ON THE DISTRIBUTION OF RADIOACTIVE ELEMENTS IN GRANITE INTRUSIVE BODIES

BY

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1. General tendencies

Up to the present, the distribution of radioactive elements in igneous intrusives has been dealt with by several investigators. Among them are Slack, H.A. and K. Whitham (1951)[1], Ingham, W.H. and Keevil, H.B. (1951)[2] and so on. According to the results by them, it is concluded that 1) it appears that small stocks and batholiths are higher in radioactivity than are the larger ones, 2) the radioactivity in a single stock or batholith tends to be concentrated towards the periphery of the intrusive body. The larger the body is, the clearer this tendency becomes. Of course this inference is applicable only in general, and exceptional case may be observed at times. The vertical distribution of radioactivity cannot avoid the rule and concentration of the radioactive elements decreases with depth to a definite low value. Such a case was observed with the Bourlamaque batholith in West Quebec Shire, in the measurement of alpha-radioactivity in a shaft as well as that of core sample of the drilled well.[2] Therefore, as measured in the eroded bodies today, the radioactivity is highest near the rim and decreases towards the center, giving the different patterns of distribution according to the shape, size and degree of erosion of the body. In Fig. 1 these relations are illustrated.

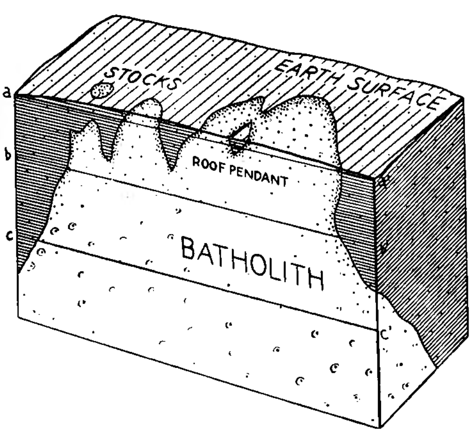

Fig. 1 Distribution of radioactivity in granitic intrusions. Density of dot shows the concentration of radioactive elements.

As seen in the illustration, in case of relatively shallow erosional level, the undulation of the top of a batholith reflects upon the distribution of radioactivity in the exposed area of the batholith. The high concentration of radioactive elements usually found near a roof-pendant may be explained by this reasoning. In a shallow level, the radioactivity decreases rather rapidly from the rim of the batholith towards the center of it, while in the deep level it shows inconspicuous change and low value even near the contact boundary with the wall rock.

According to Jeffreys, H. (1936, 1952)[3], igneous rocks of a kind for the same region reveal a considerably wide range in their radium content showing the distribution curve of Pearsen Type III. Hence the average value of radioactivity for an intrusive body differs from the mode (the most frequent value) for it. Generally speaking, the mode for a stock stands at more radioactive situation than a batholith. The typical example can be found by arranging Asayama's data[4] on the radium content in granitic rocks from three granitic intrusives in Kinki District, Japan, as shown in Table 1.

Table 1 Radium content of granitic rocks from some intrusive bodies in Kinki District, Japan.

Rocks	Type of intrusion	No. of samples	Ra content 10^{-12} g/g		
			Average	General average	Range
Hiei Granite	Stock type	14	1.25 ± 0.05	—	$0.83 \sim 2.03$
Tanakami Granite	Stock type				
Contact type		7	2.30 ± 0.34		
Central type		5	1.75 ± 0.04	2.04 ± 0.12	$1.16 \sim 3.23$
Leuco-granite type		1	1.75		
Mikumo Granite					
General type	Batholith type	9	0.76 ± 0.05	0.86 ± 0.06	$0.43 \sim 1.34$
Contact type		2	1.28 ± 0.04		

The classification of types of rock and intrusion is followed after I. Hayase[5].

The exposed area of Tanakami granite lies side by side with that of Mikumo granite and these two granites are supposed to be in close genetic relation. Also, as found by Asayama, the radium and K_2O as well as SiO_2 contents vary almost linearly in the same sense.

The distribution of radioactive elements in a batholith mentioned above, can be accountable by the general tendency that variation of rock in composition usually found in batholith, showing a continuous transition from granite on top, gabbro-diorite in medium depth, to gabbro and related mafic rocks at the bottom.

2. The causes which give rise to abnormal distributions.

The irregularity in the distribution of radioactive elements may be observed in the following cases.

1) When the original upper surface of a batholith is highly uneven, and the present level of errosion is shallow, the irregularity of distribution in radioactivity may be observed as can easily be seen in the section a-a' in Fig. 1. High radioactivity found frequently near a roof pendant may be due to similar cause.

2) The quantitive variation of the radioactivity of different parts of wall rock might give effect on the contents of radioactive elements in the intrusive body, especially when the hyprid process prevails.

3) The metasomatic replacement may take place contemporaneously with or after the intrusion of granite and may cause irregular distribution of radioactive elements.

4) Secondary enrichment of radioactive elements occurs in the fractured zone of a fault and predominant joints or fissures.

5) Penetration by many dikes or veins results in disturbance of distribution of radioactivity in the intrusive rock, especially if they are rich in volatile substances as with pegmatites.

In practice, however, usually the structure of the batholith is so complex that, in some cases, the parts of it are not only composed of intrusions of different ages, but facies of rock show considerable change as frequently observed in the marginal zone of mixed rocks where rocks of all kinds are intermingled in the most complicated fashion. As a rule the marginal zones of granitic pluton may be of more-than-average mafic composition, such as granodiorite, tonalite, diorite, shonkinite and so forth.

Considering the well-known general rule that the contents of radioactive elements decreases with a decreasing silica or potassium oxide percentages, the changes of facies or kinds of rock in the marginal zone may show the irregular and rather reverse order of the distribution of radioactive elements in contrast to that observed in the Bourlamaque batholith and other ones by Ingham and Keevil (loc. cit.).

3. Distributions of radioactive elements close to the contact boundaries.

The study of radioactivity distribution near the igneous contact was firstly commenced by the author[6] in 1951, and since then has been developed by him and his follower, S. Nisimura.[7-11] Up to the present, more than 6800 samples were measured for the radioactivity, taken from 167 sites of granite contact, the localities of which cover Honsyû, Shikoku and Kyûsyû in Japan.

The summary of the conclusions obtained is briefly as follows:

(i) The shapes of the curve showing the variations in radioactivity across contact seem to depend on the mechanism of the granite intrusion.

(ii) To the shape of the radioactive profile across contact boundary, five representative types, as reproduced in Fig. 2, can be chosen for the convenience's sake in explanations.

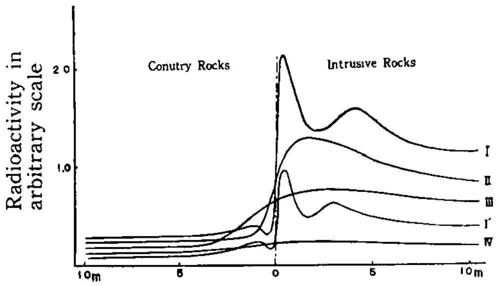

Fig. 2 Representative types of radioactivity distribution across igneous contacts.

Referring to the figure (Fig. 2), the type I is probably the radioactive profile of the typical contact metamorphism. As seen in the figure, the type I curve has a conspicuous peak showing the high radioactivity at the site very close to the boundary, where chilled marginal features are usually observed. It is very interesting that there appears usually the second peak at an average distance of 4 m from the boundary, though more flat as compared with the former. The similar phenomenon is also found in the curve of type I', the corresponding distance for the second peak being 2.5 m in average.

As the radioactivity was measured by a Lauritsen radioscope, in which ionization measured is dominantly that by alpha rays, it may be said that the two peaks are the manifestation of the existence of alpha rayers belonging to uranium or thorium series, though the partial contribution of beta rays from potassium can not be denied as the beta ray measurement by a low background counter (LBC-1, mfd. by Nihon Musen Co. Ltd.) and the analysis by JACO Spectrometer suggest.[10]

The increasing number of types I→II→III→IV implies the depths of the erosional levels of an intrusive body. In a great depth, under high pressure and temperature prevail and metamorphism will be put forth helped by the slow rate of cooling to result high hyprid action or granitization. As the result, the radioactivity distribution curve becomes flat both in country and intrusive rocks without revealing any remarkable variation across the gradation boundary. As to the type I' curve, any conclusive explanation has not been found yet, but such a distribution of radioactivity is usually found where granitic rocks show a marked change in facies and sometimes associated with ore minerals. In this view, it may be rather better to omit this type from the type standard.

4. Conclusive remarks.

It must be taken into consideration that all that mentioned above is valid as a general rule, and precaution should be paid on the respects that ultimately the distribution of the radioactive elements depends not only upon the temperature, pressure and contents, and volatile matters of the intruding granitic magma, but also upon gradients of temperature and pressure, and time duration up to the complete solidification. In this respect, the size and shape of the intrusive bodies may also play a rôle.

This paper is a summarial manuscript of our investigations on the distribution of radioactivity in granite intrusives in Japan, and as to the details, the original papers cited in the following are to be referred to.

References

1) Slack, H.A. and K. Whitham (1951): Trans. Amer. Geophys. Union, **32**, 44-48.
2) Ingham, W.N. and N.B. Keevil (1951): Bull. Geol. Soc. Amer., **62**, 131-148.
3) Jeffreys, H. (1936): Gerlands Beitr. z. Geophys., **47**, 149; (1952): The Earth, 3rd ed., 392, Cambridge Univ. Press.
4) Asayama, T. (1954): Mem. Fac. Ind. Arts, Kyoto Tech. Univ., **3**, B, 25-54.
5) Hayase, I. (1953): Mem. Coll. Sci., Univ. Kyoto, B, **20**, 247-260.
6) Hatuda, Z. (1952): Jour. Geol. Soc. Japan, **53**, 277 (Abstract).
7) ,, and S. Nishimura (1956): Mem. Coll. Sci., Univ. Kyoto, B, **23**, 286-295.
8) ,, and ,, (1958): Mem. Coll. Sci., Univ. Kyoto, B, **25**, 115-123.
9) Nishimura, S. (1961): Mem. Coll. Sci., Univ. Kyoto, B, **28**, 255-264.
10) ,, (1961): Mem. Coll. Sci., Univ. Kyoto, B, **28**, 265-284.
11) ,, (1962): Mem. Coll. Sci., Univ. Kyoto, B, **29**, 263-290.