

RADIOACTIVITY AND MINERAL DEPOSITS

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ABSTRACT

Radioactivity is important in a variety of problems in economic geology. Radiations from radioactive ore deposits provide a means of locating shallow ore-bodies. Anomalous distribution of radioactivity also may be of limited use in locating faults. Variations in radioactivity of ordinary rocks are proving useful as a means of correlating rocks, and of logging cased wells, and radioactivity produced in the more common rock-forming elements by artificial neutron bombardment likewise is proving useful as a logging method.

Studies of rocks show an increase in the proportion of radioactive elements in differentiation from basic rocks to granites and pegmatites, and have provided some insight into the mechanism of formation of radioactive ore. In non-radioactive ore-bodies, the small variations in radioactivity appear to be of no genetic significance, but occasionally may prove useful for purposes of correlation.

The rates of accumulation of helium and lead calculated from radioactivity are useful in conjunction with helium, lead, or isotopic analyses for the calculation of geological age. The helium method has the weakness that helium escapes from altered and open-structured minerals during geological time, but enough is now known about the limitations of the method to permit its use on selected material, thus reducing the error enough to be useful in problems where the age is not known by geological criteria within wide limits. The lead method, now restricted to rare radioactive minerals, may eventually be developed to the point where it may be applied to many granitic and other type rocks.

Studies of the radiogenic and isotopic history of lead ores suggest that hydrothermal ores of this type are derived from rocks or rock magmas.

GEOLOGICAL AGE

Helium Method:

Calculation of geological age from the concentrations of radioactive elements and accumulated helium (Fig. 1) is complicated by the variable degree of retention of helium by different rocks and minerals. In an unaltered Devonian granite of expected age about 300 million years, one might find: granite—helium index 90; quartz—75; feldspar—60; biotite—180; hornblende—250.

Such figures, obtained from substitution of helium and radioactivity analyses in the age equation, are clearly not absolute ages, but it is useful to express the results in this manner, using the term *helium index*.

If all granitic rocks showed nearly the same degree of retention of helium, determinations of the helium index would be useful in geological correlation, even though absolute ages were not established. As a matter of fact, rocks of one type with comparable geological histories have given the correct sequence in some cases, the best results having been obtained with basic crystalline rocks. Table 1 summarized a series of determinations on such rocks. Lane and Urry (1935) and Urry (1936, p. 1217)

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had previously found a measure of regularity in results from basic rocks.

A statistical analysis of helium age results shows that there are only about two chances in three of assigning such a rock to the correct geological period. Not only is the problem complicated by the escape of some

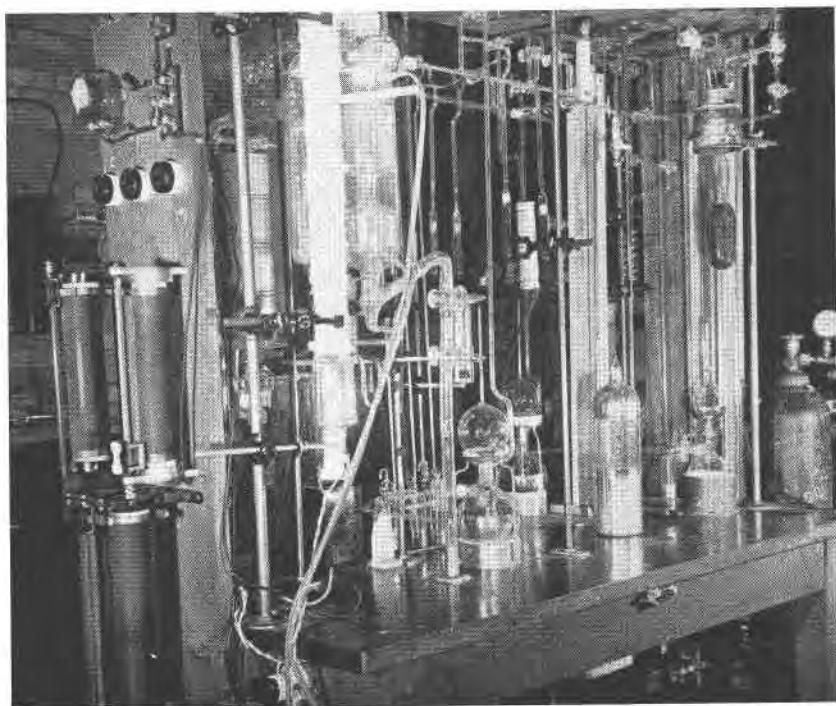


FIG. 1. Apparatus for the micro-analysis of helium.

of the helium but occasionally excess helium is present as in a diabase from Yellowknife, N.W.T.: Yellowknife diabase—1000; feldspar—100; pyroxene—1650; olivine—800; magnetite concentrate—4800; expected helium age—600.

Excess helium in rocks, however, seems to be rare, and it may be suspected by the absurdity of results, particularly when several minerals in a specimen have been studied. Geochemical considerations, together with a survey of several hundred helium indices, show excess helium most likely to be present in carbonates, and late hydrothermal minerals. In the case of the Yellowknife diabase the magnetite, associated with the titaniferous minerals, ilmenite and leucoxene is probably of deuteritic origin.

In search of an answer to questions regarding retention of helium a number of minerals and rocks have been studied (Keevil, 1941) and it

has been found that helium retentivity varies for different minerals, and that it may be affected by geological environment.

A theoretical treatment of the problem of diffusion of helium (Keevil, 1940) has suggested that it is desirable to use close-packed minerals with as nearly perfect structures as possible, with crystal dimensions greater than the range of alpha-rays, and with no excessive localization of radioactivity. Some experiments with such minerals have led to fairly promising results. As one example, Dr. H. H. Hess and the author have

TABLE 1. HELIUM AGES OF SOME BASIC ROCKS

<i>Location</i>	<i>Helium Index</i>	<i>Geological Age</i>	<i>Helium Age</i>
Yellowstone Park	12	Miocene	21
Newfoundland	53	Triassic	105
Quebec	61	Triassic	120
New Jersey	68, 69	Triassic	140
New York	89	Triassic	175
Newfoundland	65	Pre-Triassic	150
Quebec	80	Pre-Triassic	185
Scotland	80, 109	Post-Devonian	220
New Jersey	150	Post-Ordovician	340
Newfoundland	321	Ordovician	530
Wyoming	200	Keweenawan	575
Michigan	186	Keweenawan	530
Quebec	210	Keweenawan	600
Wyoming	1550	Early Pre-Cambrian	—
Manitoba	1800	Early Pre-Cambrian	—

obtained the following results using carefully selected unaltered minerals: Augite—Gilboa Quarry, Triassic diabase, 182; bronzite—malips Drift bronzitite, 742; augite—Sekukuni norite, 588; hypersthene—Sekukuni norite, 511, suggesting that most of the radiogenic helium was retained during geological time, and Hurley and Goodman have found concordant results with a series of magnetite samples (Hurley and Goodman, 1943).

Loss of helium and the presence of excess helium has been found in all of these minerals, and no criterion for the selection of perfect material has been definitely established.

No two geological samples are identical, and the problem is further complicated by the high degree of localization of the radioactive elements

in minor accessory minerals (Keevil et al., 1944) which may be present as sub-microscopic inclusions in otherwise perfect minerals. Nevertheless, the use of carefully selected unaltered minerals for helium age determinations shows some promise (Hurley, 1950).

Another method of attack is to correct helium indices for helium retentivity. Such a method has been followed in calculating the helium ages given in the last column of Table 1. Here, the helium indexes have been corrected on the basis of the average retentivity of basic rocks and its change with geological time. This method does not seem to be generally applicable, however, because of other variables which determine the final degree of retention. For example, an apparent relationship has been noted between degree of alteration, as determined with the petrographic microscope, and helium retentivity; hornblende unaltered—90% helium retained; $\frac{1}{4}$ altered—75% retained; $\frac{1}{2}$ altered, 40%; $\frac{3}{4}$ altered, 15%; altered to chlorite—5% retained. A yardstick which measures the degree of alteration is needed for this application, but this does not seem to be forthcoming until more knowledge of the effect of metamorphism on storage of helium is at hand.

In either case, it is clear that the helium method cannot be 100% reliable, and aside from further development research, present application of the method to rocks would seem to be warranted only where the age difference in question is appreciable, or where geological criteria of age are lacking.

Lead Method:

More hope of obtaining absolute ages has been held for the lead method based upon the same radioactive mechanism, but using the more stable end-product lead as a measure of time. Up to the present, however, only highly radioactive minerals have yielded enough radiogenic lead for study. This has the dual weakness of limited application because such minerals are not always available in most problems of correlation, and well-dated material is too scarce for adequate means of standardization. Furthermore, selective leaching of uranium, thorium, or lead, frequently introduces difficulties. In spite of this, results by the lead method have been consistent enough to give confidence in the method.

The scope of the lead method has been increased by the discovery of extreme localization of radioactive elements in accessory minerals of some rocks. It is probable that this is quite general, and a few milligrams of radiogenic lead might be separated from concentrates of minor minerals and subjected to isotopic analysis by means of the mass spectrometer. This may make the lead method of age determination applicable to some rocks, particularly to the important group of acidic and intermediate intrusives.

A still more promising possibility, suggested by the above localization of radioactivity, and by the discovery of E. S. Larsen that lead is concentrated in weakly radioactive potassium minerals, is that the age may be determined directly from a spectrochemical analysis for lead and a determination of radioactivity of a concentrate of accessory minerals. This method would be based upon the premise that the correction for common lead in radioactive accessory minerals would be negligibly small. A joint research program to test this method is now under way (Keevil, Larsen and Harrison, 1949).

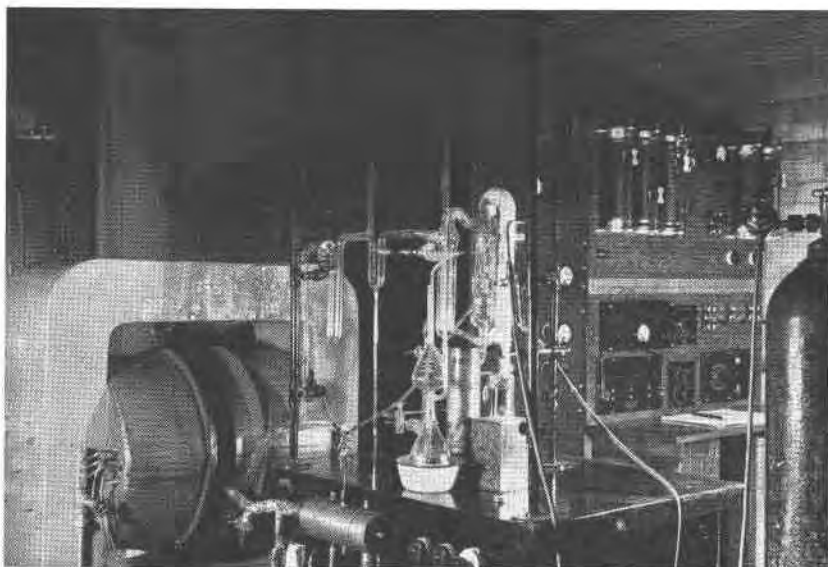


FIG. 2. Mass spectrometer for the isotopic analysis of lead.

DISTRIBUTION OF RADIOACTIVITY AROUND "NON-RADIOACTIVE" ORE DEPOSITS

General:

All of the districts included in this part of the investigation are usually considered to be of a non-radioactive type. The extreme sensitivity of radioactive experimental techniques makes possible the rapid quantitative determination of a few parts per million of radioactive elements. The results accrued are thus of geochemical as well as geophysical interest.

Porcupine Area, Ontario:

In the Porcupine area specimens from the Hollinger Dome, Preston East Dome and Coniaurum Mines were studied (Keevil, 1943). The

quartz porphyries were found to be low in radioactivity, and no significant variation was observed in samples taken at various distances from ore deposits. The activities of 22 quartz porphyries, representing the Pearl Lake, Acme, Crown, Millerton, Miller Lake, Dome and Preston East Dome porphyries, as well as others in Bristol Twp., Tisdale Twp., averaged 0.42 and ranged in activity from 0.26 to 0.67 alpha-rays emitted per milligram per hour; similarly, 66 samples of porphyry collected by E. L. Evans from the Hollinger Mine averaged 0.47. The darker-colored varieties tended to be more radioactive. Lower than average values were obtained for a specimen from the centre of the Coniaurum mass (0.28), and from the centre of the Pearl Lake mass (0.35), suggesting a distribution of radioactivity similar to that found by Ingham and Keevil (in press) for granodiorite and granitic batholiths (see also Wilson, 1949).

Two gold-quartz veins were only slightly more radioactive (0.10, 0.20) than a barren quartz vein (0.06), and two impure quartz samples separated from quartz porphyries (0.19 and 0.23) suggests a genetic relationship between gold-quartz and quartz porphyry. Similarly, the close similarity of the radioactivity of quartz porphyry pebbles in the conglomerate (0.40) with the average for 22 porphyries (0.42) indicates that the conglomerate is younger than the quartz-porphyry.

Newfoundland:

Typical ore and rock samples from the Buchans district, Newfoundland, were used for age determination (Keevil, 1943) and additional radioactivity measurements were made on other specimens. The activity of chalcopyrite in the Lucky Strike Mine (2.24) and in boulders (1.58) and mixed ore (1.40) is somewhat higher than usual, but a normal range of activities was found for other rock and mineral types in the area.

Franklin, New Jersey:

A study of the distribution of radioactivity in the Franklin and Sterling Hill area, New Jersey, and age determinations on a number of rocks and minerals have been made (Keevil, 1943).

Radioactivities of the rocks and pegmatites are summarized in Table 2. Aside from high values for the pyroxenites and basic pegmatites deep in the mines, the radioactivities are fairly characteristic of the rock types represented. The higher activity of blue limestone mixed with shale, and the lower activity when mixed with chert, are not unexpected since shales tend to be considerably more active than siliceous deposits; and the low activity of the pre-Cambrian gneiss is consistent with its antiquity. The only contact relationship noted was a tendency for the radioactivity of the white limestone to be higher near the pegmatites.

TABLE 2. RADIOACTIVITIES OF ROCKS AND PEGMATITES AT FRANKLIN AND STERLING HILL, NEW JERSEY
alphas/mg./hr.

<i>Rock</i>	<i>Franklin, N. J.</i>	<i>Sterling Hill, N. J.</i>
Trap dike	0.2-2.2 (1)*	—
White limestone	1.53 (11)	0.57 (9)
Graphitic white limestone	1.1 (1)	—
Quartzite	—	0.7 (1)
Blue limestone	0.72 (3)	0.60 (4)
Blue limestone with shale	1.9 (1)	—
Blue limestone with chert	0.4 (1)	—
Pegmatites	—	1.0 (4)
Boni pegmatite	7.1 (1)	7.5 (1)†
Pyroxenites	—	0.7-44.0 (2)
Mica amphibolites	1.2 (4)	—
Pochuk gneiss	0.58 (6)	1.2 (1)

* Numbers in parentheses refer to number of specimens analyzed.

† Mafic portion 10.5; felsic portion 5.9.

Determinations of the radioactivity of ninety mineral specimens from the Franklin area are summarized in Table 3. The highest and lowest activities were obtained for minerals from the Franklin mine, and the average for Franklin minerals was somewhat higher than that for specimens from Sterling Hill, but on the whole the activities of minerals in the two mines were comparable both in magnitude and distribution.

The high radioactivity of certain minerals and the wide range of ac-

TABLE 3. SUMMARY OF RADIOACTIVITY DATA ON MINERALS FROM FRANKLIN AND STERLING HILL, NEW JERSEY

<i>Minerals</i>	<i>Activity</i> alphas/mg./hr.
Apatite, barylite and siderite with iron olivine (separated from magnetite)	7
Vesuvianite, beryllium-vesuvianite and apatite	3.2-4.6
Schefferite, magnetite, black roepperite and sphalerite	2.0-3.0
Zincite, sphalerite, manganiferous calcite, barysilite, calcium larsenite and calcium rhodonite	1.5-2.0
Franklinite, willemite, sphalerite, tephroite, zincite, hardystonite, galena	0.9-1.5
Franlinite, calcite, barite, garnet	0.8-1.2
Willemite, friedelite, franklinite, barysilite	0.4-0.8
Franklinite, willemite, zincite, manganiferous calcite, hancockite, barite, fowlerite, hardystonite, sphalerite, calcite, roepperite, cyprene, feldspar	0.2-0.4
Franklinite, friedelite, hedyphane, sphalerite, calcite, feldspar	0.1-0.2
Zincite, galena, cyprene, franklinite, schefferite, fowlerite, calcium larsenite, calcium rhodonite, calcite, biotite, sussexite	0.0-0.1

tivity from weakly active silicates such as sussexite (0.007) to apatite (7) and thorite (about 50,000) distinguish these deposits from most others studied in this series in which the heaviest elements are distributed sparsely and nearly uniformly. This distribution of radioactivity is doubtless related to the mode of origin, since concentration of radioactivity in the later pegmatitic stages of differentiation of granitic magmas is well known. In the present instance pegmatitic minerals were generally found to be more radioactive.

The distribution of radioactivity between the minerals may be partly related to period of deposition, younger minerals being more active, but generally seems to have been controlled by chemical affinities, those minerals which are most active being those which are frequently associated with radioactive elements. The lowest activities for any particular mineral was found in the purest crystals; complex aggregates tended to be higher.

Coeur d'Alene District:

Considerable variation was found in the activities of galena ores from mines in the Coeur d'Alene district, Idaho (0.2-2.7). Specimens from the Morningstar, Sunshine, and Tamarack veins were the least radioactive, and impure galena ores were relatively high. A small decrease in the radioactivity of country rock away from the ore suggests that the ore-bearing solutions were more radioactive than country rock. Lead and zinc ore with quartz—1.4; wall rock, 2 feet from ore—1.25; wall rock, 10 feet from vein 1.00. The results summarized in Table 5 show that sulphide ores are usually lower than country rock, but note below that some relatively radioactive sulphides were found at Gilman, Colorado.

Gilman, Colorado:

A wide range of radioactivities was found for rocks and minerals in the Gilman area (0.2 to 98.6), the distribution of radioactivity in ore minerals being approximately: sphalerite and galena, Eagle Mine—0.45 (3 specimens); sphalerite and pyrite—4.8 (1); pyrite 1.4 (2); chalcopyrite 2.2 (1); beegerite, hessite, chalcopyrite and pyrite, pocket in the 20th level (possibly radioactively contaminated) 98.6. The results show that some of the ore-bearing solutions in this region must have been appreciably radioactive; a group of 15 mineralized rock samples averaged 5, and covered a range from 2 to 8 alphas/mg./hr. Another group of 19 mineralized rocks was much less radioactive (0.7) as was much of the lead and zinc ore. The average activities for the sulphides as a whole, like those in the Coeur d'Alene district, were higher than the average of all sulphides from various localities. This suggests that the radioactivity

of ore solutions of the Eastern Cordilleran metallogenetic province was relatively high, (as also indicated by the presence of radioactive ores in the district) and that conclusion is strengthened by the relatively high radioactivity of granitic and monozonitic intrusives in this region (Keevil in preparation).

Radioactivities of rocks in the Gilman area are summarized in Table 4.

TABLE 4. RADIOACTIVITIES OF ROCKS AT THE EAGLE MINE, COLORADO
alphas/mg./hr.

Rock	Geological Age	Locality		
		Newhouse 16-2 and #2 Surface and Under-ground Sect.	19-5 and 20-1, 28, 36 Sections Included Radon*	
Weber limestone	Permo-Pennsylvanian	3.0 (1)		
Weber arkose	Permo-Pennsylvanian	1.6 (2)		
Quartz monzonite porphyry	Pennsylvanian	3.0 (3)		
Zebra dolomitic limestone	Upper Leadville Mississippian	0-8 (4)	0.26 (7)	0.44 (7)
Lower Leadville limestone	Mississippian	5.6 (1)	1.0 (8)	
Parting dolomitic quartzite	Devonian	0.4 (4)		1.00 (17) 0.95 (11)
Blue dolomitic limestone	Devonian	6.3 (1)	0.8 (7)	0.41 (13) 0.65 (17)
Granular sandstone	Ordovician	0.9 (3)		
Suwatch dolomitic sandstone	Cambrian	1.0 (3)		
Purple quartzite	Cambrian	0.06-4.3 (2)		
Mineralized quartzite	Cambrian	0.15-4.8 (7)		
Unmineralized quartzite	Cambrian	0.4 (2)		
Porphyritic biotite diorite	pre-Cambrian	1.15 (2)		
Mineralized and sanded rock		4.7 (3)	0.71 (18)	1.15 (19)
Fault breccia		0.0 (1)	0.47 (9)	0.64 (8)
Miscellaneous rocks mostly blue limestone		—	0.58 (36)	

* Radon concentrations in arbitrary units of alpha-rays from radon observed per gram of sample.

The rocks in the Newhouse sections showed greater variability than usual, the effect of ore-bearing solutions apparently being to increase the radioactivity of host rock above the uniform levels of radioactivity at the time of deposition. This suggested that a radioactive metamorphic aureole might be present around the ore deposits in this locality. A detailed study of the 19-5 level, however, did not show any systematic change of radioactivity along the sections, and only a few of the mineralized samples showed small increases in radioactivity above the average radioactivity.

As a part of this investigation one hundred determinations of the radon loosely held by the sample were made about two weeks after collection of the specimens.

It will be noticed in Table 4 that the average radon concentration (shown in final column) parallels the activities, and as expected, a decrease of radon with decreasing porosity is also suggested by the results, less radon being contained by less porous quartzite. Several points where relatively high concentrations of radon were found coincided with relatively high activities of the rock, suggesting local diffusion of radon from radioactive grains; however, other high radon concentrations were associated with porous "sand" zones and fault breccias which may have been due to concentration of radon by diffusion along associated fault structures and storage in beds which acted as better reservoirs for gases. The relatively low radioactivities of ore in this particular section would seem to preclude association of these anomalies with radioactive mineralization, particularly as the activities were often low for the solid sample when occluded radon gas was high.

Two typical series of results (for specimens taken at 25 foot intervals) along the sections are as follows:

	<i>Activ- ity</i>	<i>Radon</i>		<i>Activ- ity</i>	<i>Radon</i>
Zebra limestone	0.25	0.20	Fault breccia	0.45	1.31
"Sand" dikes	0.6	1.68	Sand dike	0.4	1.34
"Sand" dikes	0.3	1.14	Blue limestone	0.4	0.42
Zebra limestone	0.25	0.82	Blue limestone	0.25	0.48
Mineralized fault breccia	0.95	1.18	Fault gouge	1.00	1.38
"Sand" mineralized pocket	0.55	0.36	Mineralized fault gouge	0.35	2.31
Parting quartzite	1.2	0.69	Pyritized "sanded" rock	—	1.03
Parting quartzite	2.0	1.72	Blue limestone	0.1	0.43
Sand pocket	0.3	0.33	Blue limestone	0.4	0.5
Parting quartzite	1.2	0.60	Blue limestone	0.1	0.2

Superior, Arizona:

In the Magma Mine, Arizona, the ores cover an average range of activity for sulphide minerals from 0.03 to 1.5 alphas/mg./hr. This is about the same as the span of activities for country rock. A suggestion of a rhythmic distribution of radioactivity was noticed in the diabase which may be related to ore-bearing solutions, but is more likely due to physical-chemical equilibria in the consolidation of the diabase.

Austinville, Virginia:

Several series of samples of Cambro-Silurian limestones and dolomites representing sections through and near the Malden and Fisher Field

ore-bodies at Austinville, Virginia, were studied, radioactivity determinations being made on 62 specimens. Minor differences in activity were found between several dolomitic limestone members: Lower Adl gray dolomite 0.17; fine grained Ribbon limestone 0.32; mottled gray Rome dolomitic limestone 0.31; Malden gray limestone and dolomite 0.25; carbide limestone 0.21; Adl gray dolomite 0.31; crude ore 0.16; mineralized contact 0.52.

As in the Couer d'Alene district, the impure mineralized border of the ore zone is somewhat higher, suggesting that ore bearing solutions were more radioactive than host rock, although the ore itself is weakly radioactive. The results in sequences for seven sections away from ore bodies were as follows:

.27, .25, .26, .27, (.61) .35, .43, .25, .18, .19, .14, .05, .27, .03, (.38)
 .37, .50, .47, .76, .68, .62, .20, .20, .20, .20, (.52)
 ore, .10, .49, .30, .11, .04, .02 (.36)
 .21, .26, .20, .16, .20, .16, .63, (over ore) .18, .20, (.08) .19
 .37, .37, .50, .41, .24
 (.20), .01, 15 (over ore) .12, .16, .02
 .15, (.07) .19, (.00) .11

The italicized values represent rock mineralized with sulphide, and the bracketed values indicate anomalous values in the series. The latter sometimes coincide with a change in the type of limestone, and in this connection it was noticed that the lighter gray specimens of dolomite and limestone are generally less radioactive than the darker varieties. In a few specimens the presence of chert and silica are associated with slightly greater activity, while some weathered specimens are quite low in radioactivity. The presence of mineralization is definitely associated with slightly increased activity, but since the mineralization is also related to fault structures it should be borne in mind that radioactivity might have been introduced by diffusion or penetration of relatively radioactive solutions along faults.

Other districts:

The results of radioactivity determinations of ore and country rock in several mining districts are summarized in Table 5.

In general gold ores are only feebly radioactive. Base metal sulphide and oxide ores show some regional variation but are generally equally or less radioactive than country rock. Pure minerals are likely to be less active than impure ore, and greater activity is occasionally associated with mineralized rock, suggesting that ore-bearing solutions sometimes contain more radioactive elements than host rock. This is to be expected when there is a close relationship of the ore to pegmatites, but not with

TABLE 5. RADIOACTIVITY OF ORE AND COUNTRY ROCK

<i>District</i>	<i>Activity of Country Rock</i>	<i>Type of Ore</i>	<i>Activity of Ore</i>
Porcupine area, E. Ont.	0.42 (22)	gold quartz	0.15 (2)
Red Lake, Ont.	0.9 (15)	gold quartz	0.0 (1)
Sullivan Mine, Ont.	0.5 (94)	quartz vein	0.00
Cournor Mine, Que.	0.5 (94)	gold-pyrite	0.00
Sudbury, Ont.	2.7 (3)	sulphides	0.9 (4)
Michipicoten Harbour, Ont.	1.4 (1)	molybdenite	0.3 (1)
Sault Ste. Marie, Ont.	—	molybdenite	1.1 (1)
Buchans, Newfoundland	0.3-2.3 (21)	sulphides	0.3-2.2 (6)
Brittania, B. C.	0.3-1.1 (6)	sulphides and schist	0.0-0.5 (3)
Jefferson City, Tenn.	0.3-3.2 (4)	sulphides with dolomite	0.3-2.7 (6)
Hanover, N. M.	—	zinc-lead ore	0.15 (4)
Mexico	1.15 (7)	sphalerite and pyrite	0.2 (1)
Coeur d'Alene district, Idaho	1.37 (4)	galena and quartz	0.4 (6)
Coeur d'Alene district, Idaho	—	galena and country rock	1.6 (5)
Magma Mine, Ariz.	0.51 (33)	sulphides	0.5 (6)
Austinville, Va.	0.26 (60)	sulphides	0.15 (2)
Gilman, Colo.	0.0-8.0 (107)	sulphides	0.2-2.2 (7)
Gilman, Colo.	—	iron, silver, copper, sulphides	98 (?) (1)
North of Great Slave Lake, N.W.T.	0.8-7.2 (3)	magnetite & sulphides	14 (1)
Baire Oriente, Cuba	9.5 (1)	pyrolusite ore	1.8 (1)
Franklin, N. J.	0.2-44 (55)	complex group	0.7 (91)
North of L. Huron, Ont.	—	iron oxides	1.46 (7)
Sterrett Mine, E. Que.	0.1 (2)	chromite	0.00 (1)
Kilmar, Que.	0.3 (7)	magnesite	0.01 (2)
Ivigut, Greenland	0.1-5 (3)	cryolite and sphalerite	0.01 (3)

later veins, which appear to be generally impoverished in thorium and uranium.

DISTRIBUTION OF RADIOACTIVITY AROUND RADIOACTIVE ORE BODIES

Colorado:

In the metallogenetic province of eastern Colorado radioactive minerals frequently occur in pegmatites, and uranium ore is mined on a small scale in several localities. Although no detailed work was done on specimens from the immediate vicinity of such mines, the granitic rocks in the region are distinctly more radioactive than normal, and radioactive ore might have concentrated from magmas which gave rise to these parent rocks.

Aside from relatively higher activities of the Silver Plume batholith

near mineralized zones, the regional differences in radioactivities found for two hundred Colorado granite specimens are due largely to differences in time of emplacement; the economic significance of the data is merely in the suggestion that parent rocks to be favorable for radioactive ore occurrence only have to reach in the magma stage, a certain minimum concentration level of radioactivity.

Great Bear Lake:

More than one hundred specimens of rocks from the vicinity of the Eldorado Mine on the southeast shore of Great Bear Lake, N.W.T., have been studied. Specimens of ore, of course, have an activity of several thousand, and a few specimens of highly altered rocks near veins were also found to be highly radioactive. In general, however, the rocks in this region are not much more radioactive than normal, the activities of specimens collected underground, a few dozen feet from ore, not being significantly different from the average for similar type rocks from more distant parts of the area.

Representative specimens of all the important types of rock near Eldorado Mine were collected through the kindness of Mr. Gilbert LaBine and Mr. E. J. Bolger. The sampling locations were distributed as uniformly as possible on the surface within several hundred feet of the coastline near LaBine Point and for some distance north and northeast beyond Glacier Lake, and also underground at fairly regular intervals, chiefly along the 500 foot and 650 foot levels, except for a group close to the number 3 vein where several rock types were sampled. Since no significant areal distribution of radioactivity was noted around the veins, a map showing exact locations is not given.

The results obtained for all except a few highly radioactive mineralized and highly altered specimens are summarized in Table 6. The radioactivities are generally higher than normal, but a surprising degree of uniformity was found in the results considering the danger of contamination by minute particles of radioactive minerals during handling. One would also have thought that the solutions would have penetrated greater distances away from the ore, relative to the zone of alteration often observed around mineral deposits. At the Eldorado Mine, high activities (exceeding 10,000) occur in the vein material and fall several thousand-fold approaching normal radioactivities within a few feet of the vein, suggesting small permeability of country rocks to the radioactive ore components. As a matter of fact, no differences were found between rocks near the mine and those miles away except in a few cases where extensive alteration or mineralization was observed. The results show that geophysical prospecting for radioactive veins of this type, by means of field counting instruments, could be used for direct location of radiation, or

TABLE 6. RADIOACTIVITIES OF ROCKS NEAR LABINE POINT AND IN THE ELDERADO MINE, N.W.T.

<i>Type of Rock</i>	<i>No. of Specs.</i>	<i>Radioactivity Range Observed</i>	<i>Average Activity</i>	<i>Average for Other N.W.T. Specs.</i>	<i>Continental Average for Corresponding Rocks</i>
		alphas/mg./hr.			
Old complex (sed. gneiss)	3	2.30-2.87	2.49		
Greenstone	2	1.50-1.63	1.56		
Sediments	23	1.24-4.47*	2.60		1.60
Vein breccia	1	—	1.87		
Chloritic alteration & sheared rock	5	2.33-6.05	3.97		
“Red alteration”	2	2.03-4.46	3.25		
Porphyry	23	1.13-3.24	2.15		0.90
Granodiorite	8	0.86-4.07	2.43	1.09 (6)	1.75
Granite	7	2.34-5.23	3.48	2.45 (81)	2.02
Aplite	2	5.40-6.23	5.82		3.20
Diabase	6	0.57-1.90	1.07	0.12 (7)	0.72

* One value 7.07.

emanation from radioactive veins, but would not be guided by a larger surrounding aureole of higher than average radioactivities of country rock except in a vague or erratic way. In glaciated regions, a guide to ore might be provided by higher soil activities in the direction of glacial movement away from radioactive ore bodies. This subject will be discussed more fully in a later section.

Aplitic rocks, probably representing a late stage of the intrusion of granite, are the most radioactive rocks at Eldorado, and often elsewhere. The sequence of radioactivities down to the least active basic rocks is normal, and this suggests that the normal course of differentiation was followed as far as the radioactive elements are concerned. Activities for granite and aplite of the same order of magnitude have been found in other localities, so that localization of radioactive ore at Great Bear Lake is likely due as much to favorable sedimentary host rocks and favorable structural channels for the passage and deposition of radioactive ore, as to the geochemical nature of parent magma.

Possibilities of Radioactive Ore in Other Areas:

Radioactivities of granitic rocks, higher than the parent body at Great Bear Lake, have been found in wide areas in West Central Alaska, North Central British Columbia, Colorado, Texas, Georgia and New Hampshire, (and locally in a number of other scattered localities in the

United States and Canada). As the magmas producing these rocks might produce radioactive ore solutions under appropriate conditions, it might be well to examine parts of these areas with radioactive geophysical methods, and to search for favorable structure conditions and suitable host rocks.

DETECTION OF HIDDEN RADIOACTIVE DEPOSITS AND STRUCTURES

Radioactive Ore:

Deposits containing appreciable quantities of uranium or thorium minerals are thousands of times more radioactive than ordinary rocks and mineral deposits, pure uranium or thorium oxides having an activity of 300,000, a monazite sand about 20,000 and radioactive zircon grains up to 15,000 alphas/mg./hr., as compared to a value of 2 for typical granitic rocks.

In considering the problem of locating hidden radioactive ore bodies from their characteristic radiations, it is important to realize that even the most penetrating gamma radiation is absorbed by a few feet of rock or overburden. The depths at which deposits are detectable can be increased through the use of more sensitive Geiger counters, or scintillation counters. Results with a Geiger counter with a sensitivity more than a hundred times that of the usual field counter are shown in Fig. 3. The usefulness of such instruments is increased by indirect radiation from material transported from the source. This includes the diffusion of radioactive emanation from the source, transport of radioactive material by solution, tracing the mother lode from active alluvial, detrital, glacial

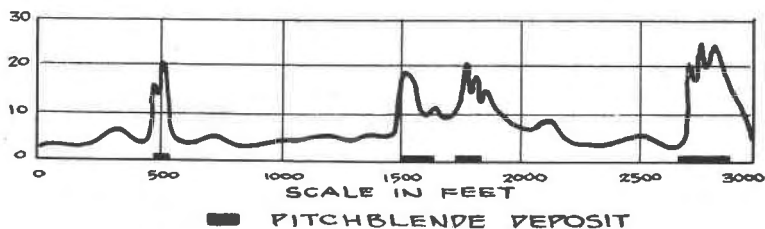


FIG. 3. Radioactivity profile from super Geiger counter survey over the Camray property, Alona Bay District, Sault Ste. Marie, Ontario. (Units are relative to a standard radium source equivalent to 3×10^{-9} R).

or secondary residual deposits, and geological guesses about the relationships of ore deposits to radioactive host rocks and structures.

Diffused radon:

The only appreciably long-lived gaseous member among all the series of radioactive elements is radon, and this has a half-life of 3.84 days, decaying spontaneously to 1 per cent of its original concentration in 3

weeks. In the past numerous attempts have been made to employ radon in geophysical exploration for the location of fault structures and mineral deposits with varying degrees of success. The writer has obtained slightly higher concentrations of radon over a fault in the Gulf Coast, as well as a slight increase in radon concentrations with depth.* Higher radon concentrations were also found over a shallow oil field in Metcalfe, Township, Ontario.

In spite of the short half-life of radon, there is enough favorable evidence to warrant exploring the method further in the location of shallow fault structures, particularly where it is likely that relatively radioactive sources at depth are present to provide a reasonable gradient.

Migrating Solutions:

The upward transport of radioactive material from the source would tend to counteract the disadvantages of the short half-life of radon, provided the radioactive members (uranium, ionium and particularly radium) parent to radon, were included in the migrating fluids.

The radioactivity might be measurable in springs or ground water, or from residual matter along faults or in detrital material and this might lead to the discovery of radioactive ore below. Professor Esper S. Larsen has noted the occurrence of radioactive minerals in springs, and Lane and Bennett have located a fault in Michigan by the locally high radioactivity of water. Occasionally contacts between formations show slight increases in radioactivity as contrasted with that of either formation suggesting that fluids, migrating along the path of least resistance, have deposited small quantities of radioactive material.

Glacial Transportation of Radioactive Material:

Glacial movement over radioactive ore would provide glacial drift in the direction of movement, with specific radioactivities higher than the regional average for normal drift. In order to test this possibility soil and rock samples were collected in the vicinity of Wilberforce, Ontario, and south to Lake Ontario. These samples were collected in connection with a field trip made for other purposes, and it is unfortunate that the deposits around Wilberforce turned out to be much less radioactive than commonly thought. There are some small pockets of pegmatite containing uranite, and some syenite bodies of appreciable size which are considerably more radioactive than regional granites and gneisses. The results showed a tendency for higher soil activities in a cone representing the direction of glacial transport.

Further tests in more radioactive areas should be made to test the

* Soil radon concentrations corrected for contributions of radon from mineral constituents. Average radon de-emanation of 8 to 10% was found in over 100 soil samples.

possibility of radioactive soil surveys as a reconnaissance method of exploration for radioactive ore.

WELL LOGGING

Correlating strata by means of their characteristic natural radioactivities is widely used in logging oil wells, particularly where the penetrating power of gamma-rays permits logging through cased wells. Radioactivity produced in the more common elements by bombardment with neutron sources also has been employed to log wells with similar counting devices. Determinations of the absolute radioactivity of samples taken from wells and comparisons with the gamma-ray logs is needed to improve calibration and interpretation.

The writer has made a few alpha-ray logs of oil and gas wells; the results of which are available upon request.

ORE-GENESIS

In the family of hydrothermal ores, lead sulphides are made up partially of radiogenic material. An average of 9.8 per cent of the lead is derived from the decay of uranium and thorium during the period before segregation of lead ore. Isotopic analyses of lead ores have shown that the average lead-uranium ratio in the source material was variable, covering the range 3.2 to 15.0. This compares with the lead-uranium ratios in granites and intermediate rocks exposed on the earth's surface (probable value 9 ∓ 4). With these facts in mind and remembering that average thorium-uranium ratios of rocks lie within the range 3 to 4, it is a simple matter to show that the atomic weight of rock lead would be close to 207.21. The range in atomic weights actually found for ore-leads fall within a narrow range entirely consistent with what would be expected for their derivation from rocks or rock magmas. As a matter of fact, the change in isotopic composition of ore-lead with geological time and the variations in composition observed, suggest that hydrothermal ores of this type were derived from sources like rock magmas whose characteristics change with time, and not from a deep-seated uniform sub-stratum as proposed by Holmes on the basis of earlier radioactivity and isotopic data.

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