain enormous tonnages of uranium. Unlike the shales and phosphates, however, the uranium content of the lignites varies considerably over short distances. Most of the deposits contain only 0.005 to 0.02 percent uranium, but some, such as those at Fall Creek and Goose Creek, Idaho and La Ventana, New Mexico, contain as much as 0.1 percent in small areas. Production of uranium from the weakly uraniferous lignites will very likely have to be as a byproduct of some other operation, such as the manufacture of steam power, and hence their utilization is dependent upon their suitability for use as fuel in competition with other lignites. Considered from this standpoint, it appears that some of the lignites in the Dakotas and in the Red Desert offer the greatest potentialities and these are being further tested by core drilling by the Survey and the Bureau of Mines now. Bony, thin lignites or carbonaceous shales might be minable for their uranium content alone if sufficient tonnages of material containing 0.1 percent of uranium can be found.

Although the lignites, phosphates, shales, placers, and vein deposits of uranium in this country offer promise as future sources of uranium, particularly as byproducts of other materials, our most important production has been and continues to be from the sandstone-type deposits of the Colorado Plateau. Resources in these deposits have supported a steadily increased production which, in fact, made the United States the world's second largest producer of uranium in 1951. Equally important is the fact that most of the discoveries of minable ore outside of the Colorado Plateau, specifically in the Black Hills area, the Pumpkin Buttes area of Wyoming, and the Lukachukai Mountains and Grants district in New Mexico, are also of this type.

The sandstone-type deposits on the Colorado Plateau are scattered over an area of more than 50,000 square miles in Colorado, Utah, Arizona, and New Mexico. Ore occurs in several formations in this area but most of the producing deposits are found in the Shinarump formation, the Salt Wash member of the Morrison formation, and the Entrada formation. In any given area most of the deposits are found in only one of these formations, even though the others may be present. Thus in Utah and northern Arizona most of the deposits are in the Shinarump; in western Colorado and the four-corners area most of the deposits are in the Morrison; and farther east in Colorado most of the deposits are in the Entrada formation. The deposits in the Shinarump are predominantly X copper-uranium ores; <u>not</u> Monument No. 2 and Utex Co. mines those in the Morrison are mainly uranium-vanadium ores; and those in the Entrada are mainly vanadium ores that contain small amounts of uranium.

The Plateau deposits range in size from mere traces of ore to roughly tabular bodies a hundred thousand tons or more in size. Probably the greatest single advance in Plateau exploration came as a result of the recognition, on the part of R. P. Fischer of the Survey, that the known deposits along the canyon rims in the Morrison were most abundant in what lined up to be a crescent-shaped belt in western Colorado, now referred to as the Uravan mineral belt. Fischer reasoned that the ore-bearing sandstone under the mesas should contain as much ore as it does in the canyon walls and therefore the chances of finding these deposits within the belt by diamond drilling would be greater than outside it. Subsequent exploration has abundantly borne this out. The Survey alone has drilled about 1.8 million feet in the Uravan mineral belt on behalf of the Commission and discovered nearly a ton of ore per foot of hole drilled. In fact, about 25 percent of the total production on the Colorado Plateau is coming from ore found during the course of this drilling.

Part of the reason for the success of this exploration has been the recognition of geologic guides to ore. Fischer and his associates have found that ore generally occurs in areas where the Salt Wash sandstone is thicker than in nearby areas, where it has a freckled appearance instead of its usual reddish-brown color, where the sandstone contains numerous mudstone partings, where these mudstones are grey instead of red, and where fossil wood is abundant. These criteria are used to define areas of favorable ground for the occurrence of uranium deposits during the course of drilling, which is done in two or three stages. The first stage consists of drilling wide-spaced holes, about 1,000 feet apart, in areas, such as a part of the Uravan mineral belt, considered likely to contain uranium deposits. The cores obtained from these holes are examined in the light of the ore guides and areas of favorable and unfavorable ground are defined accordingly. The favorable areas are then drilled with holes spaced about 200 feet apart and offset holes are later drilled in the vicinity of any holes found to contain ore. Use of these ore guides has not only helped to find ore but it has saved the great expense that would have been entailed in drilling unfavorable areas.

The Uravan mineral belt is the area of greatest production on the Colorado Plateau but important production is coming from many other areas on the Plateau, some of which are based on new discoveries or new developments. One of the most important of these is the Grants district I mentioned before. The largest deposits there occur in the Todilto limestone, but, unlike most of the other areas, ore also occurs in sandstone and in coals in other, younger formations. The Lukachukai district in Arizona is also an important new area. Exploration there by the AEC has disclosed the presence of enough ore to justify a new mill at Shiprock. Other newly discovered or newly developed deposits in the vicinity of Moab, White Canyon, and Temple Mountain, Utah, are also yielding important production. These and other important developments justify an optimistic outlook for future discoveries in other horizons and in other districts over the Plateau.

Of the sandstone-type deposits discovered outside the Colorado Plateau, those along the margin of the Black Hills in South Dakota, in the Pumpkin Buttes area in Wyoming, and in the Guadalupita district in New Mexico are the most promising. The South Dakota deposits, found in June, 1951, by Mr. Brennan of Rapid City, occur in the Lakota sandstone and much resemble the Colorado Plateau deposits in shape and size. Since the initial discovery in the Craven Canyon area in Fall River County, deposits have been found in several other localities around the Black Hills by prospectors, mining companies, and the AEC. The AEC has established a buying station at Edgemont, some ore has already been shipped, and extensive diamond-drilling exploration is in progress.

The Pumpkin Buttes deposits were found in the fall of 1951 by J. D. Love, who was checking radiometric anomalies picked up by the Geological Survey's DC-3 plane. The deposits occur in the Wasatch formation in small masses, a few inches to a few feet in diameter, that contain as much as 15 percent uranium. These deposits, now called the pumpkin-type, are too small to be minable on a significant scale. Late last summer, however, a larger, disseminated-type deposit was discovered that more resembles those in South Dakota and the Colorado Plateau. The future of the district as an important producer is dependent upon the discovery of additional deposits of this type.

The Guadalupita, New Mexico deposits consist of copper-uranium ores in gray, carbonaceous shales of the Sangre de Cristo formation. Copper has been known in this area for some time but the presence of uranium was discovered only about a year ago by C. B. Read of the Geological Survey. The uranium occurs only in amounts of 0.01 to 0.07 percent but it is possible that larger amounts may be found in unoxidized ore beneath the surface, as was found to be the case at the Happy Jack mine in Utah. This deposit will be explored further by the Survey next field season.

SUPPORTING RESEARCH

This hasty survey of the important uranium deposits of the Western States tells part of the story of the activity and progress in the search for uranium in the Western States, but the story would be incomplete without brief mention of the basic research that is under way on virtually all aspects of uranium geology, mineralogy, and geochemistry. In view of our urgent immediate need for uranium most of our efforts must be placed directly on the search for minable deposits. Nevertheless, as long-range needs have become recognized, the Atomic Energy Commission has authorized the Survey and several other organizations to undertake research on fundamental principles, the understanding of which may be confidently expected to aid in the discovery of additional deposits in the future. The research now in progress includes such diverse investigations as the distribution of uranium in igneous rocks; the behavior of uranium during weathering; zonal relationships of uranium deposits in metalliferous districts; the frequency distribution of uranium with respect to enclosing wall rocks; the mineralogy and geochemistry of uranium in black shales, phosphorites, and other materials; methods of age determination; physical behavior of radon; methods of analysis of uranium and thorium; and many others. Some of these investigations have paid dividends already and the others may be expected to do so in the future.

OUTLOOK FOR THE FUTURE

In conclusion, I would like to say a word about the outlook for the future. The 10 years of intensive search for uranium in the west have not yielded a large, high grade deposit such as some of those being mined abroad but they have led to a substantial increase in production from sandstone-type deposits, to the discovery of many occurrences of uranium in ore-grade concentrations (mostly of insufficient volume to be mined), and to the discovery of large but low-grade resources of uranium in the lignites, black shales, and phosphates. The increase in production from the Colorado Plateau speaks for itself but I may add that we believe that it will continue to increase and that the Plateau will continue to be an important source of uranium for many years in the future.

In my opinion, the many discoveries of uranium in ore-grade concentration have about the same significance as to the occurrence of larger, minable deposits as smoke does to fire. It is well known that for every large oil field there are scores of smaller ones and the same relationship holds with respect to mineral deposits. Many of us believe that the numerous occurrences of uranium in the Rocky Mountain States indicate the presence of a broad uranium province in which deposits of uranium will be found in all shapes, sizes, and materials. Discovery of the larger deposits may take time, but the enthusiasm and success of the prospectors already demonstrated coupled with the yield sure to come from basic research already in progress justifies an optimistic view of our future.

The large-low grade deposits already discovered insure our security even if discoveries of higher grade ores do not materialize. These deposits will yield uranium now only at a high price but the important thing is that they contain virtually unlimited resources that can be made available if emergency needs so demand. We may expect too that the technological advances in the next few decades will lower the cost of extraction of uranium from these rocks. If this happens, large supplies of uranium will be available for non-military purposes.