

Selected Annotated
Bibliography of the Uranium
Geology of Igneous and
Metamorphic Rocks
in the United States

GEOLOGICAL SURVEY BULLETIN 1059-E

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the U. S. Atomic Energy Commission
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BY DIANE CURTIS

SELECTED BIBLIOGRAPHIES OF URANIUM GEOLOGY

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UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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ILLUSTRATION

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SELECTED BIBLIOGRAPHIES OF URANIUM GEOLOGY

SELECTED ANNOTATED BIBLIOGRAPHY OF THE URANIUM GEOLOGY OF IGNEOUS AND METAMORPHIC ROCKS IN THE UNITED STATES

By **DIANE CURTIS**

ABSTRACT

This bibliography consists of 117 references concerned with the uranium content and radioactivity of igneous and metamorphic rocks and minerals in the United States including Alaska and Hawaii. The annotations, arranged alphabetically by author, emphasize the geologic features of rocks and minerals for which uranium determinations have been made. An index map shows the location of igneous and metamorphic rocks and minerals that have been analyzed chemically for uranium.

Indexes are provided with entries listed according to author, geographic area, and subject.

EXPLANATION OF THE BIBLIOGRAPHY AND INDEX MAP

This bibliography is an annotated list of selected reports that pertain to the uranium content and (or) radioactivity of igneous and metamorphic rocks and minerals in the United States including Alaska and Hawaii, which were publicly available as of May 31, 1956. The annotations are listed alphabetically by author, and chronologically if there is more than one report by the same author. The references are numbered consecutively for indexing purposes. The statements on the stratigraphic classification and nomenclature are those of the various authors and do not necessarily follow usage of the U. S. Geological Survey. Material added in some annotations by the present author is enclosed in brackets.

A survey of the literature emphasized the paucity of published analytical data on this subject. Consequently, many reports that contain radioactivity data (particularly those with chemical analyses for uranium) are included in the bibliography, even though such reports may have little geologic information.

The uranium contents of igneous rocks as given in some of the reports were calculated by the authors of the reports from the radium content, on the assumption that equilibrium existed between the radioactive elements. The method of analysis used to determine the radium or uranium content has been indicated in the annotation.

Data inferred from radioactivity determinations have less quantitative significance than those derived from chemical analyses.

For consistency in this bibliography, analyses given in the reports as percent U_3O_8 have been converted to percent uranium, according to the following:

$$\text{Percent } U_3O_8 \times 0.85 = \text{percent U.}$$

No papers specifically concerning the physical-chemical behavior of uranium during the crystallization of magmas were found in the current literature. However, a few general papers on the behavior of minor elements during crystallization were found, and the physical-chemical theory that they contain applies to uranium as well as to other minor elements. A selected few of these papers are included to provide some coverage of this important aspect of uranium in igneous rocks.

A number of abstracts from the foreign literature are included to provide a wide coverage of general concepts concerning the occurrence of uranium in igneous rocks. Papers relating to uranium in tuffaceous rocks are not included in this bibliography because they are in another bibliography of uranium in sandstone-type deposits (Melin, 1957, Selected annotated bibliography of the geology of sandstone-type uranium deposits in the United States: U. S. Geol. Survey Bull. 1059-C).

The index map shows the location in the United States and Alaska of igneous rocks that have been analyzed chemically for uranium. The rocks are divided into granitic (including pegmatites), intermediate, extreme differentiates, and ultrabasic (including meteorites) types, and according to whether they are plutonic, volcanic, or metamorphic. The basis of classification of the different rock types is shown on plate 2.

The areas of igneous rocks in the United States, shown on plate 2, were compiled by E. Allen Merewether from the geologic map of the United States.

ACKNOWLEDGMENTS

The author appreciates the helpful suggestions and guidance given by George J. Neuerburg. Rosemary A. Robbins furnished a partial list of titles, and E. Allen Merewether assisted in the preparation of the index map.

The compilation was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

ANNOTATED BIBLIOGRAPHY

- 1 Adams, J. A. S., 1954, Uranium and thorium contents of volcanic rocks, in Faul, Henry, ed., Nuclear geology: New York, John Wiley & Sons Inc., p. 89-98.

On the basis of available analyses, the average uranium content of basic lavas is between 0.6 and 1.1 ppm. At Lassen [Lassen Volcanic National Park, Calif.] differentiation produced dacitic lavas with 4 times as much uranium as the most basic lava analyzed, and differentiation can be expected to produce acidic volcanic rocks with at least 6 times as much uranium as the average basic lavas. Obsidians with 15 ppm are known, and extreme differentiates may have even higher concentrations of uranium. Present data indicate that thorium is about 3 times more abundant than uranium in unweathered volcanic rocks and that this ratio probably holds constant during differentiation.—*Author's conclusions*

- 2 Adams, J. A. S., 1955, The uranium geochemistry of Lassen Volcanic National Park, California: *Geochim. et Cosmochim. Acta*, v. 8, p. 74-85.

The uranium contents of samples of andesites, basalts, tuffs and dacites from Lassen Volcanic National Park, were determined fluorimetrically and ranged from 0.86 ppm in basalts to 3.6 ppm in a dacite. Values for the uranium content of similar samples determined fluorimetrically and by the direct fusion method (uranium recalculated from percent radium) are compared. The data indicate that the uranium and radium are in equilibrium.

There is a definite positive correlation between the amounts of uranium and potassium; the uranium content of the rocks increases with an increase in potash. This indicates that the potash-rich glassy phase of the rocks is the main carrier of potassium, uranium, radium, and probably thorium. The correlation between the amounts of uranium and potassium is a general expression of the correlation between the amounts of silica and uranium, because both silica and potassium increase in the residual magma during the first stages of magmatic differentiation. The author states that uranium is concentrated relative to potassium in the glassy ground-mass in the later stages of magmatic differentiation by removal of some of the potassium into the crystalline phases.

The main Lassen sequence shows a positive correlation between uranium content and "relative alpha activity" ("a measure of a complex of phenomena involving over twenty different alpha-emitting nuclides in the U^{238} , U^{235} , and Th^{232} decay series"). A deviation from this trend shown by samples from the Cinder Cone (volcanic ash, andesite, and vesicular basalt) may be due to the selective leaching of uranium from some of the weathered samples.

The author believes that some of the uranium in the Lassen lavas is concentrated in zircon.

- 3 Adams, J. A. S., and Saunders, D. F., 1953, Uranium content of the lavas of Lassen Volcanic National Park, California [abs.]: Geol. Soc. America Bull., v. 64, p. 1389.

Nineteen samples of volcanic rocks from Lassen Volcanic National Park have been analyzed for uranium, sodium, potassium, and calcium. In addition, the alpha activities were measured with scintillometers. Uranium and potassium correlate positively, indicating that both tend to be enriched as differentiation proceeds toward more siliceous lavas. In the samples studied, the uranium is enriched about fourfold, while the potassium is enriched about threefold. The correlations with calcium, sodium, and total potassium plus sodium are less well defined than the potassium correlation. The correlation between potassium and alpha particle activity under standard conditions is rather well defined.

The correlation between alpha particle activity and uranium is not well defined when all samples are included. However, the samples that are furthest from the main trend may be considered special cases—e. g., mudflows and rocks that were probably partially weathered and thus leached of part of their uranium. The main trend in the uranium content versus alpha particle activity indicates that the thorium/uranium ratio did not shift significantly during the differentiation of the Lassen lavas.—*Authors' abstract*

- 4 Adams, J. A. S., Saunders, D. F., and Zeller, E. J., 1953, Uranium content, alpha particle activity, and K_2O , Na_2O , CaO analysis of obsidians, pitchstones, and tektites [abs.]: Geol. Soc. America Bull., v. 64, p. 1389.

Seventy-four glassy rocks, including obsidians, pitchstones, and possible tektites have been analyzed for uranium fluorimetrically. Alpha activities have been measured with scintillometers. K_2O , Na_2O , and CaO have been determined on the flame photometer. The indices of refraction have also been measured. About half the samples are from the United States. The thermoluminescence of several samples was also measured, but no thermoluminescence was detected except in one obsidian from Ascension Island.

The uranium contents range from 0.77 ppm in an obsidian from Shizuoka Prefecture, Japan, to 16 ppm in an obsidian from Liparii, Italy. Few of these obsidians have as much as 0.50 percent CaO . A plot of alpha particle activity under standard conditions vs. uranium content has little scattering from linearity. This linearity indicates that the Th/U ratio is rather constant in the obsidians measured. Several geochemical interpretations of this linearity are advanced.—*Authors' abstract*

- 5 Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1954, Uranium in apatite [abs.]: Geol. Soc. America Bull., v. 65, p. 1225–1226.

Apatite contains only traces of uranium, yet as apatite is a minor constituent in most rocks and the major constituent of a few very large deposits it accounts, paradoxically, for both dispersal and concentration of uranium in nature.

Uranium is typically 0.00X percent of primary igneous apatite and 0.00X to 0.001X percent of sedimentary marine apatite. End-stage

igneous apatite may contain 0.0X percent uranium. Analogously, marine reworked apatite becomes enriched in uranium from 0.00X to 0.0X percent. This is demonstrated by the greater uranium contents of the texturally more complex phases within a single deposit.

Uranium can be secondarily leached from or introduced into apatite by ground water. These secondary changes are indicated by the existence of pronounced concentration gradients within single pebbles of apatite as well as by the redistribution of uranium among different mineral hosts in leached and altered sections of phosphorite.

It is proposed that uranium replaces calcium in the apatite structure. This is signified by several lines of investigation. Uranium and calcium contents parallel one another in sections of leached and altered phosphorite. Ionic radii of tetravalent uranium (1.05 Å) and divalent calcium (1.06 Å) are virtually identical, and most of the uranium in igneous, sedimentary, and bone apatite is tetravalent. Petrographic and chemical analyses and nuclear emulsion studies have shown that uranium in apatite is disseminated rather than locally concentrated. In addition, phosphate deposits are essentially devoid of uranium minerals.—*Authors' abstract*

- 6 Amstutz, G. C., 1951, Radioaktivitätsmessungen an den Glarner Laven: Schweizer. naturf. Gesell. Verh., 131 Jahresvers., p. 138–139.

Two samples of quartz porphyry and four samples of spilite contain 4.46, 3.08, 1.08, 1.12, 0.64 and 4.68×10^{-12} gRa per g, respectively (radium content calculated from the alpha activity of the rocks). The author believes that the radioactivity of these rocks is a function of their acidity, grain size, and proportion of minor accessories (sphene, apatite, and zircon). Part of the uranium and thorium is interstitial, the amount increasing with decreasing grain size. Structural defects in the rocks may contain much uranium or thorium, although most of the uranium and thorium probably substitutes for calcium in the minor accessory minerals.

- 7 Barth, T. F. W., 1938, Radium and the petrology of certain granites of Finland: Am. Jour. Sci., 5th ser., v. 35–A, p. 231–245.

The radium content of various types of Finnish granites is given and is compared with the percentages of biotite, potash, and ferrous oxide in these granites. In each group of granites, the total amount of radium increases with the biotite content. No correlation was found between radium and potash content or between radium and ferrous oxide content.

- 8 Becraft, G. E., 1956, Uranium deposits of the Boulder batholith, Montana: Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, Proc., v. 6, Geology of uranium and thorium, p. 270–274; U. S. Geol. Survey Prof. Paper 300, p. 117–121.

This paper is a discussion of the geology of uraniferous vein deposits in the Boulder batholith area, but it has been included here for the following observation. At the W. Wilson mine, "a few secondary minerals, mainly metatorbernite, meta-autunite, and uranophane, are sparsely distributed along and adjacent to fractures [in quartz monzonite] outside of the ore bodies, indicating the transportation and redeposition of some of the uranium by meteoric water."

- 9 Billings, M. P., and Keevil, N. B., 1946, Petrography and radioactivity of four Paleozoic magma series in New Hampshire: *Geol. Soc. America Bull.*, v. 57, p. 797-828.

Four magma series are recognized in western and central New Hampshire. This paper describes the rocks of these series and their radioactivity in terms of alphas per milligram of rock per hour.

The White Mountain magma series of Mississippian(?) age consists of alkalic rocks ranging from gabbro to granite. Radioactivity is lowest in the gabbro, norite, and diorite, and increases 4.15 times to a high of 4.56 alphas per mg per hr in samples of biotite granite. The radioactivity of individual rock specimens ranges within wide limits, indicating that the radioactive elements are irregularly distributed in the rocks. The increase of radioactivity in the granitic rocks is associated with a decrease in the potash feldspar, biotite, and apatite content; it is caused primarily by the presence of allanite and secondarily by an increase in the amount of zircon.

The rocks of the New Hampshire magma series of Late Devonian(?) age range from diorite to granite. The radioactivity increases 4.24 times from the dioritic to the granitic rocks of the series. The highest average radioactivity of the series (2.74 alphas per mg per hr) was detected in samples of the Long Mountain granite. There are not enough data on the percentages of the accessory minerals to explain this distribution of radioactivity.

The Oliverian magma series of Middle Devonian(?) age consists of quartz diorite, granodiorite, quartz monzonite, and granite. The average radioactivity increases from 1.04 alphas per mg per hr in the quartz diorite to 2.67 alphas per mg per hr in the granite. The lack of data on the percentages of the accessory minerals precludes an explanation of this increase in radioactivity.

The rocks of the Highlandcroft magma series range from diorite to granite. The average radioactivity increases from 0.59 alphas per mg per hr in the diorite to 1.44 alphas per mg per hr in the granodiorite. No quartz monzonite or granite was available for study.

In all series there was a general increase in radioactivity toward the granitic end. This increase is not caused by an increase in potash or biotite content (references 7 and 21). Except for the White Mountain series, the available data are too few to determine whether or not the quantity of radioactive accessory minerals increases toward the granitic end. Perhaps some of the minerals in the granitic rocks have a higher percentage of radioactive elements than the same minerals in the gabbroic rocks, because of a relatively higher concentration of radioactive elements in the later magma.

- 10 Brown, Harrison, Blake, W. J., Chodos, A. A., Kowalkowski, Richard, McKinney, C. R., Neuerburg, G. J., Silver, L. T., and Uchiyama, Aiji, 1953, Leaching studies of interstitial material in igneous rocks [abs.]: *Geol. Soc. America Bull.*, v. 64, p. 1400-1401.

Chemical studies of a group of plutonic igneous rocks indicate that significant proportions of many of the minor elements may be readily removed by leaching in the pulverized state with cold, dilute acid under controlled conditions. Comagmatic rocks (southern California batholith) and rocks of widely diverse geographic location and geologic history yield soluble material of rather uniform gross composition. Minor elements extracted show considerable variation, but many are considerably concen-

trated with respect to the gross rock. Up to 40 percent of the radioactive elements and rare earths in a granite may be found in leachable material, representing considerably less than 1 percent of the total weight of the rock. Greatest trace-element enrichment occurs where ionic radius and charge hinder admission of the element to the major mineral phases.

Several sources may contribute to the acid leaches. These include, in addition to solution of major minerals, minor amounts of alteration minerals, such as calcite and zeolites; certain accessory minerals, particularly if metamict; and, apparently, submicroscopic material dispersed along fractures and grain boundaries. Mechanical fractionation according to particle size and mineral composition aids the recognition of the individual contributions from the various sources. Special efforts to control external contamination have been made.

The dispersed submicroscopic material, here called "interstitial," plays an important, generally unrecognized, role in the trace-element character of igneous rocks. It particularly affects trace-element determinations and age measurements on rocks and rock minerals and may yield important information on many rock-forming and rock-modifying processes.—*Authors' abstract*

- 11 Brown, Harrison, and Silver, L. T., 1956, The possibilities of obtaining long-range supplies of uranium, thorium, and other substances from igneous rocks: U. S. Geol. Survey Prof. Paper 300, p. 91-95.

The authors discuss the distribution of uranium and thorium in igneous rocks and the possibilities of procuring a supply of these elements from igneous rocks.

The ionic radii and charges of uranium and thorium enable them to substitute for other elements (that is, zirconium and calcium) in the crystal lattice of certain accessory minerals of granite, such as zircon, allanite, sphene, and apatite.

Much of the uranium, thorium, and other minor elements in igneous rocks can be removed with a simple acid leach. The gross composition of leaches from some granites, granodiorites, and aplites are given.

Alpha-track autoradiograph studies of the distribution of the leachable radioactive elements in granites indicate that most of the radioactivity is concentrated in the microscopic accessory minerals, some of the activity occurs in the common rock-forming minerals, and a small part of the radioactivity is caused by interstitial material—such as microscopic discrete minerals and submicroscopic particles.

The more soluble accessory minerals, such as apatite, allanite (particularly if metamict and altered), thorite, and bastnaesite, contribute most of the radioactive elements to the leach extractions. Allanite and its alteration products appear to be an important constituent of interstitial material in granites and the principal source of radioactivity in granite.

- 12 Coats, R. R., 1956, Distribution of uranium and certain other trace elements in felsic volcanic rocks of Cenozoic age of the Western United States: Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, Proc., v. 6, Geology of uranium and thorium, p. 248-251.

——— 1956, Uranium and certain other trace elements in felsic volcanic rocks of Cenozoic age in Western United States: U. S. Geol. Survey Prof. Paper 300, p. 75-78.

Samples of rhyolites and dacites from Washington, Oregon, Idaho, Montana, Wyoming, Colorado, Utah, Nevada, California, and Arizona were analyzed fluorimetrically for uranium, chemically for fluorine, and spectrographically for boron, beryllium, lanthanum, lithium, niobium, xenon, tin, lead, and zirconium. The geographical distribution pattern and the statistical relations of these elements are discussed.

The data were assembled in an attempt to determine whether or not uranium provinces exist in volcanic rocks of the Western United States. The author concludes that such provinces do exist and discusses the probable causes of these regional variations in uranium content of rhyolitic and dacitic rocks.

- 13 Dalton, J. C., Golden, J., Martin, G. R., Mercer, E. R., and Thompson, S. J., 1953, Recent studies on iron meteorites—III, Determination of the uranium and thorium contents: *Geochim. et Cosmochim. Acta*, v. 3, p. 272-287.

The authors describe the following methods for the determination of the uranium and thorium content of 10-to-100 gram samples of iron meteorites: radon-thoron, fluorimetric, and alpha-particle counting with a scintillation counter. The uranium and thorium contents of 15 meteorites, determined by the various methods (not every sample was tested by all methods) are presented in tabular form. Two of the 15 samples are from the United States. The Carthage meteorite (Tennessee) and the Brenham Township meteorite (Kansas, iron phase) have uranium contents of $0.41 \pm 0.05 \times 10^{-8}$ g per g and $0.06 \pm 0.02 \times 10^{-8}$ g per g, respectively (determined by the fluorimetric method).

The authors believe that the results obtained by the fluorimetric and scintillation counting methods are the most reliable.

- 14 Davidson, C. F., 1951, The distribution of radioactivity: *Mining Mag.* [London], v. 85, p. 329-340. See p. 330-331.

This paper is mainly a summary of information about the distribution of radioactivity in various rock types.

Radioactive elements in igneous rocks are concentrated in the more acid phases of the lithosphere. Exclusive of potassium, the radioactive elements in granite are concentrated mainly in the accessory minerals, particularly in monazite, xenotime, allanite, zircon, apatite, sphene, thorite, and rarer refractory minerals of the niobate-titanate type. Biotitic rocks are somewhat more radioactive than hornblendic rocks. The roof and marginal phases of granite masses are likely to be the most radioactive. It can be shown by autoradiographs that most of the radioactivity in an unaltered granite is confined to the heavy minerals, whereas in rocks altered by pneumatolysis or by ground waters, the radioactive elements are distributed along cracks within and as coatings on the feldspars and quartz. Much of the uranium in granite seems to be relatively soluble in percolating ground waters and can be leached away to be redeposited as films of secondary uranium minerals along joint planes and fissures. In North America, the average thorium/uranium ratio of granitic rocks seems to be 3.4:1 and that of intermediate rocks, 4.0:1.

- 15 Davis, G. L., 1947, Radium content of ultramafic igneous rocks—I, Laboratory investigations: *Am. Jour. Sci.*, v. 245, p. 677-693.

This reference is concerned mainly with the description of the direct-

fusion vacuum technique used to measure the radium content of some ultramafic rocks. The results of analyses of a group of these rocks and minerals are presented in tabular form. The radium content is expressed in terms of the unit, 10^{-12} grams of radium per gram of rock. The following average radium contents of various magma suites are given:

ROCK TYPE	AVERAGE RADIUM CONTENT 10^{-12} g/g	NUMBER OF SAM- PLES
Ultramafic magma suite (dunites, partially serpentinized dunites and serpentine).....	0.009	19
Ultramafic magma suite (contact rocks—serpentine).....	.059	5
Ultramafic rocks of basaltic magma suite, crystal accumulates.....	.010	3
Secondary peridotite magma suite.....	.009	4
Meteorite:		
Metal portion.....	.0059	1
Olivine portion.....	.0004	1

The minerals and mineral separates that were analyzed include chromite, diopside, bronzite, olivine, tremolite, and serpentine minerals.

Measurements of the radium content of the chromite and olivine fractions of a sample of dunite from Addie, N. C., indicate that much of the radium of the rock is contained in one or more of the minor minerals, tremolite, serpentine, talc, and chromite: that is, serpentine and talc account for 30 percent of the total radium, although these minerals comprise only about 5 percent of the rock.

- 16 Davis, G. L., 1950, Radium content of ultramafic igneous rocks—III, Meteorites: *Am. Jour. Sci.*, v. 248, p. 107-111.

The radium content of some pallasites and iron meteorites was measured by a refinement of the vacuum fusion technique (reference 15), and is expressed in the units, 10^{-12} grams of radium per gram of sample. The uranium content (calculated from the radium content) is given as units of 10^{-8} grams per gram.

ROCK TYPE	LOCALITY	RADIUM 10^{-12} g/g	URANI- UM 10^{-8} g/g
Medium octahedrites.....	Mesa Verde, Colo.....	Average	0.33
	Carthage, Tenn.....		
	Tunda, Queensland.....		
Octahedrites.....	Edmonton, Ky.....	0.0011	0.33
	Glorieta, N. Mex.....		
Hexahedrites.....	Sierra Gorda, Chile.....	Average of metal frac- tion.	1.23
	Cedartown, Ga.....		
Pallasites.....	Salta, Argentina.....	0.0042	4.8
	Antofagasta, Chile.....		
Amphoterite.....	Brenham, Kans.....	.0164 ± .0007	4.8
Stone.....	Shaw, Colo.....	.0034 ± .0013	1.0
	Cumberland Falls, Ky...		

The results indicate that (a) the radium content of meteorites is low or lower than that of most ultramafic rocks, and (b) the metal portion of pallasites contains more radium than the silicate portions.

- 17 Davis, G. L., and Hess, H. H., 1949, Radium content of ultramafic igneous rocks—II, Geological and chemical implications: *Am. Jour. Sci.*, v. 247, p. 856-882.

The radium and uranium content of the ultramafic igneous rocks and their constituent minerals given in this article are the same as those presented in reference 15.

The analyses demonstrate the decrease in radium content with an increase in the mafic character of the rocks. The authors believe that most of the uranium in samples of ultramafic rocks (formed by accumulation of early crystals from a basaltic magma) was contained originally in the small amount of interstitial liquid trapped between the crystals.

In ultramafic rocks of the secondary peridotite suite, the radium content decreases with an increase in iron. In rocks of the primary peridotite suite, there seems to be a general correlation between the water and radium contents.

Analyses of minerals of ultramafic rocks indicate that most of the radium content of the rocks is concentrated in the late-stage minerals—tremolite, talc, and kammerite.

Petrographic descriptions of the rocks are appended.

- 18 DeVore, G. W., 1955, The role of adsorption in the fractionation and distribution of elements: *Jour. Geology*, v. 63, p. 159-190.

This article is included because it is of general theoretical application, although it does not discuss uranium.

Adsorption is advanced as a principal factor in the distribution and fractionation of minor constituents in minerals. The effects of adsorption on the processes of nucleation and crystal growth are considered as important factors in controlling compositional relationships between coexisting minerals and possibly determining certain mineral assemblages. The possibility that adsorption during crystal growth may cause slight disequilibrium conditions is indicated. The changes of the trace element content in certain metamorphic rocks between different metamorphic facies are illustrated, and the possibility is discussed that such metamorphic transformations may provide a liberation of ore-forming materials.—*Author's abstract*

- 19 Eckel, E. B., and Lovering, T. S., 1935, Microlite from Ohio City, Colorado—Exhibit V: Natl. Research Council, Rept., Comm. on Measurement of Geol. Time, 1935, p. 77-79.

A variety of microlite was identified in a group of lepidolite-bearing pegmatite dikes, in schists, in the Ohio City area, Gunnison County, Colo. The microlite, associated with lepidolite and albite, occurs as rounded dark-brown grains. A chemical analysis of the microlite is given, which includes a uranium content of 1.49 percent.

- 20 Emmons, R. C., Reynolds, C. D., and Saunders, D. F., 1953, Genetic and radioactivity features of selected lamprophyres: *Geol. Soc. America Mem.* 52, p. 89-99.

The authors believe that lamprophyre dikes and their associated radioactive materials are "(1) the products of very late reactions in the cooling

history of an igneous rock, (2) derived from the walls of a fracture under the influence of differential pressures created dilatantly, and (3) commonly gathered from small tributary fractures into larger fractures, providing a gradation from small dark 'deuteric veinlets' through dikelets to sizeable dikes.'

Radioactivity data of some lamprophyres in Wisconsin are presented in support of this theory.

- 21 Evans, R. D., and Goodman, Clark, 1941, Radioactivity of rocks: Geol. Soc. America Bull., v. 52, p. 459-490.

Although numerous previous measurements of the radioactivity of terrestrial materials have been made, most of these researches are of qualitative value only in their applications to geology, geophysics, and cosmology because of inadequate recognition of the analytical care necessary in order to obtain reliable results. In the present study of the radioactivity of terrestrial materials, a systematic program of standardization, calibration, and interchecking has been followed throughout. As a general program of helium-age research, several hundred radioactivity measurements have been made. These results represent the most reliable collection of radioactivity determinations which have yet been made within the range of concentrations involved. By combining these newer measurements with the limited number of well-authenticated earlier analyses available, average values have been obtained as follows: $1.37 \pm 0.17 \times 10^{-12}$ gRa per g for 43 acidic igneous rocks, $0.51 \pm 0.05 \times 10^{-12}$ gRa per g for 7 intermediate igneous rocks, $0.38 \pm 0.03 \times 10^{-12}$ gRa per g for 54 basic igneous rocks, and $0.57 \pm 0.08 \times 10^{-12}$ gRa per g for 28 sedimentary rocks; $3.0 \pm 0.3 \times 10^{-6}$ gU per g, $13 \pm 2.0 \times 10^{-6}$ gTh per g, and a Th/U ratio of 2.6 for 6 intermediate igneous rocks; $0.96 \pm 0.11 \times 10^{-6}$ gU per g, $3.9 \pm 0.6 \times 10^{-6}$ gTh per g, and a Th/U ratio of 4.0 for 34 basic igneous rocks. These values are substantially lower than those obtained by Jeffreys in a compilation of most of the measurements reported prior to 1936. The present averages show a more marked decrease of radioactivity with increasing basicity; the Th/U ratios are considerably greater than those compiled by Jeffreys and are in better agreement with those to be expected from geochemical considerations. Two ultrabasic rocks were found to have radioactivities comparable to the low values for iron meteorites. Specific inaccuracies in earlier investigations have been discovered. Estimates are made of the rate of production of heat by radioactive decay based on the above average values for the different rock types.—*Authors' abstract*

- 22 Evans, R. D., and Williams, Howel, 1935, The radium content of lavas from Lassen Volcanic National Park, California: Am. Jour. Sci., 5th ser., v. 29, p. 441-452.

Chemical analysis and radium contents are given for 17 samples of lavas from Lassen Volcanic National Park, Calif. The lavas range in composition from basaltic to rhyolitic (dacites and andesites predominate) and in age from Tertiary to Recent. Brief petrographic descriptions of the samples are given.

The radium content was determined using the direct-fusion furnace

technique. The average radium content of the various rock types is as follows:

ROCK TYPE	NUMBER OF SAMPLES	RADIUM 10^{-12} g/g
Basalt.....	2	0.33
Basic inclusions.....	3	.34
Andesites.....	4	.48
Dacites.....	7	.80

An illustration comparing the radium, silica, and potash content of the lavas indicates that the radium content increases with the alkalis, especially potash, and that it is not directly proportional to the silica content.

A clean separation of constituent minerals of the Lassen lavas was not possible, although partial fractionation was achieved with two samples, as shown.

CHAOS CRAGS DACITE	RADIUM 10^{-12} g/g	OLD LASSEN DACITE	RADIUM 10^{-12} g/g
Plagioclase phenocrysts.....	0.47	Lava as a whole.....	0.81
Strongly magnetic heavies (magnetite, hornblende, some glass).....	.85	Light separates (plagioclase, pale glass).....	.81
Weakly magnetic heavies (biotite, minor hornblende).....	.83	Heavy separates (iron ores, biotite, hornblende).....	.68
Residual glass.....	1.1(?)		
Dacite [in above fraction]..	.67		
Dacite [another sample; same locality].....	.93		

In the Chaos Crags dacite the residual glass (acid, potash-rich) was the most radioactive. No marked concentration of radium in the micas was noted. The variation in radium content of the two mineralogically similar dacite samples implies a pronounced inhomogeneity of radium distribution within a single lava protrusion.

The authors found no marked concentration of radium in the heavy minerals of the Old Lassen dacite; they state that much of the radium is probably in the residual glass or its microlithic inclusions.

- 23 Foye, W. G., and Lane, A. C., 1934, Correlations by radioactive minerals in the metamorphic rocks of southern New England: *Am. Jour. Sci.*, 5th ser., v. 28, p. 127-138.

Three samples of uraninite taken from pegmatite within a few feet of the pegmatite-schist contact in the Strickland quarry, Portland, Conn., have an average uranium content of 78.78 percent. Five samples of uraninite from pegmatite from the Hale quarry, also in Portland, Conn., have an average uranium content of 71.32 percent.

Four layers of a single crystal of uraninite were analyzed chemically. The uranium content ranges from 79.00 percent in the interior of the crystal to 80.14 percent in the outer layer.

The paper is mainly concerned with the application of the data to age determination studies.

- 24 Furcron, A. S., 1955, Prospecting for uranium in Georgia, Part I: Georgia Mineral Newsletter, v. 8, p. 38-46.

Uranophane, thinly coated by hyalite, occurs as a yellow coating on joint planes of the Stone Mountain granite, in quarries in the vicinity of Stone Mountain, Ga. Two samples of the yellow material contained 40.10 and 52.08 percent uranium, respectively.

Uranium minerals also have been found in several pegmatites in Georgia. In Lamar County, yellow and green secondary uranium minerals occur as incrustations on joints and in cracks of a coarse-grained pegmatite. Sodydyte and beta-uranophane in close association occur as inclusions in muscovite. A sample of the pegmatite contained 0.22 percent uranium. A brownish-black heavy primary uranium ore mineral occurs as veinlets and segregations in fresh pegmatite in Greene and Jasper Counties. An X-ray examination of the mineral showed it to be metamict.

- 25 Gabriel, V. G., 1951, The significance of radioactivity measurements in separating granites from granitized (metamorphic) rocks: Mines Mag. [Colorado], v. 41, p. 33-34, 39.

The author proposes that the radioactivity of intrusive igneous rocks should be significantly different from that of granitized sediments. On the basis of published radioactivity measurements, he states that granitic rock bodies should have a higher concentration of radioactive elements at the border, whereas the radioactivity of metamorphic rocks should be evenly distributed throughout the rock mass.

- 26 Goldschmidt, V. M., 1954, *Geochemistry*: Oxford, England, Clarendon Press, 730 p.; edited by Alex Muir. See p. 562-567.

Part 1 of this book discusses the scope and development of geochemistry, the distribution of the elements during the evolution of the earth, the evolution of magmatic rocks, a quantitative treatment of geochemical processes, the chemical composition of the cosmos and of its various separate mass concentrations, and some principles of crystal chemistry in relation to geochemistry. The second part is devoted to the geochemistry of the elements.

The ionic radius of quadrivalent uranium determines its distribution in the primary minerals of igneous magmas. A higher concentration of uranium generally is found in acidic granitic magmas than in syenites or felspathoid syenites. That uranium enters zircon in the 4-valent state is demonstrated by the characteristic absorption band spectrum of uraniumiferous zircon, which is very closely related to the absorption line spectrum of the U^{+4} ion.

- 27 Gottfried, David, 1953, Distribution of uranium in igneous complexes, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1953: U. S. Geol. Survey TEI-390, p. 240-244, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The pertinent section of this article is reprinted in its entirety as follows:

A total of 300 uranium determinations on 150 rock samples have been completed on carefully selected rocks from the following areas: Southern

California batholith; Sierra Nevada; Idaho batholith; San Juan lavas; White Mountain magma series, New Hampshire; and Front Range, Colo.

These igneous complexes underlie vast areas and are fairly typical of the average rocks exposed in the earth's crust. A general comparison of these areas indicates that for rocks of similar composition, the southern California, Sierra Nevada, and Idaho batholiths are similar in uranium content. The distribution of uranium in the San Juan lavas appears to be nonsystematic and a plot of their uranium content against their composition is erratic. The White Mountain magma series is highest in uranium content, approximately twice that of the southern California batholith. These soda-rich granites contain from 10 to 14 ppm uranium. A study of their accessory minerals showed abundant and highly radioactive zircon, monazite, xenotime, allanite, pyrochlore, and the rare mineral chevkinite. The Front Range granites appear to contain $1\frac{1}{2}$ times more radioactivity than the southern California batholith. To determine the variability of uranium content in an apparently uniform rock type, a 12-mile traverse was made across a stock of the Boulder Creek granite near Boulder, Colo. Samples were collected at half-mile intervals. The uranium content of the granite at the contact was 15 ppm U, and gradually decreased to 1.0 ppm U for the sample, 12 miles away from the contact.

Monomineralic concentrates of the major and minor accessory minerals have been made on almost all of these rocks. In view of the large number of uranium determinations required, only a few of the major minerals have been analyzed individually for uranium. The radioactivity of the accessory minerals has been studied in greater detail, as they contribute significantly to the total radioactivity of the rock. This has been made possible by alpha counting techniques which measures accurately and rapidly the radioactive content of these minerals. Among all the accessories, zircon is most common to all the igneous rocks thus far studied, although monazite, xenotime, and thorite appear to be more common than previous work has indicated. In addition the rare radioactive minerals such as pyrochlore and chevkinite were found in granites of the White Mountain magma series. The radioactivity of the zircons separated from a related group of rocks such as the southern California batholith has been investigated. There is a marked increase of the alpha activity of the zircon as the rocks from which they were separated became more acidic.

- 28 Gross, W. H., 1952, Radioactivity as a guide to ore: *Econ. Geology*, v. 47, p. 722-742.

The author suggests that the distribution of radioactivity in stocks and batholiths can serve as a useful guide to ore. Of the Canadian intrusives that were examined, those with associated ore bodies exhibited higher-than-normal radioactivity in the igneous rocks near ore structures; no such concentration was found in those intrusives barren of ore. The method is based on the following theoretical considerations and supporting evidence.

1. "Late solutions, which include the pegmatite and hydrothermal stages in a crystallizing intermediate to acid magma, will be relatively high in the radioactive elements." Evidence of the association and concentration of radioactive minerals with the products of late crystallization (such as siliceous rocks—reference 23—and pegmatites) and the concentration of radioactive elements around the grain boundaries of essential rock-forming minerals (references 33 and 81), supports the validity of this proposition.

2. "Late solutions from crystallizing magmas will tend to flow to areas of lower pressure. Normally, these solutions will be moving down a temperature gradient so that deposition from the solution will take place." In an intrusive, the direction of flow of late magmatic solutions will be toward areas of concentration of the late-crystallizing products of the magma, and hence toward areas of higher-than-normal radioactivity.

3. "Late solutions which are relatively high in radioactivity may or may not be ore carriers, but normally they will move along the same structural channelways as the ore." A comparison of the alpha activity of samples of associated intrusive rocks, ore, and pegmatites indicates that the igneous rocks have a higher radioactivity than the ore and a lower radioactivity than the pegmatites.

4. "The primary distribution of radioactivity in stocks and batholiths will not be seriously affected by alteration changes of later hypogene solutions." The radioactivity in and around six Canadian intrusives examined decreases from the granitic intrusive rocks through the altered intrusive to the ore.

"If the four assumptions made above are valid, it can be expected that in such igneous bodies as stocks and batholiths there will be a broad area of higher-than-normal radioactivity in the vicinity of relatively low pressure areas, such as major fault and fracture zones, which occur nearby. The association of radioactivity in igneous rocks to major structures will occur whether the so-called igneous body and the ore is formed from cooling magma or from heated and recrystallized sediments. Finally, the structures that are indicated by areas of higher-than-normal radioactivity may act as channelways for ore solutions or, in fact, as a locus for the ore itself. It follows, then, that zones of higher-than-normal radioactivity in large igneous-like masses will occur in the vicinity of related ore bodies that are controlled by major structural features."

- 29 Héé, Arlette, Derville, R. P., and Jarovoy, Michel, 1954, Determination of the radioactivity of the Quincy granite by the photographic method: *Am. Jour. Sci.*, v. 252, p. 736-744.

Approximate uranium and thorium contents of powdered Quincy (Mass.) granite have been determined with nuclear photographic emulsions. [Results of analyses of two powdered samples: 5.1 and 2.1×10^{-6} gU per g] Compared with previous results, obtained by different methods, the new values have a wide range, because the radioelements are concentrated in distinct centers scattered haphazardly through the rock. The radioactive centers have been localized in thin sections by the emulsion technique; they are found chiefly in sphene and ilmenite associated with riebeckite. The nuclear emulsion technique, which delineates the distribution of radioactive atoms in various accessory minerals, may be useful in the study of the problem of geologic age of rocks.—*Authors' abstract*

- 30 Hewett, D. F., and Glass, J. J., 1953, Two uranium-bearing pegmatite bodies in San Bernardino County, California: *Am. Mineralogist*, v. 38, p. 1040-1050.

The paper is a mineralogic description of two uranium-bearing pegmatites in San Bernardino County, Calif.

The Cady Mountains pegmatite body, near Hector, is in the central part of a quartz monzonite mass. The presence of betafite (a niobate and titanate of uranium) is of interest because of its rarity in American pegmatites.

This mineral contains 10.68 percent uranium. Spectrographic analyses are given of the betafite, cyrtolite, and niobian anatase found in the Cady Mountains pegmatite.

The Pomona Tile quarry pegmatite locality is in quartz monzonite. The uranium-bearing minerals found were euxenite and an unidentified mineral. Two samples of the euxenite contained 13.9 and 14.5 percent uranium, respectively. The unidentified uranium-bearing mineral contains, as determined by qualitative spectrographic analysis, from 6 to 10 percent uranium. Spectrographic analyses of the two minerals are given.

- 31 Holmes, Arthur, 1931, Radioactivity and geological time, *in* Physics of the earth—IV, The age of the earth: Natl. Research Council Bull. 80, pt. 4, p. 321–355.

This report is concerned mainly with the application of radioactivity data to age determinations. Uranium analyses, taken from published literature, are given for the following minerals from pegmatites. Uranium content, in percent, is shown in parentheses. Uraninite (55.18, 56.44), mackintoshite (19.75) yttrialite (1.45, 0.69), fergusonite (6.07) from Baringer Hill, Llano County, Tex.; uraninite (66.90) from the Ingersoll claim, Keystone, S. Dak.; samarskite (3.55, 3.72) from Devil's Head Mountain, Douglas County, Colo.; samarskite (7.14) from Petaca, N. Mex.; uraninite (74.30, average of 5) from Branchville, Conn.; uraninite (71.32, average of 5) from Glastonbury, Conn.; allanite (0.11) from Blueberry Mountain, Boston, Mass.; and uraninite (76.96, 77.77) from the Spruce Pine district, North Carolina.

- 32 Hurley, P. M., 1950, Distribution of radioactivity in granites and possible relation to helium age measurement: Geol. Soc. America Bull., v. 61, p. 1–8.

Granulated samples of acidic igneous rocks have been found to give a much higher rate of emission of alpha particles than corresponds to the known total contents of uranium and thorium. Abnormally large residual ranges of the alpha particles suggest a surficial distribution of the radioactive elements on the surfaces of the granules in the form of secondary mineral coatings. Most of the alpha-particle activity can be removed by dilute hydrochloric acid, leaving an activity corresponding to the low content of uranium and thorium found in sandstones and arkoses, in which the essential mineral grains of granites have been rounded and cleaned by attrition. The proportion of surficial activity appears to be less for granite samples taken from considerable depth below the surface than for samples from the zone of surface-water saturation. Losses of activity by acid treatment appear to be related to the degree of retentivity of helium in different igneous rocks types. Determination of the helium-age ratio before and after acid treatment suggests that the essential rock minerals contain as much helium as they should commensurate with their age and with the quantity of radioelements uniformly distributed within them, and not removable by acid. The low ratio of helium to radioactivity for the rock as a whole may be due either to loss of helium from highly radioactive areas that are easily affected by acid and thus also probably by ground waters or to actual supergene enrichment of radioelements late in the history of the rock.—*Author's abstract*

- 33 Hurley, P. M., and Fairbairn, H. W., 1955, Ratio of thorium to uranium in zircon, sphene, and apatite [abs.]: Geol. Soc. America Bull., v. 66, p. 1578.

Zircon, sphene, and apatite are important host minerals for uranium and thorium in igneous and metamorphic rocks. Several dozen samples from widely scattered localities were analyzed for these elements to observe variations in their relative abundance. Analyses were made by scintillation spectrometer.

The ratio Th/U is remarkably constant for accessory zircons separated from individual granite plutons. Average values for the following areas are: Eastern Massachusetts, 0.6; Nova Scotia, 0.2; Northern Maine, 0.6; Sudbury, Ontario, 0.3; miscellaneous, 0.6. In granite zircons in general, therefore, 90 percent of the radioactivity is due to the uranium series.

In large crystals of zircon from pegmatites the ratio is more varied with a tendency to be higher in the more radioactive samples. Average ratios for areas are: Ontario, 0.5; Carolinas, 2.2; Oklahoma, 5; Ceylon, 0.1; miscellaneous, 1.2.

Samples of sphene were found to be quite varied but with average values similar to pegmatite zircons. Coarsely crystalline apatite samples were found to be relatively rich in thorium with ratios commonly exceeding 10. The average ratio for accessory apatite is 1.3. If igneous rocks have an average Th/U ratio of about 3, there must be an enrichment of thorium relative to uranium elsewhere in the rock, other than in these minerals.—*Authors' abstract*

- 34 Hutchinson, R. M., Jaffe, H. W., and Gottfried, David, 1954, Magmatic trends and absolute age determinations of Precambrian intrusives of central Texas [abs.]: Geol. Soc. America Bull., v. 65, p. 1266.

Harker variation diagrams have been plotted for 17 intrusions: 8 Town Mountain type with 1 associated aplite; 1 Oatman type; 2 Sixmile type; 5 aplogranites, and 1 granite porphyry (llanite).

Town Mountain type granites occupy positions of lower and intermediate silica content. Aplogranites are restricted to high-silica positions. The aplite falls within the aplogranite range suggesting the aplogranites may be late-stage differentiates of Town Mountain type granites. Llanite falls within the more acid of the Town Mountain type granites and probably is the approximate aphanitic equivalent.

Oatman type granite is intermediate between aplogranites and Town Mountain granites. Sixmile granites fail to fit the curves, suggesting a separate line of magmatic descent.

Age determinations are as follows:

Town Mountain type intrusions:

Wolf Mountain phacolith.....	917 million years
Legion Creek mass.....	893 million years (av.)
Enchanted Rock pluton.....	815 million years (av.)
Sixmile type: Sixmile mass.....	822 million years
Oatman type: Sharp Mountain mass.....	857 million years (av.)

Zircon samples from Wolf Mountain phacolith and Legion Creek mass gave low-alpha counts compared with those from Enchanted Rock pluton

and suggest a different period of intrusion or possibly fractionation with the uranium and thorium having concentrated in the younger fraction. High-alpha counts of zircon from Sixmile mass and Sharp Mountain mass also indicate possible fractionation. The Town Mountain type granites probably had a common magma source, with different periods of intrusion.

Field relations confirm the age determinations. Sixmile mass crosscuts and contains xenoliths of Wolf Mountain phacolith. Enchanted Rock pluton contains xenoliths of schist recrystallized by intrusion of the Legion Creek mass.—*Authors' abstract*

- 35 Hutton, C. O., 1951, Allanite from Yosemite National Park, Tuolumne County, California: *Am. Mineralogist*, v. 36, p. 233-248.

The article is mainly a mineralogic description of allanite from two localities in Yosemite National Park, Calif. One of the samples from quartz-orthoclase pegmatite boulders in scree in the south slope of Ragged Peak contains 0.015 percent uranium. A chemical analysis of the mineral is given. An autoradiograph demonstrated inhomogeneity in the crystal. A few dense spots on the plates indicated areas of intense radioactivity in the allanite, but these radioactive areas could not be correlated with specific particles in the mineral.

- 36 Jahns, R. H., 1953, Distribution of rare elements within granites and granitic pegmatites [abs.]: *Geol. Soc. America Bull.*, v. 64, p. 1440.

The distribution and mode of occurrence of rare elements in a given igneous rock are governed by several well-known factors, chiefly: (1) composition of the magma, including concentrations of the rare-element ions; (2) pressure-temperature conditions during crystallization of the magma; and (3) charge, size, polarizability, and other properties of the rare-element ions.

During crystallization of a magma under a given set of conditions, a rare-element ion may enter the structure of a common mineral (gallium in feldspar) or a rarer mineral (cesium in beryl); it may enter, or be trapped by, a much less appropriate mineral structure (tin in muscovite), followed in some instances by transfer to an exsolved mineral; it may be concentrated in the residual fluid until it forms a mineral of its own (cesium in pollucite); or it may remain dispersed in the residual fluid until ultimately it is bound to the surface of the nearest crystal lattice.

The first three mechanisms seem to account satisfactorily for the distribution of beryllium, cesium, rubidium, thallium, lithium, niobium, tantalum, the rare earths, tin, titanium, tungsten, molybdenum, uranium, thorium, and other rare elements in granitic pegmatites and some granites. The fourth mechanism evidently becomes prominent during crystallization of other granitic rocks, especially those formed from magmas of relatively high viscosity. It results in end-stage attachment of numerous rare-element ions to the crystal surfaces of common silicate minerals. The binding is relatively weak, and these ions are readily mobilized if the host granites are altered or weathered. Despite their low concentrations, enormous quantities of rare elements might thus be leached from a single large body of granitic rock.—*Author's abstract*

- 37 Jeffreys, Harold, 1936, On the radioactivities of rocks: *Gerlands Beitr. Geophysik*, Band 47, p. 149-171.

This is a statistical summary and discussion of work done on the radio-

activity of igneous rocks up to the time of the writing of the paper. The radium content is given for samples of granites, granodiorites, granitites, hornblende granites, quartz trachytes, diorites, andesites, dacites, basalts, dolerites, diabases, norites, gabbros, plateau basalts, eclogites, peridotites, and dunites from many parts of the world. The data were compiled from published references.

It seems that the random error of observation is of minor importance and that most of the variation is between the rocks themselves. The regional variation of radioactivity is small for the same rock type.

The author suggests that plateau basalt may be the common parent of granite and basalt. The statistics presented confirm the general rule that increasing acidity is associated with increasing radioactivity. The tendency of radioactive elements to concentrate in the residual portion of magma would explain the higher radioactivity of the granitic rocks.

- 38 Johnson, D. H., 1951, Reconnaissance of radioactive rocks of Massachusetts: U. S. Geol. Survey TEI-69, 17 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

A radiometric reconnaissance using car-mounted Geiger-counter equipment was made along many of the roads in Massachusetts. A north-trending belt of rocks in the south-central part of the State was found to be abnormally radioactive. The schists, granites, and glacial material that constitute this belt had a uniformly distributed, average radioactivity of about 0.003 percent equivalent uranium, a uranium content of less than 0.001 percent, and a thorium content as high as 0.032 percent. The radioactivity is not confined to former sedimentary rocks (that is, schist) nor is it associated exclusively with any igneous rock. Most of the radioactivity is probably due to thorium.

Pegmatite layers in gneiss near Southbridge are the most radioactive rocks found within the central belt. A channel sample across one of the pegmatite bands contained 0.011 percent equivalent uranium, 0.030 percent ThO_2 , and only minor amounts of uranium. The radioactivity of the gneiss is consistently low.

The highest radioactivity noted in rocks outside the central belt is in a road cut on Highway U. S. 20 south of Worcester. A channel sample across one of the pegmatite layers in schist and gneiss contained 0.011 percent equivalent uranium, 0.001 percent uranium, and 0.032 percent ThO_2 . The radioactivity in the pegmatite seems to increase in the areas of sulfide minerals. Neither the adjacent gneiss nor the schist is appreciably radioactive.

Descriptions and analyses for uranium and thorium are given for samples of the Quincy and Ayer granites.

- 39 Joly, John, 1909, Radioactivity and geology: London, Archibald Constable & Co., Ltd., 287 p. See p. 35-45, 64-69.

The author presents an account of the influence of radioactive energy on terrestrial history. He discusses the foundations of the science of radioactivity, the principles underlying the measurement of radium in terrestrial materials, the radium in the earth's surface materials, underground temperature and radioactivity, the instability of the earth's crust and the ocean floor, the relation of radioactivity to mountain structure and the interior of the earth, the radioactivity in the exterior parts of

the earth and in the atmosphere, uranium and the age of the earth, and methods of radium analyses.

The mean radium content of igneous rocks is given as 4.2×10^{-12} grams of radium per gram of rock. Studies of pleochroic halos in minerals of certain rocks (for example, biotite in granite) indicate that the halos are caused by the radioactivity of minute inclusions of zircon and, more rarely, apatite.

- 40 Joly, John, 1930, *The surface history of the earth*: Oxford, England, Clarendon Press, 2d ed., 211 p. See p. 186.

The author states that the surface history of the earth dealt with in this volume is based directly on two recent advances in knowledge of the earth's crust, namely, radioactivity of rocks and isostasy. The nature and influence of both are explained. The author also reviews much of his own and other work on the radioactivity of rocks through 1929.

A correction is made in the figures given in Poole's 1927 paper (reference 86) for the radium and thorium content of the Oregonian plateau basalts from Oregon because only 6 of the 12 samples used in the original study were later found to be true Oregonian basalts. The corrected results read:

	RADIUM 10^{-12} g/g	THORIUM 10^{-5} g/g
Oregonian basalt (mean of 6 samples)-----	0.75	0.57

The figures for the Deccan and Hebridean basalts remain unchanged.

- 41 Keevil, N. B., 1942, *The distribution of helium and radioactivity in rocks—II, Mineral separates from the Cape Ann granite*: Am. Jour. Sci., v. 240, p. 13–21.

The Essex County granite at Cape Ann, Mass., and its common mineral constituents have been thoroughly studied by the helium age method. The granite is more radioactive than usual, probably due to active accessories associated with the femic minerals. The relative radioactivities of the femics, quartz and feldspar, are about 23:2:1.—*Author's abstract, in part*

The radium content of this alkaline granite ranges from 18.8 to 21.3×10^{-13} g per g.

- 42 Keevil, N. B., 1943, *The distribution of helium and radioactivity in rocks—V, Rocks and associated minerals from Quebec, Ontario, Manitoba, New Jersey, New England, New Brunswick, Newfoundland, Tanganyika, Finland, and Russia*: Am. Jour. Sci., v. 241, p. 277–306.

Helium and radioactivity data are presented for samples of granitic intrusives along the eastern coast of North America. The results tabulated include values for helium ($\times 10^{-5}$ cc per g), radium ($\times 10^{-13}$ g per g), thorium ($\times 10^{-6}$ g per g), radioactivity (alphas per mg per hr). Radium and thorium analyses are given only for some samples.

The radioactivity of a sample of the Fitchburg granite, from the Rollstone quarry, Fitchburg, Mass., is 2.63 alphas per mg per hr. Its minerals have the following activity (alphas per mg per hr): Quartz, 0.1; feldspar, 0.4; and tourmaline, 0.8.

A sample of migmatite in the Chelmsford granite from the Fletcher quarry, North Chelmsford, Mass., had an activity of 7.82 alphas per mg per hr. A sample of pegmatite (for the most part feldspar) from the quarry had an activity of only 0.78 alpha per mg per hr.

A radioactivity of 1.89 alphas per mg per hr was detected in a sample of the Quincy granite (a riebeckite granite) from the Swingle quarry, Quincy, Mass. The alpha activity of some of the constituent minerals is as follows: Quartz, 0.93; feldspar, 0.98; cognate xenolith, 3.45; and riebeckite and aegirite, 4.07. There is appreciable radioactivity in other minerals, probably minor accessories, that were not analyzed.

Cape Ann granite (an alkali granite) from the Johnson quarry, Cape Ann, Mass., had an activity of 3.35 alphas per mg per hr. Alpha activity of the minerals is as follows: Feldspar, 0.78; quartz, 1.34; and mafics, 10.8.

The average activity of three samples of biotite granite from a quarry near Franklin, Maine, was 2.14 alphas per mg per hr.

The younger rocks are generally more radioactive than the older rocks, and show a greater contrast in activity between their mafic and felsic portions than the older rocks. The higher radioactivity of the younger rocks may be due to later deuteritic processes such as that which caused the albitization of the Quincy granite.

There is a large range in the radioactivity of rocks and minerals from Franklin and Sterling Hill, Sussex County, N. J., the highest being 10.5 alphas per mg per hr in the mafic portion of a Precambrian basic pegmatite and the lowest being 0.00 in some of the minerals.

The alpha activity of the minerals from the rocks examined varies widely. Amphibole is about as radioactive as biotite and magnetite, pyroxene is generally less radioactive, and the feldspar and quartz are the least radioactive. The mafic constituents are probably about three times as radioactive as the felsic. The contrast between the radioactivity of the mafic and felsic fractions of a rock tends to be greater, the higher the radioactivity of the rock as a whole. The authors conclude that the radioactive elements are not distributed uniformly throughout the rocks, and that much of the radioactivity may be concentrated in the minor accessory minerals, such as apatite and zircon.

- 43 Keovil, N. B., 1943, Helium indexes for several minerals and rocks: *Am. Jour. Sci.*, v. 241, p. 680-693.

The paper is concerned mainly with the helium index and age of several rocks and minerals.

The following rock and mineral specimens were investigated: Silicates, oxides, carbonates, and a sulphate, a borate, and a phosphate from Franklin and Sterling Hill, Sussex County, N. J.: magnetite from Port Henry, N. Y., and Magnet Cove, Ark.; garnet crystals from Hot Springs, Ark., and Wrangel, Alaska; diabases and basic rocks from Yellowstone National Park (Wyo.), Michigan, and New Jersey; and rhyolite and basalt from North Attleboro, Mass.

The radioactivity of these rocks and minerals is expressed in terms of the alphas per milligram per hour. Radium ($\times 10^{-13}$ g per g) and thorium ($\times 10^{-6}$ g per g) contents are given only for the diabases, basic rocks, rhyolite, and basalt.

- 44 Keevil, N. B., 1944, Thorium-uranium ratios in rocks and minerals: *Am. Jour. Sci.*, v. 242, p. 309-321.

The uranium content (calculated from the radium content), thorium content, and the thorium-uranium ratio are given for one hundred samples of igneous rocks and minerals, mostly from the United States and Canada. A Th/U ratio of 3.2 is indicated for mafic, felsic, and intermediate rocks, but a regional grouping of the results suggests that the value may be as high as 3.5.

- 45 Keevil, N. B., 1950, Radioactivity and mineral deposits: *Am. Mineralogist*, v. 35, p. 816-833.

The article discusses the applications of radioactivity data to the solution of various problems in geology, such as geologic age and the location of mineral deposits.

The radioactivity (in alphas per mg per hr) of rocks and minerals from Franklin and Sterling Hill, Sussex County, N. J., is summarized. (The radioactivity data are taken from reference 43). The radioactivity is fairly characteristic of the rock types represented. The Precambrian gneiss has a low activity which, the author notes, is consistent with its age. Pegmatitic minerals were found to be the most radioactive. Such results are not unexpected as radioactive elements are known to be concentrated in the later pegmatitic stages of differentiation of granitic magmas. The purest crystals of minerals have the lowest activity, whereas complex aggregates tend to be more highly radioactive.

Results of radioactivity determinations (alphas per mg per hr) of ore and country rock are summarized for the following mining districts: Coeur d'Alene, Idaho, Gilman, Colo., Superior, Ariz., and Austinville, Va.

- 46 Keevil, N. B., Keevil, A. R., Ingham, W. N., and Crombie, G. P., 1943, Causes of variations in radioactivity data: *Am. Jour. Sci.*, v. 241, p. 345-365.

Because of the geochemical and geothermal importance of radioactivity data, a report is made of recent observations on the variations in the radioactivity of rocks. Variations by a factor of fifty or more are sometimes found in the radioactive content from specimen to specimen. The greatest differences occur in certain granitic rocks, the least in some sedimentary sections. Regional variations are not so pronounced, but relatively highly radioactive provinces are indicated in Colorado and Great Slave-Great Bear Lake areas and relatively barren areas in parts of Ontario and Quebec. Some laws governing the distribution of radioactive elements are indicated by the discovery that the radioactive elements are more concentrated near the border than at the core of the Bourlamaque batholith [Canada], and by additional evidence of a relationship between radioactivity and proportion of accessory minerals, chiefly apatite and zircon. Variations in the radioactivity of granitic rocks, at least, may be due entirely to differences in the amounts of such minerals in which radioactive elements are concentrated. The need for more radioactivity data is emphasized.—*Authors' abstract*

Radioactivity (alphas per mg per hr) is reported for the following: Diabase from the Palisades of New York and New Jersey; alkali riebeckite granite from Quincy, Mass.; average of granitic, other acidic, intermediate, and basic rocks from Maine, New Jersey, New York, Pennsylvania, North

Carolina, Tennessee, Virginia, Yellowstone Park (Wyo.), California, Nevada, Michigan, and Wisconsin.

- 47 Keevil, N. B., Larsen, E. S., Jr., and Wank, F. J., 1944, The distribution of helium and radioactivity in rocks—VI, The Ayer granite-migmatite at Chelmsford, Mass.: *Am. Jour. Sci.*, v. 242, p. 344–353.

Granite migmatite, taken from the Fletcher quarry at Chelmsford, Mass., has a radium content of 53×10^{-13} g per g. The rock is believed to have been formed by granitization of earlier sediments and schists.

Radioactivity data (alphas per mg per hr) are given for samples of the Chelmsford granitic rocks and associated minerals. Half the radioactivity is due to accessory minerals; and zircon, apatite, epidote, and biotite have more than five times the radioactivity of the parent rock. The fact that all the radioactive minerals in the granite migmatite were formed during the late hydrothermal stage of granitization suggests that the late hydrothermal fluids were relatively highly radioactive. The zircons present have a higher radioactivity than any other zircons from granitic rocks tested to date.

- 48 Lane, A. C., 1933, Age of the Fitchburg granite: *Science*, v. 78, p. 435.

A microchemical analysis is given of a sample of uraninite from a granite quarry at Fitchburg, Mass. The uranium content of the uraninite is 50.20 percent.

- 49 Lane, A. C., and Urry, W. D., 1935, Ages by the helium method—I, Keweenaw: *Geol. Soc. America Bull.*, v. 46, p. 1101–1120.

The paper is mainly a discussion of the results of a detailed application of the helium-age method to a suite of rocks taken at widely distributed points within a single horizon. A suite of basalts from the Keweenaw flows of upper Michigan was studied. The helium, radium, and thorium contents of 25 samples are presented in tabular form. The radium content of the samples ranges from 0.74 to 7.23 units (radium $\times 10^{-13}$ g per g). Exact locations of the samples are given, but there are no geologic or petrographic descriptions. Approximately the same group of samples are described in reference 101.

- 50 Larsen, E. S., Jr., 1954, Distribution of uranium in igneous complexes, in *Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1954*: U. S. Geol. Survey TEI-490, p. 255–261, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The uranium content is given for rocks and minerals from the following igneous suites: Modoc lavas, California; Boulder batholith, Montana; Highwood and Bearpaw Mountains, Mont.; Sierra Nevada, Bishop, Calif.; alkalic rocks, Sussex County, N. J.; and the Idaho batholith.

The uranium content of samples from the Boulder Creek batholith, Colorado, is higher in the more mafic rocks and low in the most silicic rocks. Rocks of the western border facies have as much as ten times the uranium content of other rocks of the batholith.

Results of a study of the red and green phases of the Conway granite, New Hampshire, indicate that the red phase has a consistently higher uranium content and radioactivity than the green phase. Weathered rock has a higher radioactivity than fresh rock.

- 51 Larsen, E. S., Jr., and Keevil, N. B., 1942, The distribution of helium and radioactivity in rocks—III, Radioactivity and petrology of some California intrusives: *Am. Jour. Sci.*, v. 240, p. 204–215.

Radioactivity measurements (radium and thorium content and alpha activity) were made on samples and mineral separates of the Lakeview tonalite, Bonsall tonalite, and Riverside granodiorite from the southern California batholith. The rocks are about one-third as radioactive as average granitic rocks. Inclusions of small grains of apatite, zircon, and sphene, which are highly radioactive, probably account for nearly all the radioactivity of the common rock minerals.

- 52 Larsen, E. S., Jr., and Keevil, N. B., 1947, Radioactivity of the rocks of the batholith of southern California: *Geol. Soc. America Bull.*, v. 58, p. 483–493.

Determination of radioactivity has been made on 43 rocks, carefully selected from the different mapped units of the complex Cretaceous batholith of southern California; they range from gabbro to granite. The activity of the gabbro averages about 0.3 alphas per mg per hr, that of the tonalites, 0.8, the granodiorite 1.3, and the granites over 2.0. The activity of the average rock of the batholith is about 0.9 alphas per mg per hr. Most of the rocks have been analyzed, and modal compositions are given. The radioactivity and the percentages of K_2O , SiO_2 , and PbO are plotted on a variation diagram. The variation curve for activity nearly parallels that for K_2O , and the ratio of activity to K_2O is about 0.5. The radioactivities of some rocks fall far from the variation curve, and degree of activity correlates with K_2O content. A less-marked correlation between activity SiO_2 and PbO was also noted. The K_2O , SiO_2 , PbO , and radioactivity concentrate in the residual liquid during crystallization and differentiation. PbO follows K_2O closely, as it is concentrated in the K_2O minerals, but radioactivity is very low in the K_2O minerals and is greatly concentrated in the accessory minerals.—*Authors' abstract*

- 53 Larsen, E. S., Jr., Keevil, N. B., and Harrison, H. C., 1952, Method for determining the age of igneous rocks using the accessory minerals: *Geol. Soc. America Bull.*, v. 63, p. 1045–1052.

The article is mainly a discussion of the method of determining the age of igneous rocks using the accessory minerals. The radioactivity (in alphas per mg per hr) is given for samples of the following minerals: Zircon from Oklahoma, Statesville, N. C., New Hampshire, the southern California batholith, and the Snoqualmie batholith, Washington; sphene from Vermont marble and the southern California batholith; and apatite from the southern California batholith and the Snoqualmie batholith, Washington.

- 54 Larsen, E. S., Jr., and Phair, George, 1954, The distribution of uranium and thorium in igneous rocks, *in* Faul, Henry, ed., *Nuclear geology*, p. 75–89: New York, John Wiley & Sons Inc., 414 p.

This article describes the present state of progress in the study of the distribution of uranium and thorium in igneous rocks.

The range and (or) average of the uranium content of igneous rock types in North America is summarized as follows:

<i>Rock type</i>	<i>Uranium (ppm)</i>
Stony meteorites.....	0.35-1.0
Ultramafic rocks.....	.3
Gabbroic rocks.....	.94-.96 ± 0.11
Intermediate rocks.....	1.4 ± .2-3.03
Granitic rocks.....	2.77-4.02

Preliminary evidence suggests that volcanic and hypabyssal rocks have a higher average radioactivity and uranium content than do plutonic rocks of similar composition.

As much as 40 percent of the uranium in fresh-appearing rocks is readily leachable. The distribution of leachable radioactivity is not completely known but may occur: "(1) in metamict phases of primary silicates, (2) as interstitial material derived from late-magmatic, deuteric, or hydrothermal solutions, (3) in certain nonmetamict partly soluble radioactive accessories, such as apatite, and (4) as adsorbed ions in disseminated weathering products, such as iron oxide."

Results of a study of the distribution of uranium and radioactivity in rocks of the southern California batholith show that, generally, rocks rich in Mg, Fe, and Ca and poor in silica and alkalis tend to be poor in radioactive elements. Thus the radioactivity would be low in the dark gabbros, moderate in the diorites, and highest in the silica-rich rocks.

Much of the radioactivity in igneous rocks is concentrated in zircon, sphene, and apatite. The uranium content in parts per million is given for the common rock-forming minerals and radioactive accessory minerals of the Woodson granodiorite, California batholith; the Rattlesnake granite, California batholith (calc-alkalic granite); and the Conway granite, New Hampshire (a sodic granite).

Acid rocks generally have a higher concentration of radioactive elements than basic rocks, although there are exceptions. For example, lamprophyric dike rocks may contain large amounts of uranium inconsistent with their low silica content. Calc-alkaline granites commonly contain less uranium than the alkali granites and syenites tested to date. The authors feel that "perhaps the safest generalization that can be made at this time is that the maximum concentration of uranium and thorium is found in the youngest member of a series, regardless of the particular liquid line of descent that the magma may have followed."

- 55 Larsen, E. S., Jr., Phair, George, Gottfried, David, and Smith, W. L., 1956, Uranium in magmatic differentiation: Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, Proc., v. 6, Geology of uranium and thorium, p. 240-247; U. S. Geol. Survey Prof. Paper 300, p. 65-74.

"The results reported here indicate that the change in uranium content of the successive members of any one magma series is less systematic than is the change in major oxides. How much of this variability is real—growing out of the diverse paths open to trace elements during magmatic differentiation—and how much is apparent—inherent in the traditional methods of sampling igneous rocks—remains to be determined. The

most variable rocks are those of intermediate composition; there is little or no overlap between the uranium contents of the gabbroic and granitic extremes in any one magma series. Even in the least favorable instances it is generally possible to define a trend by assembling uranium data on a relatively large number of samples. In all those series studied in which fractional crystallization may be assumed to have been the major factor in differentiation the trends are similar: uranium is enriched in the youngest rocks, these being generally high in SiO_2 and K_2O and low in CaO and MgO . The maximum enrichment (>20 ppm) is found in extreme differentiates very poor in CaO . More data are needed on those series in which processes other than fractional crystallization are believed to have played important roles. In such rocks the uranium content developed may depend upon local geological conditions."

Uranium contents are listed for the following igneous rock suites: Southern California batholith, Sierra Nevada batholith, Idaho batholith, Bearpaw and Highwood Mountains of Montana, San Juan lava series of western Colorado, Modoc lava series of northern California, Conway (N. H.) granite, and the Boulder Creek batholith, Colorado.

Results of leaching experiments indicate that leachable uranium is coated on the surface of mineral grains, and therefore deposited in the late stages of magmatic differentiation. The results of leaching experiments on samples of coarse granite show that "most of the uranium associated with the common rock-forming minerals is leachable and that such uranium is released by removal of relatively small amounts of the mineral."—*Authors' summary, in part*

- 56 Larsen, E. S., Jr., Waring, C. L., and Berman, Joseph, 1953, Zoned zircon from Oklahoma: *Am. Mineralogist*, v. 38, p. 1118–1125.

This article is mainly a mineralogic description of zoned zircons from a pegmatite body cutting the Quanah granite in the Wichita Mountains of Oklahoma. The crystals have recurrent zones of fresh and metamict zircon. Chemical and spectrographic analyses of the various zones in the zircon are given. The uranium content was determined by the fluorimetric method. A sample of fresh zircon contained 0.013 percent uranium, whereas two samples of metamict zircon contained 0.117 and 0.165 percent uranium, respectively.

- 57 Love, J. D., 1954, Pinedale area, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1954: U. S. Geol. Survey TEI-490, p. 230, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

"Extensive masses of Precambrian granite in the vicinity of Fremont Butte, on the southwest flank of the Wind River Mountains, show radioactivity that is several times background." One sample of radioactive granite from this area contained 0.015 percent equivalent uranium and 0.002 percent uranium; another sample contained 0.030 percent equivalent uranium and 0.002 percent uranium.

- 58 McKeown, F. A., 1951, Reconnaissance of radioactive rocks of Vermont, New Hampshire, Connecticut, Rhode Island, and southeastern New York: U. S. Geol. Survey TEI-67, 46 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

Traverses using car-mounted Geiger-counter equipment were made of

rocks in Vermont, Connecticut, Rhode Island, New Hampshire, and southeastern New York.

Rocks of the Grenville series, metamorphic rocks of sedimentary origin, and many granitic intrusives characterize the Hudson and Housatonic Highlands of southeastern New York and western Connecticut. The radioactivity of the Grenville rocks ranges from 0.001 to 0.240 percent equivalent uranium, with a maximum uranium content of 0.095 percent. The maximum radioactivity observed in the metamorphic rocks was 0.013 percent equivalent uranium, and that in the granite was 0.006 percent equivalent uranium. The most radioactive deposits are in pegmatites. Analyses of samples from the area show that most of the radioactivity is due to thorium-bearing minerals.

The bedrocks of the Bear Mountain area within the Highlands, N. Y., are pegmatite, gneiss, schist, and gneissic granite. Mineral analysis of a quartz-feldspar pegmatitic gneiss near Hessian Lake showed that it contains abundant zircon, lesser amounts of opaque minerals, and an unidentified uranium-bearing mineral or aggregate of minerals coating various grains of the pegmatite with a dull yellowish crust. Samples of the uranium mineral contain 0.004 to 0.065 percent uranium. The zircon also is radioactive. Near Highland Falls, N. Y., dark-gray quartz-feldspar-biotite gneiss is interbanded with lesser amounts of pinkish quartz-feldspar-biotite gneiss. Quartz-feldspar-biotite pegmatite masses and lenses are distributed irregularly throughout the gneiss. The pegmatite is the most radioactive rock in the area, containing 0.002 to 0.057 percent equivalent uranium and 0.001 to 0.005 percent uranium. The rocks south of Hessian Lake, and west of Camp Smith, N. Y. are massive fine-grained quartz-feldspar-biotite gneisses, probably in the Storm King granite. Radioactivity is limited to a few massive layers (3 to 5 feet thick) that contain 0.006 to 0.013 percent equivalent uranium and 0.003 to 0.005 percent uranium. The radioactive elements are believed to be syngenetic with the enclosing metasedimentary rocks.

A belt of abnormally radioactive rocks extends from western Rhode Island and eastern and central Connecticut through central Massachusetts into eastern Vermont and western and northern New Hampshire. The rocks have a low uranium content (a maximum of 0.001 percent uranium), and the radioactivity is due mainly to thorium. Pegmatites have a radioactivity comparable to the surrounding rocks. That part of the belt in Massachusetts is described in reference 38.

Analyses of many samples for equivalent uranium and uranium are presented in tabular form.

- 59 McKeown, F. A., and Klemic, Harry, 1953, Reconnaissance for radioactive materials in northeastern United States during 1952: U. S. Geol. Survey TEI-317A, 66 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The authors examined iron ore deposits and associated rocks in the Adirondack Mountains of New York and in the Highlands of New Jersey.

The large low-grade magnetite ore body at the Benson mines, St. Lawrence County, N. Y., is a replacement body of magnetite and hematite in microcline granite gneiss. Garnet-rich zones are the most radioactive parts of the ore body. Field tests and analyses for radioactivity indicate that the rock and ore contain from 0.002 to 0.006 percent equivalent uranium with an average of 0.005 percent equivalent uranium. Torbernite has been re-

ported from pegmatite in the northwestern part of the mine. The outcrop of pegmatite had been stripped away at the time this examination was made, but several pieces of it in the waste rock contained allanite.

Magnetite ore at the Rutgers mine, Clinton County, N. Y., is in pink syenite gneiss and plagioclase syenite gneiss of the Lyon Mountain granite gneiss, which contain numerous schlieren of pyroxene skarn. The ore contains from 0.005 to 0.010 percent equivalent uranium, and the gneiss and schlieren contain less than 0.002 percent equivalent uranium. The radioactive minerals of the ore are apatite and zircon. The authors infer that the radioactive elements are disseminated through the ore body and are not concentrated locally.

The Mineville group of magnetite mines is in the Mineville district, near Mineville, Essex County, N. Y. The Miller, Old Bed, and "21"-Bonanza-Joker are three faulted parts of one complexly folded ore bed in the Mineville group. The ore is massive and granular; apatite is a constituent of the gangue in rich as well as lean ore. Granular high-grade ore generally contains the least amount of apatite and other gangue minerals. Medium- to fine-grained ore (magnetite grains less than about 2 millimeters across) contains radioactive fluorapatite-rich layers and stringers as well as disseminated fluorapatite. Chemical analysis of a sample of hand-picked apatite grains shows a uranium content of 0.018 percent. The amount of radioactivity of various samples (ore, rock, etc.) seems to be a function of the amount, as estimated visually, of red- or flesh-colored apatite in the sample.

At the Canfield phosphate mine, Morris County, N. J., the ore is a granular aggregate of magnetite and greenish-gray apatite; quartz, feldspar, and biotite are minor constituents. Among the rocks on the dump, those with the highest apatite content are also the most radioactive. Monazite is also present in small amounts and is radioactive.

Anomalous radioactivity was noted within the Pickering gneiss and at or near the contact of the gneiss with the Franklin limestone, in the Chestnut Hill-Marble Mountain area (Northampton County, Pa., and Warren County, N. J.). The contact between the gneiss and limestone has been injected with pegmatite in some places. Thin coatings of autunite(?) were found on slickensided surfaces and on joints in serpentine in the Williams quarry. A phlogopite-rich zone along the west side of the quarry is also radioactive. The most radioactive rock in the Marble Mountain area is an aphanitic rhyolitelike-quartz sericite schist, samples of which contain as much as 0.044 percent equivalent uranium and 0.005 percent uranium. The radioactive elements were probably derived from pegmatite, and their concentration controlled by structure and lithology.

Analyses for uranium of samples from other magnetite-apatite mines and prospects, which are not significant as possible sources of radioactive elements, are presented in tabular form.

- 60 Marble, J. P., 1935, Age of allanite from Amherst County, Virginia, U. S. A.: *Am. Jour. Sci.*, 5th ser., v. 30, p. 349-352.

Three samples of fresh allanite from a pegmatite in hypersthene granodiorite in Amherst County, Va., contain an average of 0.083 percent uranium. A weathered part of the allanite contains 0.031 percent uranium.

- 61 Marble, J. P., 1940, Allanite from Baringer Hill, Llano County, Texas: *Am. Mineralogist*, v. 25, p. 168-173.

A sample of allanite from pegmatite at Baringer Hill, Llano County, Tex., contains 0.033 percent uranium. An autoradiograph demonstrates that the radioactive elements in the mineral are sparse and uniformly distributed. Petrographic studies show that the mineral has become isotropic and is metamict. A chemical analysis of the mineral is given.

- 62 Marble, J. P., 1943, Possible age of allanite from Whiteface Mountain, Essex County, New York: *Am. Jour. Sci.*, v. 241, p. 32-42.

This article is mainly a study of the use of allanite for "age-index" purposes.

Allanite crystals in granitic pegmatite were collected from several localities at Whiteface Mountain, Essex County, N. Y. Crushed, gneissic anorthosite containing as much as 5 percent of dark minerals is the host rock. The pegmatite is comprised of microcline, plagioclase, and hypersthene and accessory magnetite and allanite. There is some quartz and locally minor biotite or phlogopite. The potassium feldspar has a slight radiating tendency and a deeper pink color around the allanite crystals.

Microscopic examination of fragments of the allanite revealed that the mineral is anisotropic and strongly pleochroic, which indicates freshness and absence of alteration. Autoradiographs of the allanite show a generally uniform distribution of the radioactive elements. Five samples of the allanite contain an average of 0.069 percent uranium. A chemical analysis of the mineral is also given.

The author analyzed a sample of allanite from pegmatites in the non-titaniferous magnetites near Mineville, Essex County, N. Y. Three samples of this mineral contain an average of 0.0086 percent uranium. A chemical analysis of the mineral is given. The large water content and nearly complete optical isotropy of the mineral indicate a change to the metamict state with consequent alteration.

- 63 Marble, J. P., 1950, Lead-uranium ratio and possible geologic age of allanite from Greenwich, Massachusetts: *Am. Mineralogist*, v. 35, p. 845-852.

Anisotropic allanite from a pegmatitic lens in the Monson granodiorite at Greenwich, Mass., contains 0.095 percent uranium. A chemical analysis and optical and mineralogic descriptions of the allanite are given. The article is mainly a discussion of the lead-uranium ratio and possible age of the mineral.

This locality is now flooded by the Quabbin Reservoir.

- 64 Morgan, J. H., and Auer, M. L., 1941, Optical, spectrographic, and radioactivity studies of zircon: *Am. Jour. Sci.*, v. 239, p. 305-311.

The three varieties of zircon in granites of the Lake Superior region are the Keweenaw or normal, hyacinth, and malacon. They are distinguished by their optical characteristics, color, and crystal form. The normal variety has a low radioactivity, the highest optical indices, and the strongest birefringence. The hyacinth variety has a higher radioactivity, lower optical indices, and weaker birefringence than the normal type. The malacon variety has the highest radioactivity, the lowest optical indices, and the weakest birefringence of the three varieties. The radioactivity was measured with a Geiger counter.

The results of spectrographic analyses of 24 samples of zircon show no apparent relationship between yttrium content and radioactivity, nor between yttrium content and hafnium content.

The type of zircon present in a granite may depend on the amount of uranium available at the time of crystallization of the zircon. "This may imply that the concentration of uranium is greater in some magmas than in others, and may sometimes be indicative of concentration of uranium in the late stages of magmatic intrusion.

"The concentration of uranium in granite magmas of one intrusive period may be similar over wide areas, since granite intrusives of similar time relationships can be distinguished by the zircon variety present in them. Such similarity in concentration of uranium may mean a common, deep-seated source for the magma."

- 65 Moxham, R. M., and Nelson, A. E., 1952, Radioactive pegmatite minerals in the Willow Creek mining district [Alaska]: U. S. Geol. Survey Circ. 184, pt. 2, p. 7-10.

Samples from 11 pegmatites in the Fishhook Creek-Archangel Creek area in the Willow Creek mining district, Alaska, have an average of 0.004 percent equivalent uranium. The pegmatites, intruded into schist and quartz monzonite, probably represent end phases in the consolidation of the Talkeetna batholith. The radioactivity of the pegmatites is due to one or more of the following minerals: Uraninite, thorite, cyrtolite, and allanite. The greatest concentration of these minerals is found in association with biotite.

Six analyses of heavy-mineral separates of the pegmatites average 0.034 percent uranium.

- 66 Moxham, R. M., and West, W. S., 1953, Radioactivity investigations in the Serpentine-Kougarok area, Seward Peninsula, Alaska, 1946: U. S. Geol. Survey Circ. 265, 11 p.

Radioactive minerals in small quantities were found in the bedrock and alluvium within the outcrop area of granite at the head of Serpentine River.

Tests of radioactivity at outcrops of the granite indicate that small amounts of radioactive material is disseminated throughout the mass. Four variants of the normal granite have been recognized: early and late differentiates, and pegmatitic and fine-grained facies. All variants except the early differentiates show radioactivity in excess of the normal granite. The average equivalent uranium content of 29 samples of the granitic variants is 0.008 percent. The heavy-mineral portions of these samples average 0.034 percent equivalent uranium.

The radioactivity of the placer material and bedrock is attributable to zircon, sphene, allanite, hydrogoethite, and two unidentified secondary minerals. Neither the bedrock nor placer deposits contain sufficient radioactive materials to be of present commercial interest.—*Authors' abstract*

- 67 Muench, O. B., 1931, The analysis of cyrtolite for lead and uranium: Am. Jour. Sci., 5th ser., v. 21, p. 350-357.

A sample of hafnium-rich cyrtolite from a pegmatite dike at Bedford, N. Y., was found to contain 7.29 percent uranium. The chemical method used for the determination of uranium is described in detail. The analysis (plus one for lead) was made for age-determination studies.

- 68 Muench, O. B., 1934, The analysis of Bedford cyrtolite for lead and uranium: *Am. Chem. Soc. Jour.*, v. 56, p. 1536.

A specimen of cyrtolite from the same pegmatite as that described in reference 67, at Bedford, N. Y., was analyzed for lead and uranium to determine whether or not different specimens of minerals from the same pegmatite dike might give different ages due to a reopening of the dike from time to time. The average uranium content of 5 samples of this cyrtolite is 6.73 percent. "The lead-uranium ratio is practically the same as was obtained by the earlier determination (0.051). [Reference 67.] The result indicates that the material is uniform in age and does not favor the possibility that the dike has been reopened and material intruded."

- 69 Muench, O. B., 1950, Recent analyses for age by lead ratios: *Geol. Soc. America Bull.*, v. 61, p. 129-132.

This article is mainly a discussion of the determination by the lead-uranium ratio of the age of a sample of monazite and euxenite from pegmatite. The results of analyses for uranium are given as follows:

<i>Mineral</i>	<i>Location</i>	<i>Average percent uranium</i>	<i>Number of samples</i>
Monazite-----	Bull Creek, near Las Vegas, N. Mex.	0. 122	1
Euxenite-----	Trout Creek Pass, Colo----	3. 41	1

- 70 Narten, P. F., and McKeown, F. A., 1952, Reconnaissance of radioactive rocks of the Hudson Valley and Adirondack Mountains, New York: U. S. Geol. Survey TEI-70, 54 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

A radiometric reconnaissance using car-mounted Geiger-counter equipment was made of the Paleozoic rocks of the Hudson Valley and the Precambrian rocks of the Adirondack Mountains in New York State. The log of localities examined and analytical data are presented in tabular form. Some of the more radioactive rocks are described in detail. Those mentioned below are only those not discussed in reference 58.

The most radioactive material on the dump of an active talc mine southwest of Edwards is a coarsely crystalline pegmatite. The highest radioactivity is associated with a black material scattered through the feldspar. A selected grab sample of this material contains 0.050 percent equivalent uranium, 0.043 percent uranium, and 0.02 percent ThO₂. Trace amounts of allanite and uraninite are present.

Abnormally radioactive biotite granite-gneiss lenses were found in fine-grained mafic rock about 7 miles south of De Peyster. A grab sample of one of the more radioactive lenses contains 0.007 percent equivalent uranium and 0.002 percent uranium. Trace amounts of zircon and monazite are present, and their thorium content probably accounts for most of the radioactivity of the rock.

North of the town of Lake George, a dark-gray pegmatitic zone in gabbro, the latter intrusive into syenite, is radioactive. A grab sample of the pegmatite contains 0.024 percent equivalent uranium, 0.013 percent uranium, and 0.03 percent ThO₂. A grab sample of the syenite contains 0.004 percent equivalent uranium, 0.002 percent uranium, and 0.002 percent ThO₂. The gabbro is estimated to contain 0.002 percent or less equivalent uranium.

Pegmatite in gneiss about 6 miles southwest of Graphite is abnormally radioactive. A 3-inch zone of minerals in one of the pegmatites was the most radioactive. A sample from the zone contains 0.016 percent equivalent uranium, 0.002 percent uranium, and 0.05 percent ThO_2 .

The abnormal radioactivity of Precambrian rocks in the northwest and southeast parts of the Adirondacks is most apparent near the contacts of igneous and metamorphic rocks. Pegmatites, however, are the only known rocks in this area with concentrations of radioactive elements.

- 71 Nelson, J. M., and Narten, P. F., 1951, Reconnaissance of radioactive rocks of Maine: U. S. Geol. Survey TEL-68, 44 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

In the summer of 1948, the authors traversed the State of Maine using car-mounted Geiger-counter equipment. The maximum radioactivity noted was 0.008 percent equivalent uranium and 0.003 percent uranium. A log of localities estimated to contain 0.003 percent equivalent uranium or more, all sample localities, and field and laboratory analyses of samples are presented in tables.

The State was divided into two areas on the basis of radioactivity. Area 1 is abnormally radioactive and comprises about 1,400 square miles extending from Lewiston westward to New Hampshire. This area is one of gneiss and schist, much intruded by pegmatite. The radioactivity of the rocks of 128 outcrops ranged from 0.001 to 0.008 percent equivalent uranium with a maximum uranium content of 0.003 percent.

Area 2 comprises the remainder of the State and has low radioactivity. Granitic rocks of the coastal belt of rocks have a maximum equivalent uranium content of 0.005 percent.

Small granitic stocks are abundant in area 1, and there is an approximate correlation between the amount of radioactivity and areas where these stocks are most numerous. In the coastal belt of area 2, granitic intrusions are larger and the radioactivity is lower. The rest of area 2 has the fewest number of granitic intrusions and the least radioactivity.

The authors suggest that the probability of finding concentrations of radioactive minerals is greatest in areas containing large numbers of small granitic intrusives. The relation might be explained by assuming that the additional heat generated by radioactive elements would cause an intrusive body to stay fluid longer and thus enable it to rise higher in the intruded rocks. The concentrations of radioactive elements in granitic rocks could be a result of magmatic differentiation, formation in place from rocks originally high in radioactive constituents, or a combination of these factors.

The most radioactive metamorphic rocks in Maine are the high-grade gneiss and schist in the area west of Lewiston (area 1). In contrast, the widespread exposures of slate in northern Maine (area 2) have the lowest average radioactivity of any of the rocks examined in the State.

Included with the report is a table listing the equivalent uranium, uranium, and in few cases thorium, contents as determined by laboratory analysis of 21 samples of various igneous and metamorphic rocks from Maine. Of the samples analyzed, 10 contain less than 0.000 percent uranium, 8 contain 0.001 percent uranium, 2 contain 0.002 percent uranium, and 1 contains 0.003 percent uranium.

The authors conclude from their data that, in Maine, the granitic rocks have the highest radioactivity in their respective areas, that areas

with high-grade metamorphic rocks tend to be more radioactive than areas with low-grade metamorphic rocks, and that the mafic rocks have the lowest average radioactivity.

- 72 Neuberburg, G. J., 1955, Occurrences of uranium in veins and igneous rocks, in *Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1954 to May 31, 1955*: U. S. Geol. Survey TEI-540, p. 150-152, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The labile uranium contents of igneous rocks are considered to represent that part of the total uranium content that is most likely to have changed during the rock's history and that may, therefore, provide clues to the movement of uranium during the formation of ore deposits. Likewise, it is thought that Th/U ratios may provide additional information on the movement of uranium during a rock's history.

The leaching procedure consists of the following: 4 grams of rock, pulverized to minus 20 mesh, are leached in 800 ml of 0.05 M HNO₃ on a steam bath at a temperature of 80-85°C for one-half hour. This procedure was adopted on the basis of experiments that showed it entailed virtually complete solution of pitchblende and a variety of hexavalent uranium minerals while dissolving less than 10 percent apatite and negligible amounts of the common minor accessory minerals.

Analyses of a few zeolites showed uranium contents ranging from 0.9 ppm to 27.6 ppm. In 1937 Goldschmidt predicted that zeolites should not accommodate uranium in their structure. The finding of appreciable uranium in these zeolites may mean that it is held in cation exchange position. This is also implied by associated amygdaloidal analcite and natrolite, containing 0.05 ppm and 4.4 ppm uranium, respectively, on the assumption that analcite should adsorb no uranium while natrolite may readily adsorb it. If uranium is readily adsorbed by zeolites, surveys of areas containing zeolites may serve to identify volumes of rock through which uraniumiferous solutions have passed.—*Extracts from author's report*

- 73 Neuberburg, G. J., 1956, Uranium in igneous rocks of the United States of America: *Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, Proc.*, v. 6, Geology of uranium and thorium, p. 231-239.
- Neuberburg, G. J., 1956, Uranium in igneous rocks of the United States: *U. S. Geol. Survey Prof. Paper 300*, p. 55-64.

Uranium is an ubiquitous and exceedingly small component of all igneous rocks. The uranium content of igneous rocks largely reflects the chemistry of the rock; silicic igneous rocks generally contain more uranium than do the mafic igneous rocks within any given petrographic association. Equivalent rocks from separate petrographic associations differ in uranium content. The quantity of uranium also varies within seemingly homogeneous rock masses. There is uncertain evidence for a regional variation in uranium content of igneous rocks beyond that which can be assigned to petrographic character.

Uranium is distributed among six major environments in igneous rocks: (a) uranium minerals as such, (b) uranium disposed in the structure of the rock minerals by diadochy and in structural defects in crystals, (c) uranium held in cation exchange positions, (d) uranium in unknown form adsorbed on surfaces of crystals, (e) uranium dissolved in fluid inclusions within rock minerals, and (f) uranium dissolved in intergranular fluids.

The uranium content of these six environments varies from rock to rock, and each is thought to have differing geologic histories, such that the total uranium content of an igneous rock represents the interplay of a complex series of events taking place during and since crystallization of the rock. Thus, the total uranium contents of igneous rocks are dynamic quantities that cannot be referred to any single event. The uranium in the six environments displays differing degrees of reactivity toward and accessibility to solutions passing through the rock.

Current techniques permit crude determinations of the amounts of uranium in the different environments or in groups of the environments. Such information is of potential value to theoretical considerations and to prospecting for uranium ore deposits. Dilute mineral acids dissolve nearly all the uranium except that held structurally in the rock minerals. The quantity of uranium held structurally can be referred to the last crystallization or recrystallization of the rock minerals and is the quantity of prime importance to geochemical studies. The readily dissolved, or labile uranium of a rock is a measure of that part of the uranium content of a rock most likely to have been changed after final consolidation. If uranium aureoles exist around ore deposits, they will be measured by the quantity of labile uranium.

From study of fabric distribution of uranium, it is evident that the total uranium content of an igneous rock reflects in no way the uranium content of the melt from which it crystallized. The total uranium content of an igneous rock is the sum of (a) the amount of uranium fixed in the rock at the time of final consolidation, and (b) the amount of labile uranium that probably was changed after consolidation of the rock.

Studies of the occurrence and quantity of uranium in igneous rocks is important for two reasons: (a) these rocks are potential low-grade ores, and (b) uranium in currently minable concentrations has originated both directly and indirectly from igneous activity.

- 74 Neuberger, G. J., and Gottfried, David, 1954, Age determinations of the San Gabriel anorthosite massif, California: *Geol. Soc. America Bull.*, v. 65, p. 465.

The radioactivity of zircons from altered norite from the anorthosite massif in the San Gabriel Mountains, Calif., is 18 alphas per mg per hr and is the lowest value yet obtained for zircons separated from igneous rocks. Samples of zircon from pegmatite in the massif have a radioactivity of 50 alphas per mg per hr.

- 75 Neumann, Henrich, Mead, Judson, and Vitaliano, C. J., 1954, Trace element variation during fractional crystallization as calculated from the distribution law: *Geochim. et Cosmochim. Acta*, v. 6, p. 90-99.

The distribution of trace elements in rocks formed by crystallization is governed by (a) the laws of crystallization and (b) the laws of distribution of trace elements, that is, an element's diadochical properties, its ionic radii and chemical bonding.

The distribution law states there is a constant ratio between concentrations of any given component in any two phases of a system in equilibrium at constant temperature and pressure. This law is only approximate for essential or varietal elements, owing to widespread solid solution, but for trace elements (less than 1 percent) the error is negligible.

Distribution coefficients may be expressed as functions of the partial vapor pressure of the trace element; therefore, coefficients vary with changing temperature and composition of the solidifying magma.

The age relationships between different minerals in a crystallizing magma are equally as important as the distribution factors in considering the distribution of trace elements between minerals. For example, a trace element may have a greater distribution coefficient in mineral *B* than in mineral *A*, yet mineral *A* might contain nearly all of the trace element if it crystallized before mineral *B* and was removed from reaction in the system.

Variation with temperature may change a distribution coefficient to the extent that a mineral crystallizing from a magma may remove a trace element from that magma at high temperature, whereas at a lower temperature the magma may be enriched in the same trace element by further crystallization of the same mineral.

Variation of distribution coefficients with pressure is considered to be negligible. Thus extreme care must be used if distribution coefficients are determined by a study of naturally occurring rocks, and a determination may, in many cases, be impossible.

- 76 Ockerman, J. B., and Daniels, Farrington, 1954, Alpha-radioactivity of some rocks and common materials: *Jour. Phys. Chemistry*, v. 58, p. 926-927.

The alpha activity of 300 samples of various types of materials is reported. The materials tested include granites, limestones, bentonites, building materials, well-water residues, and plant litter. Bentonite clays with adsorbed uranium and other alpha emitters were more radioactive than granites.

- 77 Ordway, R. J., 1951, Radioactivity of some Maine pegmatites: *Maine State Geologist Rept.*, 1949-50, p. 91-106.

No commercial concentrations of uranium-bearing minerals were found in any of the pegmatites studied. About two-thirds of all the pegmatites checked with the Geiger counter were found to contain black radioactive mineral grains, probably uraninite in most instances. Invariably these black mineral grains were found to be surrounded by smoky quartz and (or) stained feldspar, with the dark color fading out gradually away from the radioactive mineral grains. Evidently the invisible rays given off by the radioactive material caused the quartz and feldspar to become dark colored. When the counter probe was moved a foot or so from these radioactive minerals, a normal pegmatite reading was obtained. Most of these uranium-bearing minerals were found in wall zones or core-margin zones.

Several pegmatites were found to contain certain areas which consistently were too radioactive for reading on the most sensitive scale of the Geiger counter. A sulfide vein cutting the Melrose pegmatite is representative of these areas. Analysis by the Trace Elements Section of the U. S. Geological Survey showed an equivalent uranium content of a 1-lb sample to be 0.09 percent—very low.

An attempt was made to delineate zones in pegmatites on the basis of radioactivity. Potassium is feebly radioactive and is present in perthite which is abundant in core and core-margin zones; potassium is absent in the plagioclase feldspars which predominate in border and wall zones.

Nearly 100 counts were made on different zones in the Red Hill pegmatites in Rumford with results which are summarized in figure 4. The average count in each zone varied from 1.5 to 2.0 times the background count—the border zone giving the 2.0 count. These results appear not to be significant.

In every pegmatite checked with the Geiger counter, large masses of perthite gave readings which were about double the background count or slightly more, whereas large quartz crystals (not smoky) gave readings which were about equal to the background count or less.

Readings taken along the margins of inclusions of wall rock or along wall rock contacts with pegmatites were double the background count or more in parts of some pegmatites, but gave normal counts in other parts of the same pegmatites and in other pegmatites.—*Author's summary, in part*

78 Page L. R., 1950, Uranium in pegmatites: *Econ. Geology*, v. 45, p. 12–34.

Both primary and secondary uranium minerals are common constituents of pegmatites, but they rarely occur in sufficient quantities to be an economic source of uranium. The physical properties and chemical composition of the more common uranium-bearing minerals in pegmatites are presented in tabular form.

Uranium-bearing pegmatites are made up of units of contrasting mineralogy and (or) texture. These units are classified as zones, fracture filling units, and replacement units. Uranium minerals are most common in intermediate zones and cores of pegmatites, although they may occur in any of the structural units. The potash-rich pegmatites are the most likely sources of uranium minerals, and soda-rich and lithia-rich pegmatites are somewhat less favorable.

This article describes some of the uranium-bearing pegmatites in the United States. At the Ruggles mine, in Grafton, N. H., uraninite associated with secondary alteration products occurs in part of a perthite-quartz-plagioclase zone surrounding a perthite pegmatite core. Uranium minerals are also in quartz fracture-filling units that cut the pegmatite.

The uranium-bearing zone at the Palermo pegmatite, Groton, N. H., is composed mainly of plagioclase, quartz, muscovite, and perthite, and contains unusual amounts of beryl and rare phosphate minerals. Uraninite and its alteration products are the principal uranium minerals.

The Bob Ingersoll Dike 2 pegmatite in Keystone, S. Dak., contains uraninite and its alteration products in an irregular lens of muscovite-albite (cleavelandite)-quartz, which may be a replacement unit.

Microlite occurs in lepidolite-quartz-cleavelandite cores in the Brown Derby pegmatite (Gunnison County, Colo.) and the Pidlite mine (Mora County, N. Mex.) and in lepidolite-rich lenses at the Harding mine (Taos County, N. Mex.).

Uranium-bearing pegmatites in Africa, Mozambique, India, Brazil, Norway, Russia, and Canada are briefly described.

“In summary, the uranium minerals in foreign pegmatites, as well as in the United States, appear to be most common in those bodies that contain an abundance of potash feldspar. Uraninite shows a close association with muscovite and biotite; betafite and allanite with biotite; euxenite and monazite with beryl and in a few deposits with muscovite; and samarskite with columbite and fergusonite. Minor amounts of uranium minerals associated with lithium minerals have been noted. Nearly all the uranium

minerals are associated with some albite, but albite is rarely the dominant feldspar. [In part, the secondary uranium minerals are] apparently the result of alteration associated with the late stages of pegmatite formation rather than of weathering."

- 79 Patterson, C. C., Tilton, G. R., and Inghram, M. G. 1955, Age of the earth: Science, v. 121, P. 69-75.

This paper is mainly a discussion of a new method of age determination.

Evidence that there is a uniformity of elemental isotopic composition in both the earth and meteorites suggests that the concentrations of lead and uranium in chondrites may be a rough measure of the concentration of these elements in the earth as a whole. The uranium content of the following meteorites was determined:

	<i>Uranium (ppm)</i>
Canyon Diablo troilite.....	0.009
Modoc total stone.....	.011
Norton County total stone.....	.010

Assuming that the earth is made of chondritic material, that it has a surface one-half covered by a 10-km-thick basaltic layer, one-half covered by a 10-km-thick granitic layer underlain by a 30-km-thick basaltic layer, and using commonly accepted values for the concentration of uranium in granites and basalt, the authors present the following:

<i>Material</i>	<i>Uranium (ppm)</i>	<i>Earth's total uranium (percent)</i>
5 km of granite.....	4	50
30 km of basalt.....	.8	40
Interior.....	-----	10

(Lead content and earth's total lead is also given but is not reported here.) The data suggest that nearly all the uranium in the earth is concentrated near the surface.

The mineral and chemical composition is given of a sample of Quaternary flood basalt from the Snake River Plains of Southern Idaho. The basalt contains 0.65 ppm uranium.

- 80 Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U. S. Geol. Survey TEI-247, 53 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

Results of analyses [chemical and radiometric] of 117 samples indicated that the Tertiary porphyry sequence in the middle part of the Front Range ranks among the most radioactive igneous series in the world, according to the present literature. With the intrusion of nonporphyritic lime-poor quartz bostonite dikes in the western half of the Central City district, the magmatic enrichment in both uranium and thorium reached a peak of more than 20 fold over the best available averages for granitic rocks.

The sequence of events in the Central City district is thought to be as follows: (1) Intrusion of slightly to moderately radioactive monzonite throughout the eastern half of the district, (2) intrusion of excessively

radioactive, nonporphyritic varieties of quartz bostonite in the western half of the district north of what was to become the area of pitchblende deposition, (3) intrusion of the highly radioactive quartz bostonite porphyry dikes with which 15 of the 17 known occurrences of pitchblende are now associated (within 500 feet), (4) deposition of pitchblende as a local and unusual variant in the regional pyritic-gold ore deposition near, but not in, the quartz bostonite porphyry dikes. The implication of the field and chemical evidence is that uranium-rich solutions given off by a cooling quartz bostonite mass at depth became further enriched by leaching uranium from the quartz bostonite channelways while en route to higher levels. Zircon, the probable host for much of the uranium and part of the thorium in the rocks, separated in reduced amounts from the youngest quartz bostonite liquids—a change which, in effect, tended to throw uranium into the residual liquid. Possible mechanisms by which uranium became concentrated with respect to thorium in the derived aqueous solutions are considered. In this connection the late magmatic introduction of fluorite and of ferric oxides may be of special significance.—*Author's abstract*

- 81 Phair, George, 1955, Distribution of uranium in igneous complexes, *in* Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1954 to May 31, 1955: U. S. Geol. Survey TEI-540, p. 237-244, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The results of heavy-mineral separations made on samples of Precambrian batholiths in the Colorado Front Range show the following: Monazite occurs only in the youngest batholiths; allanite is common in the Boulder Creek batholith (the oldest), occurs rarely in the "Silver Plume" correlatives, and is lacking in the Sherman and Pikes Peak batholithic rocks.

The average uranium content of samples of rocks of the White Mountain (N. H.) igneous series ranges from 4.7 ppm in the monzonites to 11.7 ppm in a biotite granite, the uranium content increasing from the oldest to youngest rocks. Zircon is the most uraniferous mineral in the Conway granite member of the White Mountain series.

The uranium content of allanites from acid and intermediate igneous rocks (exclusive of pegmatites) is variable.

"The main conclusions drawn from studies of the alkalic rocks in Sussex County, N. J., are (1) the relatively high-uranium contents (19-44 ppm) of these rocks show no relationship to the amounts of zircon or sphene, constituents in which the rocks appear to be abnormally enriched; and (2) in both the stock rocks and dike rocks uranium increases with SiO_2 ."

- 82 Picciotto, E. E., 1950, Distribution de la radioactivité dans les roches éruptives: Soc. Belge géologie, paléontologie et hydrologie Bull., tome 59, p. 170-198.

This article presents the results of a study of thin sections of two granites an anorthosite, and a norite. Several generalizations are made about radioactivity in granitic rocks, based on previous work done by other authors. There seems to be no direct relation between radioactivity and concentration of major chemical constituents of the rocks; biotite is

generally more radioactive than quartz, certain accessory minerals are the most radioactive, and part of the radioactivity is localized on the surface of the mineral grains of the rock.

The radioactivity data given in this article were obtained from stripping films and are expressed in units of alpha particles emitted per square centimeter per second.

Radioactivity in the Vosges granite is distributed in three ways: 54 percent of the total radioactivity is concentrated in microscopic crystalline inclusions of accessory minerals (sphene, apatite, zircon), 28 percent of the radioactivity is dispersed among the essential minerals (quartz, biotite, feldspar), but much of it is probably caused by ultramicroscopic inclusions or atomic dispersion of the radioelements. It is possible that some of the radioactivity of quartz is due to liquid or gaseous inclusions. Eighteen percent of the radioactivity is concentrated in fractures cutting the minerals or in interstitial material.

The radioactivity in the accessory and essential minerals is of primary origin. Most of the radioelements separate out from the magma in the first stages of crystallization, zircon, apatite, and sphene being the first minerals formed in granite. A residual part of the radioelements is dispersed in the essential minerals, either in their crystal structure, by association with inclusions of zircon and apatite, or by association with the liquid or gaseous inclusions of residual magmatic fluids.

The radioactivity of the fracture fillings and interstitial material, which are composed of black opaque minerals and epidote, is of secondary origin.

A sample of granite from Ile d'Elbe contains quartz, orthoclase, plagioclase, and biotite as the essential minerals, and sphene, tourmaline, apatite, and opaque minerals as the accessory minerals. The quartz and feldspar have been crushed by tectonic action and exhibit the common effects of mechanical stress. Seventy-nine percent of the radioactivity is concentrated in the inclusions of accessory minerals; 18 percent is dispersed in the essential minerals; and 3 percent is confined to fracture fillings and interstitial material—a low percentage considering the numerous cracks resulting from stress.

The radioactivity of a specimen of anorthosite from Egersund, Norway, is lower than that of the two granites studied, is much more homogeneously distributed, and is not due to inclusions. The ferromagnesian minerals are more radioactive than the feldspars.

A sample of norite from veins in the anorthosite massif has a slightly higher total radioactivity than the anorthosite.

- 83 Piggot, C. S., 1929, Radium in rocks—I, The radium content of some representative granites of the eastern seaboard of the United States: *Am. Jour. Sci.*, 5th ser., v. 17, p. 13-34.

This article presents the results of radium determination of seven igneous rocks from eastern United States. The apparatus, procedure, and calibration of the apparatus are described in detail. According to the author, "the radium determination is made by decomposing a weighed amount of pulverized rock by fusion in a flux of sodium and potassium carbonates, collecting the radium emanation thereby liberated, and determining it by means of an electroscope." The radium content is expressed

in terms of the unit, 10^{-12} grams of radium per gram of rock. The average radium contents of the rocks are given below.

<u>LOCALITY</u>	<u>ROCK TYPE</u>	<u>AVERAGE RADIUM CONTENT 10^{-12} g/g</u>	<u>NUMBER OF MEAS- URE- MENTS</u>
Stone Mountain, Ga..	Fine-grained gray biotite-muscovite granite.	4. 826	16
Mount Airy, N. C....	Coarse-grained light-gray biotite granite.	. 655	4
Ilchester, Howard County, Md.	Gray biotite diorite with accessory epidote.	1. 935	5
Woodstock, Baltimore County, Md.	Gray biotite granite with much allanite and epidote.	1. 448	5
Milford, Mass.....	Very light pink mottled biotite granite.	. 378	5
Rockport, Cape Ann, Mass.	Hornblende-biotite granite...	. 955	5
Hurricane Island, Maine.	Coarse even-grained pinkish-buff medium-gray biotite granite.	3. 740	5

The $-48+100$ mesh fraction of a sample of the Stone Mountain granite was separated into its constituent minerals according to density by suspension in Kline's solution, and a determination made of the radium content of each mineral. The results indicated that much of the radium is associated with the denser minerals, particularly with biotite and muscovite. The total radium content of all the minerals, however, is much less than the average radium content of the rock as a whole (4.826×10^{-12} grams of radium per gram of rock). This indicates that much of the radioactivity is on the surface of the mineral grains and was leached during the separation process of the minerals. To test the theory, the author boiled a part of a powdered sample in distilled water and, after testing the radioactivity of the leached sample, found that a considerable portion of the radioactivity had been removed by the leaching. Further experiments by the author on the leaching of the radioactivity of granites are described in reference 86.

- 84 Piggot, C. S., 1931, Radium in rocks—II, Granites of eastern North America from Georgia to Greenland: *Am. Jour. Sci.*, 5th ser., v. 21, p. 28-36.

The radium content of granite samples discussed in reference 83 has been redetermined. The new values are as follows:

<u>LOCATION</u>	<u>RADIUM 10^{-12} g/g</u>
Stone Mountain, Ga.....	3. 81
Mount Airy, N. C.....	. 49
Ilchester, Md.....	. 91
Woodstock, Md.....	1. 09
Milford, Mass.....	. 26
Rockport, Cape Ann, Mass.....	. 72
Hurricane Island, Maine.....	2. 79

In addition, a sample of biotite-muscovite granite from North Jay, Maine, was examined. Five samples of this granite have an average radium content of 3.39×10^{-12} g per g. The author noted that the biotite in the granite contained many pleochroic halos, and he predicted correctly that because of this the granite might have a somewhat higher uranium content.

The radium content is given also for samples of igneous rocks from Labrador, Baffin-Land, and Greenland.

- 85 Piggot, C. S., 1931, Radium in rocks—III, The radium content of Hawaiian lavas: *Am. Jour. Sci.*, 5th ser., v. 22, p. 1-8.

The radium content of 13 samples of lavas from the Hawaiian Islands ranges from 0.75 to 1.47×10^{-12} grams of radium per gram of sample, with an average of 0.96×10^{-12} g per g. There was no correlation between radium content and age of flow—all the samples representing a series of ancient to recent flows from Kilauea Crater had about the same radium content—nor was there any correlation between radium content and the chemical composition of the lavas.

The basalts tested have as high an average radium content as that of any granites examined to date by the author.

- 86 Piggot, C. S., and Merwin, H. E., 1932, Radium in rocks—IV, Location and association of radium in igneous rocks: *Am. Jour. Sci.*, 5th ser., v. 23, p. 49-56.

Samples of granite from Stone Mountain, Ga., and North Jay, Maine, contain 3.8×10^{-12} and 3.39×10^{-12} grams of radium per gram of rock, respectively. The authors found no trace of radioactive minerals in the granite samples they examined, although both granites are known to have come from areas where such minerals have been identified.

Each sample was separated into a quartz and feldspar, a biotite, and a muscovite fraction. The radium content was determined for each fraction. The results of these analyses indicate that the radium content of the granites is associated more with the micas than with the other constituents.

Samples of the granites and of the various fractions were leached (boiled in distilled water, allowed to settle, and decanted). The residue was filtered and dried, and each sample divided into two parts. The radioactivity of one part was determined immediately, whereas the radioactivity of the other part was determined after 30 days. The results of these experiments showed that some of the radioactivity was leached from the samples, but that the loss was only temporary, as the radioactivity of the leached samples was completely restored after 30 days. Apparently, leaching removes only the radioactive material, which is weakly adsorbed on the sample or easily accessible in it, and has no effect on the original radium or parent uranium contained in the sample.

Preliminary experiments on the Stone Mountain granite are described in reference 83.

- 87 Poole, J. H. J., 1927, The radioactivity of the earth's basaltic magma: *Philos. Mag.*, ser. 7, v. 3, p. 1246-1252.

This paper is for the most part a continuation of a study made by Poole and Joly in 1924 (reference 88). Poole makes a special study here of eclogites from Europe, the plateau basalts from Oregon, northwest Europe,

and India, and the island basalts from islands in the Atlantic and Pacific oceans. The electric method was used for the determination of the radium content and the solution method for the thorium content. Only the results of studies on the plateau basalts are included here.

The plateau basalts are divided into three groups: Oregonian from Oregon, Hebridean from northwest Europe, and Deccan from India. Poole's studies yielded the following results:

	RADIUM 10 ⁻¹² g/g	THORIUM 10 ⁻⁵ g/g
Oregonian (mean for 12 samples).....	0. 70	0. 57
Deccan (mean for 6 samples).....	. 77	. 46
Hebridean (mean for 8 samples).....	. 77	. 49
Mean for plateau basalts.....	. 75	. 51

- 88 Poole, J. H. J., and Joly, John, 1924, The radioactivity of basalts and other rocks: *Philos. Mag.*, ser. 6, v. 48, p. 819-832.

The radium content (determined by the electric furnace-emanation method) and thorium contents are given for the following (only those rocks from the United States are listed here, although the report includes samples from other countries): Basalt from Colorado, Washington, and Montana; diabase from New Jersey, Massachusetts, and New York; hornblende gabbro from Virginia; peridotite from Rhode Island and New York; andesite from Colorado and Massachusetts; granodiorite from Minnesota; anorthosite from Oklahoma and New York; and dacite from Colorado.

Ultrabasic rocks are noted to have a lower radium content than mafic rocks. The paper is mostly concerned with the use of the radioactivity data as a means of arriving at an estimate of the radium content of the subcrustal magma of the earth.

- 89 Quirke, T. T., and Finkelstein, Leo, 1917, Measurements of the radioactivity of meteorites: *Am. Jour. Sci.*, 4th ser., v. 44, p. 237-242.

Twenty-two meteorites were analyzed for radium using the emanation method. Among the samples tested were stone meteorites from Arizona and Kansas, an ironstone meteorite from Iowa, and iron meteorites from Kansas and Arizona. The other samples are from foreign sources. The authors found that all the siliceous meteorites were radioactive, in contrast to the iron meteorites which are almost free of radioactivity. From the data, it seems that the average stony meteorite is one-quarter or less as radioactive as the average granite.

- 90 Rankama, Kalervo, and Sahama, Th. G., 1950, *Geochemistry*: Chicago, Ill., Univ. Chicago Press, 912 p. See p. 178-180, 632-639.

The first part of this book is devoted to a general survey of the field of geochemistry and to the general laws and regularities that determine the abundance and mode of occurrence of each particular element. Part II is concerned with the geochemistry of the individual elements.

Heavy elements, such as uranium and thorium, are concentrated in the upper crust of the earth because of their property of becoming enriched in low-density rocks, such as granites and pegmatites.

Many complex pegmatites contain high concentrations of uranium because the ionic properties of uranium are not suitable for its incorporation into the structure of rock-forming minerals; and the uranium, therefore, becomes enriched in residual magmatic solutions. Uranium-

rich minerals are formed during the late stages of pegmatite deposition. Granite pegmatites have a higher concentration of uranium than nepheline syenite pegmatites.

Granitic rocks are richer in uranium than other igneous rocks. During crystallization the acidic rocks become enriched in uranium with respect to thorium.

- 91 Rodgers, John, 1952, Absolute ages of radioactive minerals from the Appalachian region: *Am. Jour. Sci.*, v. 250, p. 411-427.

The author has assembled what he considers to be all the reliable analyses (for U, Pb, and Th) and determinations that have been made on minerals from the Appalachian region, in order to recalculate the age of the minerals "in the light of presently accepted formulae and constants."

Only those analyses not reported in any other annotation in this bibliography are listed below. All the uranium analyses except one were made using standard gravimetric chemical methods. The uranium content of uraninite from the Strickland quarry (item three) was determined by microanalytical methods. All the minerals are from pegmatites.

<i>Location</i>	<i>Mineral</i>	<i>Uranium (percent)</i>	<i>Number of samples</i>	<i>Date of analysis</i>
Spinelli quarry Glastonbury, Conn.	Samarskite.....	6. 91	Best mean of 2.	1937
Hale quarry, Port- land, Conn.	Uraninite.....	71. 32	Average of 5...	1891
Strickland quarry, Portland, Conn.	...do.....	78. 78	Average of 3...	1933
Rock Quarry Land- ing, Haddam (Neck), Conn.	...do.....	74. 39	1.....	1938
Branchville, Conn. (3 different anal- ysts).	...do.....	74. 67	Average of 3...	1891
		66. 00	1.....	1907
		81. 50	Average of 2...	1880
Deer Park mine, Spruce Pine, N. C.	...do.....	74. 20	1.....	1938
Flat Rock mine, Spruce Pine, N. C.	...do.....	67. 00	1.....	1907
Do.....	Uraninite (be- fore leaching with HCl).	76. 96	1.....	1891
Do.....	Uraninite (after leaching with HCl).	77. 77		
Marietta, S. C.....	Uraninite.....	71. 19	1.....	1892

- 92 Senftle, F. E., and Keevil, N. B., 1947, Thorium-uranium ratios in the theory of genesis of lead ores: *Am. Geophys. Union Trans.*, v. 28, p. 732-738.

(1) The analyses of group samples of over 1,500 igneous rocks indicate an average value for the thorium-uranium ratio of 3.4 for granitic rocks and 4.0 for intermediate rocks. Such values would give an atomic

weight of rock lead approximately that of ore lead and thus do not support Holmes' theory that lead ore deposits have a deep-seated source. (2) Experimental data indicate that the acidic magmas, while known to contain quantitatively more uranium and thorium than basic magmas, retain relatively more uranium than thorium than do intermediate magmas in the same region. (3) There is also some evidence that a regional distribution of thorium and uranium exists on the North American continent. The thorium-uranium ratios of the Canadian Shield are lower than in the United States. There is roughly a 20 percent higher uranium content in the intermediate rocks of the Canadian Shield, but this difference is not shown by the results in granitic composite samples.—*Authors' summary and conclusions*

- 93 Shaub, B. M., 1938, The occurrence, crystal habit, and composition of the uraninite from the Ruggles Mine, near Grafton Center, New Hampshire: *Am. Mineralogist*, v. 23, p. 334-341.

Uraninite in pegmatite at the Ruggles mine occurs in all stages of alteration, from pitchy black crystals to an impalpable yellowish-white powder, together with an intermediate suite of uranium-bearing minerals which are distinct alteration products. The uraninite at this locality is unique in that it occurs chiefly as a three-dimensional dendritic intergrowth with perthitic feldspar, and also as skeleton crystals in the same material, but more commonly in albite intimately associated with perthite. Where the uraninite is intergrown with muscovite or occurs with smoky quartz, both the muscovite and the quartz are decidedly darker around the uraninite. This effect is probably a result of the radiation effects of uranium and its alteration products. A sample of fresh uraninite contains 76.38 percent uranium. A chemical analysis of the mineral is given.

- 94 Shaub, B. M., 1940, Age of the uraninite from the McLearn pegmatite near Richville Station, St. Lawrence County, New York: *Am. Mineralogist*, v. 25, p. 480-487.

This article reports on a study of uraninite from a pegmatite in highly metamorphosed limestone of the Grenville series near Richville Station, N. Y. The uraninite is found as small cubes most commonly imbedded in white quartz. The author remarks that this is most unusual as the uraninite in quartz that he has observed at other localities has been associated with smoky rather than white quartz. No orange and yellow alteration products occur with the uraninite crystals which are generally fresh and unaltered. A microchemical analysis of one of the uraninite crystals is given, indicating a uranium content of 66.90 percent.

- 95 Sims, P. K., 1954, Radioactive Precambrian pegmatite, in *Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1954: U. S. Geol. Survey TEI-490, p. 137-139, issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.*

A type of pegmatite, abnormally radioactive over a wide area in Clear Creek and Gilpin Counties [Colo.], appears promising locally as a substantial source of low-grade uranium ore. The uranium mineral is uraninite.

A radioactive pegmatite on the Highlander claim in Virginia Canyon, about a mile north of Idaho Springs, is being mined from the Hudson tunnel

and is one of several radioactive pegmatites in this part of Virginia Canyon. The pegmatites individually are lenticular bodies from a foot or less to about 30 feet thick and a few tens to perhaps a hundred feet long. They cross-cut the metasedimentary rocks they intrude. They consist predominantly of perthite, quartz, plagioclase, and biotite. The uraninite largely is associated with the biotite. At and near the surface uranophane and autunite are present. Other minerals include pyrite and molybdenite.

Geiger-counter radioactivity measurements on the pegmatite gave an average of 0.2 mr per hr and a maximum of 0.5 mr per hr. Another pegmatite, 25 feet thick, gave similar readings. Preliminary data suggest that the pegmatites in the tunnel contain on the average slightly more than 0.1 percent uranium. A higher grade product can be obtained by hand sorting; some pegmatite containing 1 percent or more uranium is present.

Other bodies of the same type of pegmatite, equally as radioactive, are known. They include the pegmatite on the Waterloo dump in Russell Gulch.

The radioactive pegmatite is thought to be related to the biotite-muscovite granite of the area, which is also more radioactive than the other granitic rocks and metasediments.—*Extracts from author's report*

- 96 Smith, W. L., and Flanagan, F. J., 1956, Use of statistical methods to detect radioactivity change due to weathering of a granite: *Am. Jour. Sci.*, v. 254, p. 316-324.

Forty-four samples of the Conway granite were collected from the red and green phases of the rock at the Redstone, New Hampshire, quarries. A large variation in radioactivity as measured by β -counting is shown between individual samples.

Inspection of the data shows that the red phase is higher in radioactivity than the green. An analysis of variance with a single variable of classification shows that the means of the fresh and weathered red phases are not significantly different, whereas a "t" test using differences between pairs of the fresh and weathered green samples shows that the means of these two sets differ significantly. From these tests and a comparison of the variances of the respective sets, it is inferred that weathering has had a significant effect on the green phase only.

It has been shown, by comparing the variance of the subsets of data with the known variance of the method of measurement, that some external factor such as variations in mineralogic composition or differential leaching or adsorption may be responsible for the variations in radioactivity.—*Authors' abstract*

- 97 Stewart, R. H., 1951, Radiometric reconnaissance examination in southeastern Pennsylvania and western New Jersey: *U. S. Geol. Survey TEM-255*, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

A radiometric reconnaissance with a car-mounted Geiger counter was made of 350 miles of road in southeastern Pennsylvania and western New Jersey.

A mineralized diabase dike in Flemington, N. J., had the lowest uranium content (0.00 percent) of any of the igneous or metamorphic rocks examined. A chip sample of a Precambrian granite dike at Glen Gardner, Hunterdon County, N. J., contains 0.002 percent uranium. Granite gneiss, the host rock of the dike, contains 0.001 percent uranium. The

uranium content of samples of the Pickering gneiss in the Chestnut Hill-Marble Mountain area near Easton, Northhampton County, Pa., ranged from 0.004 to 0.008 percent.

- 98 Stow, M. H., 1955, Report of radiometric reconnaissance in Virginia, North Carolina, eastern Tennessee, and parts of South Carolina, Georgia, and Alabama: U. S. Atomic Energy Comm. RME-3107, 33 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

The author conducted a radiometric reconnaissance of 10,000 miles of road in Virginia, North Carolina, South Carolina, Tennessee, Georgia, and Alabama. Igneous, sedimentary, and metamorphic rocks are represented in the area examined. Localities with an abnormal radioactivity of more than twice background (both a Geiger and a scintillation counter were used) are described briefly and are shown on the index and generalized geologic maps that accompany the report. Background was 0.025 mr per hr.

The Lovingsston granite gneiss is abnormally radioactive at two places in Virginia; north of Culpeper, Culpeper County, and northeast of Charlottesville, Albemarle County. The rock at both localities is biotite-quartz monzonite and augen gneiss. Analyses of two samples from the Culpeper area gave 0.068 and 1.2 percent equivalent uranium and 0.009 and 0.083 percent uranium, respectively. Monazite was determined to be the source of the radioactivity. At the Charlottesville locality, the radioactivity is concentrated in a zone of weathered schist and gneiss. One sample contains 0.40 percent equivalent uranium and 0.006 percent uranium. The radioactivity is probably due mainly to thorium.

Analyses of two samples of magnetite-bearing schist near Chestnut Knob, Henry County, Va., gave the following results: 0.054 and 0.065 percent equivalent uranium and 0.003 and 0.004 percent uranium.

Anomalous radioactivity as high as 0.40 mr per hr was detected in the Grayson granite gneiss at several localities in Grayson County, Va.

The Cranberry granite was abnormally radioactive wherever it was tested. All the radioactive areas are in proximity to prominent fault zones. In the vicinity of Hampton, Carter County, Tenn., analyses of several samples of the granite ranged from 0.043 to 0.15 percent equivalent uranium and from 0.018 to 0.11 percent uranium. In Burke County, N. C., the radioactive minerals are localized in schistose zones and shear zones. Uraninite has been identified in veins and schistose zones in the Cranberry granite in Avery County, N. C. The author concludes that favorable conditions for concentration of uranium minerals exist in the Cranberry granite where it has been faulted and sheared.

Samples of Precambrian hornblende schist and gneiss in the vicinity of Jefferson, Ashe County, N. C., contain 0.068 to 0.33 percent equivalent uranium and 0.57 to 0.22 percent uranium.

- 99 Taylor, A. O., and Powers, J. F., 1955, Uranium occurrences at the Moonlight mine and Granite Point claims, Humboldt County, Nevada: U. S. Geol. Survey TEM-874A, 16 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn. See p. 4-7, 14-16.

The Granite Point claims are at the base of a rhyolite cliff in secs. 4 and 5, T. 45 N., R. 34 E., Humboldt County, Nev. A soft green intensely

altered diabase intrusive rock is exposed in three places under the rhyolite cliff and is believed to be one of a group of small discontinuous dikes. The highest radioactivity at the property was noted in the rhyolite at the base of the cliff and ranges from 0.013 mr per hr to 0.30 mr per hr with an average of 0.10 mr per hr. A sample from the most radioactive part of the rhyolite contained 0.02 percent uranium. The radioactivity of the diabase ranges from 0.013 mr per hr to 0.03 mr per hr.

- 100 Tomkeieff, S. I., 1946, The geochemistry of uranium: *Sci. Prog.*, v. 34, p. 696-712.

Available evidence indicates that the radioactive elements are concentrated in the outer shell of the earth's crust, and that granitic rocks and rare-earth pegmatites contain more uranium than other types of igneous rocks. Uranium is concentrated in the accessory minerals of granitic rocks rather than in the common rock-forming minerals.

Uranium-bearing minerals may be classified genetically as orthomagmatic and pegmatitic, hydrothermal and supergenic, and biogenic. Uranium-bearing minerals also can be grouped into high- and low-temperature assemblages. The high-temperature minerals are characterized by thorium, lead, rare earths, tantalum, niobium, and titanium and are found in pegmatites and as accessory minerals in granite. The low-temperature minerals are not commonly found in igneous rocks.

"The concentration of uranium in pegmatites and hydrothermal veins is probably determined by the nature of the elements likely to form stable compounds with uranium, the relative abundance of these elements, and temperature-pressure factors."

- 101 Tourtelot, H. A., 1952, Reconnaissance for uraniferous rocks in northeastern Wind River Basin, Wyoming: U. S. Geol. Survey TEM-445, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service Ext., Oak Ridge, Tenn.

A reconnaissance search for uraniferous rocks in the northeastern part of the Wind River Basin was made in July and August 1951 in the course of other work. In addition to Tertiary tuffs and associated lignite, coal, and carbonaceous rocks, some radioactivity anomalies, chiefly in granite, which had been detected by airborne equipment in November 1950, were checked on the ground. A tuff of middle or late Eocene age containing 0.003 percent uranium was as high in uranium as any rock found. One sample of [Precambrian] granite [Fremont County] also contained 0.003 percent uranium. The equivalent uranium content of the granite was two to five times as large as the uranium content, presumably due to the presence of thorium.—*Author's abstract, in part*

- 102 Urry, W. D., 1933, Radioactivity measurements—I, The radium content of the Keweenaw basalts and some accessory minerals: *Am. Acad. Arts and Sci. Proc.*, v. 68, p. 125-136.

The radium content of 23 samples of basaltic and felsitic flows, and accessory minerals from the copper mines of Keweenaw Point, Mich., was determined by the emanation method. An increase of radioactivity with depth was noted at the Champion, and Calumet and Hecla mines. Samples of felsitic flows contain more radium than the basaltic flows. The radium content is higher in the younger flows than in the older flows, indicating that there is a definite correlation between radium content and

the age of the flow. The plateau basalts of the Keweenaw district have an average radium content (mean value) of 1.29×10^{-13} grams of radium per gram of rock.

The radium content of samples of the copper arsenides algodonite and domeykite is almost directly proportional to the amount of arsenic in the mineral. The author suggests that this is evidence of "a regular order in the radium content of the accessory minerals in the copper lodes according to the method of precipitation from the mineralizing solutions."

- 103 Urry, W. D., 1933, Radioactivity measurements—II, The occurrence of radium, uranium, and potassium in the earth: *Am. Acad. Arts and Sci. Proc.*, v. 68, p. 137–144.

The author presents the following pattern of the distribution of uranium and radium throughout the earth, basing his calculations on Washington's proposed mineralogical and chemical structure,¹ and using published analyses of various rock types.

	RADIAL THICKNESS (Km)	RADIUM 10^{-14} g/g	URANIUM 10^{-7} g/g
Central core.....	3400	2.5	0.74
Lithospheric shell.....	700	7.0	2.06
Ferrosphoric shell.....	700	12.0	3.53
Peridotitic shell.....	1540	20.0	5.88
Basaltic shell.....	40	28.0	8.24
Granitic shell.....	20	140.0	41.18

The analyses indicate that radioactivity decreases with depth.

- 104 Urry, W. D., 1936, Ages by the helium method—II, Post-Keweenawan: *Geol. Soc. America Bull.*, v. 47, p. 1217–1233.

This article is primarily a discussion of age determinations by the helium method.

The radium content ($\times 10^{-13}$ g per g), thorium content ($\times 10^{-6}$ g per g), and the helium content ($\times 10^{-5}$ cc per g) is given for samples of basic igneous rocks representative of most of the geologic horizons from Cambrian through Pliocene. The specimens include basalts from Washington, Oregon, Tennessee, Pennsylvania, and Massachusetts; trap rock from New Jersey, Connecticut, and New York; and diabase from Pennsylvania. Brief geologic and mineralogical notes are given for most of the specimens.

- 105 Watson, T. L., 1902, On the occurrence of uranophane in Georgia: *Am. Jour. Sci.*, 4th ser., v. 13, p. 464–466.

At Stone Mountain, Ga., uranophane is an incrustation on joint planes of the Stone Mountain granite. The uranophane is "tipped" or coated with hyalite and contains 52.08 percent uranium.

- 106 Wedow, Helmuth, Jr., 1954, Reconnaissance for radioactive deposits in the Eagle-Nation area, east-central Alaska, 1948: *U. S. Geol. Survey Circ.* 316, 9 p.

Reconnaissance of radioactive deposits in sedimentary rocks of Proterozoic and Paleozoic age, and granite of Mesozoic(?) age together with its Tertiary sedimentary derivatives, was conducted in the Eagle-Nation

¹ Washington, H. S., 1925, The chemical composition of the earth: *Am. Jour. Sci.*, 5th ser., v. 9, p. 351–378.

area, east-central Alaska, in 1948 * * *. Samples of the granite of Mesozoic(?) age and its Tertiary sedimentary derivatives average 0.005 and 0.004 percent equivalent uranium, respectively. Biotite is the chief radioactive mineral in the granite, and its radioactivity is ascribed to the presence of uranium and thorium, which occur either as impurities or in minute inclusions of other, as yet unidentified, minerals. Traces of uranium and thorium in zircon, sphene, and monazite also contribute to the total radioactivity of the granite. Zircon and monazite are the major uranium- and thorium-bearing minerals of the Tertiary sedimentary rocks derived from the granite.—*Author's abstract, in part*

- 107 Wedow, Helmuth, Jr., and Matzko, J. J., 1954, Areas adjacent to highways in the Tanana and Upper Copper River valleys, Chap. A of Reconnaissance for radioactive deposits in eastern interior Alaska, 1946: U. S. Geol. Survey Circ. 331, p. 1-32.

Graphitic schists in the Tanana and Upper Copper River valleys in eastern interior Alaska contain a maximum of 0.004 percent equivalent uranium. Other types of schist have a lower radioactivity—as much as 0.003 percent equivalent uranium. Granite and mafic rocks tested have maximums of 0.006 and 0.005 percent equivalent uranium, respectively. The radioactivity of the igneous rocks is probably due to traces of uranium and thorium in accessory minerals, such as zircon and allanite.

- 108 Wedow, Helmuth, Jr., and Tolbert, G. E., 1954, Wilson Creek, My Creek, Ben Creek, and Chicken areas, Fortymile district, Chap. E of Reconnaissance for radioactive deposits in east-central Alaska, 1949: U. S. Geol. Survey Circ. 335, p. 13-22.

A maximum of 0.005 percent equivalent uranium was found in felsic igneous rocks of the Wilson Creek and Ben Creek areas. The radioactivity of these rocks in the Wilson Creek area is probably due to traces of radioactive elements in the common accessory minerals of the igneous rocks; in the Ben Creek area it is probably due chiefly to thorium in monazite and allanite, which were identified in concentrates from gravels of streams draining areas underlain by the igneous rocks.—*Authors' abstract, in part*

- 109 Wells, R. C., 1934, Allanite from Wyoming: *Am. Mineralogist*, v. 19, p. 81-82.

A chemical analysis was made of a sample of allanite from a pegmatite northwest of Wheatland, Wyo. The mineral contains 0.017 percent uranium.

- 110 West, W. S., and Matzko, J. J., 1954, Hope Creek and Miller House-Circle Hot Springs areas, in Nelson, A. E., West, W. S., and Matzko, J. J., Reconnaissance for radioactive deposits in eastern Alaska, 1952: U. S. Geol. Survey Circ. 348, p. 7-15.

The equivalent uranium content ranges from 0.001 to 0.005 percent for granite samples and from 0.002 to 0.004 percent for aplitic dike samples in the Miller House-Circle Hot Springs area, Alaska. The author's summary, in part, is as follows:

A wide variety of radioactive minerals were found to occur in granite. Certain uranium-bearing minerals in the Miller House-Circle Hot Springs area, which are also believed to contain uranium in the Hope Creek area, appear to be primary accessory minerals in the granite. Other minerals,

such as fluorite, topaz, and several metallic sulfides in both areas, and cassiterite and wolframite in the Miller House-Circle Hot Springs area, were probably formed as a result of pneumatolytic action after the crystallization of the magma or during the late stages of crystallization. Some of the minerals in the latter group are known to be uranium bearing; therefore, it seems likely that hydrothermal solutions were partly responsible for the introduction of uranium during the process of pneumatolysis.

111. West, W. S., and White, M. G., 1952, The occurrence of zeunerite at Brooks Mountain, Seward Peninsula, Alaska: U. S. Geol. Survey Circ. 214, 7 p.

Zeunerite occurs near the surface of a granite stock on the southwest flank of Brooks Mountain, Alaska. The largest deposit is at the Foggy Day prospect. Zeunerite is disseminated in hematite which partially or totally fills openings and vugs in a highly oxidized lens-shaped body of pegmatitic granite and, to a minor extent, in openings and cracks in the weathered granite enclosing the lens. Although a few specimens from the pegmatitic lens contain as high as 2.1 percent equivalent uranium, the average content of the lens rocks is between 0.1 and 0.2 percent equivalent uranium and that of both the lens material and the surrounding zeunerite-bearing granite is about 0.07 percent equivalent uranium.—*Authors' abstract, in part*

The granite of Brooks Mountain has an average equivalent uranium content of about 0.005 percent. The amount of radioactivity is directly proportional to the quantity of zircon, monazite, and xenotime in the granite.

Analytical data are given for selected samples.

112. White, M. G., 1952, Reconnaissance for radioactive deposits along the upper Porcupine and lower Coleen Rivers, northeastern Alaska: U. S. Geol. Survey Circ. 185, p. 6-9.

A radiometric reconnaissance was made of a granitic intrusive and of lava flows in the Porcupine River area, Alaska. The rhyolitic rocks are slightly more radioactive than the granite. The radioactivity of the samples collected was due to one or more of the following: Biotite, clarkeite, hematite with uranium as an impurity, surficial weathered parts of pyrite, rutile, and three unknown minerals.

The Tertiary lava flows are not radioactive.

113. White, M. G., 1952, Radioactivity of selected rocks and placer concentrates from northeastern Alaska: U. S. Geol. Survey Circ. 195, p. 1-7.

Radiometric examination of 13 samples collected in the Mount Michelson area, northeastern Alaska, in 1948, shows that four samples of gneissic granite contain an average of 0.007 percent equivalent uranium. The heavy-mineral fractions from 3 of these 4 samples contain an average 0.052 percent equivalent uranium and 0.03 percent uranium. The heavy-mineral fractions of panned concentrates from gravels of streams draining relatively large areas of granitic rock, contain an average of 0.028 percent equivalent uranium, whereas similar heavy fractions of panned concentrates from

streams that drain areas other than those largely underlain by granitic rock contain an average of only 0.005 percent equivalent uranium.

Mineralogic study of all heavy-mineral fractions having more than 0.01 percent equivalent uranium indicates that the radioactive material apparently is confined to biotite, which in one sample contains 1.19 percent uranium. Fluorite, hematite, zircon, sphene, galena, and molybdenite, commonly associated elsewhere with uranium, apparently are disseminated in the granite with the biotite.

The presence of uranium in the biotite of the granite and of other minerals, associated with uranium elsewhere, suggests that this area should be considered in relation to others in Alaska as a possible locality to search for high-grade uranium deposits.—*Author's abstract*

- 114 White, M. G., and Killeen, P. L., 1953, Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim highlands region, Alaska: U. S. Geol. Survey Circ. 255, p. 1-10.

Radioactivity in the vicinity of Flat, Alaska, was found to be concentrated in zircons disseminated in a coarse-grained light-colored facies of monzonite. The zircons contain as much as 0.14 percent equivalent uranium and 0.12 percent uranium. The radioactive elements seem to be concentrated in reddish-brown inclusions in the zircon crystals.

Apatite is also radioactive—the equivalent uranium content ranges from 0.008 to 0.01 percent. The biotite fraction of the monzonite is slightly radioactive (0.004 percent equivalent uranium), but the radioactivity is probably due to minute inclusions of zircon and allanite(?).

- 115 White, M. G., and Stevens, J. M., 1953, Reconnaissance for radioactive deposits in the Ruby-Poorman and Nixon Fork districts, west-central Alaska: U. S. Geol. Survey Circ. 279, p. 1-9.

Reconnaissance for radioactive deposits in the Ruby-Poorman district, Ruby quadrangle, central Alaska, during July 1949, showed that two small bodies of granite in the Long area, about 30 miles south of Ruby, contain an average of 0.005 percent equivalent uranium. This radioactivity is due chiefly to a uraniferous thorium silicate, tentatively identified as uranothorite, which is disseminated in the granite. Other minerals, such as sphene, allanite, and zircon, that contain radioactive elements as impurities also contribute to the total radioactivity of the granite. The uranothorite(?) contains about 57 percent thorium and 8 percent uranium.—*Authors' abstract, in part*

- 116 White, M. G., and Tolbert, G. E., 1954, Miller House-Circle Hot Springs area, Chap. B of Reconnaissance for radioactive deposits in east-central Alaska, 1949: U. S. Geol. Survey Circ. 335, p. 4-6.

Granite of Mesozoic(?) age in the Miller House-Circle Hot Springs area, east-central Alaska, contains 0.005 to 0.007 percent equivalent uranium. The radioactivity is mostly caused by uranium in such primary accessory minerals of the granite as allanite, garnet, scheelite, sphene, and zircon. However, the presence of metallic sulfides, cassiterite, and uraniferous fluorite, malachite, and topaz in the granite or associated placers suggests the possibility of a post-emplacement or late-stage mineralization of the

granite, presumably of hydrothermal origin, as a source for at least part of the uranium. Additional reconnaissance in the area to determine the presence or absence of hydrothermal uraniferous deposits of commercial grade appears warranted.—*Authors' abstract*

- 117 Young, R. W., and Muench, O. B., 1953, The Chemical analysis of an euxenite for age determination: *Am. Jour. Sci.*, v. 251, p. 784-788.

The average uranium content of two samples of euxenite from a pegmatite at Bull Creek, near Pecos, N. Mex., was 4.010 ± 0.050 percent. Other constituents of the mineral also were determined. An autoradiograph showed the mineral to be very uniform in radioactivity.

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