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On the Structure of Granitic Complex in the Northern Part of the Takanawa Peninsula, Ehimé Prefecture

By

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with 1 Plate and 6 Text-figures

ABSTRACT. Many authors, such as H. CLOOS, E. CLOOS, R. BALK and S. v. BUBNOFF, have asserted that the structural elements imprinted in an intrusive granite mass are directly related to the physical state within the granite and the mode of emplacement. This principle is well exemplified at the Takanawa peninsula.

The granite, including in part its finer facies, in the northern part of the Takanawa peninsula is probably an extension of the Tôwa- granite in the Yanai region which is referred by Y. OKAMURA to the "Intrusive granites" (of H. H. READ) of the Ryôké granite series.

For the sake of a strong resemblance in appearance of each joint-system in the granite described, it was not always easy to discriminate one from the other, but by handling statistically the joint-systems, planar structures and the other structural elements the mode of emplacement of the granite was inquired and became obvious to a certain degree.

In view of the present knowledge, the writer wishes to make it clear that he considers that the granite in the northern part of the Takanawa peninsula occupies only a part of the southern half of a domed granite mass.

CONTENTS

I. INTRODUCTION

Problems concerning the age of intrusion of the so-called Ryôké granites and geological relations of these granites to the Cretaceous Hiroshima granite, have been a source of controversy among Japanese geologists for more than a decade (e. g., T. KOBAYASHI, 1941; M. GORAI, 1952; G. KOJIMA, 1953, –54). Especially after the 2nd World War, structural and petrological features of the country rocks and of the granites themselves of both series have been increasingly elucidated. Many important subjects of geology about these regionally distributed masses are, however, yet reserved for future studies.

The writer takes an interest in these problems. Fortunately, he had an occasion to carry on geological and petrological researches on the granitic rocks in the northern part of the Takanawa peninsula, Ehimé Prefecture, from the summer of 1953 to the autumn of 1954.

All the granitic rocks found in the northern part of the Takanawa peninsula, except newly intruded dikes, are generally referred to the younger Ryôké granites which are believed to be older than the intrusion of the Hiroshima granite (J. TAKUBO & others, 1953). Although the field now concerned is not suitable to discuss the mutual relations of both granite series noted above, it may contribute to the knowledge of the Ryôké granite to study the structural-petrological characters of the granitic rocks in this region

Plutonic rocks in the northern part of the Takanawa peninsula are to be devided into two main rock types: the one is granite and the other gabbroic rocks, among which the former occupies the majority of the area.

The writer intends to deal with the structural features of the granite following the method as advocated by Hans CLOOS, and to try to elucidate the mode of emplacement of the granite. The study was restricted within the scope of megascopic observations in the field. Of the gabbroic rocks, the writer could not enter into details as he should not go beyond the scope of this paper.

Previous works: Rocks in this region have not yet been studied in detail by any worker. But a few reports are to be remembered. J. TAKUBO and others (op. cit.) and H. MOMOI and A. KOGA (1956) studied the granite from the mineralogical standpoints. Some reports treating gabbroic rocks found in the other localities of the Ryôké metamorphic zones have been published, especially by H. YOSHIZAWA (1949). T. YOSHIMURA (1940) also studied gabbroic rocks from Kaji-shima, Ehimé Prefecture, which are probably referable to the gabbroic rocks of the present region, but no one has made a study of the gabbroic rocks of this region.

II. OUTLINE OF GEOLOGY OF THE GRANITIC COMPLEX

The granitic complex of the northern part of the Takanawa peninsula, northwest of Imabari City, consists of the following rocks: gabbroic rocks, granodiorite, minor rock bodies, fine-grained granite, granite and dike rocks, among which granite occupies approximately four-fifths of the region. Gabbroic rock masses, which are next to the granite in dimention, occupy approximately 3 square kilometers.

Except newly intruded dike rocks, the granite is the youngest rock in this region. J. TAKUBO and others (op. cit.) decided the age of emplacement of the granite of this region as 216×10^6 years by the Pb-method applied to fergusonite.* It corresponds to

* The fergusonite is one of the essential minerals of pegmatite found near Mategata, where the pegmatite, ca. 10m. x 20m. x 15m. in dimensions, occurs as a large pocket in fine-grained granite.

the Late-Palaeozoic age or/to the Early-Mesozoic age, to which have been referred the age of metamorphism and intrusion of the Ryôké metamorphic zone by many Japanese geologists. The granite represents the intrusive type of granite of the Ryôké zone, which is younger than the migmatitic type of granite as clarified by Y. OKAMURA (1957) in the Yanai region, west of the present region.

In the following, petrological features of each rock type will be briefly noted in the chronological order.

a) **Gabbroic rocks**: The gabbroic rocks are divided into two rock units (masses): i. e. pyroxene-bearing gabbroic rock (mass) and hornblende-gabbroic rock (mass). There is every reason to believe that the pyroxene-bearing gabbroic rock mass is a huge rootless mass lying on the granite. The pyroxene-bearing gabbroic rock, which can petrographically be divided into micro-quartz-gabbroic rock, pyroxene-plagioclase-gabbroic rock and tonalitic rock enclosing many melanocratic inclusions, should be hybrid affected by the granite. They permit to construct a sequence of hybridization in accordance with the distance from the contact with the granite: the tonalitic rock represents the outermost facies of the hybrid complex.

Although the petrographic features of the hornblende-gabbroic rock could not be inquired in detail, however megascopic as well as microscopic observations suggest that the rock is also a thermally metamorphosed one.

b) **Granodiorite**: The granodiorite is also a hybrid. It encloses many melanocratic inclusions near the contact with the pyroxene-bearing gabbroic rock (s. the geological map). That the granodiorite is found only at the western periphery of the pyroxene-bearing gabbroic rock may suggest the areal difference of geological or physico-chemical conditions when the granite was emplaced.

c) **Minor rock bodies**: Many small masses of syenitic rocks, granite-mylonite and "acidic rocks" are separately found here and there through the region. The writer groups them for convenience' sake in the category of "minor rock bodies". They are commonly found at summits of mountains or along mountain-ridges and generally accompanied by fine-grained granite; however, for the sake of the poorness of exposure, the geological situation of the minor rock bodies, except for the syenitic rocks, is still unknown. It can nevertheless well be pointed out that the minor rock bodies and the fine-grained granite should be closely related in their genesis.

The syenitic rocks are found in Mategata and in the northernmost headland of Imabari City (s. the geological map). It is of interest that the syenitic rock in the western area (neighbourhood of Mategata) is to be named "quartz-syenite", while that in the eastern area is adequately named "syenite" in spite of the presence of very small amount of quartz. The fine-grained granite, intervening between the syenitic rocks and the granite, is accompanied often by aplitic or pegmatitic facies which sometimes contain sodic amphibole. Thus the mode of occurrence of the syenitic rocks in the region concerned and that of Iwaki Islet, which has been repeatedly studied by several authors, are very similar.*

Summarizing the writer's observations in the field. the mode of occurrence of the syenitic rocks of the Takanawa peninsula seems to be best explained by assuming that the syenitic rocks and the accompanying pegmatitic and aplitic facies are yielded by a kind of differentiation under metamorphic conditions from the granite during/or probably after the emplacement of it.

d) **Fine-grained granite**: The fine-grained granite is, as described above, commonly found at summits of mountains or along mountain-ridges, such as Engi and Mategata, and generally intervenes between the minor rock bodies and the granite. The main mass of the fine-grained granite is found in the northernmost headland of Imabari City, where it becomes medium- to fairly coarser-grained. The fine-grained granite was intruded apparently into the pyroxene-bearing gabbroic rock as dikes or dike-like bodies with sharp boundaries, while in the granite such sharp boundaries have not been found but the boundaries are commonly obscured. The writer holds a view that the fine-grained granite may be a finer-grained facies of the granite.

e) **Granite**: The granite is hornblende-biotite-granite, which is coarse-grained and constantly contains allanite as an accessory ingredient. It is not so homogeneous, and partly contains biotite-pegmatitic granite with transitional boundaries. The planar structure of the granite is fairly remarkable in the southern area of the region, while it is weak or absent in the northern area. Basic inclusions are sporadically found.

f) **Dikes**: Dike rocks, such as aplite, quartz-porphyry, porphyrite, basalt and andesite, represent the younger intrusions than the granite. Pegmatite dikes are also very rarely found. These dikes are universally found in the various rock units. Among them, aplite and porphyrite dikes are most predominant. The prevalent trends of the various dikes are NE-SW and the walls of them are steeply inclined or vertical (Fig. 4).

III. BRIEF DESCRIPTIONS OF PETROGRAPHY OF THE GRANITE

a) **Fine-grained granite**:

The main area occupied by the fine-grained granite is the vicinity of the northernmost headland of Imabari City, where the rock is commonly medium-grained. Approaching the granite, it becomes coarser and locally porphyritic feldspar develops. In some parts it shows a weak planar structure. The boundaries between the fine-

* The corresponding syenitic rock from Iwaki Islet was already studied by K. SUGI & M. KUTUNA (1944) and lately by M. TANEDA (1952). K. SUGI & M. KUTUNA asserted that the aegirine-syenite was intruded into biotite-granite and that it shows aplitic and pegmatitic facies at its margin. (The biotite-granite may be referable to the younger Ryôké granites (Y. UMEGAKI and others, 1954)). In his short paper S. TANEDA discussed a possible mechanism to yield a sodic syenitic magma from a crystallizing granitic magma, however, the mechanism of formation of the syenitic mass was remained unproved.

grained granite and the granite are usually not sharp but transitional.

More interesting mode of occurrence of the fine-grained granite is to be found near the minor rock bodies, which, so far as the writer knows, never come in contact with the granite without the intervention of the fine-grained granite. In particular, the fine-grained granite intervening between the syenitic rocks and the granite, is accompanied often by aplitic or pegmatitic facies. Boundary surfaces on both sides of the intervening fine-grained granite have not been always decidedly confirmed.

Many small to large dikes or dike-like bodies of the fine-grained granite are also found in the gabbroic rocks, accordingly it may safely be said that the fine-grained granite is the later product than the gabbroic rocks. Some dike-like small bodies of the fine-grained granite are also occasionally found in the granite, for example in the neighbourhood of Mategata. Such bodies appear to be intruded into the granite. In most cases, however, the fine-grained granite shows a xenolith-like appearance.

Another weighty character to be noted here is that relatively larger pegmatite bodies are, without exception, restricted in the fine-grained granite. There is always a continuous transition from the pegmatite bodies to the surrounding fine-grained granite.

At all events, judging from such evidences, it seems reasonable to assume that the fine-grained granite may be neither a younger nor an older product than the granite, but may represent one facies of the granite itself, and that it is clearly younger than the gabbroic rocks.

Microscopically, the rock resembles considerably to the granite, especially near the contact with the granite. It consists essentially of biotite, muscovite, cross-hatched potash-feldspar, perthite, plagioclase and quartz; zircon and iron ores as accessories. The cross-hatched potash-feldspar is the most predominant minerals among feldspars, and myrmekite is often found. Plagioclase (An_{5-15})* is generally 1 mm. or less in length and mostly idiomorphic. Biotite occurs in small amount, but is more abundant than muscovite. Hornblende is not rare in some specimens.

It is an important characteristic that the fine-grained granite commonly contains much amount of cross-hatched potash-feldspar, which, on the contrary, occurs only in small amount or occasionally lacks in the granite. The texture of such potash-feldspar in these rocks is also different from each other. In the fine-grained granite it is common that the central part of the cross-hatched potash-feldspar is occupied by ordinary potash-feldspar. (The microscopic features of the granite will be described in the following pages.)

Summarizing the data obtained from megascopic as well as microscopic observations, it is reasonably asserted that the fine-grained granite is to be attributable to a finer-grained facies of the granite. The physico-chemical conditions under which the fine-

* The refractive indices of plagioclase were determined by the immersion method. The composition was read using the table proposed by F. CHAYES (1952).

grained granite was generated, might have also been favourable for the production of the pegmatite containing some radioactive minerals such as fergusonite and keilhauite (J. TAKUBO and others, op. cit.).

b) Granite:

The general appearance of the granite is relatively uniform through the whole region. It is massive and light-gray to white, but sometimes light-rose. Megascopically the rock shows a coarse-grained fabric, consisting of feldspars, quartz and subordinate hornblende and biotite. Large porphyroblastic grains of quartz are common, the outline of which changes from rounded grain to fusi-form, and the long diameter of which varies from 0.5 cm. to 2cm. or more. The porphyroblastic quartz in problem becomes more and more prevalent towards the north in this region. The porphyroblasts of acid plagioclase are also not rare in the northern area. They attain to 1 cm. × 3 cm. at Karatsuzaki, where many melanocratic xenoliths of the pyroxene-bearing gabbroic rock were found.

The granite has in general a weak planar structure, but the measurable planar structure is restricted in the southern seaside, particularly in the southwest of Kuô. Measurable lineation is absent.

Basic inclusions or xenoliths of rounded form are not common in the granite but sporadically found. Their origin can not be sought in the present country-rocks. The characteristic dike-like xenoliths are, however, abundantly found in the southern area, in particular in the vicinity of Kuô. They have been explained by the present writer as altered basic metamorphic dikes intruded into the granite during the emplacement and/or at the earlier stage of consolidation of the granite (T. NUREKI, 1956). The structural characters of the dike-like xenoliths will be described in the following section.

In some places a coarser variety, containing much large phenocrystic crystals of potash-feldspar and quartz, and relatively poorer in mafics, accordingly appearing as a pegmatite granite, is found in the granite. Even at a good exposure where the boundary relation between the pegmatitic granite and the granite can be clearly observed, the boundary of them seems to be gradational. A number of pegmatite pockets, 1.5 m. or less in diameter, are also found throughout the granite mass, but large pegmatite bodies as found in the fine-grained granite have never been detected. For convenience' sake, the petrography of the granite and the pegmatitic granite will be described separately.

i) *Hornblende-biotite granite*: Feldspars in the granite imply potash-feldspar, cross-hatched potash-feldspar and plagioclase, among which plagioclase is the most predominant mineral. Most of plagioclase are porphyroblastic, commonly coated with more acid plagioclase. Outer margin of plagicclase is generally ragged, and often forms myrmekite. The composition of plagicclase usually varies between An_{15} and An_{23}, but occasionally there are a little calcic plagioclases. Potash-feldspar is often accompanied by plagioclase. Cross-hatched potash-feldspar, which is very small in amount in the granite, generally occurs in potash-feldspar as if the former is coated with the thick rim of the latter. Such an interesting feature of cross-hatched potash-feldspar shows a good contrast with that in the fine-grained granite. Quartz forms large porphyroblast and frequently shows wavy extinction. Hornblende is commonly a green variety, but occasionally brownish-green one occurs as a part of green hornblende. Green hornblende is partly replaced by biotite. Biotite is brown with strong pleochroism, and more predominant than hornblende. Biotite and hornblende frequently enclose small crystals of allanite and zircon, especially the former being constantly found as an accessory.

In the intergranular space is found sporadically granoblastic matrix, which consists essentially of quartz and potash-feldspar. The granoblastic matrix is always found in most sections collected from marginal as well as interior areas of this granite region, though their develepment is extremely restricted. Such features are more commonly found in the pegmatitic granite.

ii) *Pegmatitic granite*: The rock differs chiefly from the granite in the following two characters; that is,

(1) Glomeroblasts of biotite are remarkably developed, on the other hand, hornblende is very rare or absent, and

(2) perthitic potash-feldspar and potash-feldspar are more prevalent than plagioclase in size and amount.

The glomeroblasts of biotite occur generally between porphyroblastic quartz and potash-feldspar or in the granoblastic matrix. Porphyroblastic potash-feldspar, which is 1 cm. or more in length and partly converted into perthite, is fairly developed. It usually encloses small crystals of quartz and plagioclase.

IV. Structural Data of the Granite

Reading many reports treated the "Granittektonik", one can find a general tendency that a small granite mass with a limited section tends to show more obvious and characteristic "Granittektonik" than a larger (regional) granite mass. As mentioned above, the granite, including the fine-grained granite, of the region concerned forms a part of the younger Ryôké granites, which are widely developed along the Seto Inland Sea (G. Kojima, 1953); in other words, the granite of the region is not a discrete mass, but a part of larger batholithic granite. The structural data obtained in the present field would not be sufficient to depict the structural behaviour of the whole mass of the younger Ryôké granite, however, data of the present region may contribute to the knowledge of "Granittektonik" of the Ryôké zone, as we have only a poor knowledge at present about it.

a) Method:

Areas where structural features, such as planar orientations and joints, were measurable are restricted only at the seaboard around the region described. The structural data measured have been projected on a map following the methods advocated by Hans CLOOS.

Along the seaboard various kinds of joint are found. All of them were measured at every twenty-five meters making no selection, and unless five or more joint surfaces of the same kind were found, non of the joint surfaces were plotted on the map. When one type of joint is very remarkable and shows considerable continuity, however, such joints were measured and plotted on the map even when only three or less of the joint surfaces were found on an exposure. As joints dipping with low angles tend in general to be fewer in amount on an exposure than those dipping with high angles, the former was in some cases plotted on the map even when only a single surface of joint was found at the exposure. In general three or four types of joint were recorded at every restricted portion of exposure. As a map of fairly large scale is necessary to record the structural elements at the seaboard, topographical maps of a scale of 1:5000 were prepared for field surveying. While the interior of the peninsula was mapped with a scale of 1:10000.

The total of the joint surfaces recorded is 430, among which those found in the fine-grained granite are 95. In addition to them 40 surfaces of planar structure were recorded from the granite, and 16 from the fine-grained granite. The planar structures to which various joints may be geometrically related, are found and measurable especially in the southwestern area of the region. There are no fundamental differences between the granite and the fine-grained granite in structural behaviour, as judged from the data of structural elements.

b) Planar structure:

The granite and the fine-grained granite are in part characterized by a planar structure, as mentioned above. It determines also a direction of easiest splitting of these rocks.

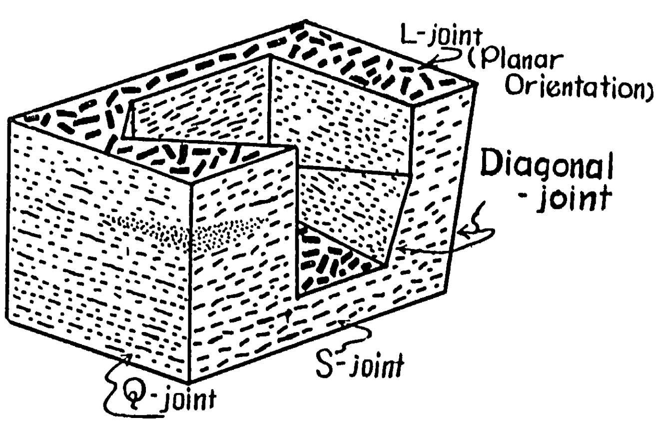


FIG. 1. Block diagram schematically illustrating the mutual relations between the structural elements of the granite.

The structure is not due to mineral banding or visual layers of any form in the rock. The planar nature of the structure arises from statistical orientation of indivisual minerals. So, this type of planar structure should be distinguished from those structures named "foliation" or "gneissosity". The structure is made up of the following elements:

i) *Mafic minerals*: The planar nature of the rocks is mainly governed by the orientation of mafic minerals. The plane containing c-axes of hornblende is approximately parallel to the basal plane of biotite. To the northwestern area the planar structure becomes obscure but it is yet traceable to some extent.

ii) *Felsic minerals*: Larger porphyritic (porphyroblastic) crystals of plagioclase and quartz are arranged more distinct than smaller crystals. Generally, however, the degree of preferred orientation of felsic minerals is lesser than that of mafic minerals, nay more, the planar nature becomes obscure in keeping with the increase of size and amount of felsic minerals.

iii) *Other elements*: Schlieren or elongated inclusions are found in part. Such inclusions have been characteristically found at the northern seaboard of Ôhama, Imabari City, where the major axes of their external form are strictly parallel to the planar orientation of the granite in this area.* The elongated inclusions described here as an example are, however, rather an exceptional case among inclusions in the granite.

No linear structures have been detected, because the major axes of elongated minerals and inclusions lie at random within the plane of the planar structure. The case i) is the most important for the planar structure of the fine-grained granite, in which nothing other than mafic minerals has a share in forming of planar structure.

c) **Joints**:

The writer measured, as described above, various joints without selection and recorded them on a map of a large scale. On the field it is not possible to distinguish between each type of joints, because of their similarity in appearance and of the variability in orientation of joint surfaces, especially of joints with steep dips. The data have been plotted on Schmidt's nets (Figs. 3a and 3b). One can find in these diagrams, however, that there are some maxima or sub-maxima which may correspond to the main joint systems as explained by H. CLOOS, R. BALK, E. CLOOS and S. V. BUBNOFF. Accordingly, the writer has divided tentatively the joints in the granite into four main systems after H. CLOOS, i. e. Q–, L–, S– and diagonal joints, which correspond respectively to maxima or sub-maxima in the diagrams. In other words, joints in the granite have been classified on the statistical ground, and afterwards the nature of each type of joints has been sought back on the field.

i) *Q-joints*: The most prevailing joints in the granite region run E-W (mainly at

* In this area, 15 major axes of the elongated inclusions and 20 planar orientations were recorded within ca. 2 x 10 square meters.

the western seaboard) and N 60° E (mainly at the eastern seaboard) with steep dipping. These joints may correspond to "Q-Klüfte" after H. CLOOS, or "cross-joints" after R. BALK and E. CLOOS. The nature of Q-joints has hitherto been reported by many workers, especially the latest information has been given by G. BISCHOFF (1956). The Q-joints in the present region do not always stand strictly at right angles to the L-joints or to the surfaces of planar structure, but in general the angles between them depart from 90° within several degrees. The angle estimated on the diagrams is ca. 90° at the northwestern seaboard (Fig. 3a) and ca. 80° in the other districts (Fig.3b).

The Q-joints in the present region show in some localities the same characteristics as pointed out by many authors: i. e. small pegmatite dikes, quartz veins and, very rarely, aplitic veins occasionally fill up the Q-joints. But, in the region, most of the joints which are referred to the Q-joints are not accompanied by such materials.

The relatively earlier generation of the Q-joints than the S-joints may, however, be suggested by the presence of these fillings, which have, as will be mentioned below, never been found along the S-joints.

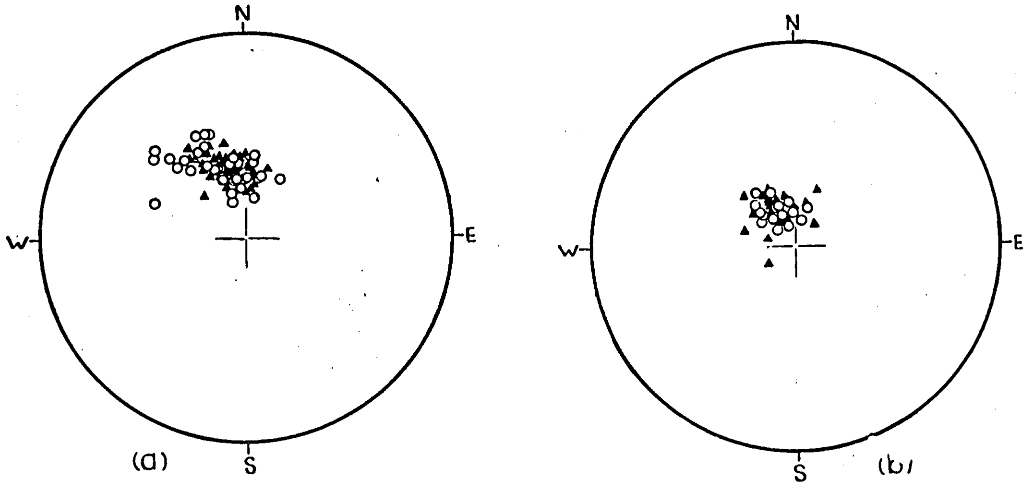
Comparing the maxima referable to the Q-joints in Fig. 3a with those in Fig. 3b, there can be found a relatively larger difference in orientation between them as mentioned above. Although the data for the Q-joints are very poor in the inland area connecting the western and the eastrn seaboard, it can safely be said that trends of the Q-joints in the present region are slightly convex towords the south, when they are interpolated through the region.

ii) *L-joints*: The maxima near the center of the diagrams (Figs. 3a and 3b) may be referred to the L-joints after H. CLOOS, which commonly occur with almost horizontal surfaces. In the northern area they dip with lower angles (ten or more degrees) than those in the southern area.

The strikes and dips of the L-joints in the southern most area along the seaboard, where the planar stucture of the granite is measurable, coincide very nearly to those of the planar structure (Fig. 2a). The same relation between them is partly found at the eastern seaboard (Fig. 2b). The average trend of the L-joints is ca. E-W at the western seaboard and N 60° E at the eastern seaboard, and also the average dip of them is about 20° towards S and the same degrees towards SSE respectively.

Sometimes thin pegmatitic veins and quartz-veins are also found along the surfaces of the L-joints, but this type of occurrence is only rarely met with for the L-joints. There are some evidences that the L-joints cut a pegmatitic vein and show a displacement of very short distance along the joint surfaces, for example at the southern seaside of Obé.

The regional change in orientations of the L-joints may be read from Figs. 3a and 3b, but it must be added that the strikes as well as the dips of the L-joints always vary within five or more degrees in each narrow area, i. e. the weak undulation of the planar



○ : Planar orientation ▲ : Plane of L-joint

FIG. 2. Equal-area projection of planar orientations and L-joints of the granite. Normals to the surfaces of joint and planar orientation have been projected on the horizontal plane. (a) Data were collected from the seaside of Kamoiké, south of Kuô. 36 planar orientations and 27 L-joints were plotted. (b) Data were collected from the seaside of Ôhama, the northern part of Imabari City. 16 planar orientations and 27 L-joints were plotted.

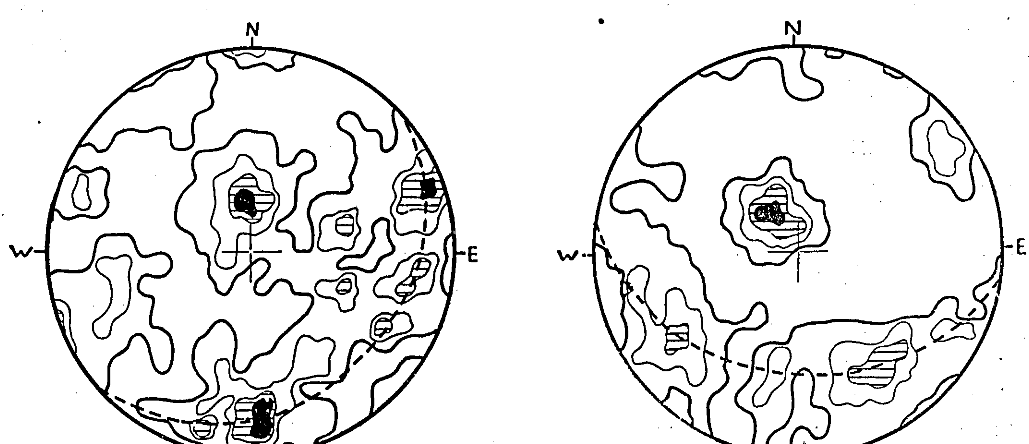


FIG. 3. Equal-area projection of joints found in the granite; (a) at the northern and the western seaboard, and (b) at the eastern seaboard of the granite region. Normals to the joint surfaces have been projected on the horizontal plane. The total of the joint surfaces plotted is 232 in (a) and 168 in (b). Contours: 1–2–3–4% per 1% area.

In (a), the central maximum area may correspond to the L-joints, the peripheral maximum dipping steeply to N or NNW may correspond to the Q-joints, and the S-joints dip also steeply to W or WSW. The remaining sub-maxima may be referred to the diagonal joints.

In (b), the peripheral maximum on the right may correspond to the Q-joints, and that on the left to the S-joints.

structures within such degrees can generally be found.

iii) *S-joints*: It seems very difficult to define the average trend of the S-joints in this region, because the S-joints are hardly discriminated from the prevalent diagonal joints in the field as well as on the diagrams. On the diagrams of Figs. 3a and 3b, the maxima or submaxima, which sustain angles of nearly 90° with those maxima referred to the Q-joints and the L-joints, may correspond to the S-joints. They trend NS – N 20° W and dip nearly vertical to 80° towards W at the western seaboard, while at the eastern seaboard, they trend N 30°–40° W and dip 60°–80° towards NE or SW.

None of the veins relating genetically to the granite, such as quartz veins and other mineral veins, have been found on the surface of the S-joint. They are often filled up by intruded dikes of far later generation.

In mechanically homogeneous rocks the S-joints may be expected to occur at right angles to the L-joints and to the Q-joints. In this region in problem, the joints which stand at right angles to the L-joints are also fairly abundant, but most of them are oblique to the Q-joints. It is not clear whether the displacement along the surfaces of the S-joints took place or not.

iv) *Diagonal joints*: The remaining joints have been tentatively included into the diagonal joints, because of difficulties of distinguishing them from the S- and Q-joints on the field as mentioned above. They have random orientations as expressed by the dispersion in Figs. 3a and 3b, but the most prevailing surfaces of the diagonal joints stand approximately at right angle to the L-joints, though their strikes are very variable. On the diagrams, accordingly, they swarm on a great circle passing two maxima which correspond to the Q-joints and the S-joints respectively.

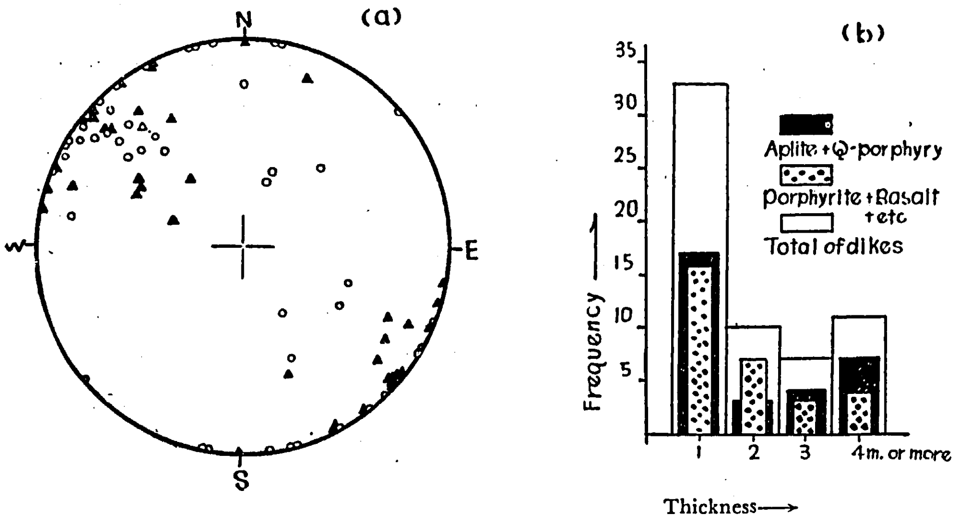
In the opinion of the writer, the diagonal joints and the S-joints might be generated under the similar physical conditions during the latest stage of consolidation or perhaps after the complete consolidation of granitic magma.

d) **Dikes and veins**:

i) *Dikes and veins*: Most of dikes found in the granite mass are far younger products than the granite. A number of veins are also in most cases branches derived from these dikes. The orientation and the frequency of occurrence of them are shown in Fig. 4. Comparing Figs. 4a, 4b with Figs. 3a, 3b, it may safely be said that the most preferable direction of these dikes had been provided by the diagonal joints of the granite.

ii) *Dike-like xenoliths**: Before leaving the section IV mention should be made of the dike-like xenoliths, for they give some important keys for deciphering an episode

* The name "dike-like xenoliths" is given after their petrographic characters. Genetically to say, the dike-like xenoliths should be named as "xenolith-like dikes", because they must have been intruded into the granite as dikes when the granite was yet considerably plastic, and successively they have suffered a thermal effect by the surrounding granite. The witer dealt, accordingly, with the "dike-like xenoliths" as "xenoliths" in the foregoing section III, but in the present section treating structural features of the granite he dealt with them as "dikes".



○: Aplite+Q-porphyry ▲: Porphyrite+Basalt+etc.

FIG. 4. Stereographic projection and histogram showing the relation between frequency and thickness of various dikes, which have been intruded into the granite long after the complete solidification of the latter. The predominant trends of dikes are ca. NE. Total of the plotted points is 61.

in the history of consolidation of the granitic magma. Here, the structural characters of the dike-like xenoliths will be described, for a consideration on the origin of them was already reported by the present author (T. NUREKI, 1956).

Various modes of occurrence of the dike-like xenoliths are shown in Figs. 5 and 6.

As judged from Fig. 5, the general trends of the dike-like xenoliths vary from E-W to N 40° E, and they dip towads S or SE. They seem to be originally sheet-like dikes and to incline commonly steeper than the planar structure of the granite in this area. While the strikes of these xenoliths approximately coincide with those of the planar structure. But such occurrences as shown in Fig. 6 are not rare. Thus in some cases the walls of dike-like xenoliths conform, but in a very narrow extension, to the planar structure of the granite. However, so far as the writer knows, the conformable boundaries of these xenoliths could hardly be pursued over one meter: they soon change their directions so as to intersect the planar structure.

The planar structure of the granite does not appear to be strongly disturbed near the dike-like xenoliths, owing to the intrusion of the latter. At some localities where the dike-like xenoliths are developed closely, the orientation of the planar structure of the granite is somewhat variable, but it is not unlikely to attribute this variation in orientation of the planar structure to the disturbance caused by the intrusion of the dike-like xenoliths, because dip angles of the planar structure of the granite are commonly variable within five or more degrees within a narrow extension. Nevertheless there

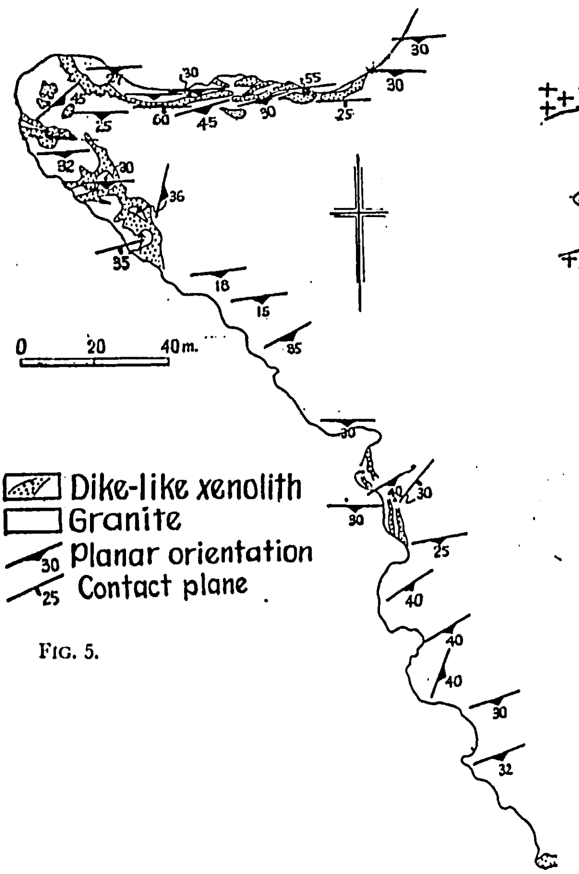


FIG. 5.

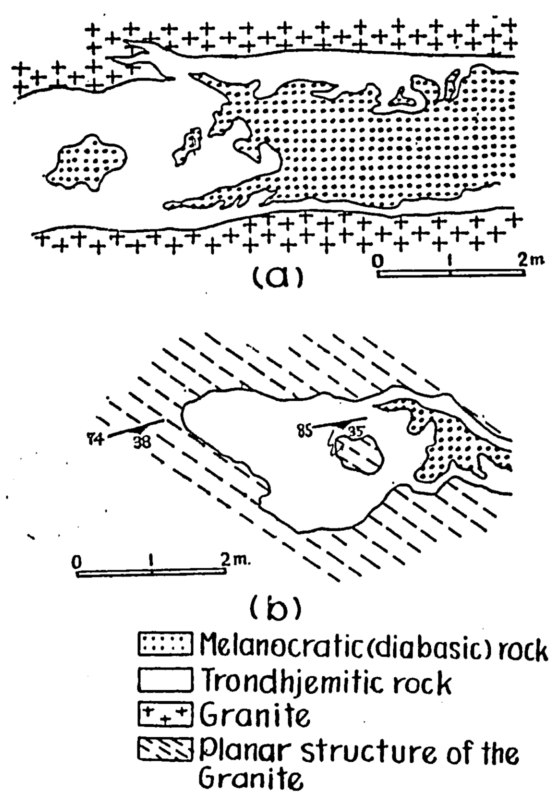


FIG. 6.

FIG. 5. Geologic reconnaissance map of the seaside of Kamoiké, south of Kuô, showing the mode of occurrence of the dike-like xenoliths.

FIG. 6. Sketches of the dike-like xenoliths at the seaside of Kamoiké. (a) Common case of the mode of occurrence of the dike-like xenoliths. (b) Showing the relation between the planar structure of the granite and the contact surface of the dike-like xenolith. The melanocratic (diabasic) interior does not directly come into contact with the granite without intervention of the trondhjemitic part. The contact boundary of the dike-like xenolith with the granite coincides in part with the planar structure of the granite, but it becomes soon oblique to the latter.

remain yet some possibilities that the orientation of the planar structure of the granite would be disturbed by the intrusion of the dike-like xenoliths.

No sign of displacement of the dike-like xenoliths along the surfaces of the planar structure of the granite has been detected. Sometimes white attenuated ptygmatic veins run into the granite along the surfaces of the planar structure from the trondhjemitic margin of the dike-like xenoliths (Fig. 6).

V. SIGNIFICANCE OF THE STRUCTURAL DATA

a) Origin of the planar structure:

The granite in this region belongs probably to the younger Ryôké granite of intrusion type, and may be the eastern extension of the Tôwa-granite in the Yanai region (Y. OKAMURA, 1957). Y. OKAMURA comes to the conclusion that the Tôwa-granite represents an intrusive granite in the "granite series" after H. H. READ (1949): it has been intruded into gneisses and granites, which correspond to autochthonous~parautochthonous granites in the "granite series.". His opinion is also consistent with the data attained by the present writer.

Several alternatives are conceivable about the origin of the planar structure. It is unlikely in the present case to assume that it represents a remnant or gneissose banding of an older structure, because the granite is apparently an intrusive type of granite which was once intensely homogenized and mobilized. Also it may be rejected to interpret it as formed secondarily after the granite has completely consolidated.

R. BALK (1937) suggests the principal relation between the layered structure of granite and its wall, saying that "the friction of a magma along relatively stationary walls results in layers parallel to that wall, whereby the first stimulus is given by the unequal composition of different portions of the magma". At the Takanawa peninsula the situation calls for a rather different conception, as such stationary walls can not be found in the region. There seems, therefore, no reason for considering that a huge roof had once covered the granite near the present surface of mountains.

The main cause by which the planar structure of the granite was generated should therefore be sought in the movement plan of the magma, which was at least in part a viscous fluid at the time of its emplacement. Now the friction within the magma along the pluton-roof (Plutondach) which was the earliest product through the consolidation history of the granite, becomes an important factor for the formation of the structure. The present writer has an opinion that the planar structure of the granite is to be attributed to flowage, which might have taken place approximately perpendicular to the principal direction of upward movement (up swelling) and along the pluton-roof of the granite magma. Thus, as a result of such movement plan of the magma, the layered structure of unequal composition of the granite might have been formed parallel to the direction of flowage within the mobile magma.

b) Generation of joints and their structural meanings:

Joint-systems have been interpreted as products by tensional stress imposed in a rock during the last stage of consolidation of magma (H. CLOOS, E. CLOOS, S. v. BUBNOFF and others). After the writer's observation the formation of joints is believed to have commenced at the later stage of consolidation of the granite magma, and have continued to a time far after the completion of solidification of the granite.

In the granite of the region, thin aplitic and pegmatitic veins penetrating into the Q- and L-joints are not rarely found. While no such veins fill the S-joints and the diagonal joints, which clearly cut and sometimes displace the Q- and L-joints. These facts suggest the time intervals in the generation of each type of joints: the Q- and L-joints belong to the earlier generation and are followed by the S- and diagonal joints. The Q-joints in the Fichtelgebirge are interpreted by G. BISCHOFF (1956)* as the system formed at the first place among various joints, however at the Takanawa peninsula it is not possible to define whether the splitting of the Q-joints was commenced earlier or later than that of the L-joints.

The planar structure might, as discussed above, have been formed during the time of up swelling of the granite magma. This structure defines the mechanical inhomogeneity of the granite, which later affects the orientation of joints: the planar structure has prepared the direction of splitting, perpendicular or parallel to it respectively, for the Q- and L-joints at the stage when tensions within the solidifying magma began to have been relieved by rupture. The planar structure has also affected the direction of intrusion of basic dikes, which have been intruded into the granite when it was yet considerably plastic and mobile.

The writer believes that both of the S-joints and the diagonal joints were splitted simultaneously but through a long time after the complete solidification of the granite magma. That the diagonal joints are generally trending towards various directions, is mainly due to the physical inhomogeneity within the granite, i. e. the splitting in the solidified rock has taken place in the various directions from a part to another within a huge but a mechamically restricted circumstance. Due to such inhomogeneous nature within the granite, the angles between the three joint-systems are also not strictly rectangular.

c) **Mode of emplacement:**

The room-problem which has been long discussed in connection with the genesis of granite, can not be fully discussed in the present paper, because the wall rock is practically lacking in the region now concerned.

As mentioned in the foregoing sections, the Q-joints at the western seaboard trend

* In his study of the younger granite of the western Fichtelgebirge, G. BISCHOFF (1956, p. 67) said: "Die Q-Klüfte müssen m. E. als erster Ausgleich auftretender Dehnungsspannungen in einem sich aufwölbenden Plutondach erklärt werden. ......Die flach-schräge Intrusionsdruckkomponente wird zunächst einmal ein Aufreißen von Klüften senkrecht zu ihr verhindern, so daß die druckparallele Q-Klüftung für den ersten Spannungsausgleich geradezu prädestiniert ist.......Auch die fast flache horizontale L-Klüftung ist das Ergebnis der Aufwölbung, und ich sehe in ihnen den Ausgleich von Gleitspannungen. ...... Die vielen S-Klüfte sind m. E. in sehr verschiedenen Zeiten aufgerissen und folgen lediglich dieser guten Spaltbarkeit. Die Spaltbarkeit geht jedoch auf die Granittektonik zurück..." The writer consents to his view, and no essential discrepancy between the Fichtelgebirge and the Takanawa peninsula has been found in regard to the order of succession in the formation of various joints.

ca. E-W and steeply incline towards N, while those at the eastern seaboard trend ca. N 60° E and steeply incline towards NNW. The L-joints and the S-joints also change their trends and inclinations in accordance with the Q-joints. The areal tendency of development of these joints can be seen in Map 3, and Figs. 3a and 3b.

Data from the interior are practically lacking, but, examining such structural data imprinted in the granite in problem as shown in the foregoing figures, the following deduction can be made:

(1) The trends of the Q- and L-joints appear to draw an arch, being convex towards the south, and in accordance with the change of them the S-joints are oriented in fan-shape, diverging towards the south.

(2) The planar structure and the L-joints of the granite incline towards S with higher angles in the southern half of the region than those in the northern half, i. e. in general ca. 30° to 40° and 10° to 20° respectively.

(3) The variation in inclination of the Q-joints is, on the other hand, not so regular as the case of the L-joints.

(4) The planar structure of the granite is remarkable in the southern half of the region in problem, however, it becomes fainter to the north: — this corresponds to the fact that the granite becomes coarser and less layered at the approach of the central part or the interior of the granite mass.

The fan-shaped development of the Q-joints has been reported by such authors as H. CLOOS, S. v. BUBNOFF as an indicator to know the principal direction of movement of a magma. According to their opinions, the principal direction of movement of a magma runs from the convergent side to the divergent side of the fan. At the Takanawa Peninsula the direction of intrusion of magma can not strictly be decided; however, considering the trend of joints and other structures, it may be inferred that the principal direction of movement of the granite magma trends probably from N or NNW to S or SSE with steep plunge towards N as deduced from the inclination of the Q-joints. The fan-shaped development of the S-joints may give in this case a significant indication for deciding the principal direction of movement of intruding magma: the rivet of the fan can be traceable towards the north. Successive addition of granite magma from the deeper level has resulted in swelling of the whole granite magma. As the result of the upward swelling of the magma, a dome-stucture of the granite was accomplished, the southern half of which is represented by the granite mass of the region.

VI. CONCLUDING REMARKS

1. The granite in the northern part of the Takanawa peninsula may belong to the younger Ryôké granite, which represents an intrusive facies of the Ryôké granite series. None of the country rocks by which the granite magma was structurally con-

troled at the time of its emplacement have been found in the region concerned, except for the gabbroic masses in the northernmost area of the region.

2. Fine-grained granite is found here and there at summits of mountains or along the mountain-ridges in the granite region: the rock is interpreted as a finer facies of the granite. The appearances and frequency distribution of various joints in the fine-grained granite are similar to those in the granite.

3. Significant structural elements imposed in the granite in problem are joint-systems and planar structures. No linear structure has been found. The joints were divided after the classification by H. CLOOS into four categories, i. e. the Q-, L-, S- and diagonal joints. The Q-, S- and diagonal joints have steep inclinations, while the L-joints incline with low angles and they are splitted in accordance with the planar structure.

For lack of exposure, structural data are very poor in the interior of the region, however, the general tendency of orientations of various kinds of joints through the whole region can be interpolated as follows: (1) the trends of Q-joints draw an arch, being convex towards the south, (2) the S-joints run in fan-shape, diverging towards the south, and (3) the L-joints and the planar structure in the southern area incline steeper towards the south than those in the northern area.

4. Interpreting these structural data, the writer has arrived at the conclusion that the principal direction of movement of the granite magma is probably N-S or NNW-SSE, and that successive addition of magma from the deeper level has resulted in the swelling of the whole magma, consequently a domed granite pluton has been formed, the southern half of which is now represented by the granite mass of the region concerned.

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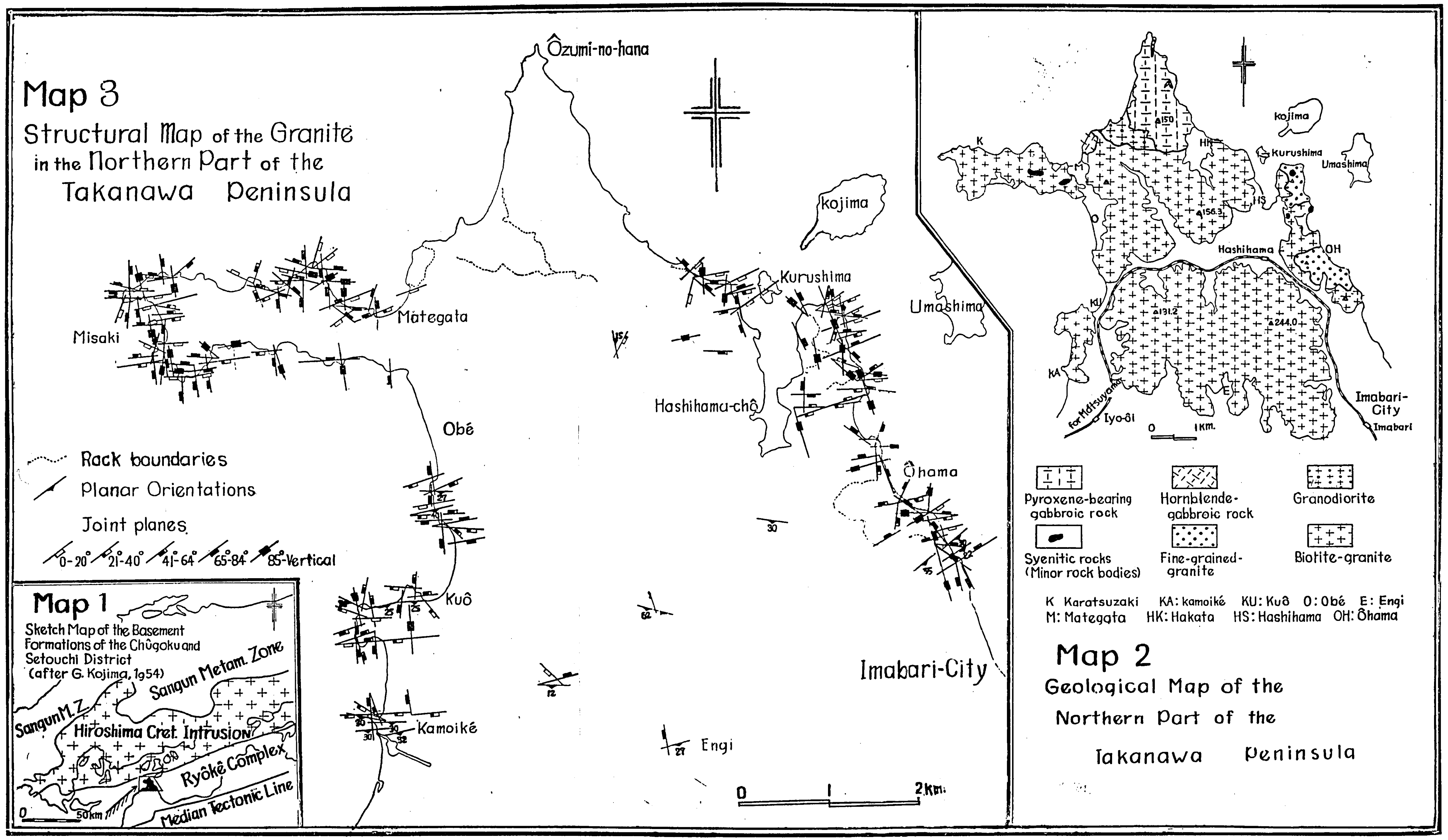
Map 3
Structural Map of the Granite in the Northern Part of the Takanawa Peninsula
Ôzumi-no-hana
kojima
Kurushima
Umashima
Misaki
Mategata
Obê
Hashihama-chô
Ôhama
Kuô
Kamoiké
Engi
Imabari-City
Rock boundaries
Planar Orientations
Joint planes
0-20°
21-40°
41-64°
65-84°
85-Vertical
0
1
2Km.
Map 1
Sketch Map of the Basement Formations of the Chûgoku and Setouchi District (after G. Kojima, 1954)
Sangun Metam. Zone
Sangun M. Z.
Hiroshima Cret. Intrusion
Ryôkê Complex
Median Tectonic Line
0
50km
Map 2
Geological Map of the Northern Part of the Takanawa Peninsula
kojima
Kurushima
Umashima
Hashihama
OH
Imabari-City
Imabari
Iyo-ôi
for Matsuyama
0
1Km.
Pyroxene-bearing gabbroic rock
Hornblende-gabbroic rock
Granodiorite
Syenitic rocks (Minor rock bodies)
Fine-grained-granite
Biotite-granite
K Karatsuzaki KA: kamoiké KU: Kuô O: Obê E: Engi
M: Mategata HK: Hakata HS: Hashihama OH: Ôhama