

THE RADIUM CONTENT OF LAVAS FROM LASSEN VOLCANIC NATIONAL PARK, CALIFORNIA.

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OBJECTS AND METHOD OF STUDY.

The variation in the radium content of the dominant igneous rock types is fairly well-known. Comparatively little work has been done, however, to determine the variation within definite igneous provinces and to locate the distribution of the radium in the several rocks. It may be anticipated that when more studies of this type have been completed, especially if supplemented by petrographic descriptions and chemical analyses, much will be learned concerning the rôle of radium in igneous differentiation.

Studies of radioactivity have already been made on lavas from two regions of recent and present-day volcanism. Joly¹ has analysed many of the post-1631 products of Vesuvius, and Piggot² has examined many of the Hawaiian lavas. But the range of rock types in these fields is relatively small, and few other than basaltic flows are available. All the more desirable did it seem to us to determine the radium content of the lavas of the Lassen region. Here there is a wider variety of Tertiary and recent lavas than that of any other volcanic cone in the Cascade chain. Although andesites and dacites predominate, the flows range in composition from basaltic to rhyolitic. Moreover, abundant chemical analyses have already been made, the age-relations of the flows are well-known, and the principal types have been described and figured.³ Accordingly, specimens were selected ranging in age from the oldest (upper Pliocene or lower Pleistocene) to the youngest (1915

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¹ Joly, J.: On the Radioactivity of certain lavas. *Phil. Mag.*, **18**, 577-586, 1909.

² Piggot, C. S.: Radium in Rocks, III. The Radium content of Hawaiian Lavas, this Journal, **22**, 1-8, 1931.

³ Williams, Howel: The Volcanic Domes of Lassen Peak and Vicinity, California, this Journal, **18**, 313-330, 1929. 3a. The Dacites of Lassen Peak and Vicinity, California, and their basic Inclusions, *idem*, **22**, 385-403, 1931. 3b. Geology of the Lassen Volcanic National Park, Univ. Calif. Publ. Bull. Dept. Geol. Sci., **21**, 195-385, 1932.

lava of Lassen Peak), and in composition from the most basic basalt to the most acid dacite.

The direct-fusion furnace technique was employed for removing the radon, which was then measured in a double ionization chamber apparatus,⁴ all ionization currents being photographically recorded.⁵ The apparatus was calibrated with a standard radium solution supplied by Professor S. C. Lind, which had been prepared from pure RaCl_2 previously compared with the International Radium Standard by the U. S. Bureau of Standards.⁶

We are greatly indebted to Professor C. A. Anderson for supplying specimens, descriptions, and analyses of the dacites of Bumpass Hell, and to Mr. Arthur Kip for assistance in carrying out the radium determinations.

PETROGRAPHIC NOTES.

The following brief descriptions are inserted for convenience of reference; fuller accounts may be found in two earlier papers. To correspond with the arrangement of the analyses in Table 1, the rocks are described in an order of increasing acidity.

1. *Basalt, Mount Harkness.* This dense dark gray basalt is the most basic lava flow yet analysed from the Lassen region, and is the poorest in radium. Pale green augite granules make up 35 per cent of the bulk; titanomagnetite 15; and about half the rock consists of microlithic labradorite. Interstitial glass is almost wholly lacking. Chemically, the flow is notable for its extremely high content of titania. Of all the Lassen lavas this resembles most closely the Oregonian plateau basalts. For a fuller description of the Harkness basalt see U. C. Bull.,⁷ pp. 277-278; fig. 27B is of a similar lava.
2. *Basalt, northeast of Butte Lake.* A recent flow of blue black basalt composed of labradorite and augite, chiefly as microliths but occasionally as small phenocrysts, in a matrix of magnetite-charged glass. Feldspar comprises about 60 and augite about 20 per cent; olivine is a rare accessory. (U. C. Bull., p. 367; resembles fig. 60B.)

⁴ Evans, R. D.: *Rev. Sci. Inst.*, **4**, 223-230, 1933.

⁵ Evans, R. D.: *idem*, **6**, 1935 (in press).

⁶ Lind, S. C., and Roberts, L. D.: *Jour. Amer. Chem. Soc.*, **42**, 1170-1177, 1920.

⁷ Abbreviation for reference 3b.

3. *Basic inclusion, in old dacite of Lassen Peak.* From 40 to 50 per cent of a typical inclusion consists of labradorite laths; 40 per cent of basaltic hornblende, partly or wholly replaced by magnetite and, rarely, augite. A little biotite is present in most specimens. The residue is a clear, pale brown glass and, occasionally, a little interstitial quartz. The analysis quoted is of an inclusion similar to that tested for radium. (U. C. Bull. p. 331; also this Journal, 22, 398-399, fig. 6a, 1931.)

A basic inclusion from the dacite of Raker Peak (not included in Table 1), is almost identical with the above. It carries 0.30×10^{-12} gram Ra per gram rock. Unfortunately no chemical analysis is available.

4. *Basic inclusion from dacite flow of 1915, Lassen Peak.* Contrasted with the hornblende-rich inclusions in the older dacites of the peak, the basic inclusions in the 1915 lava are devoid of that mineral. Hypersthene, green augite and relic grains of olivine are the ferromagnesian constituents; these with magnetite and andesine lie in a matrix of pale brown glass. (U. C. Bull., p. 333 and fig. 48; this Journal, 22, 400, fig. 7a, 1931.)
5. *Andesite, Raker Peak, roadside quarry on Hat Creek.* Pale gray lava consisting essentially of minute laths of andesine-labradorite (51 per cent), granules of augite (18), orthopyroxene (5), and a sprinkling of magnetite (2) in a glassy matrix (24 per cent). (U. C. Bull., p. 288; fig. 31B.)
6. *Andesite, near Supan's Springs, Brokeoff Volcano.* Half the rock consists of porphyritic acid labradorite; about a quarter of hypersthene with subordinate augite and the remainder of pale gray glass stippled with granular magnetite and microlithic labradorite. The analysis quoted is an average of four probably similar andesites of the Brokeoff Volcano. (Almost identical with lava illustrated in U. C. Bull., fig. 19A.)
7. *Andesite, Badger Mountain.* Brown glass ($n = 1.502 \pm .002$) makes up about half the volume; zoned phenocrysts of labradorite are plentiful; hypersthene exceeds augite in amount; granular magnetite is dispersed throughout. (U. C. Bull., pp. 238-240; differs from fig. 10B in paler color of glass, occurrence of magnetite in discrete grains, and in greater amount of hypersthene.)
8. *Dacite punice, 1915 eruption of Lassen Peak.* Pale gray glass froth. Except that glass constitutes about 80 per cent of the volume and crystals only 20 per cent, the rock resembles the 1915 dacite described below. (U. C. Bull., p. 333.)

9. *Andesite, Crystal Lake.* The pale gray platy lava forming the cliffs overlooking Crystal Lake has this percentage composition: plagioclase (andesine and acid labradorite), 75; augite, 14; hypersthene, 5; magnetite, 4, and interstitial glass, 2. (U. C. Bull., pp. 221-222, fig. 5.)
10. *Dacite, Bumpass Hell.* Andesine is the chief phenocryst; with it are crystals of augite, hypersthene and quartz, a few badly altered flakes of biotite in a pilotaxitic base with a little interstitial glass.
11. *Dacite, 1915 eruption of Lassen Peak.* 60 per cent is a gray glass ($n = 1.485 - 1.500$) speckled with magnetite dust, granules of pyroxene and microlithic plagioclase; 30 per cent is made up of zoned phenocrysts ranging from oligoclase to acid labradorite; 5 per cent of porphyritic hypersthene and diopsidic augite, and the remainder of biotite, accessory basaltic hornblende, olivine, and quartz. (U. C. Bull., p. 332; this Journal, 22, 394-395, 1931.) Analysis quoted is not of identical specimen tested for Ra but an average of two similar rocks.
12. *Dacite, old lava forming bulk of Lassen Peak.* About a third of the rock is a pale glass, cloudy with magnetite dust and stippled with microliths of plagioclase; about half is formed of porphyritic andesine; the remainder consists largely of basaltic hornblende, fewer crystals of brown biotite, green augite, hypersthene, and quartz, attended by the usual magnetite and apatite. (U. C. Bull., pp. 330-331; this Journal, 22, pp. 393-394, and fig. 4a, 1931.) Analysis quoted is an average of four similar dacites from Lassen Peak.
13. *Dacite, north dome of Chaos Crags.* A hornblende-mica hyalodacite with this percentage content: 40, colorless, pumiceous glass rich in potash ($n = 1.51$; U. C. Bull.) (Analysis 17, Table 1); 40, phenocrysts of oligoclase-andesine (anal. 16 of Table 1); 20, biotite, hornblende, hypersthene, augite, and accessory magnetite, apatite and quartz. (U. C. Bull., pp. 361-362; this Journal, 22, p. 393 and fig. 5, 1931.) Analysis quoted is an average of two similar dacites from the same locality.
14. *Dacite, Raker Peak.* The most acid dacite and most radioactive of the Lassen lavas yet examined, consists of the following: colorless glass ($n = 1.499 \pm .002$; 45-60 per cent); phenocrysts of oligoclase-andesine (30 per cent); quartz (2 per cent), green hornblende, biotite and accessory magnetite and apatite. (U. C. Bull., p. 294.)

15. *Altered dacite, Bumpass Hell.* White, powdery exterior of an altered dacite block from a hot spring. Opal is by far the principal constituent; associated with it are kaolin, alunite and tridymite, the last-named partly residual but chiefly secondary.
16. *Porphyritic plagioclase from dacite of Chaos Crags.* Most of the feldspar phenocrysts in this lava are strongly zoned and reveal a range in composition between medium andesine and basic oligoclase.
17. *Glassy groundmass of dacite, Chaos Crags.* This acid, potash-rich glass ($n = 1.510$) is crowded with gas bubbles and lightly sprinkled with microlithic plagioclase and dusty iron ore.

DISCUSSION OF RESULTS.

As long ago as 1905, Lord Rayleigh⁸ pointed out that there is in general a concentration of radioactive constituents in the acid rocks. The results of the present investigation add to the long list that verifies this generality. However, it will be seen from figure 1 that the content of radium in the Lassen lavas is far from being directly proportional to that of silica; the scattering of points on either side of the radium curve is wide. In this connection, it is of interest to note that Piggot⁹ found the most radioactive of the Hawaiian lavas to be that poorest in silica, a nepheline-melilite basalt from Oahu, whereas the most siliceous and alkaline lava examined, a trachyte from near Hualalai, carries no more radium than the basalts of Kilauea.

The following table presents the average radium content of the main petrographic types in the Lassen region.

	Ra $\times 10^{-12}$ g./g.	Range	Average SiO ₂ %
Average of 2 basalts	0.33	0.30-0.35	51.13
Average of 3 basic inclusions ..	0.34	0.16-0.55	? 55.14
Average of 4 andesites	0.48	0.28-0.70	60.72
Average of 7 dacites	0.80	0.58-1.14	66.65

Figure 1 also shows that radium increases with the alkalis, especially with potash. A similar relation has recently been observed by Rössner¹⁰ in the granite-diorite complex of the Gleinalgebiet. Nor may it be fortuitous that the most

⁸ Strutt, R. J.: (Lord Rayleigh), Proc. Roy. Soc., 77A, pp. 472-485, 1905.

⁹ *Op. cit.*, 1931.

¹⁰ Rössner, Hilde: Ueber den Radiumgehalt der Gesteine des Gleinalpenkerns, Min. u. pet. Mitt. 44, pp. 494-504, 1933.

TABLE I.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO ₂	47.43	54.83	55.14	57.16	57.85	59.62	61.93	62.62	63.50	63.80	63.86	67.24	69.04	70.93	92.20	65.77	76.75
Al ₂ O ₃	13.19	17.05	19.10		16.71	17.43	16.37		16.76	17.55	16.96	16.53	15.69	14.31	1.02	21.51	12.32
Fe ₂ O ₃	5.63	1.47	6.16		.88	2.62	1.15		1.49	1.28	1.24	3.60	1.02	1.30	nil	tr	1.36
FeO	7.04	5.79	.54		4.93	3.12	3.90		2.80	2.44	2.91	2.13	1.64	1.26	.40		
MgO	5.20	5.47	4.23		6.07	3.41	3.26		2.90	2.02	2.78	2.13	1.31	.94	nil		nil
CaO	9.39	7.72	8.36		8.30	6.57	6.24		5.80	2.60	5.16	3.89	3.23	3.24	.35	5.72	1.18
Na ₂ O	2.58	3.60	3.71		3.04	3.76	3.37		3.59	2.70	3.95	3.74	4.16	4.30	tr	5.92	3.55
K ₂ O	1.79	1.77	1.04		1.18	1.73	2.00		2.22	1.82	2.09	2.22	2.90	2.76	tr	.83	3.98
H ₂ O+	1.38	.73	.91		.32	.91	.74		.35	2.80	.41	.74	.59	.65	1.65		.54
H ₂ O—	2.02	.27	.16		.16	.16	.18		.21	1.85	.08	.36	.31	.16	2.80	.34	
TiO ₂	4.00	1.25	.52		.60	.58	.60		.65	.55	.53	.36	.31	.26	1.25		
P ₂ O ₅	.55	.42	.18		.13	.18	.16		.18	tr	.14	.07	.09	.12	tr		
MnO	.12	.11	.11		.09	.17	.08		.07	tr	.06	.04	.11	.06	nil		
BaO	.04	.03	tr		.02	.04	.04		.03		.05	.07	.07	.05	n.d.		
SrO	n.d.	n.d.	.07		n.d.	.02	n.d.		n.d.		.02	tr	.03	n.d.			
Total	100.36	100.51	100.07	57.16	100.28	100.16	100.02	62.62	100.55	99.89	100.30	100.63	100.19	100.34	100.05	100.09	99.68
Ra x 10 ⁻¹²	0.30	0.35	0.16	0.55	0.36	0.28	0.60	0.80	0.70	0.58	0.70	0.81	0.67	1.14	0.35	0.05	?1.1

1. Basalt, Mount Harkness.*

2. Basalt, northeast of Butte Lake.*

3. Inclusion in old dacite, Lassen Peak.

4. Inclusion in 1915 dacite, Lassen Peak.*

5. Andesite, Raker Peak.*

6. Andesite, near Supan's Springs, Brokeoff volcano.

7. Andesite, Badger Mountain.*

8. Dacite pumice, 1915 eruption, Lassen Peak.*

9. Andesite, Crystal Lake.*

10. Dacite, Bumpass Hell.* Includes 0.48 SO₃.11. Dacite, 1915 eruption, Lassen Peak. Includes 0.02 ZrO₂; 0.02 S; 0.02 F.

12. Dacite, old lava of Lassen Peak.

13. Dacite, north dome of Chaos Crags.

14. Dacite, Raker Peak.*

15. Altered dacite, Bumpass Hell.* Includes 0.03 S; 0.35 SO₃.

16. Plagioclase, from dacite of Chaos Crags.

17. Residual glass from same.

* Identical specimens analysed for radium and main oxides.

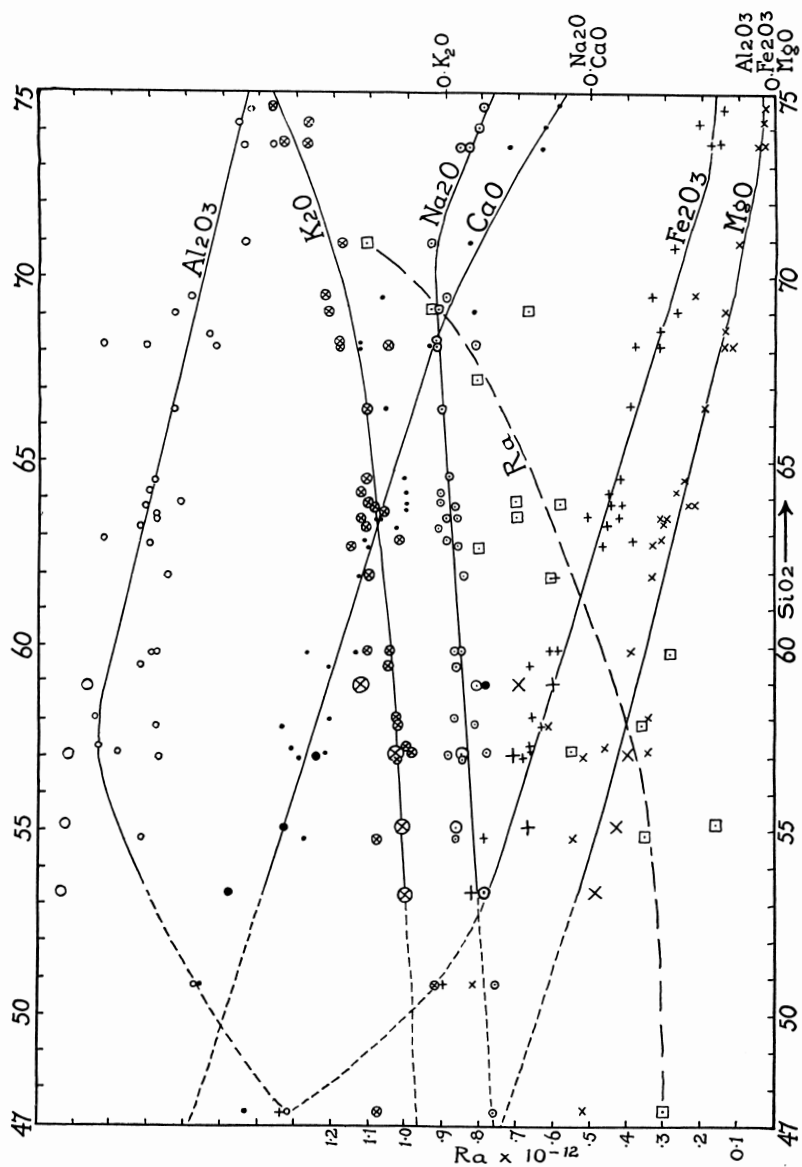


Fig. 1.

radioactive lavas yet examined, those of Vesuvius, are, despite their basicity, unusually rich in potash (averaging more than 7 per cent K_2O).

As a whole the lavas of the Lassen region are relatively poor in radium. It is true that Urry¹¹ gives the mean value of 56 basalts as 0.28×10^{-12} gram Ra per gram of rock, but the only basalts poorer in radium than those of Lassen are the Keweenaw flows and certain basic lavas from the Gwalior Series in India. The Tertiary plateau basalts and those of Hawaii and Vesuvius, for example, are much more radioactive. Indeed in Poole and Joly's list¹² of the general means of radium contents of basalts, all contain more than twice the content of the Lassen basalts, and those of the Western United States contain 1.69×10^{-12} gram Ra per gram of lava. There is much less radium in the Lassen andesites than in those of Hungary¹³ ($1.64-2.38 \times 10^{-12}$ Ra g./g.) and in that from Maui¹⁴ (0.90×10^{-12}). Similarly, most of the acid lavas examined from other parts of the world are decidedly more radio-active than those of the Lassen region.

CONCENTRATION OF RADIUM IN THE LASSEN LAVAS.

The data concerning the location of radium in igneous rocks are meager. It may be of value to summarize them here. Waters¹⁵ found that the light fraction and the magnetite of a rotted Cornish granite were non-radioactive. The residue was mainly tourmaline, but the radium was largely concentrated in anatase or rutile. In the Dalbeattie granite¹⁶ he found it chiefly in allanite, with less in magnetite, titanite, and apatite; in the Mourne granite chiefly in zircon and some titaniferous mineral; and in a gneiss from the Inner Hebrides the radium was again concentrated in zircon. Fletcher,¹⁷ examining the Leinster granite, discovered most of the radium in the zircon-bearing micas. In one specimen, the quartz contained no

¹¹ Urry, W. D.: The Occurrence of Radium, Uranium and Potassium in the Earth, *Proc. Amer. Acad. Arts and Sci.*, **68**, pp. 137-144, 1933.

¹² Poole, J. H. J., and Joly, J.: The Radioactivity of Basalts and other Rocks, *Phil. Mag.*, **48**, pp. 819-832, 1924.

¹³ deFinály, S. S.: The Radium content of some Hungarian Rocks, this *Journal*, **24**, pp. 306-310, 1932.

¹⁴ Piggot, C. S.: *op. cit.*, 1931.

¹⁵ Waters, J. W.: Radioactive Minerals in common Rocks, *Phil. Mag.*, **18**, pp. 677-679, 1909.

¹⁶ *Idem*, **19**, pp. 903-904, 1910.

¹⁷ Fletcher, A. L.: The Radioactivity of the Leinster Granite, *Phil. Mag.*, **21**, pp. 102-111, 1911.

radium, the feldspar 0.52×10^{-12} Ra g./g., and the muscovite 0.72×10^{-12} Ra g./g. One halo-bearing biotite carried as much as 11.87×10^{-12} Ra g./g.; Urry¹⁸ observed that the bases of certain Keweenawan basalt flows were less radioactive than their upper parts, supposedly because they were less feldspathic. Holmes¹⁹ states that the radioactive constituents in a pegmatite from Blueberry Mountain, near Boston, Massachusetts, are orangite-thorite, zircon, titanite, and allanite. In the Stone Mountain granite of Georgia, Piggot²⁰ found the muscovite to carry 27.5×10^{-12} Ra g./g., biotite 11.3×10^{-12} , but quartz and feldspar only 1.65×10^{-12} Ra g./g. The corresponding values in the North Jay granite of Maine were 20.7, 20.7 and 1.6×10^{-12} Ra g./g. Among the plutonic rocks of the Gleinalmgebiet, Rössner²¹ found the most radioactive to be those rich in alkali feldspar and tourmaline; and Piggot states that uranophane is always found near relatively large accumulations of tourmaline in the Stone Mountain granite. Curiously enough, Piggot²² determined the potash feldspars of the Stone Mountain granite to be less radioactive than the plagioclase. Hirschi,²³ in his studies of the intrusive rocks of the Aar massif, found that high potash values were associated with high content of radioactive elements of the uranium-thorium series, independently of the content of silica.

With rare exceptions, the lavas of the Lassen region do not lend themselves to a clean separation of their constituent minerals. All but a few are of such fine grain or of such a texture that isolation of the crystals is not practicable. Bromoform separations were made of the light and heavy constituents in the dacites of Lassen Peak and the north dome of the Chaos Crags. The heavy fraction of the latter dacite was then divided into weakly and strongly magnetic parts. Finally, by the use of a needle, porphyritic feldspars were extracted from untreated samples of the Chaos Crags dacite. The following results were obtained.

¹⁸ Urry, W. D.: The Radium content of the Keweenawan Basalts and some accessory minerals, *Proc. Amer. Acad. Arts and Sci.*, **68**, pp. 125-136, 1933.

¹⁹ Holmes, Arthur.: *Physics of the Earth, IV, Age of the Earth*, Bull. 80, Nat. Research Council, pp. 342-343, 1931.

²⁰ Piggot, C. S. and Merwin, H. E.: Location and Association of Radium in Igneous Rocks, *this Journal*, **23**, pp. 49-56, 1932.

²¹ Rössner, Hilde: *op. cit.*

²² Piggot, C. S.: Radium in Rocks I, *this Journal*, **17**, pp. 15-34, 1929.

²³ Hirschi, H.: Radioaktivität der Intrusivgesteine des Aarmassivs. *Schweiz. min. u. pet. Mitt.*, **7**, pp. 98-114, 1927.

Chaos Crags Dacite.

	$\text{g} \times 10^{-12}$ Ra per gram	% in rock	Proportional Ra value in 1 gram of rock	
Plagioclase phenocrysts	0.047	c.40	0.019	} Dacite as a whole: 0.67×10^{-12} g./g.
Strongly magnetic heavies.....	0.85	5.45	0.046	
Weakly magnetic heavies.....	0.83	4.30	0.036	
Total			0.101	

The strongly magnetic fraction is composed chiefly of magnetite and hornblende with a little glass adhering; the weakly magnetic fraction is almost entirely biotite with a slight admixture of hornblende. The remaining half of the rock is an acid, potash-rich glass (anal. 17, Table 1) with sporadic microliths of plagioclase and a little dusty magnetite. Assuming that no radium was lost during the bromoform separation—which seems to us a reasonable assumption—this residual glass must be the most radioactive part of the dacite and carries about 1.1×10^{-12} gram Ra per gram. Contrary to the experience of most workers, we find no marked concentration of radium in the mica. Neither did Joly in his studies of the Vesuvian ejecta. The lowest radium value which he obtained from any of the post-1631 lavas of Vesuvius was 7.8×10^{-12} gram Ra per gram, and yet a biotite from one of the lavas carried only 2.6×10^{-12} gram Ra per gram. The low radium value of the plagioclase in the Chaos Crags dacite should occasion no surprise.

Old Lassen Dacite.

	$\text{g} \times 10^{-12}$ Ra per gram	% in rock
Lava as a whole.....	0.81	
Light separates	0.81	95
Heavy separates	0.68	5

A clean mineralogical separation of the old dacite forming Lassen Peak was not possible. The light fraction consisted chiefly of plagioclase and pale glass, some of the glass containing dusty iron ores and rare crystals of biotite and hornblende. The heavy fraction was made up principally of iron ores, biotite, and hornblende. Again, contrary to the experience of most workers, we find no marked concentration of radium in the heavy minerals. Indeed, if the plagioclase of the Lassen dacite is as weakly radioactive as that of the Chaos Crags

dacite, it seems probable that much of the radium is located in the residual glass or in its microlithic inclusions.

VARIATION OF RADIOACTIVITY WITH AGE.

In the basic, potash-rich lavas of Vesuvius, the content of radium is unusually high; moreover Joly found it to increase in general from the flows of 1631 to those of 1906. Similarly, Urry observed an increase of radioactivity from the oldest to the youngest of the Keweenawian basalts. On the other hand, Piggot's work on the lavas of Kilauea shows that a "very old lava" from the north edge of the crater, the 1870-1880 flow, 1894 and 1921 flows all carry 0.94×10^{-12} gram Ra per gram of rock. Likewise, Farr and Florance²⁴ could see no direct correlation between the age and radium content of certain igneous rocks from the sub-Antarctic islands of New Zealand.

Such data as we have from the Lassen lavas show no dependence of radium content on age. Indeed the oldest and youngest flows examined—namely those of Crystal Lake (Anal. 9, Table 1) and the 1915 dacite of Lassen Peak (Anal. 11)—resemble each other in their content of the principal oxides more closely than any of the other lavas of the region, and each carries 0.70×10^{-12} gram Ra per gram of rock. The old dacite of Lassen Peak is slightly more radioactive than the 1915 lava, but it is also more siliceous; a basic inclusion from the 1915 flow, though carrying only a little more silica, contains more than three times as much radium as an inclusion from the old lava forming the bulk of the peak. Of the two basalts tested, that from Mount Harkness is pre-glacial and the other is extremely recent, yet their radium contents are almost the same.

Finally, it should be remarked that of two samples of dacite from the north dome of the Chaos Crags, one contains 0.67×10^{-12} gram Ra per gram of rock and the other 0.93×10^{-12} . Yet in their content of the principal oxides the dacites of this protrusion vary little (U. C. Bull., p. 365), and under the microscope their mineralogical content appears to be quite uniform. The maximum observational uncertainty in the radium determinations is 0.02×10^{-12} gram Ra per gram of rock; the variation in the dacite is, therefore, a real one and implies a pronounced inhomogeneity of distribution within a single lava protrusion.

²⁴ Farr, C. C., and Florance, D. C. H.: *Phil. Mag.* 18, pp. 812-816, 1909.

INFLUENCE OF HOT SPRINGS.

Analyses 10 and 15, Table 1, are of fresh and altered dacites from Bumpass Hell. Although the ferromagnesian constituents, feldspars, and glass of the original dacite have entirely disappeared in the alteration, leaving a residue of almost pure opal, the radium content has only been reduced from 0.58 to 0.35×10^{-12} gram Ra per gram of rock. We are at a loss to account for the radium in the altered lava. Professor C. A. Anderson informs us that in certain mud pots in the Devil's Kitchen, there is a concentration of zircon, whether mechanically or by selective solution is uncertain, but he has detected none in the specimen from Bumpass Hell. Of the radioactivity of the Lassen hot springs nothing is known.

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