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Guides to prospecting for uranium and thorium in New Hampshire and adjacent areas

by

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GUIDES TO PROSPECTING FOR URANIUM AND THORIUM IN NEW HAMPSHIRE AND ADJACENT AREAS

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Introduction

The national need for additional sources of energy, particularly non-fossil fuel energy, has directed more attention to the nuclear fuels--uranium and thorium. New Hampshire is a potential source of these elements, but to date no economic deposits have been found within New Hampshire or any other New England state. There are, however, several anomalous occurrences of these elements that might lead to the discovery of economic deposits, provided appropriate geologic study and exploration are undertaken. Part of the needed geologic investigations must be carried out by governmental agencies and part by private companies, if exploration is to be successful.

It is the purpose of this report to evaluate the possibilities of finding economic deposits of these nuclear fuels in New Hampshire and adjacent states by reviewing information concerning: (1) the known occurrences of uranium and thorium, (2) the types of deposits that might be found, (3) the possible source rocks of these metals, (4) the structures that might be favorable for containing economic deposits, (5) the geologic conditions that may conceal such deposits at the surface, and (6) the zoning of metal deposits.

Acknowledgements

This paper was originally prepared in 1976 for use of the New Hampshire Governor's Council on Energy and Minerals with the intent of revising it for publication in a scientific journal. Acknowledgement of specific sources of information and pertinent illustrations have been omitted from this generalized version in an attempt to improve the readability for the non-geologist and lessen the cost of reproduction.

Many persons, particularly Marland P. Billings and John B. Lyons--members of the Council--have over the years acquired and published the basic geologic information upon which the success of the search for uranium and thorium in New Hampshire will depend. Many of the more critical data are contained in the state publications, listed in the Bibliography, which unfortunately are mostly out of print. Glenn Stewart, chairman of the Council, has contributed immensely by making available information from cores obtained in drilling the Conway Granite at Redstone, N.H. in his "hot rock" geothermal project. Numerous other persons, especially those in the United States Geological Survey and Atomic Energy Commission (now Department of Energy) during the late 1940's and the 1950's, are responsible for acquiring data that have led to understanding the various types of radioactive deposits that are known or might be found in the State and adjacent areas.

Acknowledgement is also made of those prospectors who were first to recognize many of the occurrences and bring them to the attention of the geologists.

Uranium and Thorium Occurrences

All rocks have a natural radioactivity resulting from the disintegration of potassium, uranium, and thorium in the rock-forming minerals; thus each rock has its own characteristic background radioactivity. A few rocks such as the Conway Granite of Mesozoic age are sufficiently radioactive to be considered as possible ores, but not all of the rocks mapped as Conway Granite have the same uranium and thorium content. Consequently, in prospecting it is important to know the normal background of radioactivity for each lithologic type and to search for areas of anomalous amounts, either higher or lower than average. The higher radioactivities indicate the addition of these elements by some geologic process, such as from the solutions active during hydrothermal alteration, and the lower ones indicate removal of these metals by processes, such as leaching during weathering. Both types of anomalies indicate that uranium and thorium have been moved around in the rocks and the problem is to find where and under what conditions it was deposited in sufficient amounts as to make an economic deposit.

Uranium and thorium minerals have been known for many years in several localities in New Hampshire; many areas are known to have anomalous radioactivity but no specific uranium or thorium has been identified to date. Most of the known occurrences are in coarse-grained feldspar-, quartz-, and mica-rich rock called pegmatite. These rocks contain a wide variety of primary and secondary uranium and thorium minerals, but the small size of the pegmatite deposits found to date precludes economic mining for these elements alone. Such deposits when mined for other minerals may produce small amounts of these ores as a byproduct. In only a few places in other parts of the world have such deposits been economic when mined for uranium and thorium alone. Therefore, the New Hampshire pegmatite areas are not considered to be very favorable places to prospect; the only possibility is in finding several deposits close enough together to mine as a unit.

Secondary, yellow uranium minerals were exposed in a fracture zone crossed by Interstate 89, just south of the New London-Newport interchange. This deposit is of vein type and indicates the presence of primary uranium minerals in this structure and also suggests the possibility of finding additional deposits of this type in the surrounding area. (The Governor's Council for Energy and Minerals had a grant from the U.S. Geological Survey to map and study this area in 1976.)

Primary uranium minerals have been reported from an intrusive breccia at the contact of the Kinsman Quartz Monzonite (Devonian) and the Conway Granite at the Basin in North Woodstock, New Hampshire. Uranium and thorium minerals have been identified also as minor components of the Conway Granite in the White Mountains area. These occurrences together with data derived from a 3,000-ft drill hole in the granites at the Redstone quarry in North Conway (drilled for a "hot rock" geothermal experiment by the Council under contract with the Department of Energy) suggest the possibility of finding high-grade uranium deposits related to the Conway Granite and other White Mountain Plutonic-Volcanic Series rocks. (The Council's grant from the U.S. Geological Survey included study of this area.)

The Conway Granite has been known for many years as one of the World's largest low-grade resources of uranium and thorium. It is estimated to contain about 11 ppm of uranium and 53 ppm of thorium. Present technology and costs preclude mining, but the Council, with an eye to the future, has a joint metallurgical project with the U.S. Bureau of Mines to investigate the recovery of urnaium and thorium as a byproduct of mining feldspar, quartz, and other useful minerals. This project also will provide data that will be needed when the price of these metals warrants the use of this rock as an ore.

The only other nonpegmatitic high-grade uranium occurrences in New England known to the writer are in Vermont and Connecticut. Primary uranium minerals occur in amphibolite and feldspar gneiss of Precambrian age in a zone several miles long near Manchester, Vermont; in fluorite and phosphate in several places in the Clarendon Springs (Milton) Dolomite from Milton, Vermont north to the Quebec border; in a vein containing nickel and copper in the Walcott, Vermont area; and in sandstones of Triassic age in Newgate, Connecticut.

Types of Uranium and Thorium Deposits

Uranium and thorium deposits, in general, can be classified as syngenetic and epigenetic. Syngenetic deposits are those in which the ore minerals are an integral part of the rock and formed at the same time as the rock, such as the uranium- and thorium-bearing accessory minerals in granite, or the heavy minerals in a sandstone, or uraniferous shales and phosphate rock. Epigenetic deposits are formed by the addition of uranium or thorium to the host rock as in veins and replacement deposits.

In many places the primary minerals formed in both types of deposits are altered by subsequent weathering, erosion, and redisposition to secondary minerals. All types of deposits can be expected to occur in New Hampshire and adjacent areas, but in slightly different geologic environments.

The primary ores of uranium commonly contain black minerals, such as uraninite, which is oxidized by surface waters to form yellow and green secondary minerals, such as autunite and torbernite; under some conditions black secondary minerals can also form. In a few places syngenetic deposits may contain primary yellow minerals; the epigenetic deposits are commonly composed of yellow minerals. The primary thorium minerals are mostly darkcolored and commonly weather to reddish secondary minerals. Both the primary uranium and thorium minerals usually are associated with primary reddish hematite contained in alteration zones that are distinct from, but commonly confused with, hematitic alteration related to weathering of iron minerals.

The geologic environments in New Hampshire and adjacent areas favor the finding of primary or secondary uranium and thorium minerals in the following rock associations: (1) as disseminations in igneous rocks, particularly in the alkalic varieties, (2) as vein or replacement deposits in igneous and metamorphic rocks, and (3) as epigenetic and syngenetic deposits in sandstones and other clastic rocks, shales, and limestone or dolomite and their metamorphic equivalents. New types of epigenetic deposits not recognized elsewhere also may be found in metamorphosed sedimentary rocks because of metamorphic pressures that cause redistribution of uranium.

The various types of radioactive deposits are described at length in the literature; only a few such sources of information are given in the bibliography.

Source Rocks

The ultimate source of all uranium and thorium is the interior of the Earth. These elements are brought to the surface by magmas and then redistributed by a number of geologic processes including the crystallization of magma (molten rock) into igneous bodies and veins; the weathering and erosion of igneous bodies and veins and the redisposition of these weathering products into sedimentary rocks; and the metamorphism of both igneous and sedimentary rocks to gneiss, schist, quartz, and marble. During the crystallization of magmas part of the uranium and thorium may be trapped in minerals of the igneous rocks and part may be released from the magma as gaseous fluids which find their way upward in the Earth's crust along zones of weakness such as fractures and faults to areas of lower temperature where they condense to hydrothermal solutions that, in turn, form primary epigenetic deposits in veins and replacement deposits. When these deposits and the igneous rocks are exposed at the surface they are weathered; the soluble part of the uranium and thorium is redistributed by ground water and surface water to form secondary epigenetic deposits in rocks and syngenetic lacustrine and marine deposits. The insoluble part, usually the complex silicates, niobates, and phosphates, is redistributed by water and wind to form syngenetic deposits in clastic sedimentary rocks. In effect, weathering produces the secondary mineral deposits formed on land and the syngenetic deposits formed in the seas and lakes.

Weathered Rock Sources

In New England there were five times during which geologic conditions were favorable for leaching uranium from large quantities of rock and having it form continental sandstone-type ore deposits similar to those in the western United States. These conditions existed at the (1) end of Precambrian time, (2) end of Ordovician time, (3) end of Devonian time, (4) end of Permian time, and (5) end of Tertiary time. Not all of these events are recorded in New Hampshire rocks.

The Precambrian gneisses, schists, and quartzites mapped in New England are in part the metamorphic equivalents of continental or shallow marine clastic rocks derived from deeply saprolitized and weathered terrains of igneous and volcanic rocks on the shield areas to the north and west. These are mixed with marine volcanic flow and clastic rocks probably derived from the east. Any uranium solutions derived by the leaching of the igneous rocks and veins of shield areas precipitated either in the feldspathic and quartzose clastic sediments as epigenetic deposits of the continental sandstone type or in carbonaceous shales under marine conditions. The insoluble uranium and thorium minerals, if concentrated, would be syngenetic placer deposits in the quartzose parts of the Precambrian-Cambrian sequence. Because of subsequent metamorphism (Acadian orogeny) such deposits would have the characteristic of black primary ores and would be associated with magnetite rather than hematite or other iron oxides.

If the source of uranium and thorium is from leaching of older rocks this Precambrian terrain is favorable for prospecting.

At the end of Ordovician time the marine volcanic rocks and sediments, as well as the associated intrusive rocks (Highlandcroft Plutonic Series) were deeply weathered. The feldspars were thoroughly saprolitized. Reworking by the Silurian seas produced clean quartz clastic rocks and highly aluminous shales. Uranium leached from Ordovician rocks would have gone directly to the ocean; only the insoluble varieties of uranium and thorium minerals would have been concentrated as placers in the Silurian beach sands. These now would have been metamorphosed to new minerals associated with specularite or magnetite.

A long period of weathering and erosion began at the end of Devonian time and continued into Pennsylvanian time when continental sandstones and conglomerates were formed in southern New England. There was an opportunity for uranium to be leached from both metamorphosed volcanic and plutonic rocks over much of New England and moved to the Pennsylvanian basins of deposition where organic matter and volcanic debris could act as precipitants to form epigenetic deposits. Thus, this area closely resembles other areas of Pennsylvanian rocks as to favorability for uranium deposits.

At the end of Permian time orogenic forces produced a Basin-and-Range type terrain. Rapid weathering of older crystalline rocks resulted in the sediments accumulated in Triassic time. Any leaching of uranium and deposition might have produced deposits of the continental sandstone type. Such a deposit is at Newgate, Connecticut, preserved in the down-dropped Triassic sequence along the Connecticut River. The interlayered volcanic rocks in this sequence provide possible alternative sources for this uranium.

During Jurassic time volcanism produced a terrain favorable for the leaching of volcanic rock and deposition of uranium, but most of these rocks were stripped by weathering and erosion from the land area and were deposited on the present continental shelf. This type of condition favorable for leaching extended through Tertiary time.

The sedimentary rocks thus formed throughout geologic time are now under water except for a few places in southern New England as on the Connecticut River (Triassic), at Martha's Vineyard, Massachusetts (Cretaceous), and at Brandon, Vermont (Tertiary) or were removed by erosion during glaciation. Any deposits formed by ground water or accumulation in placers are now gone except perhaps offshore.

Thus, the only likely source rocks of uranium and thorium deposits in New Hampshire are igneous rocks except for deposits that might occur in the Precambrian(?) Massabesic Gneiss (Sriramadas, 1966) in southern New Hampshire and the small area of Triassic rocks in the southwestern corner of the State.

Igneous Rock Sources

Five plutonic series of igneous rocks have been described in New Hampshire and adjacent areas. Each, in the opinion of the writer, has specific characteristics of composition, mode of emplacement, type of differentiation, and history that allow an evaluation of their favorability as a source of uranium and thorium deposits.

The oldest, the Highlandcroft Plutonic Series, of Ordovician age, is more deeply eroded than the others and consequently any epigenetic deposits associated with its emplacement probably have been destroyed; if not, they are most likely high-temperature veins that have been metamorphosed.

The earliest plutonic series of Middle Devonian age, the Oliverian, was emplaced by forceful injection and domed up the overlying country rock just prior to the metamorphism of the Acadian orogeny. The known Cu, Zn, and Pb sulfide deposits associated with these rocks were originally formed at too high a temperature to have contained appreciable uranium or it has been lost during metamorphism. The depth of weathering also is unfavorable. If any uranium was present, it probably was redistributed in the metamorphic aureoles around these deposits.

It is remotely possible that these, as well as the Highlandcroft rocks, did produce epigenetic deposits of the sandstone type in the enclosing clastic volcanic rocks or that such deposits formed by the leaching of these volcanic rocks at the end of Ordovician time. If so, they are now metamorphosed; those in the low-grade zone would perhaps still contain the uranium in situ, but those in the middle- and high-grade zones more likely would be depleted in uranium.

The New Hampshire Plutonic Series of Late Devonian age includes a group of syntectonic rocks emplaced during the period of highest temperature and orogenic stress in the Acadian orogeny. One of the earliest formations, the Bethlehem Gneiss, is spatially associated with the main uraniferous pegmatites of New Hampshire, which suggests that the uranium available in the magma went into the pegmatites rather than into veins and other deposits. The Bethlehem Gneiss is less radioactive than the next younger unit, the Kinsman Quartz Monzonite, suggesting that the orogenic stresses acting on wall rock kept all the available uranium in the Kinsman as it crystallized. The youngest unit, the Concord Granite, is associated with pegmatites, some of which contain uranium, but to date there is no evidence that any uranium escaped to form veins. The binary phase of this granite near Lake Sunapee contains as much as 14 ppm uranium according to Ernest P. Beroni of the Department of Energy. The Concord Granite commonly is more radioactive than the Kinsman rocks, suggesting that most of the uranium is still in the granite and little escaped to form veins. The abundance of associated granite dikes and pegmatites and the granite's mode of intrusion (stoping), however, suggest that physical conditions at the time favored the escape of uranium and therefore this rock should not be ruled out as a source of uranium for primary epigenetic deposits.

Rocks of the Upper Devonian plutonic series are more radioactive than those of the older plutonic series and are associated with large massive sulfide deposits in New Brunswick. These sulfide deposits are devoid of radioactive materials (almost cosmic background). The level of erosion argues against any of these Devonian plutons being the source of epigenetic uranium deposits, particularly in high- to middle-grade metamorphic wall rocks. Such rocks probably were too plastic during metamorphism to allow the formation of fractures along which fluids could escape.

The rocks of the White Mountain Plutonic-Volcanic Series (Mesozoic), however, are better potential sources of both uranium and thorium because of their alkalic composition and mode of emplacement. These magmas were intruded into brittle rocks at relatively shallow depths and caused the development of contact breccias and assoociated fractures and faults in the host rocks. The repeated injections of these magmas and the resulting abrupt changes in physical and chemical conditions favored the escape of volatile fluids at several periods that could distribute metals outward along fractures to form vein deposits. It is probable, however, that the main source of uranium was from parts of the magma chamber that are not exposed. The associated mafic dikes, particularly lamprophyres containing calcite, appear to be favorable indications, because such dikes, elsewhere in the World, are associated closely in time and space with uranium deposits. Such a dike was intersected by the Council's drill hole in the Conway Granite at Redstone, N.H. where it cut the youngest facies of the Conway Granite; it in turn was cut by calcite veinlets, another association favorable for finding uranium. Argillitic alteration of the Conway Granite and hematitic alteration zones at the edges of veins and as irregular areas in the granites also are characteristic of uraniferous veins in other areas. The uranium deposit at Lake Sunapee is associated with a lamprophyre dike rock containing a central zone that in places is entirely carbonate. The distribution of the dikes of the White Mountain Plutonic-Volcanic Series is not well known. Many have been called Triassic in age, and only a few of them have been shown on the available maps; nevertheless, their general distribution is in areas near rocks known and mapped as belonging to the White Mountain Plutonic-Volcanic Series. Theoretically, the most favorable place of uranium deposits would be in areas where these dark dike rocks occur without their plutonic associates, thus indicating lower and more favorable temperature conditions for the formation of uranium mineral deposits.

It is suggested that at the time the dike rocks were expelled from a subjacent magma chamber, the resulting decrease in pressure caused uraniferous gaseous fluids to become immiscible and to escape from the main magma. These fluids worked their way upwards and laterally along fractures and porous layers (pipe lines) into areas where the temperature and host rocks were favorable for deposition. The site of deposition may be many miles away from the source provided the thermal conditions there were unfavorable. The dike rocks, in general, probably reach their final position in the crust slightly earlier than the uranium veins because a common place for deposition of uranium minerals is along contacts of dikes. In most districts, however, at least one such dike is found that cuts the uranium veins.

Unfortunately the distribution of dike rocks in New Hampshire and adjacent areas is not shown on many maps and therefore it is difficult to select the most favorable areas for epigenetic uranium deposits or to fully understand the structural relationships that existed at the time of formation of dikes and veins. In addition, existing maps give little data concerning joints and fracture systems. However, the available data plus that from LANDSAT images and other photographs give some insight into the structural relationships and allow the designation of those structures most likely to be favorable as pipelines for the uraniferous fluids and those most favorable as depositional sites of economic deposits.

During the cooling of the White Mountain Plutonic-Volcanic Series magmas, prior to the escape of dikes and uraniferous fluids, accessory minerals containing uranium and thorium, such as zircon (U) and monazite (Th), crystallized as an integral component of the rock; the amount varying with relative abundances of other rock-forming minerals. In general, the older and more mafic rocks contain smaller amounts of these minerals than the younger rocks, such as the Conway Granite.

The uranium and thorium contents of the crystallized rock and the magma increase as differentiation proceeds as long as the magma chamber is not disrupted by stresses. If disruption occurs the magmatic fluid can escape upward as dikes, and there also is a loss of uraniferous fluids. The geologic history of the White Mountain Plutonic-Volcanic Series indicates that such disruptions occurred many times in contrast to the other plutonic series. For this reason alone prospecting should be focused on areas in and near rocks of the White Mountain Plutonic-Volcanic Series.

Host Rocks

The types of host rocks favorable for uranium and thorium deposits available in New Hampshire and adjacent areas are for the most part of low porosity and permeability. They are primarily silicate rocks. Thus, the vein or disseminated types of deposits become the primary targets for prospecting and those rocks suited to maintain open fractures are most favorable. Equigranular rocks such as those of the White Mountain Plutonic-Volcanic Series and the binary phase of the New Hampshire Plutonic Series are perhaps the most likely hosts.

The epigenetic occurrences of uraniferous fluorite in northwestern Vermont are in dolomitic rocks of Cambrian age as are the syngenetic uraniferous phosphate deposits. Black shales and other organic-rich rocks in Vermont also are chemically favorable hosts for syngenetic deposits of uranium. In the southwestern United States, shales of Devonian age are abnormally rich in uranium. No such shales, or their metamorphic equivalent, are known in New Hampshire or the adjacent states. The Silurian black shales and schists, however, are slightly more radioactive than those of Devonian and Ordovician age, perhaps because of higher potassium content.

Sandstone, one of the most favorable host rocks in other areas because of its porosity, is known only in a very small area in southwestern New Hampshire at the north end of the Triassic basin that extends across Massachusetts and Connecticut along the Connecticut River valley. In Newgate, Connecticut, such rocks contain uranium associated with copper. Sandstone, interlayered with dolomite and limestone of Cambrian age, in western Vermont is red in places owing to the effects of hematitic alteration which is believed to be associated with mineralized solutions that introduce uranium. In New Hampshire, somewhat less-favorable host rocks include the gneisses of the Highlandcoft, Oliverian, and New Hampshire Plutonic Series; the feldspathic gneisses and amphibolites of the Ammonoosuc Volcanics of Middle Ordovician age; the quartzites of Silurian age; the volcanic units of the Littleton Formation of Early Devonian age; and the Massabesic Gneiss of Precambrian(?) age. The least favorable host rocks are the schists and gneisses of Ordovician, Silurian, and Devonian age, although in areas of high-grade metamorphism they also can be expected to hold open fractures. In the low-grade zones fractures tend to swing into parallelism with the cleavage. Similar rocks in other areas of New England would have the same characteristics.

Carbonate-rich rocks are rare in New Hampshire and southern New England but abundant in western Vermont and parts of Maine. Chemically they and their metamorphic equivalents--marble, calc-silicate, and amphibolite--are favorable for the precipitation of uranium from solution. The Fitch Formation of Silurian age contains the most significant carbonate units in New Hampshire. They were originally limestones, calcareous sandstones, and calcareous shales. Less-extensive calcareous zones are known in the Devonian and Ordovician rocks. In other parts of New England, especially in Vermont, carbonate rocks are more widespread throughout the Paleozoic part of the stratigraphic section and are interlayered with sandstones (now quartzites). They perhaps owe their induration to silicification that accompanies the introduced hematite and uranium. They and the associated carbonate rocks perhaps are the most favorable host rocks in northwestern Vermont. In eastern Maine there are several sandstones of diverse ages that deserve attention as possible hosts. In eastern Massachusetts and Rhode Island some of the sandstones of Pennsylvanian age contain hematitic stains suggesting that they also should be considered as hosts for uranium deposits.

Favorable Structures

The available geologic maps show insufficient detail to allow the pinpointing of structures in which uranium or thorium deposits of economic importance might be deposited. They do, however, provide the basic geologic background for selecting broad areas favorable for prospecting and for more detailed mapping. Reinspection of this basic geology, using recently-acquired radiation and magnetic data and information derived from space photographs allows one to select smaller and more favorable parts of these broad areas and points to additional areas not previously considered favorable.

The main geologic units of New Hampshire trend northerly, parallel to folds formed during the Acadian orogeny of Devonian time. These folds have been cut by major faults and fault zones, which are not shown on existing maps, and by others, such as the Ammonoosuc thrust which has been mapped. These faults and fault zones appear to have been formed in at least two periods, one at the end of Paleozoic time and another in post-Triassic time that is probably related to the intrusion of the White Mountain Plutonic-Volcanic Series.

The older faults are mainly broad zones of thrusting along which rocks have moved miles or tens of miles. The largest of these zones trends northeast and dips north across southern New Hampshire and Maine and extends southwestward across Massachusetts and Connecticut. Several individual large faults have been identified and mapped in this zone in southern New England; smaller ones have been identified in southeastern New Hampshire but are not shown on existing maps. Associated with these northeast-trending faults are smaller thrusts that strike east and dip north and others that strike north and dip east or west.

The Ammonoosuc thrust fault, which forms the Connecticut River valley, is a west-dipping structure that trends north as do the east-dipping Lake Champlain and Taconic thrust zones in western New England. The northern parts of these zones have northeast trends in northern New Hampshire and Maine, and in Quebec, respectively.

There are many subsidiary faults associated with these main trends that might serve as structurally favorable areas for deposition of metals, such as uranium, especially in places where these older structures have been reopened by movements in post-Triassic time.

The younger group of structures appears to be related to the injection of the subjacent magma from which the White Mountain Plutonic-Volcanic Series formed. In general, the main structures trend across the earlier fault zones in a northwest direction. Few of these structures have been mapped in New England, but they show as lineaments on photographs taken from space. Movement along these zones is measured in tens or at most thousands of feet; they are essentially zones of shear fractures with subsidiary tensional fractures that trend east or north. These subsidiary fractures are probably the most favorable sites for uranium deposition.

The largest northwest-trending lineaments shown on the LANDSAT images are in a zone between Lake Winnipesauke and Cherry Mountain in New Hampshire. They extend northwest to Lake Champlain and southeast into Maine. They enclose the area occupied by the main mass of White Mountain Plutonic-Volcanic Series rocks. The southernmost limit of these northwest-trending lineaments is just south of Lake Sunapee. This zone of weaker lineaments extends southeast to the coast and northwest into New York. It includes the sites of the southernmost units of the White Mountain Plutonic-Volcanic Series in New Hampshire and Vermont.

The association of favorable source rocks and favorable structures to serve as pipelines for uraniferous solutions to areas in which depositions could occur suggests that much of central and northern New Hampshire is a good area for prospecting. Extrapolation of these ideas to Maine and Vermont also seems justified.

An additional lineament trend appears to be associated with uranium occurrences in southwestern Vermont. A strong lineament trends north-northeast from near the southwestern corner of the state across the Green Mountains structure to Mt. Ascutney. This lineament also could be related to the favorable source rocks to the north.

Zoning of Metal Deposits

Northwest of the main mass of rocks of the White Mountain Plutonic-Volcanic Series in the White Mountains of New Hampshire are a number of occurrences of metallic minerals that seem to be related to the intrusive rocks and also to the most prominent lineaments shown on the photographs from space. The known gold occurrences are closest to the source rocks, with the copper occurrences farther to the west. Distribution of metal deposits in Vermont has not been studied in detail by the writer but there are copper occurrences at the Udal mine in Walcott where uranium occurs with nickel. The uranium known at Milton, Vermont, and to the north occurs with fluorite. This sequence of metals and associated elements suggests the possibility of temperature zoning of elements outward from the White Mountain rocks along fracture zones that appear to form the strong lineaments. If so, this would be of considerable aid in prospecting for both uranium and thorium.

Concealment of Deposits

There are several geologic factors that will make the discovery of uranium and thorium deposits in New England more difficult than in some other areas of the United States.

The main topographic surface of New Hampshire and New England was formed in Cretaceous and Tertiary time when the area was deeply saprolitized; thus most veins and other zones of weakness in the area were etched into deep valleys that later were scoured by ice and covered by till in Pleistocene time. Meltwaters from the ice were concentrated into these old valleys and deposited sands, gravels, and clays in them. As a result, radiometric studies of this area will not be readily interpreted, although the signature of the bedrock can be picked up in most places.

The deep Tertiary-age valleys also indicate a much lower water table than at present and consequently the movement of uranium from surficially high areas will tend to make radioactivity lower at the surface and may mask the presence of secondary deposits. Thus low rather than high radioactivity may mark vein structures that contain uranium below the surface. The Sunapee deposit is an example of a secondary deposit that never did reach the surface until it was exposed by road building. It may have been at the surface at the point where this structure and the water table intersected the surface in Tertiary time, a spot now covered by Lake Sunapee. This geologic relationship suggests that the intersection of the northwest-trending structure on the northeast of Lake Sunapee and the east-trending uraniferous zone is a good place to find additional secondary deposits, but it also implies that the primary ore would be in the opposite direction and up-structure. Knowledge of the pre-Pleistocene drainage systems would be very helpful in finding buried deposits of this type.

It follows from the above considerations that the economic deposits of the vein type are likely to be found under lakes, streams, and swamps; areas at least in part owned by the State and thus subject to state control and state royalties.

Summary of Guides to Prospecting

Prospecting for uranium and thorium minerals is primarily carried out with instruments that measure the radioactivity of their daughter products formed as the elements disintegrate with time. However, unless these daughter products form at, or are carried to, the surface by water or air, the presence of a deposit can go unnoticed.

Finding a concealed deposit requires the use of many types of data, such as are obtained from geologic, geophysical, and geochemical studies that will allow the selection of a target for physical exploration, such as trenching, drilling, or shaft-sinking. The most fundamental data are those collected in geologic study of known deposits in other areas and coupled with the geologic data available in the new area. There are many mineralogic associations that suggest the presence of radioactive materials, such as smoky to black quartz, yellow beryl, and dark-purple to black fluorite. The following items have been selected as appropriate guides to areas favorable for deposits in New Hampshire and adjoining areas.

Syngenetic Deposits

1. Areas of alkalic rocks, particularly those that are rich in potassium. In New Hampshire this includes all rocks of the White Mountain Plutonic-Volcanic Series; however, current data suggest that pink Conway Granite is the most favorable rock for containing low-grade deposits of uranium and thorium.
2. Areas of binary granite of the Concord type. One analysis of the granite near New London shows 14 ppm of uranium according to E. P. Beroni of the Department of Energy.
3. Areas of quartzites, particularly those of the Clough Formation (Silurian). These might contain fossil placers rich in thorium as well as in uranium.
4. Pegmatites, particularly those near masses of Bethlehem Gneiss. Economic deposits are not likely unless areas of numerous, closely spaced bodies are found that can be mined on a large scale.
5. Graphitic schists in zones of low-grade metamorphism.
6. Phosphatic limestones and dolomites as in northwestern Vermont.

Epigenetic Deposits

1. Areas near the northwest-trending lineaments shown on satellite photographs are probably most favorable for prospecting although a north-northeast-trending lineament southwest of Ascutney is probably equally important.

2. The zonal distribution of metal occurrences within the northwest lineament areas indicates a decrease in temperature westward toward Lake Champlain from the main White Mountain batholith area and, therefore, the better uranium prospects are outward from the gold deposits of the Lisbon area and the copper deposits in the Mt. Gardner, New Hampshire, area.

3. The presence of abnormal mercury on faults and in vein materials appears to be related to the White Mountain plutons and indicates the probable presence of low-temperature and possible uranium-rich fluids.

4. Hematitic alteration of the primary type--usually an off-color red, pink, or purple--occurs along veinlets in the Conway Granite to depths of more than 2800 ft, in dolomites in the Lake Champlain area, and along fractures and faults in southern New England, Maine, and New York. In other parts of the World this is a common hypogene alteration of wall rocks at the edges of veins of uranium and thorium.

5. Calcite-bearing dike rocks appear to be spatially related to uranium in other parts of the World as they are at Sunapee deposits. Dark dike rocks of Jurassic or younger age appear to be guides to favorable areas.

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