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Variation in Radioactivity across Igneous Contacts

By

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Abstract

Distribution of radioactive matter along traverses across contact boundaries has been investigated by means of the radioscope, with a Lauritsen element designed specially for the pulverized samples of feeble radio-activity such as rocks and minerals. Trials of thirty six sites of igneous contact have revealed interesting radioactive changes suggesting that only in special instances other compositional changes are also linear or simple logarithmic. The radioactive variations have been found not only in wall rocks but also in intrusive rocks, and those in the latter are more conspicuous than in the former.

The critical interpretation of the radioactive profile will be left for another day when data obtained for contacts of a greater number of different igneous bodies will be accumulated, and petrological as well as chemical inquiries will be done. In this sense, this paper is preliminary in character, but it may suggest that the radioactive method is one of the helpful methods of investigating igneous contacts.

Introduction

Migration of material is naturally believed to have occurred from the intrusive body into wall rocks. The compositional variations resulting from this transfusion may, if disclosed, throw light on the mode and scope of contact metamorphism. The belt of metamorphosed rocks surrounding a plutonic intrusion, what is called a metamorphosed aureole, may have a width of a few hundred meters in some cases, but the highest degree of metamorphism will be attained in a relatively narrow zone close to the contact, where the water and other volatile matters transferred from the intruded magma can reach. The controlling factors of contact metamorphism are various and the following are of importance: (1) The temperature which is different for different types of magma and depends upon the size of the intrusive mass; the higher the temperature is, the greater the effect is. (2) The quantity of volatile matters transferred which depends upon the richness in gaseous constituents of the intruded magma. (3) The kind of volatile matters passed into the rocks in contact with intrusives; whether the volatile matters are of much greater chemical activity or not. (4) The susceptibility of change of the country rock due to the original composition of it by contact metamorphism ; it is well known that sandstones are less metamorphosed than clayey rocks and pure limestones less than impure ones in the sense that formation of new minerals indicates the degree of metamorphism.

With the complex action of these controlling factors, it will be easily supposed that the compositional changes in wall rocks are not simple in the direction normal to the plane of contact. By the present study it has been found that not only in the wall rocks but in the intrusive body itself, remarkable changes in radioactivity have existed, and they are more conspicuous in the latter than they are in the former. The mode of variation in radioactivity across contact seems to be classified into several types, and the type is supposed to differ according to the way of contact. Accordingly, it is possible that different sites of contact of an intruded mass, as a rule, show the radioactive variation of the same type.

The existence of variation in radioactivity in the intrusive body near the contact plane has formerly been reported by one of the present authors (H)[1)] before the Geological Society of Japan at its 59th Annual Meeting (1952). W. H. Dennen[2)] recognized the like phenomenon in his spectro-chemical study on compositional changes across contacts. The ranges treated by him, however, were several inches on either side of the contact, while in our case they are several meters or more.

What the change in radioactivity across contacts means is a problem to be discussed later.

Method of Investigation

Up to the present, 36 sites of contact have been studied by the radioactive method in order to determine the variation of radioactivity across these critical zones. A series of specimens was collected along a line perpendicular to the observed contact. Each specimen, about 150 grams or more, was pulverized to the fineness to pass through 28 meshes. 60 grams of it was used in the radioactivity measurement. With ordinary rocks, the powder layer without pressing is about 5mm in thickness on the pan with a diameter of 12cm. The measurement was made by means of a radioscope with a Lauritsen element,[3)] specially designed and constructed by the author (H) for measuring feeble ionization by radioactive rays from the rock powder (Fig. 1). In the present measurement, the Al-foil screen at the bottom of the ionization chamber was removed so as to utilize efficiently the ionization by alpha rays from the surface of the specimen. With ordinary Lauritsen type radioscope, the removal of the foil screen would cause jumping up and clinging to the fiber of the element of fine particles from the surface of the powder specimen by the electrostatic attraction. In this radioscope, this difficulty is avoided by using a mesh screen instead of a foil screen. The spacings and fineness of the mesh wire are so chosen that loss

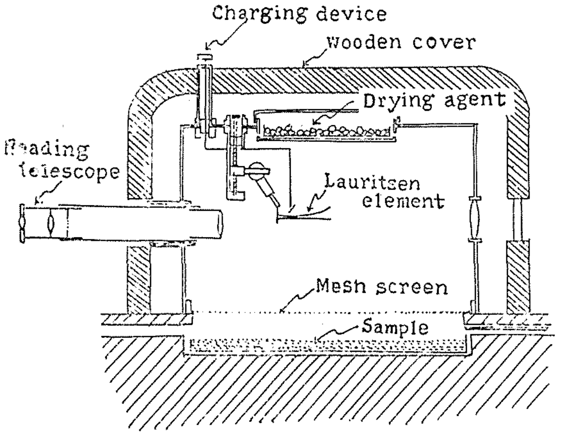

Fig. 1 Radioscope with Lauritsen element.

of the effective cross-sectional area for the alpha radiation is very small without losing the function of the mesh screen.

Critical Examinations in Using the Modified Lauritsen-type Radioscope

(1) *Correction for tracking error:* Just as in the case with a metal-leaf electroscope, the present radioscope cannot avoid the change of scale value with respect to the position on the scale. It is, therefore, necessary to reduce the shifting rate R_1 of the indicator obtained at any position of the scale to that R_0 which would be gotten at a difinite position, for example, the centre of the scale. For carrying out the reduction, the values of reduction factor R_0/R_1 were used, which were beforehand determined. In any case, each observed shifting rate was multiplied by the reduction factor R_0/R_1, R_1 being corresponding to the mean position of the initial and final readings on the scale,

(2) *Relation between observed radioactivity and amount of the sample powder:* With the sample pan used, 10 grams of the sample powder was just enough to cover the whole area of it. As the amount of the sample powder increased, the ionization also did, but the ionization-amount relation was not linear and the curve representing it approached asymptotically to a maximum value of ionization with 60–70 grams of the granite powder sample. In case of hornfels, the maximum was usually reached with a less amount 40–50 grams, probably due to greater compactness than that of granite powder. Throughout the present study, 60 grams of the pluverized sample was used.

(3) *Effect of grain size of the powder sample:* If the upper limit of the

grain size of the pulverized sample differs, the observed radioactivity also dose, owing to presumable change of the effective surface area for the radiations going into the inside space of the ionization chamber. Accordingly, in order to find the effect of grain size, a sample was crushed step by step, changing the upper limits of grain size to 8, 10, 14, 20, 28, 35, 40 and 48 meshes, and each was put under examination. The results showed no remarkable difference, especially for the grain size smaller than 20 meshes. This will be explained by the fact that the finer the grains, the more even is the surface of the sample on the pan. In practice, as previously mentioned, samples of grain size smaller than 28 meshes were used.

(4) *Reproducibility of the measurement:* To test the reproducibility of the measurement, repeated observations were made for one and the same sample on different days. The following is the example of one of the results.

Sample: Graniteville granite, Ill., U. S. A.
Radium content: $(3.3\pm0.2)\times10^{-12}$ gr. Ra/gr.

No. of obs.	Date	Radioactivity (div./min.)
1	Nov. 1, 1955	0 478
2	〃 2	0.483
3	〃 3	0.450
4	〃 4	0.484
5	〃 8	0.481
6	〃 9	0.471

From these, radioactivity of this sample is found to be 0.475 ± 0.004 in division per minute, the annexed figure being the probable error.

Thus the reproducibility of the measurement was found to be fairly good, such that probable error of the mean of six observed activities was slightly less than 1 %, and that for a single measurement a little less than 5 %. As for the different rocks of low radioactivity, the error of the mean activity may increase to a few percent.

(5) *Relation between observed shifting rate of indicator (radioactivity) and amount of radioactive matter in the sample:* It is quite important that the shifting rate of indicator is proportional to the radioactive contents of the sample. To verify this relation, observation was made with a series of sample of hornfels mixed with various amounts of borax-glass powder containing U_3O_8 (7.53×10^{-3} gr. U/gr.) keeping the total weight of the samples unchanged, The result shown in Fig. 2 reveals that in the range of the

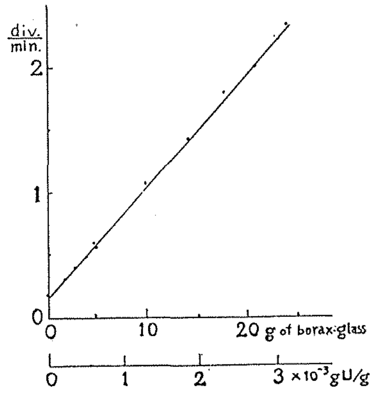

Fig. 2 Observed radioactivity vs. amount of radioactive matter.

present intensity of radioactivity, the shifting rate of indicator is in a linear relation with the amount of borax-glass powder added. For the stronger radioactivity, however, it is presumed that the shifting rate will not keep pace with the radioactivity of a sample owing to the increasing re-combination of ions produced by radioactive rays.

Localities investigated

(1) Near Tachiki-kwannon, Ôtsu City, Shiga Pref.

The granite of this locality forms a part of the Tanakami granite stock and metamorphosed rock is hornfels of the Paleozoic era. The granite is a coarse-grained biotite-granite except extremely near the contact boundary where it changes into a fine-grained one as is usually the case. The radioactivity distribution found across contacts is shown in Fig. 3 (a), (b), (c), (d), (e), in which the ordinate denotes radioactivity expressed in the shifting rate (div./min.) of the indicator

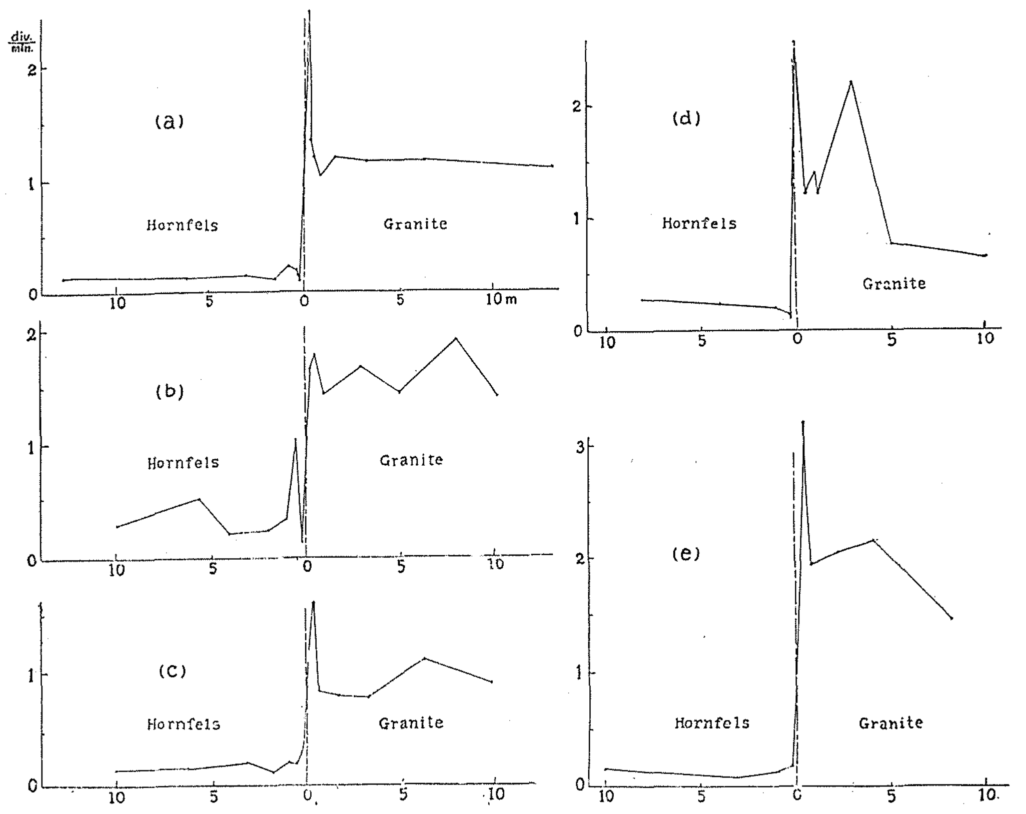

Fig. 3 Radioactive profiles. (Tachiki-kwannon)

of the radioscope, and the abscissa a distance from the contact boundary in meters.

(2) The south-west part of Kiryû, Kamitanakami Village, Kurita District, Shiga Pref.

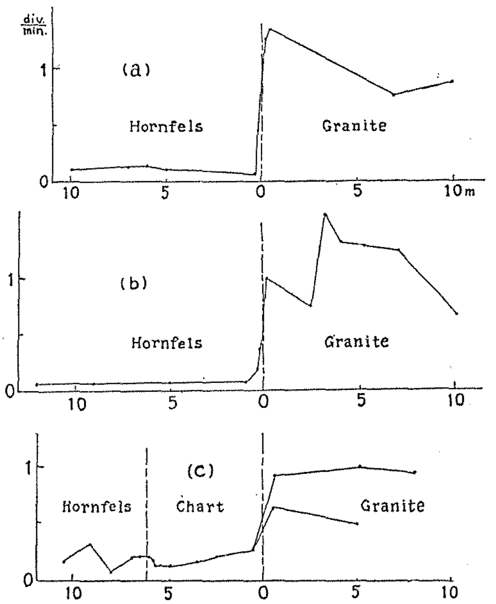

Fig. 4 Radioactive profiles. (Kiryû)

The granite here is also of the marginal part of the Tanakami granite stock. The Paleozoic rocks are altered to hornfels by contact metamorphism. The main granitic rock of this locality is mostly a fine-grained biotite-granite. The radium content of the granite here has been determined by T. Asayama[4] to be 2.06×10^{-12} gram per gram of rock, a little higher value than the average for Tanakami granite. The radioactive distributions at three sites of contact are shown in Fig. 4 (a), (b), (c). In these sites sampling was not satisfactory owing to lack of exposures of the rocks.

(3) The Hira Range ; (i) southeast of Bô, Kuzukawa Village, Shiga District, Shiga Pref.

At this locality the intrusive is the rock known as Hira granite which occupies the area in the northwestern part of Lake Biwa. At the contact zone, medium-grained biotite-granite and hornfels are common. The distribution of radioactivity is given in Fig. 5 (a), (b).

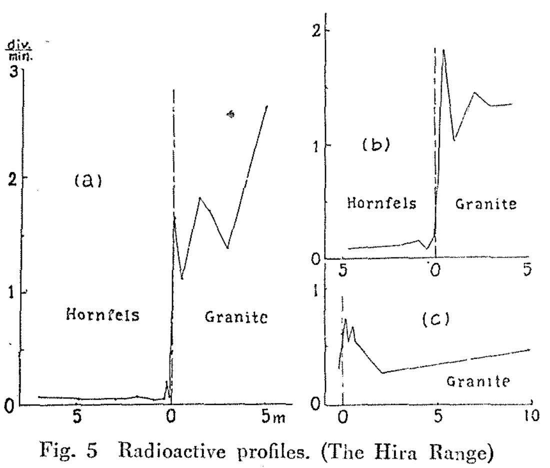

Fig. 5 Radioactive profiles. (The Hira Range)

(ii) The northeast part of Hôrai Peak.

The granite of this locality forms the south part of the Hira granite area and exposes dike-like in a narrow zone in the Paleozoic rock. The result is shown in Fig. 5 (c).

(4) Near Mt. Gozaisho, Ichihara Village, Gamô District, Shiga Pref.

The granite here is generally white to gray, coarse-grained biotite-granite. The principal ingredients of this rock are quartz, orthoclase, microcline, labradorite and biotite. This granite is older than the Sugi-Pass granite-porphyry described next. The Paleozoic rocks consist mainly of hornfels. The radioactive profile across contact is shown in Fig. 6.

(5) The Sugi-Pass near Oike Mine, Ichihara Village, Gamô District, Shiga Pref.

The granite-porphyry of this locality makes a very strangely differentiated mass, showing quartz-porphyritic to granite-porphyritic differentiates. The Paleozoic rocks are altered to hornfels by contact metamorphism by the Gozaisho-granite just described, and in this contact zone rocks are exceedingly crushed, and ore-deposits (mostly of chalco-pyrite and pyrrhotite) are formed. In Fig. 7 (a)–(h) are shown the radioactivity distributions across contacts, and among these figures Fig. 7 (d) is considered to be a case of high contamination.

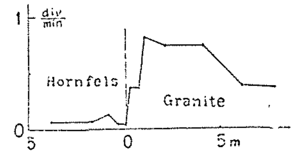

Fig. 6 Radioactive profiles. (Mt. Gozaisho)

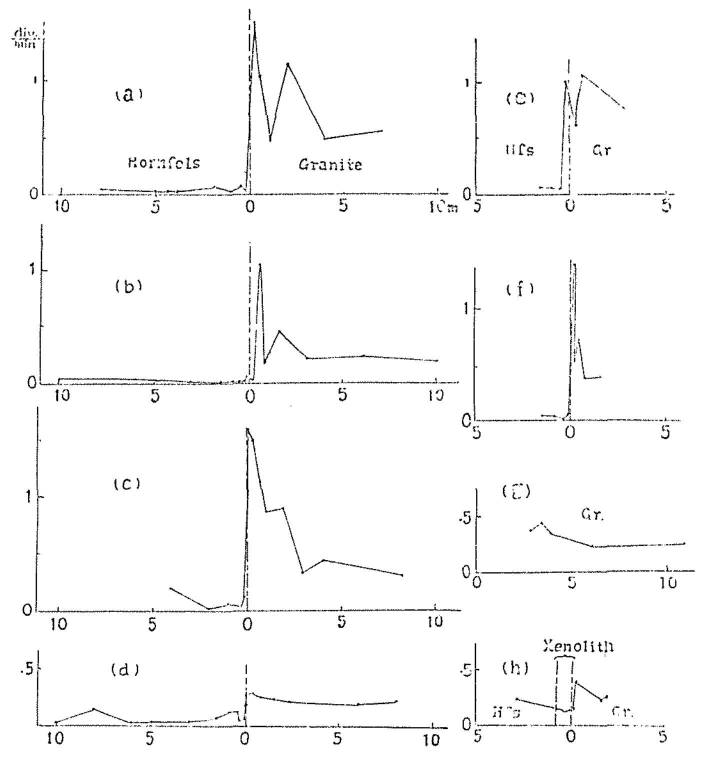

Fig. 7 Radioactive profiles. (Sugi-Pass)

(6) Near Kasagi Town, Sôraku District, Kyoto Pref.

(i) Watsuka, northwest part of Kasagi: The granite is generally a fine-grained biotite granite. At this locality the transition across contact zone is usually gradual and the sedimentary rocks are intensely metamorphosed. Fig. 8 (a)–(f) shows the radioactivity profiles.

(ii) Yagyû, northeast part of Kasagi: The granite here can be classified into two different types; that is, the types with and without schistosity. At the contact zone, schistose, hornblende-bearing biotite-granite, coarser than Watsuka-type granite, is more common. The contact zone forms a wide zone of gradual transition (Fig. 9).

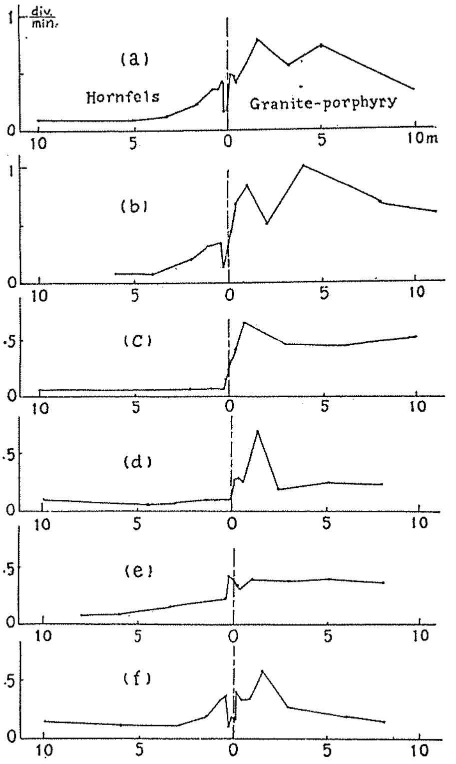

Fig. 8 Radioactive profiles. (Watsuka, Kasagi)

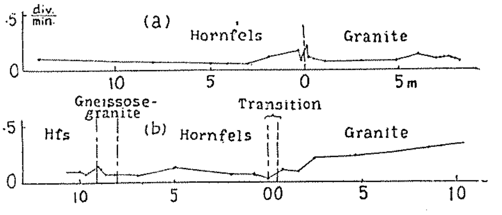

Fig. 9 Radioactive profiles. (Yagyû, Kasagi)

(7) Northwest part of Kameoka City, Kyoto Pref.

At this locality igneous rock is medium-grained biotite-granite, and Paleozoic

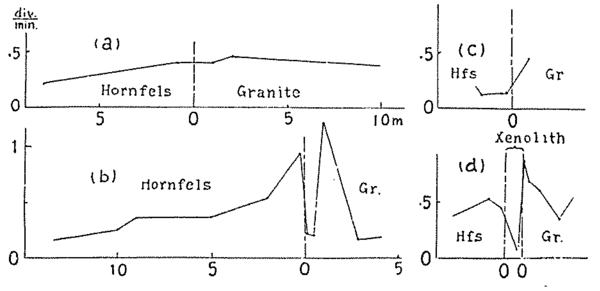

Fig. 10 Radioactive profiles. (Kameoka)

rock at the contact zone is hornfels. As outcrops are very few near the contact zone, the number of samples tested is so scanty that a definite trend was not obtained. For the result, refer to Fig. 10 (a), (b), (c), (d).

(8) Kitashirakawa, Sakyô Ward, Kyoto City.

At Mt. Daimonzi and Gobessho, the samples for the test were collected across the contacts at the margin of the Hiei granite area. The results of the radioactive test are shown in Fig. 11 (a) (Daimonzi) and Fig. 11 (b), (c) (Gobessho).

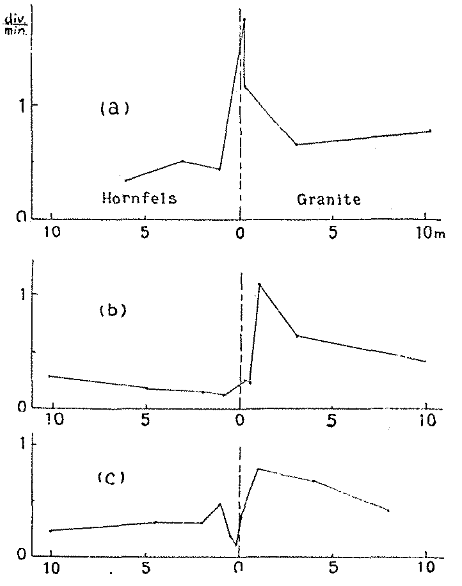

Fig. 11 Radioactive profiles. (Kitashirakawa)

Discussion of the Results

The Profile curves showing the radioactivity distribution across contacts may be classified into several types. In Fig. 12 the curves representing each type are schematically drawn. It seems that, with some exceptions, the resemblance of the trends of the curves obtained for a few traverses at a locality, or strictly for one and the same intrusive body, is fairly good, provided that the following details are taken into consideration: (i) Spacing of sampling may have modified the shape of the distribution curve, especially near the contact. Examples of such cases were found on many occasions (e. g. see Fig. 4) in which field conditions obstructed sampling by the decomposition of rocks or topographical difficulties. (ii) Movement of intrusive magma may have caused along its way differences in chemical and physical conditions of contact. (iii) Ununiformity of country rock may have produced different reactions with intruding magma.

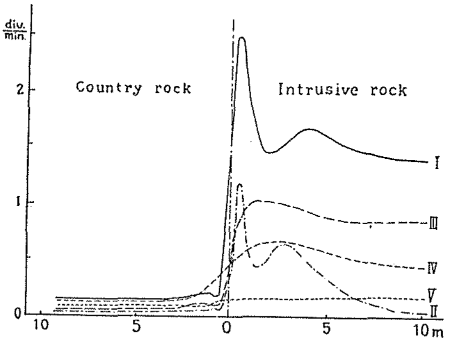

Fig. 12 Types of radioactivity distributions across contacts.

The types classified are as follows. However, owing to the small number of locality surveyed, the present classification is a tentative one.

The first type: This type of radioactivity distribution was found at the margin of Tanakami and Hira granite stocks [Fig. 3, Fig. 5 (a), (b)] Inside the country rock, the radioactivity generally remains constant towards the contact boundary, usually showing a slight wavy variation in front of it, and there suddenly appears a remarkable peak just beyond it followed by a second peak at two or three meters from the boundary.

The second type: The second type found near Sugi-Pass [Fig. 7 (a)–(g)] is quite similar to the first type except that the decrease of radioactivity in the invading rock with increasing distance from the boundary is conspicuous. It is likely that the intrusive magma in this locality was subjected to considerable differentiation during making the way towards the country rocks.

The above two types of radioactivity distribution are probably a representation of the typical contact metamorphism.

The third type; This type of radioactivity distribution was found at granite contact near Mt. Gozaisho (Fig. 6), Kiryû at the margin of Tanakani granite stock [Fig. 4 (a)–(c)] and at the Shiga-side of the Hiei granite area (Fig. 11 (b), (c)). The main features of this type are lack of definite peak, and gradual decline towards the wall rock. It is somewhat questionable whether Kiryû may be a proper example, as the samples were not collected there with desired intervals owing to the decomposition of rocks.

The fourth type: As seen in the examples shown in Fig. 8 (a)–(f), the radioactivity distribution across contact near the Watsuka river shows a striking contrast to those of the first and second types. A gradual increase of radioactivity in wall rock towards granite, continuing beyond the boundary and forming a hump there is the general feature. A possible explanation of this gradual change in radioactivity is given by low grade of granitization.

The fifth type: As above mentioned, this type of distribution was found at Yagyû, Kasagi Town (Fig. 9). The contact boundary is rather obscure and the transition as seen by the rock facies is quite gradational. The radioactivity, too, follows the similar course of distribution in obscureness and gradation of transition. In addition, the radioactivity keeps a low value over the intrusive and country rocks. In greater depth, the reaction of contact metamorphism would have continued very long at elevated temperature to encourage diffusion and, consequently, to give rise to a tendency of equalizing the chemical composition. On the other hand, as Ingham, W. N. and N. B. Keevil[5] have pointed out, it will be usual that radioactivity shows a decrease with the depth in a batholith or a stock. According to this, it is supposed that the present surface of the ground on which samples were collected represents a deeper level of the igneous mass, where once granitization has prevailed.

It is worth noting that the localities where the radioactive distributions of the fourth and fifth types have been found are in the zone of the Ryôke metamorphics.

Conclusive remarks

By the present investigation, it has been found that radioactivity distribution normal to the contact boundary showed variations not only in the country rocks but also in the invading rock, and the variations in the latter are more conspicuous than those in the former. The shapes of variation in invading rock are tentatively classified into five types, but this classification may be modified in future when more data will be obtained.

Acknowledgement

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