CANADA

PROSPECTOR'S GUIDE

FOR

URANIUM AND THORIUM MINERALS IN CANADA

(Reprint of Second Edition)

BUREAU OF MINES
MINES, FORESTS AND SCIENTIFIC SERVICES BRANCH
DEPARTMENT OF MINES AND RESOURCES
OTTAWA, CANADA
1950

CONTENTS

56983—2

INTRODUCTORY

IN the interval since the impact of the first—and, it is to be hoped, the last—atomic bombs, broke upon the world in August, 1945, the public has been made amply aware, through the press and radio, of the enormous significance which the discovery of means for releasing nuclear—or atomic—energy must inevitably have in the general world economy.

Most persons by this time know that the element *uranium* has played the chief rôle in this development, and that uranium at present serves as the essential raw material, or fuel, used as the source of power. It follows, therefore, that the provision of greatly increased supplies of uranium has become a matter of paramount importance, and one that is now engaging the active attention of the governments of all major countries.

Uranium, being a metal, occurs in minerals and ores, in the same way as copper, iron, lead, zinc, or any of the other metals commonly used in industry, and it is therefore natural that the broad facts relating to the character, mode of occurrence, and means of distinguishing uranium minerals, should be of especial interest to miners and prospectors. To meet the need for such data, the Bureau of Mines has issued this information circular.

For the sake of simplicity, the type of data presented has intentionally been restricted to elementary coverage of the bare essentials; more detailed information on particular phases of the subject can readily be found in standard textbooks on mineralogy.

Although the circular deals mainly with uranium, *thorium*, an element having somewhat similar properties and which usually is found associated with uranium, also is of potential interest as an alternative source of atomic power. Accordingly, certain information on thorium minerals has been included.

Although thorium may later come into demand, it is, at present, of only secondary interest and the Canadian Government is not as yet prepared to purchase thorium minerals or ores.

DOMINION GOVERNMENT CONTROL AND REGULATIONS

It is to be noted that both uranium and thorium are covered in recent Dominion Government regulations known as the Atomic Energy Regulations of Canada, made under The Atomic Energy Control Act, 1946. These Regulations came into force on April 1, 1947, and are administered by the Atomic Energy Control Board, Ottawa. Generally speaking, radioactive materials and information concerning them may only be dealt with as permitted by the Regulations, or by an Order of the Board, but the necessary provisions have been made to enable prospecting and exploration for radioactive minerals to be carried on as nearly as possible in the usual way. The present position has been summarized for the purposes of this circular, with the approval of the Board, as follows:

(1) No special order of the Board is required to permit prospecting so long as no mineral other than samples for analysis and hand samples for the usual purposes is removed from the claims.

(2) The Board is to be promptly informed of the places of origin and character of radioactive minerals discovered by any person, after the discoverer has had an opportunity of staking his claims. If the necessary information is sent in with samples to an analyst, it may be forwarded with the results of the analysis to the Chief, Geological Survey, Department of Mines and Resources, Ottawa, which for this purpose acts for the

Board. Otherwise, this information should be sent to the Chief, Geological Survey, as soon as the results are known, or, in the case of a discovery on unstaked property, as soon as the discoverer has had an opportunity to stake.

(3) Persons performing analyses of radioactive minerals may report the results to the persons for whom the analyses were performed, provided that (where the analysis is not done by the Department of Mines and Resources) a similar report is at the same time sent to the Chief, Geological Survey.

(4) The persons for whom such analyses were made may (subject to any specific order of the Board in the case of actual mining operations) make public the results at any time after the Board has been informed.

(5) There is provision in the Regulations requiring a permit from the Board for the carrying out of exploration and development work on any property. This does not refer to the prospecting work necessary to making the discovery, but, rather, is required for any program of work designed to develop a discovery after the discoverer has staked his claims. Such orders will contain appropriate provisions as to the handling of samples (including bulk samples for mill tests) and the furnishing of information to the Board and will permit the operator to receive and communicate information as to the results of analyses.

(6) Specific orders of the Board are required to permit mining operations involving removal of radioactive material in excess of sample quantities. These orders will contain appropriate provisions with regard to security both as to material and as to information.

It is recommended that anyone proposing to engage in prospecting or mining for radioactive minerals first obtain a copy of the Regulations and familiarize himself with their provisions. Copies may be obtained from the Secretary, Atomic Energy Control Board, Ottawa.

The terms of the Government offer to purchase uranium ores and concentrates as embodied in the announcements made by the Right Honourable C. D. Howe on March 16, 1948, and December 20, 1948, are as follows:

The Government will purchase through Eldorado Mining and Refining (1944) Limited, or other designated agency, acceptable uranium-bearing ores and concentrates on the following basis:

(1) A minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8) in the ores or concentrates will normally be required.

(2) Price will be based upon the uranium content of the ores or concentrates, and will be at the minimum rate of $2.75 per pound of contained U_3O_8 f.o.b. rail, and will be guaranteed for a period expiring March 31, 1955.

(3) The price includes all radioactive elements in the ores or concentrates, but consideration will be given to the commercially recoverable value of non-radioactive constituents by adjustment of price or by the re-delivery of the residues containing such constituents.

(4) Under special circumstances, consideration may be given to payment of a higher price, or to acceptance of ores or concentrates of lower grade.

(5) All operations will be carried on subject to the provisions of the Atomic Energy Regulations of Canada.

Wartime restrictions on the staking of land containing radioactive minerals in the Northwest Territories, the Yukon, and the Provinces of Manitoba, Saskatchewan, and British Columbia, have been relaxed and mining claims may be staked in accordance with the usual procedure established by the Department of Mines and Resources, or by the Provincial Mines Departments, as the case may be.

The present pamphlet has been prepared by officers of the Bureau of Mines at the request of the Atomic Energy Control Board. H. S. Spence, of the Mineral Resources Division, prepared the Section dealing with radioactive minerals. F. E. Senftle, of the Radiation Laboratory, prepared the Section on the "Use and Care of the Geiger Counter".

Inquiries for further information should be addressed to—

The Director,
Mines, Forests and Scientific Services Branch,
Department of Mines and Resources,
OTTAWA, Canada.

SECTION I

BY

H. S. Spence

URANIUM MINERALS

The number of known minerals which contain uranium in some amount is quite large (over fifty species are listed), but most of these are rare and can be considered at present of only mineralogical or specimen interest. In many, also, the uranium present is not an essential constituent, but is more in the nature of an accidental impurity, and the content of the element is so low and so variable that these minerals are of little practical importance as a source of uranium. Even at this time, when there is such a live interest in even low-grade uranium ores, such minerals are likely to be of little value as an economic source of the element, and it would be unwise to spend time and money in prospecting for them or in attempting to mine for them, if found.

The bulk of the world supply of uranium up to the present has been obtained from deposits of the following minerals:

Pitchblende, and secondary alteration products of:

Carnotite—Tyuyamunite
Autunite—Torbernite

Of these, only pitchblende is a primary mineral. The others are of secondary origin, and have been deposited through the agency of circulating waters at or near the surface, or are the result of weathering in place of original pitchblende.

PRIMARY MINERALS

Primary uranium minerals are dominantly black, conspicuously heavy, and of a metallic or sub-metallic appearance.

Pitchblende, the richest and most important, is compact and massive, with no evidence of crystal form or structure. It sometimes is found with botryoidal, or kidney-like, surfaces and a radiated texture. Pitchblende is distinctly a vein-forming mineral, and is usually associated with cobalt, nickel, silver, and copper.

Almost all of the other primary uranium minerals, including *uraninite*, a crystal variety of pitchblende, are confined in their occurrence to granitic rocks, more especially to pegmatite, which is a "giant", dyke-forming type of granite in which the chief component minerals, feldspar, mica, and quartz, occur in large crystals or masses. The variety of uranium minerals found in such association is large, and for the most part these are of complex composition, being multiple oxides of uranium, tantalum, columbium, titanium, iron, and the rare-earth elements. They are mostly black to dark brownish red in colour, conspicuously heavy, often of a sub-metallic appearance, and usually occur in the form of well-developed crystals up to several inches in length. It is characteristic of such minerals that the rock enclosing them is usually stained or coloured a deep brownish red and any patches or zones of conspicuously reddish colour in a paler pegmatite groundmass are worthy of examination for the possible presence of uranium minerals. Sometimes, also, small traces of conspicuously coloured canary-yellow or orange powdery crusts of secondary uranium minerals occur surrounding such crystals and serve to confirm their nature. It is not uncommon for pegmatitic uranium minerals to be concentrated in zones containing large nests or aggregates of black mica, and the rock around such mica, as well as the mica crystals or books themselves, should be given particular examination. The occurrence, also, of a black, coal-like hydrocarbon mineral (thucholite or anthraxolite), which will burn,

in a pegmatite is suggestive of the presence of uranium, and this material itself often contains a considerable amount of the element.

As a rule, such minerals occur rather sparsely disseminated in the host rock, though occasionally they form small nests or pockets. Owing to their complex composition, which would make chemical treatment for recovery of the contained uranium difficult and expensive, their variable and often only small content of uranium, and the usually limited quantity present, they can be considered as of only problematic value as uranium ores. However, it is of decided interest to have all new discoveries of such minerals placed on record, in case it may prove desirable to have the occurrences investigated more thoroughly at a future date.

Primary uranium minerals are rather prone to alteration and breakdown under weathering agencies, and for this reason they are seldom likely to be found with their fresh outward characteristics preserved in surface outcrops. Many of the species found in pegmatites tend to become externally friable and coated with a rusty crust when severely weathered, due to oxidation of the contained iron. Pitchblende, as well as its variety uraninite, may weather to a greenish cast, and both are liable to exhibit characteristic and vividly coloured yellow and orange secondary alteration products.

The foregoing remarks apply more specifically to conditions as they are likely to exist in Canada. In regions of deep weathering, as in tropical countries, it is common for most primary uranium minerals to suffer a complete alteration, in place, to secondary compounds. Certain Madagascar pegmatitic species are usually heavily altered to a yellow powder; the same holds for uraninite from Tanganyika; and at the famous pitchblende deposit in the Belgian Congo, the veins were found to be almost completely oxidized to a considerable depth, with the formation of ore consisting of a wide variety of spectacular and brilliantly coloured uranium compounds.

Possibly owing to ease of weathering, primary uranium minerals do not commonly form placer deposits, and few instances of such occurrences are known. However, some sections of the Rand banket conglomerate, in South Africa, have been found to carry detrital grains of *uraninite*, or *pitchblende*; and placer deposits of *thorianite*, a thorium mineral containing considerable uranium, occur in Ceylon. Any beach or river sands containing an important amount of heavy black minerals are worth investigating for the possible presence of uranium/thorium minerals. (*See also below*, under Monazite.)

Since, through surface weathering, pitchblende may break down into a variety of secondary uranium alteration products, all of which exhibit extremely brilliant and characteristic yellow, orange, or green colours, such compounds noted in a vein outcrop, or gossan, offer definite evidence of the presence of pitchblende at depth.

Pitchblende frequently is associated with cobalt-nickel-arsenic minerals, which also weather readily to form characteristically coloured pink (cobalt) and green (nickel) powdery alteration products. The association of a heavy, massive, black mineral with such compounds may be taken as strongly suggestive that the former is pitchblende.

SECONDARY MINERALS

As already stated, deposits of secondary uranium minerals have originated through the precipitation of uranium salts derived from primary minerals and carried in solution by surface or circulating waters. The minerals formed in this way are mainly compounds of uranium with such other elements as calcium, copper, lead, vanadium, etc.

Only rarely, as in the case of the famous occurrence in the Belgian Congo, have such minerals been found as a rich replacement in situ of primary ore. More usually, they have been deposited in rather sparse amount on cracks, joints, or solution channels in rocks which either originally contained primary minerals or which occur overlying or adjacent to occurrences at depth of such minerals. Occasionally, deposits of this last type have proved rich enough to work for their uranium content, as in Portugal, Russia, and Australia. If carried in solution by surface waters into basins or other favourable catchment areas, uranium salts may be deposited as rich concentrations of secondary minerals. In such event, carbonaceous matter in the form of decaying vegetation (or oil) is particularly favourable to deposition, as in the case of the *carnotite* occurrences in Colorado and Utah, the uraniferous peaty muds of Madagascar, and the lignitic "kolm" of Sweden.

The bright and extremely characteristic yellow, orange, or green colour of most secondary uranium minerals serves to attract attention to them, and is the most ready means of visual identification. Since such minerals are formed most often in hot, arid, or tropical regions, it is regarded as unlikely that important concentrations of them will be found to occur in a heavily glaciated country such as Canada. Even small traces of them, however, may prove of value as indicating the possible presence of richer primary ore at depth.

THORIUM MINERALS

It is not uncommon for certain primary uranium minerals, more especially those found in pegmatites, to contain moderate amounts of thorium. Certain varieties of *uraninite*, the crystal form of pitchblende, found only in pegmatites, are fairly rich in thorium, but, on the whole, straight thorium minerals which might be regarded as commercial sources of the element are much less common than uranium minerals and only a few are known. Most of even these few are of rare occurrence and of only mineralogical interest, and up to the present practically the entire world supply of thorium has been obtained from the single mineral *monazite*.

Monazite is of complex composition, consisting mainly of cerium and other rare-earth elements, with up to 18 per cent of thorium. It is a non-metallic mineral, yellow to reddish brown in colour, conspicuously heavy, and of crystalline character. It occurs as tabular crystals in pegmatite dykes, and as small grains in rocks intruded by granite or pegmatite, but most of the commercial supply is obtained from rich concentrations formed by wave action in beach sands along the coasts of India, Brazil, and Australia. Similar beach deposits are known in Ceylon, Florida, Malay, and the Netherlands Indies, all of which have furnished small quantities.

It is doubtful if occurrences of monazite in rock would be of economic interest at the present time, but such occurrences are worthy of record and might be of value as indicating the possible presence of nearby placer deposits, particularly if they exist in coastal areas.

Any extensive beach sand areas conspicuously rich in heavy black minerals are worthy of sampling for a possible monazite content. The black metallic mineral in such sands is likely to be *ilmenite*, an important ore of *titanium*, and often associated with it are *rutile* and *zircon*, both valuable industrial minerals.

The richest thorium mineral known is *thorianite*, a heavy, black metallic mineral which occurs in small cubic crystals in pegmatites. It is known in commercial amounts only in alluvial placer deposits, and is an exceedingly rare mineral, whose principal source is Ceylon.

Allanite is a complex mineral containing cerium and other rare-earth elements; it may carry up to three per cent thorium. Its occurrence is confined to pegmatites and granite, and in the former it is sometimes found in very large crystals. Allanite is a heavy, non-metallic mineral, black when fresh, but usually altered externally to a brown colour. An outer brown and friable crust is typical for allanite, and usually serves as a ready means of identifying it. While allanite has not so far come into consideration as a commercial source of thorium, it might serve as such if found in sufficiently rich deposits. For this reason any new discoveries of the mineral are worth placing on record.

Thorium is not precipitated out of solution in circulating waters, as is uranium, and hence important deposits of secondary thorium minerals are unknown, or are of relatively small importance. Small traces of thorium occur in the sinter of certain radioactive springs in Germany, France, and other countries, and in some cases recovery of thorium has been made from such sources. In view of the relative abundance of monazite, however, this mineral, as well as perhaps other primary thorium minerals originating in pegmatitic or granitic rocks, is likely to remain, for the present at least, the most important source of the element.

TABLE I

List of the More Important Uranium Minerals

(Chief commercial species in capitals)

Name	Uranium, per cent	Type and occurrence	Distinguishing characteristics
PITCHBLENDE	50-80	Primary In veins, often associated with silver, nickel, cobalt, and bismuth.	Dull black metallic, massive, without crystal form, texture, or cleavage. Sometimes with botryoidal or kidney-like surfaces. Smooth, irregular fracture. Brittle, very heavy. Streak or powder, black to greenish black.
URANINITE	65-80	Primary In pegmatite dykes, scattered through quartz and deep red or stained feldspar. Sometimes in nests in and around black mica.	Usually as well-formed, up to 1 by 3 inches, square, prismatic, or platy crystals, single or in groups. Submetallic appearance, with lustre ranging from brilliant to resinous. Mostly brittle, with irregular fracture. Colour deep black, through brown to yellow. Conspicuously heavy. Often altered externally and with a brownish crust. Pale streak or powder. Transparent to translucent in thin splinters. Thucholite is a black, coal-like hydrocarbon substance that will burn, and that sometimes replaces original uraninite.
Samarskite	9-18		
EUXENITE	1-4		
Fergusonite	2-5		
Ampangabeite	12-19		
BETAFITE	15-27		
Mackintoshite	21		
Uranothorite	1-10		
Ellsworthite	19		
Thorianite	12-33		
Hatchettolite	15		
Thucholite	2-8		

TABLE I—Concluded

Name	Uranium, per cent	Type and occurrence	Distinguishing characteristics
CARNOTITE (*a*)	54	Secondary (*a*) As local concentrations in sedimentary deposits. (*b*) On joints and cracks in granite, skarn and various other rocks. (*c*) Alteration products in situ of original primary pitchblende or uraninite. Most of these species are known only from the Belgian Congo, where they constitute the ore mined.	Most of these minerals occur in soft, powdery or earthy aggregates of minute crystals, or as massive crusts. Autunite and torbernite form larger, flat, platy crystals. All of the minerals are characterized by intensely vivid colours in shades of yellow, orange, or green, which serve to distinguish them from oxidation products of most other metallic ores. Economic deposits of secondary uranium minerals, in general, are formed only in hot, arid regions, and are unlikely to occur in Canada. Even small traces of such minerals, however. may serve as useful indicators of nearby primary ore.
TYUYAMUNITE (*b*)	54		
AUTUNITE (*b*)	60		
TORBERNITE (*b*)	60		
PARSONSITE (*c*)	32		
SKLODOWSKITE (*c*)	67		
KASOLITE (*c*)	49		
BECQUERELITE (*c*)	90		
SCHOEPITE (*c*)	87		
CURITE (*c*)	74		
SODDYITE (*c*)	86		
Gummite (*c*)	61-75		
Uranophane (*b*)	53-66		

TABLE II

List of the More Important Thorium Minerals

(Chief commercial species in capitals)

Name	Thorium, per cent	Type of occurrence	Distinguishing characteristics
MONAZITE	4-18	Primary In pegmatite dykes, granite, and gneiss or schist intruded by granitic rocks. Economic deposits confined to beach sand concentration or placers.	Monazite occurs in flattened, tabular, and often well-formed crystals of a dark red, brown, or yellowish colour. Non-metallic appearance, fairly hard, brittle, and shows good cleavage. Pale streak or powder. Translucent in thin splinters. In beach sands, usually associated with ilmenite, zircon, and rutile. Thorianite occurs in small cubic crystals of black metallic appearance. Hard and brittle. Heavy. Grey streak or powder.
THORIANITE	38-93		

TABLE II—Concluded

Name	Thorium, per cent	Type and occurrence	Distinguishing characteristics
Thorite (*x*)	48-71	Primary In pegmatite dykes, scattered through quartz and reddish or stained feldspar. Sometimes in nests in and around black mica.	In general, same as for the pegmatitic uranium minerals listed in group 2 in Table I. Some species contain appreciable amounts of both uranium and thorium. Those marked (*x*) are the commonest and most likely to be of economic interest. Allanite is black when fresh, but is usually severely altered externally to a brown colour. Small crystals are sometimes abundant in granitic rocks, and in pegmatites the mineral may occur in large crystals 20 pounds or more in weight.
Uraninite (*x*)	2-14		
Allanite (*x*)	1-3		
Xenotime	2-3		
Yttrialite	12		
Eucrasite	36		
Priorite	2-17		
Aeschynite	11-17		
Polymignite	4		
Ampangabeite	1-2		
Annerodite	2		
Pyrochlor	5-7		
Yttrocrasite	8		
Samarskite (*x*)	1-4		
Cyrtolite (*x*)	1-2		
Euxenite (*x*)	1-4		
Thucholite	10-12		

AIDS IN IDENTIFYING URANIUM AND THORIUM MINERALS

General, broad information on the character and mode of occurrence of uranium/thorium minerals has been given in the preceding section. Such information will serve as a guide to the distinguishing features of such minerals and to the type of formation or rock in which they are likely to be found and where they should be looked for.

The following notes in part present a résumé of what has already been said, with emphasis on the principal outward characteristics of the minerals, add a few more details that may aid in their visual identification, and, in addition, outline more definite means for determining their nature.

OUTWARD CHARACTERISTICS—APPEARANCE, WEIGHT, FORM, COLOUR, ETC.

Pegmatitic Minerals

Pegmatitic minerals that contain uranium/thorium, in amounts ranging from small traces to substantial amounts, may exhibit a metallic or non-metallic character and appearance. Often, it may be difficult to decide off-hand into which of these categories a particular unknown mineral should be placed, since many black species appear to be metallic, and only on examination of small fragments under a strong lens or a microscope does their non-metallic nature become apparent. This is evidenced by the fact that thin chips or splinters are translucent, usually exhibiting a characteristic red or brown colour, even though the massive mineral itself may appear opaque.

In general, it may be said that *any conspicuously heavy, black or dark-coloured* minerals discovered in a pegmatite should be tested for possible uranium/thorium content. Such minerals may be difficult to distinguish visually from *magnetite* and *ilmenite*—both common in pegmatites, or from rarer *tantalite-columbite, wolframite,* and *cassiterite.* Greater weight serves to distinguish them from *black tourmaline*, one of the commonest dark-coloured pegmatite minerals, and also from hornblende.

Pegmatitic uranium/thorium minerals usually, though not always, occur as well-formed crystals, which may be of cubic, prismatic, or tabular form. In general, such crystals do not measure over 3 inches by 1 inch in size. They may occur as single scattered individuals, but usually they tend to be concentrated in localized groups or zones.

The presence of a bright yellow or orange crust or powder surrounding a dark mineral is almost conclusive evidence that it contains uranium; and small plates or scales of a yellow or emerald green colour on cracks and joints in a rock are a useful indicator of nearby primary uranium ore.

In dykes composed of pink or red feldspar, the colour of the spar around uranium/thorium minerals is usually of a conspicuously darker brick-red shade; in white feldspar dykes, such minerals often cause a brownish or black discoloration in the enclosing rock.

A conspicuous radial fracturing of the feldspar or quartz surrounding a mineral inclusion in pegmatite rock is also often a useful indication that the inclusion contains uranium/thorium. *Cyrtolite*, a variety of *zircon*, which often contains small amounts of uranium/thorium, is particularly prone to exert a pronounced shattering effect in its host rock, and even small crystals may give rise to strong cracks radiating outward several feet from them.

Pitchblende

As already stated, pitchblende is the only uranium mineral known to occur in the form of definite veins or lodes. It may be difficult to identify with any certainty by its outward characteristics; when relatively pure, however, its exceptional weight serves to suggest its nature. The absence of any indications of crystalline or grain structure, or of cleavage, is helpful, the mineral breaking with a smooth, irregular fracture and having a dull, somewhat greasy or pitchy appearance or lustre. It sometimes occurs in botryoidal, or kidney-like masses, or crusts, which under a lens are seen to have radiated structure. In this last form, pitchblende somewhat resembles hematite iron, but it may readily be distinguished from hematite by the black or greenish black colour of its streak or powder, which for hematite is a strong red.

Secondary Minerals

Secondary uranium minerals are those formed by the alteration of primary species by weathering or other natural agencies. They may be found replacing the original minerals in situ, but more commonly have been precipitated out of solutions derived from such minerals.

Deposition may have occurred adjacent to the primary source, on cracks and joints in the enclosing rock; or the dissolved salts may have been carried considerable distances by circulating or surface waters, with the formation of rich concentrations in certain favourable areas. The *torbernite-autunite* deposits of South Australia and Portugal are examples of the first type of deposition, and the second type is represented by the *carnotite* occurrences in Colorado and Utah.

Generally, a tropical, or a hot and arid, climate is necessary for the formation of important deposits of secondary uranium minerals, and it is unlikely that occurrences of this nature will be found in Canada,

where recent glaciation has removed much of the original surface. However, such minerals are important in that they may serve, even in small traces, as indicators of the possible nearby presence of primary ore, and accordingly they are briefly mentioned here.

The only two species commonly exhibiting distinct crystal form are the so-called "uranium micas", *torbernite* and *autunite*. These occur in small, brittle, cleavable plates, which for *torbernite* are of an *emerald green colour*, and for *autunite* are bright *lemon yellow*.

The other species for the most part occur as either powdery coatings or soft massive material made up of exceedingly fine particles. Intense and vivid colours, in shades of bright yellow, orange, and green, are the chief distinguishing features of such minerals and serve at once to attract attention to them. Most of them are salts of uranium and various other metals, and a large number of such minerals are known.

MODE OF OCCURRENCE OF URANIUM MINERALS

Summarizing what has been said above, the following are the main points to be noted in connection with the mode of occurrence of uranium minerals.

Broadly speaking, the occurrences may be divided into the following three main types:

(1) Individual crystals, or nests, pockets, or similar aggregates of crystals—usually of small size and extent—sparsely and irregularly scattered through dykes of *granite pegmatite*. The variety of uranium minerals occurring in this manner is large, and embraces a large proportion of the known species.

The distinguishing characteristics of such minerals are black colour, metallic appearance, heaviness, and good crystal form.

(2) *Veins*, or *lodes*, of similar character to the general run of those of other metallic minerals such as zinc, lead, copper, etc. *Pitchblende*, the richest and commercially the most important ore of uranium, is the only primary uranium mineral that occurs in deposits of this type. It may be the dominant mineral, or, as sometimes the case, be in the nature of an accessory in veins of other metallic ores, notably those of silver, cobalt, and nickel. Pitchblende is characterized by black colour, metallic appearance, greasy or pitchy lustre and dense, massive texture. It never exhibits crystal form, but sometimes occurs in layers or bands having botryoidal or kidney-like surfaces.

(3) Deposits of a *bedded*, *replacement*, or *stockwork* character, in which the uranium minerals are a minor constituent of secondary origin and nature and have been emplaced through the agency of surface or circulating waters. Occurrences of this type may be found in both sedimentary and igneous (granitic) rocks, and usually they carry little, if any, trace of primary uranium minerals.

Secondary uranium minerals found in such deposits are characterized by vivid and brilliant colours in tones of yellow, orange, or green. They are usually in the form of soft powder, crusts, or tufts, occasionally being more massive. They seldom exhibit distinguishable crystal form, except in the case of the two commoner species *torbernite* and *autunite*, which occur in small well-developed thin plates.

DETERMINATION BY RADIOACTIVITY METHODS

All minerals containing uranium/thorium are radioactive; that is, they emit energy in the form of spontaneous radiation, and this may be detected by several fairly simple means. It is not possible, however, to distinguish between the emission from the two elements

except by precise laboratory methods. Close geochemical affinity, also, exists between uranium and thorium, and many minerals containing either element—more especially the pegmatitic species—frequently carry the other as well, in which case the radiation is of a dual nature, and may lead to wrong conclusions being drawn.

Photography. One of the simplest means for detecting radiation from minerals is to place the specimens on an ordinary photographic plate or film in a light-tight box and allow it to remain undisturbed for about 36 to 48 hours. On developing the negative, any marked uranium/thorium content will be evidenced by a distinct image, or auto-radiograph of the specimen. Intensity of such image, or self-photograph, is a rough measure of the degree of radioactivity of the mineral, and thus of the amount of uranium/thorium present. This amount, in turn, governs the time of exposure required to produce a well-defined picture. To avoid possible misleading effects due to pressure or chemical action on the photographic emulsion, it is sometimes advised to interpose a thin sheet of paper between the specimen and the film. Production of a smooth face on the specimen by sawing or grinding is advantageous and results in a much clearer and more defined image being formed.

Recent refinements in the making of radiographs of mineral specimens employ a special type of light-desensitized film. This distinguishes between uranium and thorium radiation, when both elements are present, by the relative intensity of the image.

It may be noted that it was the accidental exposure of a photographic plate to the radiation from a specimen of uranium ore which led to the original discovery of radioactivity.

Visual. For many years, a simple means of detecting radioactivity in minerals in the field was by the use of a small pocket device known as a *spinthariscope*, or *scintilliscope*. This consists of a short brass tube provided with a cap bored with a small hole in which a magnifying lens is inserted. Below the lens is cemented a small square glass prism, the lower end of which is coated with zinc sulphide powder. If a small fragment of strongly radioactive mineral is held close to this coated surface, some of the radioactive particles emitted impinge on the grains of powder and cause a succession of momentary flashes of light, readily seen through the lens. For best effect, it is necessary to conduct the experiment in a dark place, and to have the observer's vision thoroughly adjusted to darkness for a period of several minutes.

Recent progress in developing improved radiation-measuring devices has produced an instrument termed a *scintillation counter*. This makes use of the luminescent properties of certain crystalline substances when exposed to gamma radiation, the intensity of which is measured by the number of light flashes produced by the substance in a given period. The principle involved is that of fluorescence, as in the case of the spinthariscope described above, and of which the new instrument is a more highly developed type. As yet, only laboratory models have been perfected, but it is expected that portable field units will become available in the near future, and these may in time make obsolete the Geiger type of counter described in the following pages, and which at present is the tool universally used for detecting and measuring radioactivity.

One of the most reliable and widely-used instruments for detecting and measuring radioactivity has long been the *gold-leaf electroscope*. This makes use of the property possessed by radioactive materials of releasing the electrical charge on two small strips of gold leaf through ionization of the air in a small chamber in which they are suspended. By comparing the rate of discharge effected by a measured quantity of powdered and carefully sized material made from an unknown sample with that produced by a similar amount of a standard of known composition, a fairly close and rapid estimate of the degree of activity, and hence of the uranium content, of the test sample can be made. By such means, a great deal of time-consuming chemical analytical work can be eliminated, particularly in mills and refineries engaged in producing and treating uranium ores. Any thorium present in the test samples, of course, destroys the efficiency of the method, since thorium also is radioactive. For reliable results, the electroscope requires to be employed in a laboratory and is hardly suited to field use.

It is sometimes stated that the portable *ultra-violet light lamp* is a useful tool in prospecting for uranium minerals. This is true to a limited extent only, since only certain of the secondary species and none of the richer primary minerals exhibit any fluorescence under ultra-violet light, whether short or long wave. The utility of the lamp, therefore, would be confined to a few fluorescent secondary minerals, only one of which —*autunite*—has so far been found to occur in sufficient quantity to be of any particular economic interest. Accordingly, for practical purposes, prospecting for uranium mineral deposits by fluorescent means is not to be recommended, particularly as we now have a much more simple and practical tool for detecting even small traces of uranium/thorium minerals in the instrument described below.

Electronics. The above-mentioned, and, by comparison, relatively crude means of detecting or measuring radioactivity in minerals or other substances have more recently been supplanted by much more delicate and precise methods provided by an instrument known as the *Geiger counter*. This is a device employing radionic principles, whereby radioactive emission can be directly registered, measured and recorded, either in the form of sound or in other ways.

For field use on minerals, either broken out as specimens or in place, small, portable, light-weight units, equipped with dials, ear-phones, "blinker" flash bulbs, and built-in amplifiers, have recently become available and are proving of considerable value to prospectors engaged in a search for uranium/thorium ores.

In its original, rather cumbersome form, the instrument has long been employed with conspicuous success for locating radium lost or mislaid by hospitals and doctors, and numerous instances of recovery of valuable radium from such locations as garbage dumps, incinerators, drains, etc., by its use are on record.

Development of more elaborate laboratory instruments of this type has now reached a stage, where, with the aid of known standards, very precise measurements of uranium/thorium can be made, thus dispensing entirely with the need for chemical analysis and giving results in only a fraction of the time formerly required. Even greater refinements are possessed by models capable of registering selectively the radiation from uranium and thorium, thus establishing which element is responsible for the radioactivity of a mineral, and, if both are present, the relative amounts of each.

It may be noted that the portable type of Geiger counter, designed for prospecting use is essentially a *detecting*, and not a *measuring*, instrument. It will register even small increases in the radioactivity of minerals and rocks above the normal count, and will indicate, either by sound, light-flash, or dial reading, whether a specimen or area is "hot". Within limits, it will indicate the *degree* of radioactivity up to a certain point, thus enabling material or ground to be selected for recording and more detailed examination later. It cannot be used, however, to give even a rough approximation of the actual amount of uranium/thorium present, since various factors may confuse the issue.

Portable counters are of fairly rugged construction, and can be packed around with little risk of damage,

provided reasonable care is exercised. Details of operation are readily acquired and call for no special skill or training. With a little experience and with proper recognition of their limitations, they provide an indispensable tool for the prospector undertaking a search for uranium/thorium minerals.

CONCLUSION

The general broad characteristics of uranium/thorium minerals, and their usual mode of occurrence, have been outlined above. These notes, and the various field aids described which may be used to determine a radioactive content in rocks and minerals, should prove of considerable assistance in identifying specimens and areas of possible value.

It should be recognized, however, that the mere discovery of a mineral, deposit, or area, which possesses the outlined characteristics for a uranium/thorium content is no guarantee that such content will prove sufficient to be of economic interest. Decision on this point is a matter for expert examination and appraisal, and often will require considerable detailed laboratory investigation. In the event of any such discovery, a full record of the locality, nature, and extent of occurrence, and samples of the mineral or rock, should be sent to the Chief, Geological Survey, Department of Mines and Resources, Ottawa, who will take steps to have a laboratory report made on the material.

Note:—A valuable booklet, which contains a great deal of information on character, distribution, and mode of occurrence, of uranium and thorium minerals, as well as on aids that may be used in prospecting for and detecting such minerals, has recently been published. Anyone desiring a concise source of reference on this subject, and particularly anyone proposing to engage in prospecting for uranium/thorium minerals, would be well advised to obtain a copy of "*Handbook of Uranium Minerals*", by J. DeMent and H. C. Dake, 2nd Edition, 1948. The book is obtainable from The Mineralogist Publishing Company, 329 S.E. 32nd Avenue, Portland 15, Oregon, U.S.A., at the price of $2.00.

SECTION II

BY

F. E. Senftle

USE AND CARE OF THE GEIGER COUNTER FOR THE DETECTION OF RADIOACTIVE MINERALS

Since the discovery of the radioactive properties of thorium and uranium, many new instruments and techniques have been found which can be of great value to the prospector. For the most efficient and reliable results, the prospector would be well advised to equip himself with one or more of these new devices. Any one type of detection instrument may have some distinct advantage. For example, photographic plates have a cumulative effect over a period of time, as well as being very economical, but it has been found that the most practical instrument for locating radioactive anomalies is the Geiger counter. All the other methods can be used with the Geiger to facilitate detection of radioactive ore, but by themselves are not so efficient and trustworthy.

DESCRIPTION

Space does not permit a detailed description of the Geiger counter here. However, a brief description of its action is as follows: Radioactive ores give off penetrating radiation called gamma rays. Within the instrument is a Geiger tube, across which is placed a high voltage. When a gamma ray is absorbed within this tube, a discharge takes place, and the tube conducts a current momentarily. This short pulse is amplified and recorded in the operator's ear-phones as a "click".

Ordinarily, cosmic rays also produce a similar effect, and hence, there is always a continuous series of "clicks" heard in the ear-phones due to this cause. This is called the "background count". When a source of radioactivity is directly beneath the instrument, the "clicks" come at a much faster rate than the background rate. The rest of the Geiger detector is made up of an electronic amplifier, and batteries.

The Portable Field Geiger Counter for the Prospector

The modern prospector model Geiger counter used for field work consists of two general types:

The first is comprised of a single box unit with self-contained tubes, batteries, and amplifier circuit. This is carried over the shoulder in a special canvas bag.

The second type has the counter tube mounted in a separate probe unit on the end of several feet of flexible cable. The rest of the counter is housed in a box and carried over the shoulder similarly to the first type. The advantage of the probe is that activity within small crevices may be more easily localized.

Experience shows, however, that localization of activity can be done quite conveniently with the self-contained unit, and for the prospector who is interested in the minimum of gadgets to handle, this unit is probably the more practical. On the other hand, for underground surveying, where localization of activity in a stope may be important, a probe detector is more suitable.

For the convenience of those who wish more information on these counters, the details of several Canadian makes are briefly described below.

One type of counter manufactured in Canada comprises both a light and a heavy model, neither of which has a probe unit. The smaller model is approximately

3 by $6\frac{1}{4}$ by $8\frac{1}{4}$ inches, and weighs $6\frac{1}{2}$ pounds complete. This unit is self-contained and is equipped with ear-phone detection only.

The larger unit is 4 by 8 by 10 inches and weighs 15 pounds. This instrument has a rate-meter attached by a belt worn about the waist. The meter records the rate at which the clicks are heard in the ear-phones. This type is particularly useful where an accurate count survey is to be made, as it eliminates the necessity of counting the clicks.

Another type of counter also available in Canada is of the probe type. All the components, including the probe, are contained in a rugged metal cabinet, $12\frac{1}{4}$ by $11\frac{3}{4}$ by $4\frac{1}{4}$ inches, and the complete instrument with batteries weighs 17 pounds. Besides ear-phones, this unit is also equipped with a visual flasher that blinks along with the clicks in the phone. A counting rate-meter is mounted on the front panel.

Other makes are available besides the above-mentioned examples. Most of the manufacturers advertise in the technical publications, and further details as to price can be had by writing to the manufacturers.

OPERATION AND PRECAUTIONS IN THE USE OF THE GEIGER COUNTER

As has been mentioned before, the counter will record a background count, due to the ever-present cosmic rays as well as to random gamma rays. The normal background will vary over short periods of time, but over a longer period it should be relatively constant at from 5 to 50 pulses a minute, depending on the counter. Variations from this count can be due to several causes:

In walking over different types of bedrock, the average background will usually vary. For instance, a noticeable variation in background will be found in crossing a limestone-granite contact. As a rule, limestone is quite inert, but granite usually contains a proportion of radioactive constituents. Again, a relatively large area, say 150 square feet, of comparatively weak radioactive (0·1 to 0·5 per cent) material may cause a comparable response to that of a small crevice filled with high-grade ore.

A distinct decrease in the counting rate is sometimes encountered when entering a depression, especially if the sides are steep. The reason for this is that in such a location the counter is shielded from the cosmic rays from outer space to a greater extent than when on flat open ground. The prospector must learn to familiarize himself with these obvious changes in counting rate, since they cannot be controlled.

Other changes in counting rate are due to causes that can be controlled to a large extent. The most important of these is contamination. It must be remembered that the Geiger counter is an extremely sensitive instrument. For this reason, care must be taken to prevent radioactive dust and dirt from entering the canvas carrying-case, and to guard against contamination from the operator's clothes. It must be kept in mind that grab samples and specimens should never be carried with the instrument.

If, when the Geiger counter is being used, a heavy thunderstorm threatens, it is best to stop work until the storm has well passed. Lightning flashes and disturbed conditions in the air sometimes cause spurious counts in the counter.

Another effect which must be taken into consideration is that due to overburden. Overburden or bedrock capping a radioactive deposit will act as an effective radiation shield. Experience has shown that 3 feet of earthy overburden will cut off practically all of the detectable radiation.

One of the most important points that should be stressed in the use of the Geiger counter is the rate at

which a certain area is surveyed. As a radioactive vein or shear zone is approached, there will be very little increase in the counting rate until the instrument is almost over the vein. This is due to the shielding action of the wall-rock flanking the vein or shear zone. For this reason, the operator must walk slowly in order to avoid missing a small anomaly.

Counter Response Due to Radiation from Potassium

In addition to anomalies liable to be encountered due to the causes mentioned in the preceding paragraphs, there is a further factor which prospectors need to take into account and which may cause misleading conclusions to be drawn, particularly when the more sensitive dial-type of counter is being used. This is counter response due to radiation from *potassium-bearing minerals.* Commonest of such minerals are potash-feldspar and mica, both of which are universally present in acid igneous rocks of granitic and syenitic type, as well as in gneisses, schists, etc. High-potash feldspar (microcline or orthoclase) commonly contains 12 to 14 per cent potash (K_2O), and the potash content of the commoner varieties of mica (muscovite, biotite, and phlogopite) is in the range of 7 to 10 per cent.

Recent laboratory determinations by the Radioactivity Section, Bureau of Mines, Ottawa, of the potassium content of previously analysed samples of feldspar by beta radiation counter showed a close check. Field readings by portable counter were also taken on a number of pegmatite dykes worked for potash feldspar in the Ottawa district, and it was found that the response varied from $2\frac{1}{2}$ to $3\frac{1}{4}$ times background (average of eight deposits, 3 times background). These results confirm that radioactivity due to potassium minerals appreciably affects the Geiger counter, and that responses of 2 to 3 times background may be expected, and are to be discounted when traversing areas in which rocks rich in such minerals are prominent.

Counter Response from Secondary Uranium Minerals

Although not likely to be of particular import in Canada, where conditions are not favourable for the occurrence of significant deposits of secondary uranium minerals, the following points may be mentioned.

A proportion of the total counter response from uranium minerals is due to *radon gas*, one of the several radioactive decay products of uranium. In the case of dense, compact primary uranium minerals, such as *pitchblende, samarskite*, etc., a large proportion of such gas is trapped or absorbed within the mineral and will contribute to the amount of overall radiation from it.

On the other hand, most secondary uranium minerals (e.g. *autunite, torbernite, carnotite*, etc.) have a much lower specific gravity (are less dense) and they also tend to occur in open-textured, powdery or earthy, crusts or aggregates of minute individual grains or crystals. Such material permits of a greater escape (emanation) of free radon, and of its radioactive decay elements, than a dense, impermeable primary mineral, even though both contain the same amount of uranium.

It follows, therefore, that counter response from a deposit or specimen of such secondary uranium minerals may cause misleading conclusions to be drawn, especially if such response be compared with that of a check piece of *pitchblende*, or of some other primary mineral. The former may appear to be lower in uranium than it actually is. Radon loss from different specimens of even the same material may vary widely, and can be a serious source of error unless the samples are treated to prevent escape of the gas and then stored for a few weeks to restore the radon equilibrium.

A further source of error exists in the case of secondary uranium minerals of comparatively recent formation, or age. Even though the uranium content be the same, the older (geologically) the mineral, within the range set by the natural decay rate of uranium, the higher will be its radium content, and consequently the greater its radiation emission. *It is the radium content of a uranium mineral that mainly causes counter response, and not the uranium itself.* The radium content starts to build up within a mineral from the time of its formation, and a period of about 600,000 years is required to elapse before the full decay cycle of uranium, through its various radioactive break-down products to lead, is accomplished and the final, stable stage of complete uranium-radium equilibrium is reached. (A period of 400,000 years suffices to effect about 99 per cent equilibrium.) It is this end-ratio that enables the radium content of a geologically-old uranium mineral to be computed without chemical determination of the radium. In addition, the age of the mineral may similarly be deduced from the amount of lead it contains, that is, from its lead-uranium ratio.

Care of the Instrument

In regard to the care of the instrument, a few words may be said. It should be protected from rough treatment or dropping. Most field units, however, are built to stand a normal amount of abuse.

Most of these instruments are not adapted for use in an excessively humid environment, as, for example, in a very wet mine. Such conditions destroy the internal insulation, and usually an hour or two of such operations will shorten the life of the Geiger tube. On the other hand, the Geiger counter can usually be used continuously in a normal rain-storm on the surface, where there is free circulation of air and the humidity is moderate. Care should be exercised to carry it in a waterproof canvas case, where direct contact with water can be avoided.

The instrument should not be placed where it may be overheated, such as near a campfire. The batteries in the counter will be destroyed if overheated.

Typical Systematic Methods

Once a certain amount of experience is gained with the Geiger counter in the field, it is recommended that some systematic method be used. One of two procedures may be followed.

The first is general reconnaissance. The day's survey is planned in advance and the path to be followed is dictated by the geology and the topography of the area. Often the prospector may direct his course by what he finds when actually on the ground. This reconnaissance plan is followed when very little is known about the radioactivity of the region.

In the second procedure, when an area is known to be radioactive, and it is a matter of localizing the various showings of activity for later correlation, a grid survey can be made. The area is marked off on a grid system of about 20 feet to a side. One-minute counts are taken at each station and recorded on a gridded map. After the grid is complete, contour lines may be filled in and the anomaly outlined. This method is a time-consuming job and is recommended only for localized work where an active deposit is to be outlined. For general prospecting the first method is the more practical.

Servicing the Geiger Counter

The Geiger counter is a highly technical piece of equipment and should not be tampered with by those unacquainted with its mechanism. It is advisable, however, for the prospector to take an extra set of batteries when on an extended trip. Batteries are easy to replace and this can be done without danger of doing harm to the instrument. If a new set of batteries fails to make the unit function, it is advisable to return the instrument to the manufacturer. Most firms will gladly repair a faulty unit for a small fee.

APPENDIX

EXAMINATION OF SAMPLES BY DEPARTMENT OF MINES AND RESOURCES

When a prospector finds a deposit which indicates the presence of radioactive minerals he should forward a representative sample to the Chief, Geological Survey, Department of Mines and Resources, Ottawa. Usually, a pound or two pounds of each sample will be sufficient.

The sample should be accompanied by a letter giving, in as exact detail as possible, the locality from which the sample was taken, a general description of the field rocks in the area and their relationships, the apparent extent of the deposit, and any other information that might have a bearing on determining the potential value of the deposit.

The Geological Survey will examine the sample for radioactivity and, if it appears to be of potential importance, a detailed analysis will be made and a report will be forwarded to the prospector in accordance with the regulations of the Atomic Energy Control Board.

Should the deposit appear to be promising, an officer of the Department of Mines and Resources may be assigned to make a field examination on behalf of the Atomic Energy Control Board.

Prospectors should bear in mind that the same economic conditions as govern the development of any other mineral deposits apply to the commercial development of deposits of radioactive minerals, viz., in case the material is low grade, much larger tonnage must be in sight than if the ore were high grade, before the deposit can be regarded as being of commercial interest.

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1950

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
[illegible]