MEMOIRS OF THE COLLEGE OF SCIENCE, UNIVERSITY OF KYOTO, SERIES B,
Vol. XXXII, No. 4 Geology and Mineralogy, Article 11, 1966

The Ryoke Metamorphic Zone of the Kinki District, Southwest Japan: Accomplishment of a Regional Geological Map

By

Hajime YOSHIZAWA, Waitsu NAKAJIMA* and **Kyoichi ISHIZAKA**

Geological and Mineralogical Institute, University of Kyoto

(Received Dec. 8, 1965)

Abstract

A new regional geological map of the Ryoke metamorphic complex in the Kinki district is presented, and also, the geology and geological structure are described briefly for the explanation of this map. The metamorphic rocks of sedimentary origin, in general, fold in wavy forms and with gentle dips, wave lengths of which are 10-15 km in the northern and central part, i.e., the main part of the complex, and 4-5 km in the southern part, i.e., the Median Tectonic Zone which thrusts itself to the Sambagawa metamorphic complex. Based on their metamorphic grades, the metamorphic rocks of the sedimentary origin are classified into three groups, zonally arranged from the north to the south and stretched in the E-W direction; the slate group characterized by chlorite and biotite, the schistose hornfels group by cordierite and andalusite, and the banded gneiss group by sillimanite. The schistose hornfels group again appears in the southern most part. Judging from these mineral assemblages, the metamorphism of the complex, as a whole, is obviously of higher temperature and lower pressure. In this highly metamorphosed area, seen at present, basic rocks, granodiorites and fine-grained granites intruded, the last two of which are grouped as the granitic rocks of the earlier stage. These rocks form large dome-shaped bodies trending in the E-W direction, which axis approximately situates in the highest metamorphosed zone. Besides these, comparatively small dome-shaped masses are observed. After these intrusions, discordantly to the E-W structures, coarse-grained granites, i.e., the granitic rocks of the later stage, injected generally into the geologically low lands between these dome-like masses and in the synclinal parts of the metamorphics of sedimentary origin; the granites of this kind form frequently basin-shaped masses.

The age of the metamorphic rocks of sedimentary origin and all the granitic rocks of the earlier and the later stages are of the Cretaceous Period, according to the Rb-Sr and K-Ar geochronological determination.

The southern part of the Ryoke complex, i.e., the Median Tectonic Zone, has a large amount of basic rocks, which, in this respect, resembles to the Sambagawa complex neighbouring to the south of the Ryoke massives.

The mutual relation between the Ryoke granites and the granites in the northern Kinki district neighbouring to the north of the Ryoke complex, are also described, with special references to the boundary between these two rock groups.

* Dep. Earth Science, Faculty of Education, Kobe University.

I Introduction

The Ryoke metamorphic terrain in the Kinki district is located in the central part of that metamorphic belt which develops in the Inner Zone of Southwest Japan. In the Kinki district, the Ryoke metamorphic complex develops over a wide area, running nearly E-W over a length of approximately 150 km and a width of approximately 50 km, in which many kinds of metamorphic and granitic rocks develop extensively and continuously, and are exposed well as compared with other districts. Moreover, these rocks are exposed almost continuously from the northern to the southern limit and also from the eastern to the western limit of the metamorphic terrain without so much interruption.

Thus, the Kinki district offers a more suitable field for the study of the geology and petrology of this metamorphic complex than other districts such as the Yanai and the Shinshu area. However, little has been known so far, about this metamorphic terrain developing in the Kinki district, although those of the Shinshu and the Yanai districts have been investigated comparatively in detail. Furthermore, this metamorphic complex, geologically, has been one of the least cultivated areas of the geological units developing in the Kinki district; its geological structure has remained obscure for long years: Only very small areas, for example, the Kasagi and the Mitsue districts were studied comparatively in detail in the past. No regional study covering the whole Ryoke metamorphic terrain has ever been attempted.

Detailed studies of small restricted areas, are undoubtedly important in the study of metamorphic geology and petrology. However, without a regional study covering the wide area of the metamorphic complex, like this study on the Kinki district, it will be almost impossible to know exactly the geological structure of the metamorphic complex and to understand the nature of its regional metamorphism. It will be very helpful for the study of the metamorphic geology of the Ryoke metamorphic complex, and of the metamorphic zone in Japan, if an areal geological map of this metamorphic terrain can be obtained.

No regional geological map suiting our purpose has ever been published with respect to the Ryoke metamorphic complex. Therefore, the present writers have been engaged in the study of the geology of this metamorphic terrain in the Kinki district for some ten years in the past: Yoshizawa (24) (26) has carried out a study on the geology of the eastern part (the main area in Mie Pref.) of this metamorphic terrain, Nakajima (16) (17) (18) has studied the central part (mainly the so-called "Yamato plateau" in Nara Pref.), and Ishizaka (8) has investigated the western part (mainly the boundary area between Nara and Osaka Pref.) of this metamorphic complex. From the standpoint stated above, the writers attempted, as a first step, the compilation of a regional geological map covering the whole Ryoke metamorphic complex exposed in the Kinki district, by using the results they have obtained.

Several small blank areas, near the boundary areas of the eastern, central and western parts, remain to be surveyed. The writers together conducted field surveys several times in these areas in the course of the compilation of this geological map. However, there was not enough time for the writers to carry out a detailed survey. For these areas, data were borrowed from other investigators' studies for the compiling of the geological map (7) (12) (18) (20).

Although the compilation of this regional map is a joint work of the present writers, each writer is responsible for the data from the area where he has investigated.

The main purpose of this paper is to present a new regional geological map of the Ryoke metamorphic complex in the Kinki district: The geology, petrography and geological structure of the metamorphic rocks, therefore, will be described only summarily in this paper.

II Geological and petrographical outlines of the metamorphic and granitic rocks

The Ryoke complex of the district described below consists of metamorphic rocks of sedimentary origin, basic rocks and granitic rocks which are composed of granodiorites, fine-grained granite and coarse-grained granite. These rocks are milonitized in the southern margin.

The metamorphic complex, in this district, can be divided into the following four zones from the north to the south, namely slate zone, schistose hornfels zone, banded gneiss zone and again, schistose hornfels zone, as will be explained later.

1. Metamorphic Rocks of Sedimentary Origin

The original rocks from which metamorphic rocks of sedimentary origin were derived, are mainly silicious rocks, i.e., banded chert and sandstone. Besides these rocks, mudstone, diabase and a small amount of limestone are also recognized. Among these, mudstone develops in the northern part of the central and eastern area, namely in the northwest of Kasagi in the central area and in the north of Suzuka River in the eastern area: It occurs abundantly in the low grade metamorphic zone, i.e., slate zone.

In the highly metamorphosed zone, a considerable amount of mudstone develops; mainly, in the schistose hornfels zone and subordinately in the lower metamorphosed part of banded gneiss zone.

Most of banded gneiss zone consists of silicious rocks, interbedded with a small amount of pelitic rocks. Limestone occurs in small lens-shaped bodies and is very small in amount, in each metamorphic zone. A small amount of schalstein develops, mainly, in the northeastern part of the studied area. However, in the culminating part of the metamorphic grade, it is generally difficult to distinguish it from the fine-grained basic rocks of igneous origin which will be described later.

The main minerals in each metamorphic zone, are as follows:

slate zone	in pelitic rocks;	sericite, biotite, quartz, plagioclase (albite), ±chlorite.
	in basic rocks;	chlorite, biotite, actinolite, plagioclase (albite), quartz, epidote, calcite.
schistose hornfels zone	in pelitic rocks;	biotite, muscovite, cordierite, andalusite, plagioclase (oligoclase), K-feldspar (microcline), quartz, garnet.
	in basic rocks;	green hornblende, plagioclase (oligoclase-andesine), ±quartz, ±biotite, ±diopside.
banded gneiss zone	in pelitic rocks;	biotite, muscovite, sillimanite, ±cordierite, garnet, K-feldspar (microcline), plagioclase (oligoclase-andesine), quartz.
	in basic rocks;	brownish-green hornblende, plagioclase (andesine), ±quartz, ±biotite, ±diopside.

Judging from this mineral assemblage, the regional metamorphism of this terrain is obviously of lower pressure and higher temperature (14) and of a regiothermal character.

2. Basic Rocks

Basic rocks are usually in concordant relation to the surrounding metamorphic rocks of sedimentary origin and are generally considered to be older than granitic rocks in intrusion time. They consist of fine-grained basic rock, coarse-grained basic rock and quartz diorite. Various facies are further recognized in each rock body: The intrusion time of these rocks may not be the same.

Most of the basic rocks intruded prior to or in the earlier stage of the matamorphism. However, some of them are considered to have intruded in the period between the emplacement of the earlier stage granite and that of the later stage granite, judging from the occurrence of the basic rocks; some of the basic rocks traverse highly discordantly the granite of the earlier stage, according to the observation of their outcrops. At any rate, it goes without saying that all these basic rocks were metamorphosed.

Among these rocks, fine-grained basic rock, occupying a large part of these basic rocks, usually occurs in sheet shape. It is dark green, fine-grained, massive and sometimes weakly foliated. The mineral assemblage of this rock is usually as follows; hornblende-(biotite)-plagioclase-quartz. An=40-80. It may be derived mainly from diabase or microgabbro. Rarely, relics of pyroxene are observed in this rock. This fine-grained basic rock is frequently granitized to quartz diorite. These two kinds of rocks, when the scale is small, are not distinguished from each other in the geological map.

Quartz diorite is generally medium- to coarse-grained, massive or weakly foliated. Various facies, from biotite quartz diorite to biotite granodiorite, can be recognized. At least a part of it is derived from fine-grained basic rock by granitization as mentioned above. The mineral assemblage of quartz diorite is almost identical with that of fine-grained basic rock, namely hornblende-biotite-plagioclase-quartz. An=35-70.

Coarse-grained basic rock usually occupies the top area of the granitic rocks in dome-shaped masses and forms isolated bodies, as is seen typically at Mt. Ikoma. The occurrences of these coarse-grained basic rocks, as well as the fine-grained rocks, continue well in the direction of the general trend of the metamorphic complex. Two linear occurrences of the coarse-grained basic rock bodies are recognized: one (north) consists of Ichidaisan-Kônoyama-Taneo-Fukudayama, and the other (south), the masses which trend eastward, starting from Mt. Miwa.

These coarse-grained basic rock bodies are mostly meta-norite consisting of olivine-hypersthene-cummingtonite-hornblende-plagioclase rock. (An = 50-90). Porphyroblastic hornblende containing poikilitically plagioclase, develops in this rock. Rarely, cortlandite or anorthosite are observed in the norite body as metasomatized facies. The coarse-grained basic rocks are considered to be later than the fine-grained basic rock in intrusion time.

3. Granodiorites

There are two varieties of granodiorite; one is gneissose granodiorite and the other massive granodiorite. Gneissose granodiorite, in general, is subconcordant, and almost no strong contact effect is found between this rock and the metamorphic rocks of sedimentary origin.

Broadly speaking, the contact between these two rocks is concordant. However, it is frequently observed at outcrops that granitic rock takes an injection behaviour towards the gneiss of sedimentary origin, even if both rocks are seemingly concordant with each other.

This gneissose granodiorite occurs only in sillimanite gneiss zone and frequently accompanies basic rocks. It tends to be located in axial part and limb of anticlinal folding, and further develops as if it were surrounding the main metamorphic rock area in the middle and southern parts of the studied area.

This rock is generally greyish, medium-grained, strongly or weakly foliated granodiorite~tonalite. The minerals constituting this rock are; biotite, hornblende, plagioclase, (potash feldspar), quartz. An=30-40. The colored minerals contained in this rock are usually hornblende and biotite. However, the amount of hornblende is quite variable: Biotite granodiorite facies sometimes occurs. Besides hornblende and biotite, diopside is observed rarely in this gneissose granodiorite. This rock may have intruded in the culminating period of the metamorphism, and accordingly may be one of the oldest of the granitic rocks (in the earlier stage of the granitic intrusions).

Massive granodiorite occurs with close association to the above-stated gneissose granodiorite. It develops widely around Mt. Amagoi in the eastern area and around Gose in the western area. Typical massive granodiorite usually takes the shape of pluton. It is generally greyish, medium- to coarse-grained, massive biotite-hornblende granodiorite~tonalite (An=30-50). However, except for the typical massive granodiorite constituting Mt. Katsuragi, this rock developing along the Median Tectonic Zone in the southern part of the central and western areas, has been turned into weakly schistose biotite-hornblende or biotite granodiorite, suffering protoclastic movement. Furthermore, cataclastic texture is distinct in these schistose rock, on a fairly large scale.

A small rock body, occuring at Ômine, in the northeast of Kasagi in the central area, may also belong to this facies.

Andalusite, together with quartz, microcline and muscovite, is crystallized in a pegmatite in the gneissose granodiorite, near Okugano in the eastern area.

4. Fine-grained granites

Fine-grained granites occur mostly in the sillimanite gneiss zone. They develop well near the axial part of the metamorphic complex, and are associated closely with metamorphic rocks of sedimentary origin or fine-grained basic rock. They are usually isolated from coarse-grained granite mentioned below, generally with septa of the gneiss of sedimentary origin. The largest body is located near Fukawa, forming a large dome on the northern side of the highly metamorphosed zone in the central part of the studied area. These fine-grained granites are generally in subconcordant and subharmonic relation with the wall rocks: They give no distinct mechanical or thermal effect to the wall rock of the gneiss of sedimentary origin and usually carry a few xenolithes of the wall. However, as will be mentioned later, these granites occasionally occur discordantly with the wall rocks. In this respect, it is considered that the fine-grained granites are not of the same period.

Fine-grained granites are divided into the following three facies; porphyrytic granite, fine-grained granite proper and aplitic granite. These fine-grained granites may not be the same in the point of their intrusion time.

Porphyrytic granite occurs in the southern limb of Fukawa granite body and has its eastern extension. A rock, nearly equivalent to this porphyritic granite, develops around Sakawa in the southwest of Kasagi in the central area*.

Porphyrytic granite is, in general, fairly varied in its rock facies. It is generally white to grey in color, medium-grained and fairly foliated. Microcline porphyroblast develops conspicuously in this granite. It is usually biotite granite~granodiorite. The mineral assemblage of this granite is as follows; biotite—(garnet)—microcline—plagioclase (An=20-40)—quartz.

Fine-grained granite proper occupies a large part of this granite group and has various rock facies; some of it is in subconcordant and transitional relation to the metamorphic rocks of sedimentary origin, while some distinctly intrudes into metamorphic rocks and granodioritic rocks, for instance, at an old castle site near Azumasaka, northwest of Mt. Kongo, in the western area. It is generally greyish to white, fine- to medium-grained, massive, weakly foliated, garnet-bearing biotite granite or two mica granite. An=20-25.

Sometimes, microcline porphyroblastic crystals, although usually difficult to identify with the naked eye owing to their being contained in the same colored media, develop in this granite.

Aplitic granite occurs frequently in the metamorphic rocks of sedimentary origin, and is usually small in its scale. There are two kinds of aplitic rocks, although in the geological map they are not distinguished from each other; one is aplitic granite in the ordinary sense, and the other is derived from fine-grained granite by cataclastic and hydrothermal metamorphism. The latter type of aplitic granite develops widely near Ôuda in the southern part of the central area and near Niu in the southern part of the eastern area. Cinnabar deposits develop in and around these aplitic granite bodies.

5. Coarse-grained Granites

Coarse-grained granites generally occur in large-scaled bodies, occupy a large part of all granitic rocks, and furthermore a considerable part of the Ryoke metamorphic complex in the Kinki district.

---

* Arita and Nakajima; Koya type II granite, Hara; Sakawa granodiorite

This granite is discordant and non-harmonic with the structure of the surrounding metamorphic rocks of sedimentary origin and granodiorite, and gives distinct mechanical and thermal effect to them, especially in the area of the lower metamorphic grade. It contains abundant xenolithes and shows conspicuous flow structure in the inner part of the body, for instance, in the north of Hase, in the central area. The degree of discordancy of this granite with the neighboring metamorphic rocks increases from the south to the north in this surveyed metamorphic complex. The granite body which is situated in the northern part of the studied area is most discordant with the metamorphic rock, the typical example being the Yagyu granite body, situated in the west of Igaueno in the central area. Usually, it contacts with gneissose granodiorite and the metamorphic rocks of sedimentary origin to form a basin- or semi-basin-shaped structure.

The coarse-grained granite also has various rock facies. Typically, it is greyish, coarse-grained, porphyrytic and occassionally weakly foliated hornblende-biotite granite. An=20-40. The amount of hornblende is quite variable; biotite granite facies develops in some part; especially in the rock located in the northern marginal part of the metamorphic complex.

Leucocratic granite is a member of the coarse-grained granite, which occurs closely associated with the latter at Ide in the Kasagi district in the central area and also at Ogochi in the eastern area. The leucocratic granite is white, coarse-grained, massive and is very homogeneous throughout the rock body and carries almost no inclusions. An=20-30.

The coarse-grained granite group, as a whole, is comparatively young in the time of intrusion (in the later stage of the granitic intrusions).

6. Mylonitic Rocks

Various rock facies are recognized in mylonitic rocks. They are conveniently divided into augen granite, porphyroid-like mylonite and Hälleflinta-like mylonite. Few mylonitic rocks which are derived from metamorphic rocks of sedimentary origin are observed throughout the studied area. Augen granite develops around Tatsuno in the southern part of the central area and also around Niu in the southern part of the eastern area. Of these augen granites, the latter corresponds to the eastern extension of the former.

The augen granite which develops around Tatsuno is more weakly milonitized as compared with that around Niu: It is gradational to porphyritic granite which belongs to coarse-grained granite.

Porphyroid-like mylonite (protoclastic) develops widely in the southern part of the eastern area. Characteristically this rock contains porphyroclast of plagioclase and hornblende. The original rocks are considered to be mainly gneissosse granodiorite. This mylonite is derived by the protoclastic movement during the upheaval of this area in the time of emplacement of the granitic rocks of the earlier stage.

Hälleflinta-like mylonite (cataclastic) usually develops along the Median Tectonic Line. It also occurs along other faults, (thrust), although they are of small scale. Hälleflinta mylonite is derived from the cataclastic movement, and original rocks may be mainly basic rocks, granodiorite and coarse-grained granite.

Quartz porphyry, lamprophyre and other dike rocks occur, intruding into those rocks stated above. They develop fairly abundantly in the northern and southern marginal part of the investigated area.

In the Median Tectonic Zone, mainly in the western part of the studied area, Izumi group, or its equivalent, develops. In the eastern area, this rock occurs locally as patches surrounded by thrusts in the granitic rocks.

Cenozoic sedimentary rocks, such as Miocene and Plio-Pleistocene sediments, develop considerably in the Ryoke metamorphic terrain: The Nijô group in the western area, the Muro group, with abundant volcanic rocks in the central area and the Ichishi group developing sporadically in the eastern area, are striking examples of the Miocene sediments. The Kobiwako group developing widely in the northern part of this metamorphic complex and the Osaka group developing mainly in the western part, belong to the Plio-Pleistocene sediments.

III Geological structure and metamorphism

1. The Metamorphic Grade of the Metamorphic Rocks of Sedimentary Origin

The metamorphic grade of the metamorphic rocks of sedimentary origin will be discussed.

i) Eastern area

Along the Suzuka River which runs parallel to the Kansai Line, massive hornfels crops out, which is characterized by the crystallization of biotite as metamorphic mineral. The area between the Suzuka River and the vicinity of the Hattori River and Nagano River, belongs to schistose hornfels zone, which is characterized by the presence of cordierite as metamorphic mineral: In this zone, andalusite should appear, as well as cordierite, judging from the fact that the former mineral occurs commonly in the schistose hornfels zone in other districts. However, no occurrences of andalusite have yet been known in the schistose hornfels zone in this area. This may be due to the fact that this schistose hornfels, cropping out in small area owing to the intrusion of coarse-grained hornblende-biotite granite, consists mainly of psammitic rock in which a few thin seams of limestone are interbedded, and only a small amount of pelitic rock: The alumina content in the original rocks of the schistose hornfels, may be too small to produce andalusite.

The broad area south of the schistose hornfels zone consists of banded gneiss zone, which is characterized by the occurrence of sillimanite as metamorphic mineral*.

ii) Central area

In the north of the Kizu River in the Kasagi district, weakly metamorphosed slate zone develops widely**.

The area in the south of the Kizu River, belong to the schistose hornfels zone with coexistence of andalusite and cordierite, and the banded gneiss zone characterized by the occurrence of sillimanite. Between these two zones, a transitional zone, andalusite and sillimanite crystallizing together, is observed.

Between the slate zone and schistose hornfels zone, a kind of sheared rock develops which is identical to the microbreccia described in Article 8.

iii) Western area

In this area, occurrences of metamorphic rocks of sedimentary origin are extremely few. As a result, exact determination of the metamorphic grade based on the metamorphic sediment, is difficult in this area. On the 1 km southeast from Hiraishi, in the south of Mt. Nijo, a small schistose hornfels body with the width of approximately 7m occurs surrounded by gneissose granodiorite and has cordierite in it.

In short, in the northern part of the studied area, it is considered that sillimanite isograd on the north, extends to Nagano River—Hattori River—Kamo Town, from the east area to the central area. Although in the west area, this sillimanite isograd is assumed to extend to a part in the north of Mt. Ikoma, this area is intruded by biotite-hornblende granite.

The schistose hornfels zone, is very narrow in its width as compared with the banded gneiss zone. This banded gneiss zone seems to develop widely and extend to the Median Tectonic Zone which is located in the southern limit of the Ryoke matamorphic complex.

In the southern part of the studied area, schistose hornfels zone, again, occurs as described above. It has been, also, reported that in the Mitsue district belonging to the Median Tectonic Zone, the transitional zone, in which andalusite and sillimanite co-

* The zone was named "the Ryoke northern marginal zone" by one of the writers (W. N.) (1960).

** On a summit, 2 km NW from Kayumi, the southern margin of this area there are the metamorphic rocks of sedimentary origin injected by metabasitic rocks which are considered as schistose hornlels judging from their textures, though sheared by the movement of the Median Tectonic Zone, exist, appears again (20). In the other areas of the southern part, excluding the Mitsue district, basic rocks develop extensively, while metamorphic rocks of sedimentary origin occur quite rarely. Furthermore, because of the duplication of mylonitizations, especially because of the cataclastic mylonitization, the metamorphic rocks here suffered undoubtedly a retrogressive metamorphism. Thus, the metamorphism in this area is considered to be complicated. However, the existence of the schistose hornfels zone in the southern part of the studied area suggests that the degree of the metamorphic grade decreases towards the Median Tectonic Line and therefore the highest part of the metamorphic grade lies in the north of the Median Tectonic Line.

The region where the metamorphic grade reaches its maximum degree is considered to lie about 10～15 km north from the Median Tectonic Line and to extend approximately in E-W direction. The An composition in plagioclase in the metamorphic rock also reachs its maximum value (An 35) in this core part.

2. Fold Structure of the Metamorphic Rocks of Sedimentary Origin

Fold structure can be followed by the orientation pattern of the foliation observed in metamorphic rocks: It is clear from the field observation that foliation is nearly parallel to the original bedding plane of sedimentary rocks.*

Generally speaking, metamorphic rocks become fewer in their occurrences towards the south, and appear only locally as thin-layered bodies in granitic rocks and as septa between granitic rock masses.

Eastern area: The metamorphic rocks derived from the sedimentary rocks, are exposed most extensively and continuously in the Nunobiki area in the eastern district, and takes distinct fold structures. As the results of a detailed investigation of this district, the following characteristics of the folding of these metamorphic rocks were observed, although the folding structures become somewhat complicated because of the later faults traversing the limb part of the fold; this folding, in general, is gentle and wavy, the wave-lengths of the fold structures being between approximately 10 and 15 km and the axes of the folds trend E-W or WNW.

In the Mylonite Zone of the southern part, the fold structure of the metamorphic rocks is more indistinct as compared with the case of the northern area, namely the Nunobiki area, because the metamorphic rocks of sedimentary origin occur rarely and their distribution is quite complicated. But the wave length of the folding in this area,

* Locally, ptygmatic fold which has complicated folding pattern with high dip, occurs. The ptygmatic folding is mainly due to the difference in rigidity of rocks: It is generally restricted to a small area and is usually observed in the area where rocks having different rigidity are in contact with each other, namely, in the pelitic rocks occurring as interlayered beds in psammitic rocks and also, in the area where the metamorphics contact with granitic rocks.

is assumed to be approximately 4-5 km and the folding pattern generally dips steeply as compared with that in the north.

Central area: In this area, these metamorphic rocks occur somewhat locally forming blocks, because many granitic rock bodies develop. But the folding structure is not so different from that observed in the eastern area.

Western area: In this area, as has been mentioned previously, occurrences of metamorphic rocks are very few. A small metamorphic rock body which has fold structure, is observed in the Tatsuta area. This is the only metamorphic rock mass observed in this area.

It is to be noted that the axes of the foldings in the metamorphic rocks plunge gently eastward in the eastern area and westward in the central and the western areas.

It is not an easy job to establish the stratigraphy of the metamorphic rocks, because there are no distinct differences in the lithological facies of the metamorphic rocks, and moreover, granitic intrusions occur extensively in this district. Broadly speaking, the metamorphic rocks in the northern part of the investigated area are considered to have been derived from silicious rocks (sandstone or chert) and aluminaceous rocks (shale) which contain a small amount of limestone lens. In the middle part, silicious rocks seem to increase in amount. In the southern part, namely the highest part of the metamorphic grade and in the Mylonite Zone, namely the vicinity of the Median Tectonic Line, the metamorphic rocks consist of a small amount of silicious rocks and a large amount of fine-grained basic rocks with interbeds of silicious rocks. Judging from the distribution of these rocks, it is considered that the upper strata of the metamorphic rocks are located in the northern part, and the lower strata appear towards the south.

As will be mentioned later, broadly speaking, the main part of the emplacement of basic rocks, especially coarse-grained basic rocks and gneissose granodiorite, corresponds to this highest part of the matamorphic grade.

3. The Occurrence of Granitic Rocks of the Earlier Stage—the Formation of Large Dome-Shaped Granitic Masses Extending in E-W Direction

The area with the dominate development of the gneissose granodiorite and fine-grained granite, i.e., the granitic rock of the earlier stage, is situated in the highest metamorphosed zone. Judging from the plunging pattern of foliation of the gneissose granodiorite and fine-grained granite, these are assumed to form large dome-shaped masses, although they are of complicated shape owing to the intrusion of later stage granitic rocks and afterward faulting. The main axis of the dome-shaped masses lies on a line connecting Inohara town—the south part of Nara City. Moreover, the location of the main axis of these dome-shaped masses coincides approximately with the axis of highest metamorphic grade. Judging from this point and the metamorphic mineralogy as mentioned above, there is an intimate geographical and geological relation between the metamorphism and the granitic activity. In the eastern axial part of this arrangement, massive granodiorite occurs in the gneissose granodiorite. Generally, there is observed no distinct boundary between this massive rock and the surrounding gneissose granodiorite. These two rocks are, of course, analogous with each other mineralogically.

In the northern and southern limbs of the dome-shaped masses stated above, bedded fine-grained basic rock bodies which are scanty in the northern part of the studied area, increase in amount, and coarse-grained basic rocks occur sporadically. These basic rocks are distributed around these dome-shaped masses and more southern area, as mentioned above.

In the part adjacent to the Median Tectonic Zone in the western area, another dome-shaped mass is assumed to exist, although it is in smaller scale, as compared with the large-shaped masses mentioned above. In this dome-shaped mass, also a comparatively large lens-shaped massive granodiorite develops trending from the east to the west and turns transitionally into gneissose granodiorite towards the north. The dip of the gneissosity of rocks is usually northward in this area. The southern half of this dome-shaped mass is considered to be overlain by the Izumi Group. Besides these two dome-shaped mass groups, several dome-like rock bodies, which are generally of smaller scale as compared with the foregoing large dome-like bodies, are assumed to exist. A granite body, occurring near Koya in the west of Kasagi, is an example.

It is to be noted that the granitic rocks forming the dome-like bodies belong to massive granodiorite and fine-grained granite groups.

4. The Existence of an Anticlinal Structure having a Trend in N-S Direction

In the eastern part of the area of Mt. Sanbosan which is situated on the central area near the Median Tectonic Line, the direction of the extension of the rocks constituting this metamorphic complex is almost similar to that of the Median Tectonic Line, namely, E-W or ENE. A further eastern extension of these rocks is assumed to change its direction to NE, in the east of Ise bay. On the other hand, in the western part, the same rocks clearly change the direction of distribution to WNW or NW. Judging from these facts, a distinct geological structure in N-S direction, which is almost at right angles to the E-W folding structure, is considered to exist and to form a large anticlinal structure. Accordingly, the above-mentioned arrangement of the metamorphic rocks, the writers consider, was formed by the structural control of both N-S and E-W direction. This anticlinal fold in N-S direction is considered to be branched off into two anticlinal folds in the vicinity of Nabari and Igaueno, namely Y-shaped, judging from the distribution of the rocks which have developed in the northern part, especially of the metamorphic rocks of sedimentary origin; one of the branched folds seems to extend to Mt. Suzuka, namely, in the direction of NNE, and the other seems to extend to Kizu, namely, in the direction of NNW. The basement rock under the Igaueno basin, i.e., hornblende-biotite coarse-grained granite situated between these two folds, may be controlled in its occurrence by this under-structure (Unterbau) stated above.

5. The Emplacement of the Granite of the Later Stage (Hornblende-biotite Coarse-grained Granite)

This granite is clearly different from the granitic rocks of the earlier stage in many respects. It is characteristic that this granite is intruded among those rock bodies which constitute the dome-shaped mass, and have mechanically and thermally strong effects on the metamorphic rocks of sedimentary origin, especially in the northern part of this investigated area. The granite body trending in NW—WNW direction, from Mt. Ikoma to Mt. Takami, the rock body* developing around Igaueno, and a small body occurring in the west of Matsusaka City, etc., are considered to belong to this kind of granite group.

These granite bodies, broadly speaking, intruded into geologically low lands between the dome-shaped masses or into the basin-shaped parts of pre-existing rocks, as clear from the geological map. In this respect, the coarse-grained granite is distinctly different from other granites which occur constituting the dome-shaped masses.

The marginal part of the intrusive body of this granite, in general, is clearly basin-shaped. This can be supported not only from the arrangement of the patterns of foliation frequently observed in the granite body but from the differences in rock facies.

6. Structural Summary of the Ryoke Zone

From the results stated above, the geological structure of the Ryoke metamorphic rocks in the Kinki district can be summarized as follows: The metamorphic rocks of sedimentary origin have complicated wavy fold structure in the E-W direction. In the area comparatively near the mylonitization zone mentioned above, there occurs the zone in which the metamorphic grade is high. The metamorphosed basic rock and the granitic rocks of the earlier stage form large dome-shaped masses which trend in the

* the so-called "Yagyu granite"

E-W direction, reaching from Inohara to the south of Nara. The axis connecting these dome-shaped masses coincides approximately with the culmination axis of the metamorphic grade. Comparatively small dome-shaped masses are also observed, e.g., in the northwest of Gojo. The granite of the later stage generally intrudes into geologically low lands between dome-shaped masses and in the synclinal part of the metamorphic rocks of sedimentary origin and forms frequently basin-shaped masses. As a result of these structures, the rocks which constitute this metamorphic complex, viewed on a regional scale, have a structure stretching E-W or NEE in the east part from Mt. Sambosan, and NW-WNW in the central to the west part. Thus, a large distinct arc structure, having the concave side on the north, is observed. From this point, existence of a large folding in N-S direction is considered.

A great number of basic rock bodies interbedded with metamorphic rocks, which develop in the granite situated in the north of Suzuka River in the northern margin of the eastern area, are distributed in the direction of NNE, connecting Amebikiyama-Myojôdake-Fukutoku-Tsuedate. The distribution of these basic rocks may represent a part of the right wing of this arc structure. In this respect, however, further studies are required as to the unmetamorphosed Palaeozoic formation developing in the north of this metamorphic terrain. This arc structure may be possibly related to those of the Palaeozoic formation developing in the Kinki and the Chûbu districts.*

Furthermore, the fold structure in N-S direction is considered to extend to Ôdai mountain range and to be related to the formation of the backbone of the Kii Peninsula. However, a more detailed investigation may be required.

7. The Metamorphism and Movement of the Median Tectonic Zone

After the intrusion of the granitic rocks of the later stage, the movements of the Median Tectonic Zone were happended.

These two kinds of movements, i.e., the movements of the Ryoke Zone proper and of the Median Tectonic Zone, are not independent with each other, but the latter movements are considered as the later stage representatives of the Ryoke movements, judging from the field observation and microscopical investigation of rocks.

In the region in the north of the present Median Tectonic Line, i.e., the boundary between the Ryoke metamorphic complex and the Sambagawa metamorphic complex, the so-called mylonite zone, having a width of 5-6 km, develops. The rocks constituting this area, consist mainly of augen gneissose granite, porphyroid-like granodiorite, protoclastic fine-grained basic rocks, and also Hälleflinta-like mylonite which is de-

* On the structure of the Palaeozoic Formations of the Chûbu District, One of the writers (H.Y.) was given many useful suggestions from Dr. H. Isomi.

rived from the above-stated rocks. Augen gneissose granite and porphyroid-like granodiorite are the results of the protocrushing, operated under a stress condition during the intrusion and crystallization of coarse-grained porphyrytic granite, granodiorite etc., which develop in the north of the mylonite zone. Both augen gneissose granite and porphyroid-like granodiorite are considered to have experienced a crushing which is of higher grade than that which operated on these rocks in the northern area.

The rocks stated above were crushed again after their solidification, i.e., in the time of cataclastic movement and turned into Hälleflinta-like mylonites. This consideration is supported by both the results of field survey and microscopic observation. Hälleflinta-like mylonites mainly develop in a definite rock unit or in boundary parts between different rock units. These protoclastic and cataclastic operations are generally due to the upheaval movement, a kind of thrusting of the Ryoke metamorphic complex over to the Sambagawa metamorphic complex, even though the upheaval is small in amount. Hälleflinta-like mylonite generally has a foliation which dips steeply northward and shows somewhat horizontal lineation.

A number of cinnabar deposits occur, near Niu and Ôuda, in the east and central area in the vicinity of "aplitic" granite body or in the body itself which was leucocratized by cURSHING and hydrothermal alteration. This granite is considered to have been derived from one of the granites of the earlier stage. The ore genesis of cinnabar deposits has been related to the magma of the Muro volcanic rocks by some investigators. But the present writers consider that it should be related genetically to this 'aplitic" granite, judging from the geological and petrological features of this granite.

8. Mutual Relation between the Coarse-grained Hornblende-biotite Granite of the Later Stage in the Ryoke Zone and the Granites in the Northern Kinki District

The granites*, the granites in the northern Kinki district, occurring in the north of this surveyed area and contacting with this kind of Ryoke granites, are the Suzuka granite and the Mikumo granite. Of the latter two, the Suzuka granite is younger. The Mikumo granite grades into this Ryoke granite, but the Suzuka granite is different from the Ryoke granite, in their rock-texture and mineralogy. In the part of contact between this Ryoke granite and the Suzuka granite, and also in the transitional zone between the Ryoke granite and the Mikumo granite, there are hard microbreccias having high dips and are several ten meters wide. The microbreccia in these two parts are considered to be the same, judging from the field survey. This relation is observed at the northern mountain slope of Igaueno and at the southern slope of Suzuka Pass.

* These granites were already discussed in "H. Yoshizawa et al.: Geology and Petrography of Hira granite and Mutual Relations between Granites in the Northeastern Kinki District, Japan" (1965).

This microbreccia zone elongates from Suzuka Pass in the east to Kizu River in the west. Between Igaueno and Kasagi, this microbreccia was covered by the Plio-Pleistocene sediments and afterwards cut by a Pleistocene fault with an elongation direction almost similar to that of the microbreccia. In the west of Kasagi, this microbreccia zone changes its direction to WNW, on which trend appears, from Ide to Mt. Kannabi, a kind of leucocratic biotite granite.

It is considered by the writers that this hard microbreccia is the mylonitic product of the time when the Ryoke metamorphosed members thrusted themselves up to the unmetamorphosed Palaeozoic Tamba members and therefore is similar to the Hälleflinta mylonite of the southern part in formation age.

The writers, moreover, have the opinion that this microbreccia running ENE-WNW, is to be accepted as the northern border of the Ryoke metamorphic zone in the Kinki district. Generally speaking, in the northern Kinki district, granites situated northwardly are younger than those situated southwardly (25).

Besides the geological structure stated in this chapter, tectonic lines which have the direction of N-S and NNE∼NE are observed, and traverse the Miocene and Plio-Pleistocene sediments.

9. Geochronological Investigation

The metamorphism and granitic activities in this metamorphic zone and the granitic intrusion of the northern Kinki district had continued almost throughout the Cretaceous Period ranging from 130 m.y. to 70 m.y.*, according to the Rb-Sr and K-Ar age determinations made by one of the writers (K.I.). The detailed geochronology of this metamorphic zone, will be discussed fully in another paper (9).

References

1) ARITA, T. (1949): On the Kasagi granitic intrusives and the related metamorphic complex, Yamato district, Japan. *Jour. Geol. Soc. Jap.*, **55**, pp. 99—104 (in Japanese with English abstract)
2) HARA, I. (1962): Studies on the Structure of the Ryoke Metamorphic Rocks of the Kasagi District, Southwest Japan. *Jour. Sci. Hiroshima Univ*, C, **4**, pp. 163—224.
3) HARATA, T., ISHIDA, S., ONISHI, I. and TOKUOKA, T. (1963): Plio-Pleistocene Deposits in the Izumi Region. *Earth Sci.*, **66**, pp.1—8.
4) HAYAMA, Y. (1960): Geology of the Ryoke Metamorphic Belt in the Komagane District, Nagano Pref., Japan. *Jour. Geol. Soc. Jap.*, **66**, 773, pp. 87—101.
5) HAYAMA, Y., MIYAGAWA, K., NAKAJIMA, W. and YAMADA, T. (1963): The Kashio Tectonic Zone, Urakawa to Wada Area, Central Japan. *Earth Sci*, 66, pp. 23—31.
6) HOSOMI, M. (1933): Geology of the eastern part of the Izumi Group. Grad. thesis, Geol. Min. Inst., Univ. Kyoto (unpublished)

* Majority of the data showed 110-90 m.y.

7) IIZUKA, Y. (1932): Geological map (1/75,000) "Nojiri". Geol. Surv. Jap.

8) ISHIZAKA, K. (1961): On the granitic rocks in the Mt. Katsuragi—Mt. Kongo area. M.S. thesis, Geol. Min. Inst., Kyoto Univ. (unpublished)

9) ISHIZAKA, K. (1966): A Geological and Geochronological Study of the Ryoke Metamorphic Terrain in the Kinki District, Japan (to be published in *Mem. Coll. Sci., Univ. Kyoto*, B).

10) IWAO, S. (1940): The Origin of the Basic Inclusions in the Granitic Rocks of the Yanai District, Japan, and their Petrographical Features. *Jap. Jour. Geol. Geogr.*, **17**, pp. 164—172.

11) KATADA, M., ISOMI, H., YAMADA, N., MURAYAMA, M., and KAWADA, K. (1961): Geology of Japanese Central Alps and Its Western Area (3). *Earth Sci.*, **57**, pp. 12—23. (in Japanese with English abstract)

12) KISHIMOTO, F. and HIRAYAMA, K. (1957): Geol. Map. (1/50,000) "Yoshinoyama" and its expl. text. Geol. Surv. Japan. (in Japanese with English abstract).

13) KOBAYASHI, T. (1951): Regional Geol., Japan (General remarks). (in Japanese)

14) MATSUSHITA, S. (1953): Regional Geol., Japan (Kinki region). (in Japanese)

15) MIYASHIRO, A. (1961): Evolution of Metamorphic belts. *Jour. Petrol.*, **2**, pp. 277—311.

16) NAKAJIMA, W. (1957): On the Ryoke Plutonic rocks in the vicinity of Tsukigase Village. Scientific Research Report, "Tsukigase", pp. 18—46. (in Japanese).

17) NAKAJIMA, W. (1959): The History of Ôuda Town, (Geological Section). (in Japanese).

18) NAKAJIMA, W. (1960): Geology of the northern margin of the Ryoke zone in the Yamato Plateau. *Earth Sci.*, **49**, pp. 1—14. (in Japanese with English abstract).

19) OGATA, M. (1959): On the plutonic rocks in the Suzuka Mountain Range. *Earth Sci.*, **43**, pp. 1—10. (in Japanese with English abstract).

20) OKAMURA, Y. (1960): Structural and Petrological Studies on the Ryoke Gneiss and Granodiorite Complex of the Yanai District, Southwest Japan. *Jour. Sci. Hiroshima Univ.*, C, **3**, pp. 143—213.

21) SUWA, K. (1956): Plagioclase twinning in Ryoke metamorphic rocks from the Mitsue-Mura area, Kii Peninsula. *Jour. Earth Sci., Nagoya Univ.*, **4**, pp. 91—122.

22) YAMAMOTO, A. (1952): Geology of the southwestern area of Tanabe Town, Kyoto Prefecture. Grad. thesis, Geol. Min. Inst., Univ. Kyoto. (unpublished)

23) YAMASHITA, N. (1957): Mesozoic Era. (in Japanese)

24) YOSHIZAWA, H. (1949): On the norites having zonal arrangement in the Ryoke Zone, Southwest Japan. (in Japanese) *Earth Sci.*, 1, pp. 1—6.

25) YOSHIZAWA, H. (1952): The Metagabbroic Rocks Bearing Ferriferous Minerals in the Ryoke zone, Japan. *Mem. Coll. Sci., Univ. Kyoto*, B, **20**, pp. 55—68.

26) YOSHIZAWA, H. et al. (1964): Geol. Map (1/200,000) of Mie Prefecture.

27) YOSHIZAWA, H., ISHIZAKA, K., KANEKO, K. and KAWAHARA, M. (1965): Geology and Petrography of the Hira Granite, and Mutual Relations between Granites in the Northeastern Kinki District, Japan. *Mem. Coll. Sci. Univ. Kyoto.*, B, **31**, no. 4, pp. 279—289.

727-72

Geological Map of the Ryōke Complex of the Kinki District, Japan

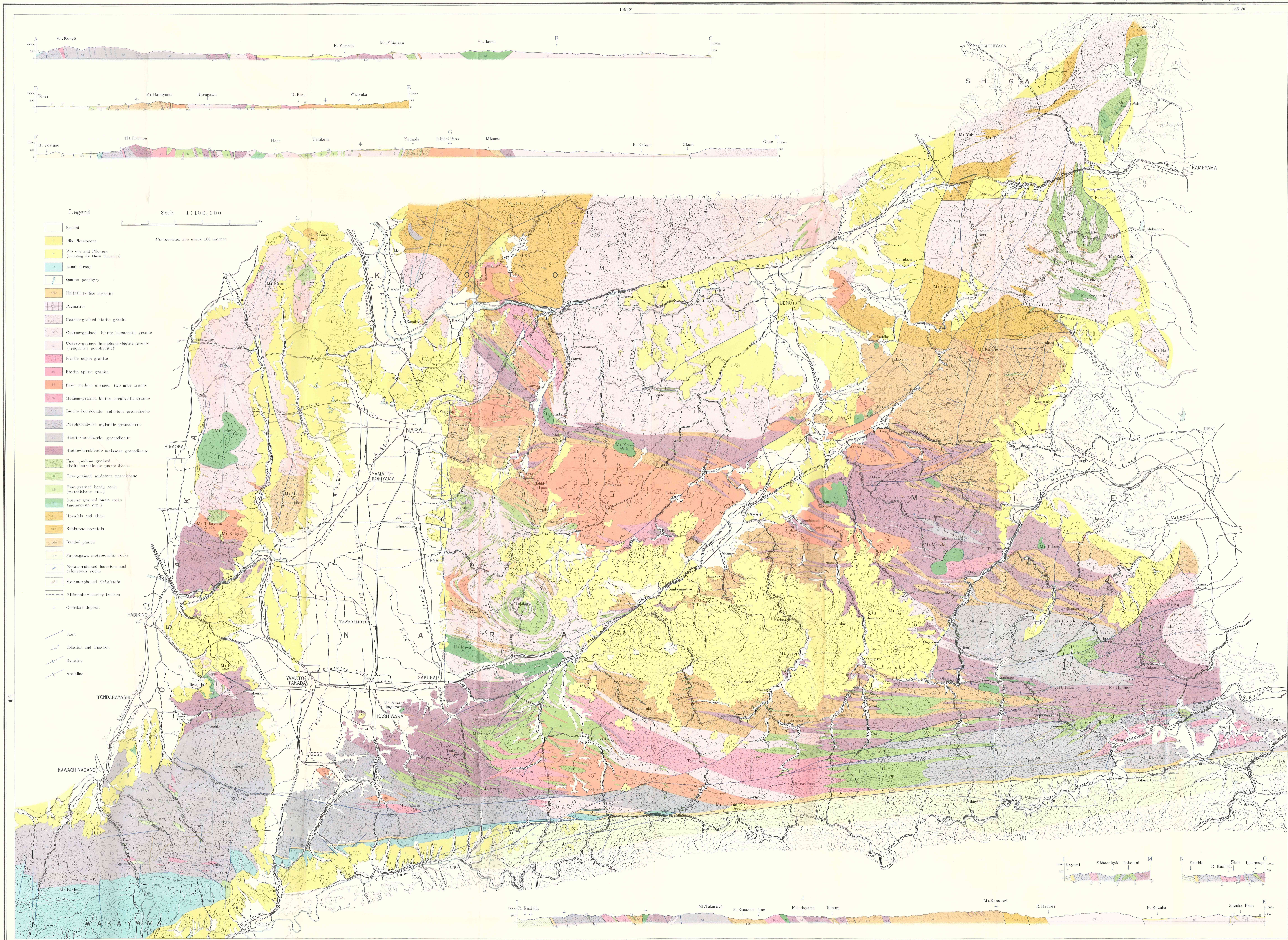
1965

By Hajime Yoshizawa, Waitsu Nakajima and Kyōichi Ishizaka

GEOLOGICAL MAP OF THE RYŌKE COMPLEX OF THE KINKI DISTRICT, JAPAN

1965

By Hajime Yoshizawa, Waitsu Nakajima and Kyoichi Ishizaka



Drawn by Sanzō Mori

Printed by Toppan Printing Co., Ltd. Japan