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Nature of the Ryôke Regional Metamorphism and Plutonism

By

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Abstract

Regional metamorphism and the older granitic intrusions in the Ryôke zone took place in a term between late Jurassic to early Cretaceous. On the other hand the younger granitic intrusions did in late Cretaceous. The Ryôke regional metamorphism and plutonism occurred not in accompaniement with the subsidence of the Honshû geosyncline but in rather non-subsidence region. They do not belong to the so-called axial plutono-metamorphic zone of the orogenic belt.

The metamorphism is characterized by both low solid- and low water-vapour pressures, and has a nature very similar to contact metamorphism around granite pluton. The older granitic intrusions bear the intimate connection with the metamorphism and acted on as main heat-source of the latter. They have distinct geochemical and mineralogical characters from other Cretaceous granitic rocks in the inner zone of southwest Japan. This feature is resulted from the fact that they took activities in the Ryôke zone, a special zone.

It is still to be elucidated that the colossal heat-energy, sufficent to high-temperature metamorphism and formation of vast granitic magmas, is concentrated to the long narrow Ryôke zone. It must be a phenomenon to be explained in regard to the geological developments of the Japanese Islands since the Honshû orogeny to the late-Mesozoic acid igneous activities.

It becomes to be generally accepted that the Ryôke regional metamorphism and plutonism belong to the late-Mesozoic acid igneous activities as a whole. However, the mutual relations to the Honshû orogeny have also to be paid attention to.

I. Introduction

Even nowadays, it is regarded in some quarters that the Ryôke zone corresponds to the so-called "axial plutono-metamorphic zone" of the orogenic belt. However, in view of the nature of metamorphism and the geological situation of the Ryôke zone, it is very difficult to consider that the metamorphism and plutonism took place in accompaniement with the subsidence of the Honshû geosyncline. On the other hand, the younger granitic intrusions in the Ryôke zone belong to the late-Mesozoic acid igneous activities, extensively occurred in the inner zone of Southwest Japan. Therefore, it still remains problematic as regard to the situation of the regional metamorphism and the older granitic intrusions of the Ryôke zone in the geological

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developments of the Japanese Islands.

Here, to answer the question what is the Ryôke zone, the author would like to inquire its geochronological aspects and nature of plutonism and regional metamorphism.

II. Historical Review

Outline of history of researches and changes of point of view on the Ryôke zone has been summarized in RESEARCH GROUP FOR THE RYÔKE BELT (1975) and KUTSUKAKE (1977). In this section the essential points related to the above-mentioned aspects will be briefly touched.

The name "Ryôke" was first adopted by HARADA (1890) to a series of gneisses, having common features, as "Riokeschiefer". (This term means such rock types as, mica schists, mica gneisses and schistose to gneissose granites). And it has no means to show any geological units in the Japanese Islands. In those days, these rocks have been regarded to be Pre-cambrian (Archean) in age. Thereafter, in 1920's the evidences of transition of the Ryôke metamorphic rocks to the nearly non-metamorphic Palaeozoic formations were confirmed by ISHII, then it became to be considered that the Ryôke zone was formed by the orogenesis undergone from late Palaeozoic to early Mesozoic (SUGI, 1933). Summarizing the geohistory of the Japanese Islands, KOBAYASHI (1941) proposed the opinion that the Ryôke zone as well as the Mikabu and the Sambagawa belts are the axial part of his Sakawa orogenesis of late-Mesozoic. He regarded the Ryôke zone to be plio-magmatic zone. After the World War II, young geologists, mainly members of the Association of Geological Collaboration, carried out investigations in various fields. For the Ryôke zone, KOIDE's (1949) monumental work on the granitic and metamorphic rocks in the Dando-san area, Aichi Prefecture, performed under the difficult condition during the War, played a leading function. In these circumstances, the opinion opposing to KOBAYASHI's appeared, represented by GORAI (1952, 1955) and YAMASHITA (1957), that the Ryôke zone was formed by the Honshû orogeny of late-Palaeozoic to early Mesozoic. The general view on the Ryôke zone up to 1960 can be summarized as follows; sedimentation and diagenesis of Carboniferous to Permian formations (Honshû geosyncline) → Ryôke plutono-metamorphism (Honshû orogeny, *sensustricto*) → upheaval and erosion of the Ryôke zone → eruption of acid volcanic rocks, such as the Nôhi rhyolites in the inner side of the Ryôke zone → intrusions of the Naégi-Agematsu granites (KATADA *et al.*, 1961). But, in 1960's isotopic age determinations on the granitic and metamorphic rocks of the Ryôke zone were carried out by both K-Ar and Rb-Sr methods and other methods. The data are mostly concentrated between 70 and 100 m.y., and no Triassic ages have been obtained. On the other hand, various new informations were taken on the nature of the Ryôke regional

metamorphism, and it became to be considered that the metamorphism took place not in the axial part of the orogenic belt but non-subsidence region (HAYAMA, 1962). Moreover, in 1965 the Inagawa granite which had been regarded to be a representative of the older granites in the Ryôke zone, was found to be intruded into the Nôhi rhyolites (SAKAI *et al.*, 1965; YAMADA, 1966). This finding presented an important problem to the chronology of the Ryôke plutonism. Thereafter, the granites in the Ryôke zone of the Chûbu district are divided into the 'pre-Nôhi granites' and the 'post-Nôhi granites' on the basis of the activity of the Nôhi rhyolites (RYÔKE RESEARCH GROUP, 1972). Obviously the post-Nôhi granites form the volcano-plutonic association with the Nôhi rhyolites, and belong to the late-Mesozoic acid igenous activities. On the other hand, the age of the Ryôke regional metamorphism and the pre-Nôhi granites is not settled so far (RESEARCH GROUP FOR THE RYÔKE BELT, 1975).

III. Geochronology

Geochronological aspects of the Ryôke zone has been discussed in some detail in another paper (RESEARCH GROUP FOR THE RYÔKE BELT, 1975). Here, essential points will be reproduced.

As mentioned above, the younger granitic intrusions in the Ryôke zone took place in late-Cretaceous. But, the age of the Ryôke regional metamorphism and the older granitic intrusions is now considered to be before middle Cretaceous and go back up to late-Jurassic. They never go back to either Triassic or late Permian in age contrary to several authors' opinion.

IV. Nature of the Regional Metamorphism

It has been pointed out from the early days of researches that the Ryôke regional metamorphism has a character of contact metamorphism around granite pluton. SUGI (1933), a pioneer of modern metamorphic petrology in Japan, called it "contact metamorphism wide-spread in regional scale". (Prior to him, T. OGAWA had a similar view.)

In this connection, ISHIOKA (1974) suggested that the Ryôke regional metamorphism should be called "regional thermal metamorphism", characterized by K-feldspar-cordierite association in pelitic rocks.

Besides the above-mentioned association, andalusite commonly occurs as characteristic mineral in pelitic rocks. Moreover, biotite and muscovite go into reaction to form K-feldspar-cordierite association in the early stage of the metamorphism, and obvious chlorite zone is absent. Andalusite-sillimanite transition and muscovite

breakdown are recognized as metamorphic reactions in pelitic rocks. These mineralogical features must be resulted from the metamorphism that has taken place under low-solid as well as low-water-vapour pressures (HAYAMA, 1962, 1964). The metamorphic condition is schematically shown in KUTSUKAKE (1977, Fig. 28).

Although the character of the metamorphism is very similar to that of contact metamorphism, it is not exactly the equivalent. For example, the association of muscovite-sillimanite-K-feldspar-quartz, that has never been recorded from contact metamorphic rocks, is usually found in the Ryôke metamorphic rocks, and it is due to the local balance of water-vapour pressure and speed of dehydration (KUTSUKAKE, 1977). In view of Mg-Fe partitioning between coexistent garnet and cordierite, it is suggested that the metamorphism took place under slightly higher pressure than usual contact metamorphism (ONO, 1969, 1977; KUTSUKAKE, 1977).

From the present distributional pattern of metamorphic zones in the Ryôke zone of the Chûbu district, it can be reconstructed the thermal structure at the time of metamorphism. This geothermal status can not be explained by slightly higher geothermal gradient than usual, but it calls for comparatively large efficient heat-source of temperature of 700~800°C (TURNER, 1968). It must be a granitic magma. Therefore, the Ryôke regional metamorphism must be caused by the vast granitic intrusions of the older group, represented by the Tenryûkyô granite in the Chûbu district, in batholithic extent. As the main cause of thermal upheaval owes to the granitic intrusions, so it can be said that the metamorphism is of a type of contact metamorphism.

Generally accepted schema of metamorphism and granitization, which occur in accompaniement with the subsidence of the orogenic belt after the geosynclinal stage, can not be adopted to those of the Ryôke zone. It is not appropriate to apply the concept of axial plutono-metamorphic belt in the classic orogen theory of STILLE-KOBER's sense to the Ryôke zone.

ASAMI (1971) found a staurolite-bearing mica schist from the Hazu area, Aichi Prefecture. Accordingly, SUWA (1973) insisted that the Ryôke regional metamorphism should be divided into the two stages; the earlier one is of low to moderate pressure intermediate type, and the later one of andalusite-sillimanite type facies series of MIYASHIRO (1961). However, it is not necessarily required to divide the metamorphism into two stages of different natures, as it is also possible to consider that the metamorphism in the Hazu area took place under slightly different condition from those of other areas. Recently, ASAMI (1977) stated that these staurolite-bearing mica schists are formed under higher pressure than another areas in the Ryôke zone. Taking the original rock of the staurolite schist into consideration, it is not proper to regard the rock to be a fragment of the basement complex, but it is a common Ryôke metamorphic rock.

V. Basic and Ultrabasic Rocks

In the Ryôke zone, there occur sporadically small masses of basic and ultrabasic rock in the granites and metamorphic rocks of sedimentary origin. These rocks would bring about informations on the basement of the Ryôke zone, and have a role of time-markers of the plutonism and metamorphism.

The present author has already reported the results of his studies on these rocks in several papers (KUTSUKAKE, 1970, 1973, 1974, 1975a, 1978), and also attempted to make formulations (KUTSUKAKE, 1975b). In this section he briefly summarizes the present available results for further study.

Basic rocks are classified into two large clans; the so-called "metadiabase" and "metagabbro". Cortlandtite is a sole ultrabasic rock so far reported.

(1) *"Metadiabase"* is found in the metamorphic rocks of sedimentary origin in dyke or sheet-like form. They are generally several metres to several tens of metres in width, and rarely attain to ten kilometres in extent, as that of the Toyone-mura area (KUTSUKAKE, 1975a).

The main rock type is fine-grained dark greenish coloured and compact rock, composed mainly of plagioclase, hornblende, biotite and quartz, sometimes with cummingtonite and/or potash feldspar. It usually shows metamorphic granoblastic texture, but, frequently preserves ophitic to subophitic texture of the original igneous rock. Blastoporphyritic plagioclase is dirty and calcic, and sometimes retains original high-temperature (volcanic) optics. Granitization is recognized for all over the mass, and various acid products are formed, such as tonalitic to adamellitic rocks. Even the rock, which seems to be equivalent to the original rock, is rich in K_2O and poor in MgO. Thus, metasomatism must have played an important role during metamorphism (ISHII and YAMADA, 1962; ONO, 1971; KUTSUKAKE, 1970, 1975a).

These rocks in general lack in schistosity and include gneisses as xenolith. Therefore, the original igneous rocks must have intruded into the sedimentary rocks being metamorphosed and suffered the continued metamorphism together with the host rocks, under the influence of metasomatism. Their original rocks seem to be aluminous tholeiitic dolerite.

(2) *Gabbro*

It has been pointed out that norites show zonal arrangements. Especially in the Kinki district, two zones of their arrangements can be recognized (YOSHIZAWA, 1949; YOSHIZAWA *et al.*, 1966). Gabbroic rocks are mainly olivine norite, and subordinately pyroxene-hornblende gabbro.

In view of the crystallization sequence of minerals, they are of typical calc-alkaline series. Charactiristically plagioclase is calcic, attaining to anorthite. These rocks probably belong 'calcic gabbro' (WILKINSON, 1967), like the San Marcos gabbros in the southern California batholith (MILLER, 1937).

Between the gabbro and its host granite, reaction zones are formed, and more acid dioritic facies is developed at its margin. Gabbro mass which occurs in the metamorphic rocks, does not give contact metamorphism to the neighbouring rocks. Therefore, they must have intruded in solid-state after the culmination of the Ryôke regional metamorphism. As regard their metamorphism, it is characteristically of retrogressive one, from amphibolite to green schist facies and to still lower facies. This metamorphism does probably not correspond to the regional metamorphism, but took place during the upheaval of the mass.

Hornblende gabbro mass structurally concordant to the surrounding granites, such as that of the Hatsuse basin in the Kinki district, must bear intimate genetical relations with the granites. The gabbro probably represents the basic portion and the granites do the acid one resulted from the differentiation of intermediate magma.

(3) *Cortlandtite* was formed as cumulate from basic magma which took place crystallization under high water-vapour pressure in the middle crust beneath the Ryôke zone. The residual magma later solidified to the above-mentioned norites. Cortlandtite is intruded in solid-state into the gneiss, and suffered retrogressive metamorphism during upheaval of the mass, as in the case of gabbro (KUTSUKAKE, 1978).

(4) *Metamorphosed basic dykes* in the granites have attracted attention of many investigators, and have been called "dyke-like xenolith". Recently, NISHIURA RESEARCH GROUP (1974) and ISHIOKA (1974) described these dykes in detail. These dykes are intruded after consolidation of the host granite, and suffered metamorphism and granitization. These effects are not due to the Ryôke regional metamorphism, but to the later magmatic activity of the host granite. The original rocks are considered to be tholeiitic dolerite. Since SEDERHOLM's (1923) work, it has been generally taken the view that basic dykes represent an important episode to separate the orogenic cycles. However, in the Ryôke zone it is not settled so far as to the meanings of these dykes.

VI. On the Granites

Since KOIDE's (1949) work, classification of granites in the Ryôke zone into the 'older' and 'younger' groups became routine. The older granites are structurally harmonic and concordant to the surrounding metamorphic rocks, and seem to bear intimate connection with the regional metamorphism. Generally they show schistose to gneissose structure. On the other hand, the younger granites give contact metamorphism to the surrounding metamorphic rocks, and structurally discordant to them. Generally they exhibit massive appearence.

In the Chûbu district, it is proposed by RYÔKE RESEARCH GROUP (1972) that the Ryôke granites can be classified into the 'pre-Nôhi' granites and the 'post-Nôhi' granites, in relation to the activity of the Nôhi rhyolites.

The younger granites (post-Nôhi granites) are regarded to belong to the late-Mesozoic acid igneous activities, and form the volcano-plutonic association with the Nôhi rhyolites. The older granites are considered to have been formed in deeper levels in view of their structural and petrological characters.

Recently, on the Ryôke granites mineralogical (hornblende, biotite, oxide minerals, etc.) and geochemical (strontium, oxygen isotope and D/H ratios, etc.) investigations have been carried out by several researchers (KAGAMI, 1973; KURODA *et al.*, 1974; HONMA and SAKAI, 1975; TSUSUE and ISHIHARA, 1974; KANISAWA, 1975; SHIBATA and ISHIHARA, 1976), and their characteristics are being elucidated. The results and consequences are well summarized in HONMA (1976).

The older granites have exchanged the materials between the metamorphic rocks on a vast scale, and released hydrothermal solutions rich in alkalies prior to their intrusions. So the "metadiabases" have suffered intense granitization for all over the mass, and various migmatites are formed in the Yanai district (OKAMURA, 1960; HONMA, 1974a).

These granites show low Fe^{+3}/Fe^{+2} ratio for whole rock composition as well as constituent mineral composition. They are poor in oxide minerals and essentially lack in magnetite. It is considered to have been formed under low-oxygen fugacity condition (TSUSUE and ISHIHARA, 1974; HONMA, 1974b; KANISAWA, 1975).

On the other hand, intrusions of the younger granites separated the original Ryôke metamorphic terrain into several blocks, and made it difficult to be restored. Moreover, they gave contact metamorphism to the surrounding Ryôke metamorphic rocks, and it became difficult to lay down the metamorphic zonation for the regional metamorphism.

From the central part of the Kinki district to the Setouchi and Shikoku districts, the younger granites are distributed in the side near the Median Tectonic Line, and the Ryôke metamorphic rocks and the older granites occupy the narrow belt to the north (KUTSUKAKE *et al.*, 1979; YAMADA *et al.*, 1979).

VII. Geological Situation of the Ryôke Regional Metamorphism and Plutonism

Various explanations may be possible as to the situation of the Ryôke plutono-metamorphism in the geological developments of the Japanese Islands. There may be no contradictions to regard that the younger granitic intrusions belong to the late-Mesozoic acid igneous activities. But, the situation of the regional metamorphism and the older granitic intrusions still remains problematic. As mentioned above, the metamorphism is considered to have taken place in the non-subsidence region, and it went not in accompaniement with the subsidence of the Honshû geosyncline. The

concept of the so-called axial plutono-metamorphic zone of the orogenic belt can not be adopted to the Ryôke zone, and it was not formed in the core of the Honshû orogenic belt. On the other hand, the original sediments of the Ryôke metamorphic rocks are now made clear to extend into late Triassic (~Jurassic) in age. If the time of the metamorphism is late-Jurassic, time-interval between the sedimentation and the metamorphism becomes to be very short. Thus, it is not strained to consider that there are no inevitable consequences between the Ryôke plutono-metamorphism and the development of the Honshû geosyncline. Although there are much confusions on the definition of the Honshû orogeny, we can not deny away the possibility of the mutual relation between the two events, even if the Ryôke zone does not correspond to the axial plutono-metamorphic zone. However, in the Mesozoic tectonic movements in the circum-Pacific region, geological phenomena very similar to those of the Ryôke zone are known preceeding to vast acid volcano-plutonism (HAYAMA, 1971). Therefore it is proper to consider that the Ryôke plutono-metamorphism forms a part of the late-Mesozoic igneous activities, extensively occurred in Southwest Japan, as their initiative phenomena (HAYAMA, 1962).

It is sure that the Ryôke zone, a narrow and long belt extending to 1500 kilometres in length, bears special geological nature, having a character of tectonic zone. The mechanism and cause of heat concentration are still to be elucidated, for high-temperature metamorphism and extensive granitic plutonism. It must be a problem to be explained in regard to the geological development of the Japanese Islands during Mesozoic Era from the Honshû geosyncline to the late-Mesozoic acid igneous activities.

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References

ASAMI, M. (1971): Finding of staurolite-bearing pelitic schist in the Ryôke metamorphic belt of central Japan. *Proc. Japan Acad.*, **47**, 511–516.

——— (1977): Two modes of occurrence of staurolite from the Ryoke metamorphic rocks in the Hazu area, central Japan. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **72**, 205–219.

GORAI, M. (1952): Origin of the Japanese Islands (I, II, III). *Nature (Shizen)*, **7** (3, 4, 5) (in Japanese).

——— (1955): *Igneous petrogeny* (in Japanese). Assoc. Geol. Collab. Japan, Tokyo.

HAYAMA, Y. (1962): Mutual relations between the Sangun, the Sambagawa and the Ryoke metamorphic belts in South-west Japan. *Earth Science (Chikyû Kagaku)*, No. 63, 25–32 (in Japanese with English abstract).

——— (1964): Progressive metamorphism of pelitic and psammitic metamorphic rocks in the Komagane district, Nagano Pref., central Japan. *Jour. Fac. Sci., Univ. Tokyo, Sec. II*, **15**, 321–369.

——— (1971): The nature of the Mesozoic acid igneous activities in the North America Cordillera. *Earth Science (Chikyû Kagaku)*, **25**, 108–128 (in Japanese with English abstract).

HONMA, H. (1974a): Major element chemistry of metamorphic and granitic rocks of the Yanai district in the Ryoke belt. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **69**, 193–204.

——— (1974b): Chemical features of biotities from metamorphic and granitic rocks of the Yanai district in the Ryoke belt. *ibid.*, **69**, 390–402.

——— (1976): Genetic relationship between the Hiroshima and Ryoke granites as indicated by some geochemical evidences. *Papers Inst. Thermal Spring Research, Okayama Univ.*, No. 45, 33–46 (in Japanese with English abstract).

——— and SAKAI, H. (1975): Oxygen isotope study of metamorphic and granitic rocks of the Yanai district in the Ryoke belt, Japan. *Contr. Mineral. Petrol.*, **52**, 107–120.

ISHII, M. and YAMADA, T. (1962): On the granitization of metadiabase in the vicinities of the Koshibu River, Nagano Prefecture. *Jour. Geol. Soc. Japan*, **68**, 109–117 (in Japanese with English abstract).

ISHIOKA, K. (1974): Finding of an orbicular structure at Kinno, Nagano-ken, and its bearing on the genesis of the Tenryukyo granite. *ibid.*, **80**, 593–618.

KAGAMI, H. (1974): A Rb-Sr geochronological study of the Ryôke granites in the Chûbu district, central Japan. *ibid.*, **79**, 1–10.

KANISAWA, S. (1975): Chemical composition of hornblendes of some Ryoke granites, central Japan. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **70**, 200–211.

KATADA, M., ISOMI, H., YAMADA, N., MURAYAMA, S. and KAWATA, K. (1961): Geology of Japanese Central Alps and its western area, (3) Geologic structure of Ryôke zone. *Earth Science (Chikyû Kagaku)*, No. 57, 12–23 (in Japanese with English abstract).

KOBAYASHI, T. (1941): The Sakawa orogenic cycle and its bearing on the origin of the Japanese Islands. *Jour. Fac. Sci., Imp. Univ. Tokyo, Sec. II*, **5**, 219–578.

KOIDE, H. (1949): *Dando granodioritic intrusives and their associated metamorphic complex.* Assoc. Geol. Collab. Japan, Monograph, No. 3, 37 pp. (in Japanese).

KURODA, Y., SUZUOKI, T., MATSUO, S., and KANISAWA, S. (1974): D/H fractionation of coexisting biotite and hornblende in some granitic masses. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **69**, 95–102.

KUTSUKAKE, T. (1970): On the Ryôke granitic and metamorphic rocks in the Toyone-mura area, Aichi Prefecture, Japan. *Mem. Fac. Sci., Kyoto Univ., Ser. Geol. & Mineral.*, **37**, 133–160.

——— (1973): Structure and petrography of the Hatsuse basin in the Ryôke zone of the Kinki district, Japan. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **68**, 37–57.

——— (1974): Petrology of the gabbroic rocks in the Ryôke zone of the Toyone-mura area, Aichi Prefecture, Japan. *ibid.*, **69**, 52–74.

——— (1975a): Metabasites in the Ryôke zone of the Toyone-mura area, Aichi Prefecture, Japan. *ibid.*, **70**, 177–193.

——— (1975b): Basic rocks in the Ryôke zone. *MAGMA*, Nos. 41·42, 14–17 (in Japanese).

——— (1976): Distribution of major and some minor elements in pelitic metamorphic rocks in the Ryôke zone of central Japan, in comparison with the non-metamorphic 'Palaeozoic' shales. *Mem. Fac. Sci., Kyoto Univ., Ser. Geol. & Mineral.*, **42**, 107–129.

——— (1977): Petrological studies on the Ryôke metamorphic rocks in the Toyone-mura area, Aichi Prefecture, Japan. *ibid.*, **43**, 49–110.

——— (1978): Cortlandtite from Tomiyama-mura, Aichi Prefecture, Japan —— A contribution to the genesis of cortlandtites in the Ryôke zone. *ibid.*, **45**, 55–67.

———, HAYAMA, Y., HONMA, H., MASAOKA, K., MIYAKAWA, K., NAKAI, Y., YAMADA, T., and YOSHIDA, M. (1979): Geology and petrography of the Ryôke belt in the Shodo-shima Island and the eastern Sanuki region. *Mem. Geol. Soc. Japan*, No. 17, 47–68 (in Japanese with English abstract).

MILLER, F. S. (1937): Petrology of the San Marcos gabbros, southern California. *Bull. Geol. Soc. Amer.*, **48**, 1397–1425.

MIYASHIRO, A. (1961): Evolution of metamorphic belts. *Jour. Petrol.*, **2**, 277–311.

NISHIURA RESEARCH GROUP (1974): Ryoke metamorphic rocks of the Nishiura peninsula, Aichi Prefecture, central Japan, with special reference to metamorphosed dykes. *Earth Science (Chikyû Kagaku)*, **28**, 71–85 (in Japanese with English abstract).

ONO, A. (1969): Zoning of the metamorphic rocks in the Takato-Siojiri area, Nagano Prefecture. *Jour. Geol. Soc. Japan.*, **75**, 521–536 (in Japanese with English abstract).

——— (1971): Chemical reaction between amphibolite and gneiss, Takato district, Ryôke region. *Jour. Japan. Assoc. Min. Petr. Econ. Geol.*, **66**, 147–155 (in Japanese with English abstract).

——— (1977): Temperature and pressure of the Ryoke gneisses estimated by garnet-cordierite geothermometer. *ibid.*, **72**, 114–117.

RESEARCH GROUP FOR THE RYÔKE BELT (1975): Review and comments on the studies of the Ryôke plutono-metamorphism——with special reference to its geochronological aspects. *Assoc. Geol. Collab. Japan, Monograph*, No. 19, 203–208 (in Japanese with English abstract).

RYÔKE RESEARCH GROUP (1972): The mutual relations of the granitic rocks in the Ryôke metamorphic belt in central Japan. *Earth Science (Chikyû Kagaku)*, **26**, 205–216 (in Japanese with English abstract).

SAKAI, E. *et al.* (1965): Preliminary report of the succession of intrusions of the Mesozoic igneous rocks in the areas of Mizunami-shi, Ena-shi, Nakatsugawa-shi and Ena-gun, Gifu Prefecture. *Bull. Aichi Gakugei Univ.*, No. 14, 61–71 (in Japanese).

SEDERHOLM, J. J. (1923): On migmatites and associated Pre-Cambrian rocks of South-western Finland, Part I. The Pellinge region. *Bull. Comm. géol. Finlande*, No. 58.

SHIBATA, K. and ISHIHARA, S. (1976): Regional variation of the initial $^{87}Sr/^{86}Sr$ ratios of the plutonic rocks Japan. *Program 83rd Ann. Meeting Geol. Soc. Japan, Matsumoto*, p. 307 (in Japanese).

SUGI, K. (1933): General remarks on the metamorphic rocks of Japan——with special reference to the Ryôke metamorphic rocks. In Iwanami-Kôza: *"Geology, Palaeontology, Mineralogy and Petrology"* (in Japanese). Iwanami, Tokyo.

SUWA, K. (1973): Metamorphic rocks occurring along the Median Tectonic Line in the Japanese Islands: Ryoke and Sambagawa metamorphic belts. In *"Median Tectonic Line"* (R. SUGIYAMA, ed.), pp. 221–238 (in Japanese with English abstract). Tokai Univ. Press, Tokyo.

TSUSUE, A. and ISHIHARA, S. (1974): The iron-titanium oxides in the granitic rocks of Southwest Japan. *Mining Geol.*, **24**, 13–30 (in Japanese with English abstract).

TURNER, F. J. (1968): *Metamorphic petrology: mineralogical and field aspects.* xi+403 pp. McGraw-Hill, New York, etc.

WILKINSON, J. F. G. (1967): The petrography of basaltic rocks. in "*Basalts*", **1** (H. H. HESS and A. POLDERVAART, eds.), 163–214. Interscience, New York.

YAMADA, N. (1966): Finding of a Ryôke granite intruding into the Nôhi rhyolite, and its significance. *Jour. Geol. Soc. Japan*, **72**, 355–358 (in Japanese).

YAMADA, T., HAYAMA, Y., KAGAMI, H., KUTSUKAKE, T., MAENO, S., MASAOKA, K., NAKAI, Y., and YOSHIDA, M. (1979): Geology of the Ryôke belt in the Sennan district, Osaka Prefecture, Japan. *Mem. Geol. Soc. Japan*, No. 17, 209–220 (in Japanese with English abstract).

YAMASHITA, N. (1957): *Mesozoic Era* (in Japanese). Assoc. Geol. Collab. Japan, Tokyo.

YOSHIZAWA, H. (1949): On the norites having zonal arrangement in the Ryôke zone of the southwest Japan. *Earth Science* (*Chikyû Kagaku*), No. 1, 11–16 (in Japanese).

————, NAKAJIMA, W., and ISHIZAKA, K. (1966): The Ryoke metamorphic zone of the Kinki district: Accomplishment of a regional geological map. *Mem. Coll. Sci., Univ. Kyoto, Ser. B*, **32**, 437–454.