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Contributions to the Knowledge of Mutual Relations between Three Metamorphic Zones of Chûgoku and Shikoku, Southwestern Japan, with Special Reference to the Metamorphic and Structural Features of Each Metamorphic Zone

by

George KOJIMA

CONTENTS

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Introduction

Three metamorphic zones in Southwestern Japan The basement geology of Southwestern Japan is characterized by zonal arrangement of older formations and their metamorphic equivalents. The northern zone is composed of Palaeozoic rocks and crystalline schists of low grade, and is named the **Sangun**[1] **metamorphic zone.** The central zone, just north of the Median Dislocation Line, is characterized by batholithic intrusives of granodioritic rocks and thermally metamorphosed rocks, including banded gneisses, and is named the **Ryôke**[2] **metamorphic zone.** Along the southern boundary of the Ryôké metamorphic zone, bordered by the Median Dislocation Line, a zone of crystalline schists is developed, which is named the **Sambagawa**[3] **metamorphic zone.** The distribution of these three metamorphic zones in Southwestern Japan is sketched in the adjoining figure (Fig. 1)

Interpretations, hitherto proposed, on the mutual relations between the three metamorphic zones Metamorphic rocks of the basement geology in Japan have been mainly studied by metamorphic petrologists, independently, in separate districts, and the mutual relations and systematic historical development of the metamorphic zones, to which these metamorphic rocks belong, have been unduly neglected till quite recently. In 1941, T. Kobayashi summarized the Palaeozoic and Mesozoic geology of Japan, and correlated the genetical history of basement metamorphic zones with the epicrustal movements. He distinguished between the Akiyoshi orogenic cycle (late-Palaeozoic~early-Mesozoic) and the Sakawa orogenic cycle (middle-~late-Mesozoic). After Kobayashi, the Sangun and the Hida[4] metamorphic zones represent the axial metamorphism of the Akiyoshi orogenic cycle, and the Ryôké and the Sambagawa

1) The name "Sangun" is derived from the Sangun mountainland in Northern Kyûshû (Fukuoka Prefecture), where crystalline schists are rather extensively exposed.

2) The name "Ryôké" is derived from the Ryôké district in the upper drainage-basin of the River Tenryû in the Chûbu provinces, Central Japan.

3) The name "Sambagawa" is derived from the River Sambagawa, a tributary of the River Toné, in the Kantô mountainland, Central Japan.

4) The Hida metamorphic zone comprises gneisses, crystalline schists of either higher (such as sillimanite-, cyanite-, and staurolite-bearing schists) or lower grade, and granitic intrusive rocks. Districts of the Hida metamorphic zone had been disregarded till quite recently, for the sake of difficulty of communication. Since Kobayashi's paper was published, our knowledges of the Hida metamorphic zone have been much advanced by the members of the "Research Group of Hida", and some metamorphic and intrusive rocks are regarded as the pre-Gotlandian (probably pre-Cambrian) basement rocks of the Chichibu geosyncline. Regrettably, however, the geological synthesis of the Hida metamorphic zone has not been published until now. According to our present knowledge of the Hida metamorphic zone, Kobayashi's interpretation seems untenable.

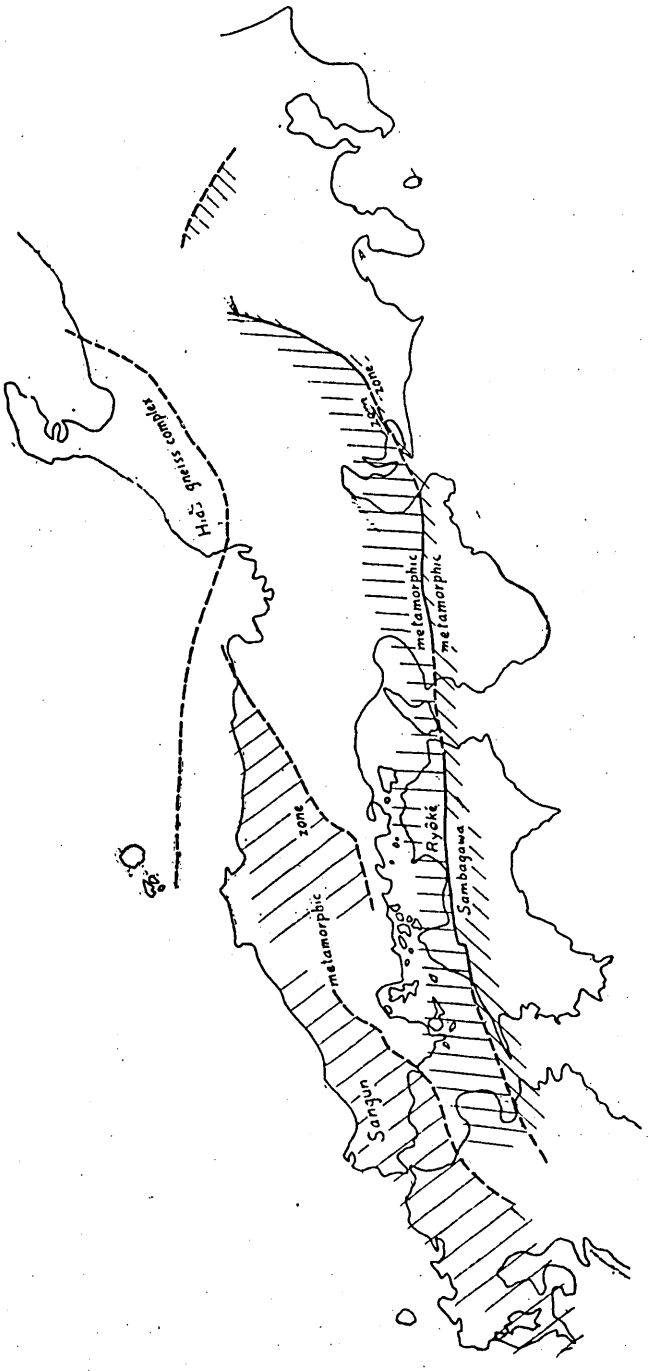

Fig. 1. Sketch map of three metamorphic zones in Southwestern Japan

metamorphic zones were formed during the Sakawa orogenic cycle. The correlation between metamorphisms and epicrustal movements of the Akiyoshi and Sakawa orogenic cycles after Kobayashi is tabulated in Table 1.

Table 1

Correlation between metamorphisms and epicrustal movements of the Akiyoshi and the Sakawa orogenic cycles. (after T. Kobayashi, 1941)

	Metamorphism	Epicrustal movement	
Cretaceous	Ryôké injection	Oga phase	Sakawa o. c.
Jurassic			
	Nagatoro (Sambagawa) metamorphism	Toyogatake epeirogenesis	
Trias	Hida meatmorphism Sangun metamorphism	Akiyoshi phase Epeirogenesis	Akiyoshi o. c.
Permian			

After the IInd World War, metamorphic zones of Japan have been surveyed by a number of geologists, and the structural and petrological features of these zones have been much clarified,

In 1952, M. Gorai published a paper on the origin of the Japanese Islands in Japanese. Gorai's interpretation on the formation of metamorphic zones in Southwestern Japan may be tabulated as follows:

1. The greater part of metamorphic rocks in the Hida gneiss complex may be the products of the pre-Gotlandian (probably the Pre-Cambrian) metamorphism and hybridism, forming the basement of the Chichibu geosyncline.
2. Metamorphic rocks and the associated granitic intrusive rccks in the Ryôké metamorphic zone and crystalline schists in both the Sangun and the Sambgawa metamorphic zones were formed during the orogenic phase of the late-Palaeozoic or the early-Mesozoic.

The essential difference of Gorai's view from Kobayashi's interpretation, concerning the origin of the three metamorphic zones in Southwestern Japan, lies in that the Akiyoshi orogenesis was not restricted in the Inner Zone of Southwestern Japan, but that in the Outer Zone effects of the late-Palaeozoic or the early-Mesozoic orogenesis are also traceable. In spite of the denial by Kobayashi, this view has become a wide-spread belief among the Japanese geologists, owing to surveys in the Mesozoic and the Palaeozoic terrains in

the Outer Zone by T. Matsumoto (1947), T. Matsumoto and K. Kanmera (1949), K. Kammera (1950), K. Ichikawa, et al. (1953), etc.

Geological and petrological researches made by the writer and his collaborators on the three metamorphic zones in Chûgoku and Shikoku, Southwestern Japan The present writer has deen engaged in the geological and petrological researches in the Sambagawa metamorphic zone since 1940. The main field work has been carried out in the central mountainland of Shikoku since 1943, and along with this, researches have been done in the Iwakuni-Yanai district, Yamaguchi Prefecture, in the Ryôké zone, and in the Sangun zone in the Chûgoku provinces, especially in the Tokuyama district, Yamaguchi Prefecture. Some results were already reported (G. Kojima 1944, 1950, 1951A, 1951B, 1951C, 1953; G. Kojima and D. Sasaki, 1950; G. Kojima and C. Mitsuno, 1950: G. Kojima and Y. Okamura, 1952).

Subjects treated in this paper In this paper, the writer intends to treat the mutual relations between the three metamorphic zones in Southwestern Japan, espacially based on the data acquired by the writer and his collaborators in Chûgoku and Shikoku. Detailed descriptions of each districts are not intended. The metamorphic history of the central core zone of orogenic belt should be elucidated from various aspects of research, as the changes, which occur in the deeper zone of orogenic belt, have to be reflected on the characters of epicrustal phenomena. Nevertheless, in this paper, data on the epicrustal phenomena are not treated. They should be properly discussed on the other occasion by "soft-rock-geologists". In this paper, the mutual relations between the three metamorphic zones are discussed, mainly based on the data related to the metamorphic and structural features of each metamorphic zone: — in other words, the subjects are discussed on the standpoint of "hard-rock-geologists". The writer wishes "soft-rock-geologists" would criticize the subjects with their data.

Acknowledgement The subjects treated in this paper have been discussed with many geologists interested, especially with Dr. M. Gorai and Prof. T. Matsumoto. A large part of field survey was carried on by the kind assistance of Messrs. K. Hide, Y. Okamura, H. Yoshida, G. Yoshino, C. Mitsuno, H. Takeda, and the other members of the "Research Group of the Metamorphic Zones in Southwestern Japan". To the many people mentioned above, the writer wishes to express his sincere thanks. The field survey was enabled by the Grant in Aid for Scientific Researches from the Ministry of Education.

Sangun metamorphic zone[1]

(A) Distribution

T. Matsumoto (1951) distinguished the basement older formations in North Kyûshû and West Chûgoku into the following zones:

(1) Northern metamorphic zone (Sangun - Toyogatake - Iwami coastal region)

(2) Central zone of the non-metamorphic Chichibu Palaeozoic group (including limestone formations of Hirao and Akiyoshi)

(3) Southern metamorphic zone (Asakura-Tagawa-Motoyama-Yamaguchi-Tokuyama)

The northern and the southern metamorphic zones are designated the "Sangun" and the "Tagawa" (or "Motoyama") metamorphic zones, respectively, by some writers. In Chûgoku, the northern ("Sangun") metamorphic zone is traceable from Toyogatake to the coastal region of Shimane Prefecture. Crystalline schists in Tottori Prefecture may belong to the northern zone (Fig. 2).

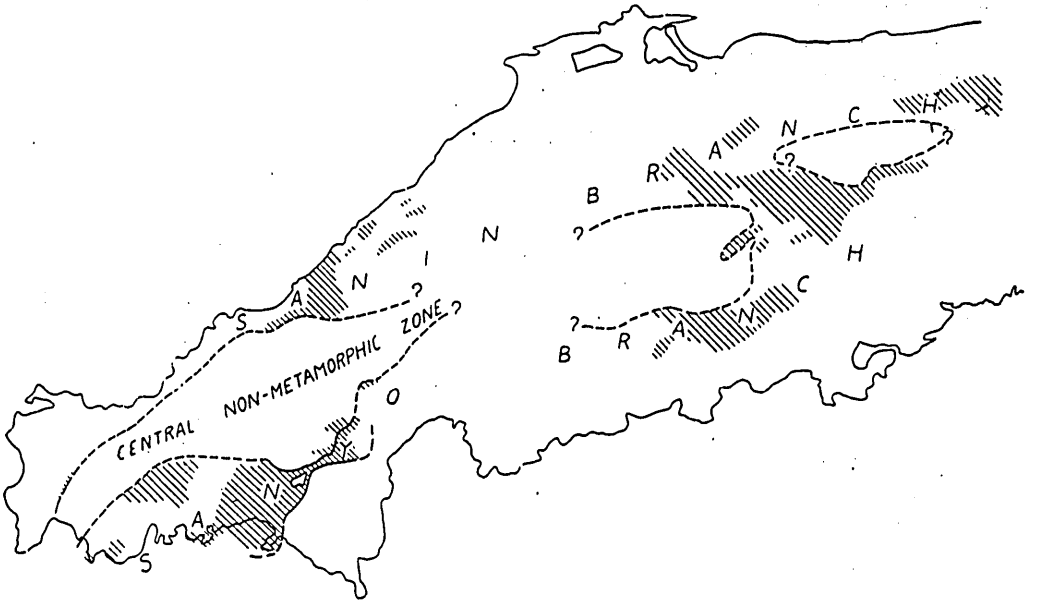

Fig. 2. Distribution of crystalline schist district in Chûgoku

1) Descriptions of each metamorphic zone are not intended to cover all the subjects concerning metamorphism and structural geology, but they may be confined to the facts, which are believed to be important to understand the mutual relations between metamorphic zones.

The distribution of the metamorphic rocks is rather patchy, and separated from each other by younger granitic intrusives[1] and either Tertiary or Mesozoic volcanic and sedimentary formations. In this paper, the zone, which includes the above mentioned metamorphic districts, is named the **San-in branch** of the Sangun metamorphic zone.

The eastern extention of the southern ("Tagawa") metamorphic zone in North Kyûshû is represented by crystalline schist districts of Motoyama-misaki, Yamaguchi, Tokuyama, Kawayama, Fuchû, and Tsuyama in Chûgoku (Fig. 2). The distribution of the metamorohic rocks is also patchy, and separated from each other mainly by the Cretaceous granitic intrusives. In this paper, the zone, including the above-listed metamorphic districts, is named the **San-yo branch** of the Sangun metamorphic zone.

In Chûgoku, the central zone of the non-metamorphic Chichibu Palaeozoic groups is also found between the San-in and the San-yô branches of the crystalline schist zone. The non-metamorphic Palaeozoic rocks, belonging to the central zone, are mainly distributed near Akiyoshi, in the eastern region of Yamaguchi Prefecture, and in the Taishaku-Atetsu region. To this zone belong the famous limestone formations of Akiyoshi, Zômeki, and Taishaku-Atetsu. The zone of non-metamorphic Palaeozoic rocks is called, in this paper, the **central non-metamorphic zone.**

(B) Stratigraphy

As the distribution of the crystalline schist districts is sporadic, and each individual district is relatively narrow, the stratigraphic succession of beds is hardly established. Since 1946, the writer and Messrs. Y. Okayama and G. Yoshino have been engaged in geological survey in the Tokuyama-Kawayama area, and the following stratigraphic succession of metamerphic and non-metamorphic beds has been tentatively proposed.

The upper formation : —— The upper formation is mainly non-metamorphic.[2] In some places (e. g. at Deai[3]), the lowermost portion is represented by semi-schists of sandstone and slate origin. The formation consists mainly of beds of sandstone and slate, with intercalated schalstein, siliceous tuff, chert, and limestone. The most distinct feature of

1) The age of these intrusives is believed to be the Cretaceous or the early-Tertiary.

2) The upper formation is rather affiliated to the central non-metamorphic zone than to the San-yô branch of the Sangun metamorphic zone. In the Tokuyama-Kawayama area, however, the metamorphic beds are changed gradually to the non-metamorphic Palaeozoic beds at several places. So, the stratigraphical relation between the metamorphic and the non-metamorphic formations can be ascertained in the area.

3) 山口縣玖珂郡錦町出合

the upper formation is the predominance of sandstone (graywacke-type). Sandstone beds in the middle and upper portion of the formation are often characterized by the abundant presence of angular chips of slate.[1] The upper limit of the formation is not ascertainable. The thickness of the formation, now exposed, exceeds 2,000 m. The upper formation of the Tokuyama-Kawayama area may be correlated lithologically to the Ota group of the Akiyoshi area, the age of which is believed the Pennsylvanian ~ the upper Permian.[2]

The middle formation : — The middle and the lower formations are represented by the crystalline schist beds. At several places (Deai, Kiyahara,[3] Funotani[3]), the metamorphic beds of the middle formation are overlain conformably with non-metamorphic or semi-metamorphic beds of sandstone and clay-slate, which belong to the lowermost portion of the upper formation. But, in general, the terrain of the upper formation is divided from the schist region by the Kitayama overthrust[4] (G. Kojima & D. Sasaki, 1950). The uppermost member of the middle formation is green-semi-schists, derived from basic tuffaceous rocks, intercalated with black-semi-schists of slate origin, which are overlain conformably with alternation beds of sandstone and clay-slate, often with basic tuff, of the upper formation. The middle formation is characterized by the predominance of green-schists, which are believed to be derived from basic pyroclastic and effusive rocks.[5] Quartz-schists, often with hematite, sometimes piedmontite-bearing, and limestone accompany the green-schists. The other members of the middle formation are black-schists of slaty origin. Sandstone-schists are rarely found. Serpentinite is relatively abundant, and often intimately associated with green-schists. Owing to faulting, the thickness of the middle formation is not precisely ascertainable, but it may attain 2,000~3,000 m or more. The lowermost portion of the formation is represented by black-schist beds, which overlie conformably the sandstone-schist of the lower formation.

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1) The angular chips of slate are predominated in the lower portion of each individual sandstone bed.

2) after R. Toriyama: Geology of the Akiyoshi district. Rep. Western Branch, Geol. Soc. Japan, No. 12, 1953, mimeographed in Japanese.

3) 山口縣玖珂郡廣瀨町木谷原・府谷

4) It must be mentioned that the schist beds, bordering on the upper formation with the Kitayama over-thrust, belong to the middle formation, not to the lower formation.

5) The original composition of the green-schists is almost exclusively basic (mainly basaltic). The only exception has been found by the writer and C. Mitsuno near the Tsuboi mine, Okayama Prefecture (岡山縣久米郡大井町・旧大井西村坪井鉱山南方). There can be found semi-schists derived from acidic tuff and liparite.

The lower formation; — As mentioned above, the lower formation is overlain conformably with the middle formation. The most part of the schist region of the Tokuyama-Kawayama area is occupied by the schists of the middle formation, and the lower formation is exposed in the north-eastern part of Tokuyama-shi and near Shimaji-mura.[1] The lower formation is characterized by thick beds of sandstone-schists. Sometimes, the thickness of the sandstone-schist bed exceeds 700 m. Besides sandstone-schists, the formation comprises black-schists of pelitic origin, and rarely green-schists and quartz-schists. Although the lower limit of the formation has not been exposed, the total thickness may attain 2,000～3,000 m.

Summing up all the basement formations of the Tokuyama-Kawayama area, the total thickness attains 6,000～8.000 m or more, and the crystalline schist beds, which belong mainly to the middle and the lower formations, attain 4,000～6,000 m or more in thickness. The "*Tsuno group*"[2], which has been proposed by the writer and his collaborators (1951) for the crystalline schist complex in the Tokuyama-Kawayama area,[3] should be defined to be identical with the middle and the lower formtaions described above. The age of the deposition of the Tsuno group has not been ascertained by any palaeontological data, but it may safely be said that it is the pre-Pennsylvanian.

(C) Metamorphism

The crystalline schists of the Sangun metamorphic zone in Chûgoku are mainly referred to the green-schist facies. The main types of the crystalline schists are as follows:

Crystalline schists, derived from pelitic sediments: — The main constituents are quartz, muscovite (or sericite), albite, and graphitic matter. Often, chlorite is found. The compositional banding is highly developed. The secondary, high-angled slip-planes cut the schistosity plane, showing a false cleavage structure.

Crystalline schists, derived from psammitic sediments: — The main constituents are quartz, muscovite (or sericite), accompanied by subordinate albite, chlorite, calcite, and graphitic matter, Among clastic grains, those of plagioclase have been twisted, fractured, and albitised, while quartz

1) 山口縣佐波郡島地村・串村・和田村
2) 都濃層群
3) Kojima, G., et al.: General survey on the geological structure and history of the region of older formations and granitic intrusives in the Iwakuni, Yanai and Tokuyama districts (Abstract, in Japanese). Journ. Geol. Soc. Japan, 57, (670), p. 302, 1951.

grains have been utterly shattered and recrystallized. The rocks are relatively competent. The compositional banding is not distinct. The secondary high-angled slip-planes are developed.

Crystalline schists, derived from basic pyroclastic and effusive rocks : — These are characterized by chlorite, epidote, and albite. Fine, dusty matter, which may be mainly titanite, is almost always found. Actinolitic amphibole is rarely developed. Sometimes, quartz is found, especially in the green-schists of pyroclastic sediment origin. Calcite is rather common. Schistosity is highly developed in the green-schists of pyroclastic sediment origin, while in those, derived from massive igneous rocks, schistosity is less distinct. Relics of the original rocks are very rare. In several specimens, augite relics are detected.

Other members of crystalline schists : — Crystalline limestone and quartz-schists are found in intimate relation to green-schists. In the quartz-schists, hematite, sericite, and rarely garnet and piedmontite[1] are found. Some serpentinites have been changed to srpentine-schists.

Judging from the above petrographic features, the main part of the crystalline schists of the Sangun metamorphic zone in Chûgoku is included in the chlorite zone of the normal regional type of metamorphism, or may be referred to the muscovite-chlorite subfacies of the green-schist facies after Turner and Verhoogen (1951). In the north of Tokuyama-shi, however, schists have been found carrying biotite. The biotite is a greenish-brown variety, and is arranged approximately parallel to the schistosity plane. It is distinguishable from the biotite in thermal aureole near the Cretaceous granitic intrusives in respect of colour and fabric. The green-schists, associated with the biotite-schists, are characterized by hornblende, epidote, and plagioclase. Judging from these features, the schists in the north of Tokuyama-shi may be referred to the biotite-chlorite subfacies of the green-schist facies. The stratigraphical horizon of these schists corresponds to the middle and lower parts of the middle formation, and the lower formation.[2]

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1) In the Sangun metamorphic zone, piedmontite-bearing quartz-schists have been reported by some writers from several localities (Kinoshita, K. & H. Takehara, Journ. Japan. Assoc. Miner. Petr. Econ. Geol., **15**, (2), 1936 (in Japanese) ; Shibata, H., Journ. Geol. Soc Japan, **40**, (478), 1933 (in Japanese)). The occurrence of piedmontite is much rare in the Sangun metamorphic zone, as compared with that in the Sambagawa metamorphic zone. No piedmontite has been found in the Ryôké metamorphic zone.

2) Biotite-schists of the biotite-chlorite subfacies have not yet been reported from any other parts of the Sangun metamorphic zone in Chûgoku. In North Kyûshû, the biotite-schists have been found in the Minô mountainland (水縄山地—福岡縣八女郡) by the writer and T. Inoué (T. Inoue : On the geology of the Minô mountainland (abstract, in Japanese). Journ. Geol. Soc. Japan, **58**, (632), p. 272, 1952). The crystalline schist region in the southern part of

The problem, whether the higher grade crystalline schists than the green-schist facies were formed at the time of the Sangun metamorphism, has not yet been decisively answered. In the Sangun and the Seburi mountainlands, Fukuoka Prefecture, the presence of rocks of the higher metamorphic grade, such as plagioclase-amphibolites and biotite-quartz-schists, has been generally known among geologists. These higher grade metamorphic rocks are intimately associated with the older granitic intrusives, which have been named the "older granites of North Kyûshû" (Itoshima-type)[1] by T. Matsumoto (1951). The older granitic intrusives penetrated the metamorphic complex concordantly or sub-concordantly, and basic hybrid rocks have been locally formed[2] (Y. Karakida, 1951). These higher grade metamorphic rocks, including hybrids, have been interpreted by the writer and T. Inoué,[3] and also by T. Matsumoto (1951), as derived from low grade metamorphic rocks of the Sangun metamorphic zone under the thermal effect related to the older granitic intrusion.

Owing to the incompleteness of data at the present time, we can not conclusively decide, whether the higher grade crystalline schists were formed at the time of the Sangun metamorphism, or whether granitic intrusion accompanied the Sangun metamorphism. But, the facts that the metamorphic beds are generally confined to the middle and the lower formations of the Palaeozoic group, that the geological structure of the metamorphic region is characterized by gentle folding, and that, in the main portion of the Sangun zone in Chûgoku, no granitic intrusives, such as the older granites of North Kyûshû, have been found, may suggest that, by the Sangun metamorphism, only the lower members of the Chichibu Palaeozoic group were changed to low grade crystalline schists, mainly of the green-schist facies. The intrusion of the older granites of North Kyûshû may have been related to the later act of plutogenesis[4] of the late-Palaeozoic orogenesis of Southwestern Japan.

Fukuoka Prefecture and in the northern part of Kumamoto Prefecture is named the Chikugo metamorphic region by T. Matsumoto et al. (Geology and its significance of the metamorphic region of the Chikugo mountainland. Abstract in Japanese, Journ. Geol. Soc. Japan, **59**, (694), p. 301). The lithological succession of the schist beds bears some resemblance to that of the Tokuyama-Kawayama area. The biotite-schists are found in the formation, correlated to the lower formation of the Tokuyama-Kawayama area.

1) The age of the intrusion of the older granites is now generally believed to be the late-Palaeozoic or the early-Mesozoic.

2) Kojima, G. & T. Inoué: On the granitic and metamorphic rocks in the vicinity of Ito-mura, Itoshima-gun, Fukuoka Prefecture (abstract, in Japanese . Jonrn. Geol. Soc. Japan, **53**, (622-627), pp. 70-71, 1947.

3) ibid.

4) Recently, Y. Karakida has reported that the Itoshima type-granodiorite and the related Fukué-type granites show effects of shearing action at the time of intrusion, and has suggested that

(D) Geological structure

Owing to the block-movement in the Mesozoic and in part in the Tertiary, it is difficult to elucidate the original geological structure of the metamorphic regions. But, in several areas, where crystalline schists are rather exensively exposed, the original geological structure can be analysed.

The original structure is rather simple. In short, the metamorphic terrains are characterized by gentle folding, a wave-length of which is 10 ± km. The recumbent type of folding is only exceptionally found.

The gentle folding structure of the metamorphic formations is in a marked contrast to the rather complicated structure of the non-metamorphic formations in the central non-metamorphic zone. The over-turned fold of the Akiyoshi limestone formation is a famous example, which may be interpreted as resulted from the difference in competency of material between limestone and the other sediments. Recumbent fold or isoclinal fold has also been reported in the Ota formation.[1] The difference in geological structure must be attributed to the difference in geological condition at the time of deformation between the non-metamorphic upper zone and the metamorphic lower zone (C. E. Wegmann, 1935, 1953). In this respect, the structural relation between non-metamorphic and metamorphic formations is an attractive problem to geologists.

(E) Relation between the Sangun metamorphic zone and the central non-metamorphic zone

Between the Sangun metamorphic zone and the central non-metamorphic zone, the following three types of relation are detected (cf. Fig. 3).

(1) *The non-metamorphic formations overlie conformably the metamorphic formations :* This type of relation is clearly seen in the vicinity of Hirose, Kuga-gun, Yamaguchi Prefecture. As mentioned in the section of stratigraphy, the non-metamorphic upper formation overlies conformably the metamorphic middle formation. Sandstone and slate of the lowermost portion of the upper

the Itoshima-type granodiorite and the Sangun metamorphic rocks may be products of the same act of orogenesis (Y. Karakida; A problem in the Sangun metamorphic zone. mimeographed, in Japanese. "Schist" — Rep. Research Group Metam. Zone SW Japan, No. 2, 1953). This fact is important to clarify the geological condition at the time of intrusion of the Itoshima-type granodiorite, but the deduction, suggested by Karakida, seems to have to be scrutinized in many respects.

1) R. Toriyama, op. cit., 1953. The writer and H. Yoshida have also analysed a recumbent type of folding in the upper formation of the Hirose district (山口縣玖珂郡廣瀨町北部)

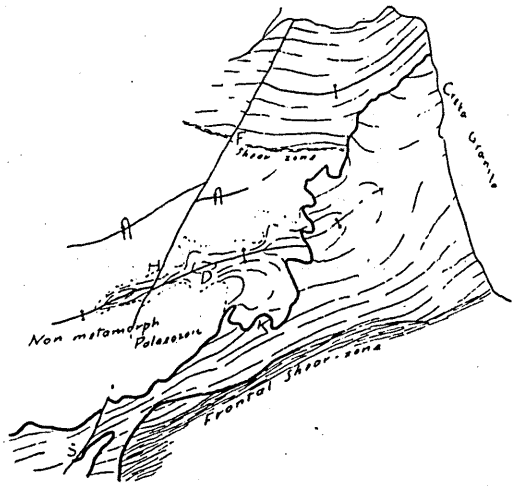

Fig. 3. Geological sketch map of the Hirose-Kawayama district, showing three types of relation between the Sangun metamorphic and the non-metamorphic formations (1 : 300,000)

formation and basic tuff of the uppermost portion of the middle formation have been changed to semi-schists. The thickness of beds of semi-schists is relatively thin (about 100 m). The **semi-schist surface,** which may be defined as the boundary surface between semi-schists and non-metamorphic rocks, is nearly parallel to the bedding surface at Hirose and Deai, but, approaching the Kawayama mine, the semi-schist surface is gradually shifted to the upper horizon of the upper formation.

This type of relation between non-metamorphic and metamorphic formations has also been found in the other areas, e, g. in the central metamorphic area in Okayama Prefecture. In North Kyûshû, T. Matsumoto (1951) has reported that the Hirao limestone formation overlies conformably phyllitic beds of the Tagawa metamorphic zone. In all these cases, the metamorphic formations are overlain conformably by the non-metamorphic formations.

(2) *Shear-zone develops between the non-metamorphic and the metamorphic belts:* This type of relation is also found in the Hirose-Kawayama district (Fig. 3). In Fukazu-mura[1] and Hongô-mura[1] in the district, a shear-zone develops between the northern belt of crystalline schists (mainly belonging to the middle formation of the district) and the southern belt of non-metamorphic rocks (belonging to the upper formation of the district). The shear-zone is 100 ～ 200 m in width, trending almost E-W. The dip of the shear-plane is ca 50° to N. The shear-zone consists of shear-slates near the non-metamorphic belt and black-semi-schists near the metamorphic belt, each containing teared blocks of sandstones. The teared blocks are mostly lenticular or

1) 山口縣玖珂郡深須村・本鄉村

spindle-shaped. The shear-zone may be interpreted as formed through the up-thrusting movement of the northern metamorphic belt at the later phase of the metamorphism.[1]

Up to now, this type of relation has only been analysed by the writer and H. Yoshida in the above mentioned district, but, also in the other districts in the Sangun metamorphic zone, this type of relation will be detected in future.

(3) *The non-metamorphic terrain thrusts over the metamorphic terrain:* The over-thrust, dividing the non-metamorphic from the metamorphic terrain in the Tokuyama-Kawayama area, has been named the **Kitayama over-thrust** by the writer.[2] In the metamorphic area near Yamaguchi, the similar relation has been detected by G. Yoshino,[3] and there the over-thrust has been named the **Saigatao[4] over-thrust.** In both cases, the hanging wall is the Ota formation or the upper formation, and the foot-wall is the schist beds, referable to the upper horizon of the middle formation. Noteworthy is the fact that the stratigraphical gap between the hanging wall and the foot-wall ia very narrow. This fact shows that the over-thrust surface is nearly parallel to the bedding surface, and that it is located near the semi-schist surface, which represents a discontinuity surface between materials of different crystallinity. As to the age of formation of the Kitayama over-thrust, we can only say that it is the pre-middle-Cretaceous. In this respect, more data are requested.[5]

Ryoke metamorphic zone

(A) Distribution

The Ryôké metamorphic zone is characterized by metamorphic rocks, intimately related to granitic intrusion. The southern boundary of the zone is marked by the Median Dislocation Line, while the northern boundary is obscured by the intrusion of the Cretaceous granites, which are extensively exposed on the northern half of Setonaikai (Inland Sea) and on the southern half of Chûgoku. The Ryôké metamorphic zone proper may be tentatively

1) Mica flakes in black-schists, which are found in the shear-semi-schist, show effects of bending and twisting.

2) G. Kojima: On the relation between the so-called "phyllites" and the Chichibu Palaeozoic, north of Tokuyama, Yamaguchi Prefecture (abstract, in Japanese). Journ. Geol. Soc. Japan, 53, (622-627), p. 85, 1947.

3) The detailed description of the area is being prepared by Yoshino.

4) 才ヶ峠 (山口縣玖珂郡眞良田村－綾木村)

5) To the problem of the age of formation of the Kitayama over-thrust is genetically related to the formation of the Kawayama ore deposit, which is located in the shear-zone between crystalline schists and slightly metamorphosed Palaeozoic rocks (G. Kojima & D. Sasaki, 1950).

defined as demarcated by the Median Dislocation Line and the southern intrusion boundary of the Cretaceous granites. The zone is composed of the older (Ryôké) granitic intrusives and the related metamorphic rocks, such as banded gneisses and biotite-schists. The distribution of the metamorphic rocks is rather patchy, and it is only in the Yanai-Iwakuni area that the systematic study of the metamorphism and plutonism is possible.

(B) Stratigraphy

The Palaeozoic formations of the metamorphic and least metamorphic region in the Yanai-Iwakuni district are characterized by thick beds of banded chert,[1] the thickness of each bed of which attains several hundred meters or more. The associated rocks are mainly slates and sandstones and their metamorphic derivatives. Small lenses of limestone are contained. Schalstein and diabase are rather rare. The total thickness of the formations attains 3,000 m or more. The upper and the lower limits of the formations are not ascertainable. The writer and Y. Okamura have named the formations the **Kuga group**[2] (Kojima and Okamura, 1952).

Owing to the thermal metamorphism related to the intrusion of the Cretaceous granites, no direct palaeontological data are available as to the age of sediments of the Kuga group in the Yanai-Iwakuni area. In the frontal shear-zone of the Sangun metamorphic zone (later described), however, Okamura has found fossils of fusulinids in a limestone lens, and they have been judged by Dr. H. Yabe as the Permian fusulinids (*Neoschwagerina* or *Yabeina*). As the limestone lens in question has been found in shear-slate in the frontal shear-zone, the original horizon of bed is not ascertainable. But, judging from the associated rocks, it can safely be said that the limestone belongs to the Kuga formation.

As the terrain of the Kuga group and the Sangun metamorphic zone are demarcated by either the frontal shear-zone or the Suétaké-gawa tectonic line (later described), the direct relation between the Kuga group and the Tsuno group or the Ota group can not be ascertained.

(C) Metamorphism

H. Koide[3] has studied the Ryôké metamorphic and the related plutonic

1) Banded chert is composed of alternating bands of siliceous (amorphous or crystalline) and clayey materials. The thickness of the siliceous band is commonly several centimeters, while that of the clayey band is less than 1 cm.

2) 玖珂層群

3) H. Koide: Dando granodioritic intrusives and their associated metamorphic complex (in press); H. Koide: ibid. (abstract of the above paper, in Japanese), mimeographed, Monograph Assoc. Geol. Collab., No. 1, 1949.

rocks in the Dando district, Aichi Prefecture. He discriminated between the older and the younger intrusions and the associated metamorphisms. The main metamorphic area of the Dando district has been classified by Koide into the following successive zones, related to the older plutonism:

Zone of schistose hornfels.....Potash-alumina-addition and silica-subtraction

Zone of transitional rocks.....Potash-alumina-metasomatism, accompanied by metamorphic differentiation

Zone of banded gneisses..... Soda-addition anb alumina-subtraction, accompanied by metamorphic differentiation

In the Yanai-Iwakuni area, the block-movement and the intrusion of the Cretaceous granite somewhat confused the zonal arrangement, but the similar relation is traceable in the area between Iwakuni and Obatake.[2]

Rocks of the zone of schistose hornfels have properties of biotite-schists, in which biotite flakes are arranged parallel to the schistosity plane. The schistosity plane often crosses the bedding plane. The compositional banding as a result of metamorphic differentiation of the biotite-schists is not developed.

Rocks of both the zone of transitional rocks and the zone of banded gneisses have properties of biotite-gneisses. To the north of Obatake, a belt of gneissoze granodiorite (Naruto granodiorite[2]) is found between thick beds of siliceous banded gneiss, which has been derived from banded chert. Tracing the belt of the gneissoze granodiorite to NE, the gneissoze granodiorite gradually merges into biotite-banded-gneiss of argillaceous origin. Judging from geological and petrographical data, the gneissoze granodiorite in question has been interpreted by the writer and Y. Okamura (1952) as a product of *in situ* granitization of argillaceous sediments. From Murozumi to the northwestern part of Yashiro-jima (O-shima), a zone of gneissoze granodiorite (Gamano Granodiorite[3]) is fringing the zone of banded gneiss. The Gamano granodiorite stands in concordant relation with the metamorphic zone, and the trend of gneissoze banding of the granodiorite is also in harmony with the structural trend of the metamorphic zone. As, except its intrusion character, the Gamano granodiorite is very similar to the Naruto granodiorite, the writer and Okamura have interpreted the Gamano granodiorite as a type of granodiorite of anatectic origin. The Naruto and the Gamano granodiorites represent the older intrusives of the Yanai-Iwakuni area in the Ryôké metamorphic zone. The genesis of the older granodiorite intrusives is closely related to the metamorphism of country rocks.

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1) 山口縣玖珂郡鳴門村大畠
2) 鳴門花崗閃緑岩
3) 蒲野（山口縣大島郡蒲野村）花崗閃緑岩

The larger part of the Ryôké zone is occupied by the younger granodioritic intrusives,[1] which stand in discordant relation to the older intrusives and the related metamorphic zones.

The Ryôké metamorphism is characterized by the prevalence of thermal and metasomatic effects, closely related to the intense plutonism. Metamorphic zones, commonly found in metamorphic regions of the normal regional metamorphic type, such as almandine-, staurolite-, and cyanite-zones, are totally lacking in the Ryôké metamorphic zone. The metamorphic rocks are characterized by minerals of thermal metamorphic type, such as andalusite, cordierite, sillimanite, etc. To the outer (north) side of the zone of schistoze hornfels (biotite-schist), lies the zone of the non-metamorphic Palaeozoic rocks, and the zone of the muscovite-chlorite subfacies is lacking.

Judging from these characters of metamorphism, it can be said that the Ryôké metamorphism was not the type of normal regional metamorphism, but that the metamorphism occurred under intense thermal and material addition into the zone of intense plutonism. The thermal and metasomatic effects suppressed the effects of shearing. This character of metasomatism stands in marked contrast to that of the Sangun metamorphism.

Relation between the Sangun and the Ryoke metamorphic zones

(A) Intermediate non-metamorphic zone between the Sangun and the Ryoke metamorphic zones

Between the Sangun and the Ryôké metamorphic zones lies a zone consisting mainly of non-metamorphic rocks of the Palaeozoic groups.[2] The zone has not suffered the metamorphism of the late-Palaeozoic or the early-Mesozoic, i. e. the Sangun and the Ryôké metamorphisms. In this paper, this zone is called the **intermediate non-metamorphic zone.**[3] The distribution of the zone may be read in Fig. 1 and Fig. 2.

Owing to the thermal metamorphism related to the Cretaceous granites, the stratigraphical and palaeontological studies of the formations in this zone

1) The age of intrusion of the younger granodioritic intrusives is also believed to be the late-Palaeozoic or the earely-Mesozoic.

2) The zone is not exclusively composed of the Palaeozoic groups. There can be found sediments and igneous rocks of the Mesozoic (perhaps, mainly of the Cretaceous). These rocks have mostly been thermally metamorphosed in relation to the intrusion of the Cretaceous granites.

3) In the previous paper of the writer and Okayama (1952), the zone was named the "Ryôké outer zone", and the presence of shear-zone was interpreted as a result of shearing movement, related to the Ryôké metamorphism. As this interpretation has proved to be erroneous, the designation of the zone is changed in this paper.

are very scanty. As above described (p. 31), at least a part of the formations (Kuga group) of the zone in the Yanai-Iwakuni area can be referred to the Permian. In Hiroshima and Okayama Prefectures, exposed areas of the intermediate non-metamorphic zone are patchy and narrow, forming roof-pendants of the Cretaceous granites. At Dôdo,[1] Okayama Prefecture, K. Konishi (1952) has reported the occurrence of an early Permian conglomerate, containing pebbles of fossiliferous limestone.[2]

The lithological character of formations of the zone is very similar to that of the original formations of the Ryôké metamorphic zone. They are mainly composed of slates, sandstones, and banded cherts. The boundary line between the intermediate zone and the Ryôké zone can not strictly be drawn. Passing from the former to the latter zone, non-metamorphic slates are gradually changed to schistose hornfels or biotite-schists.

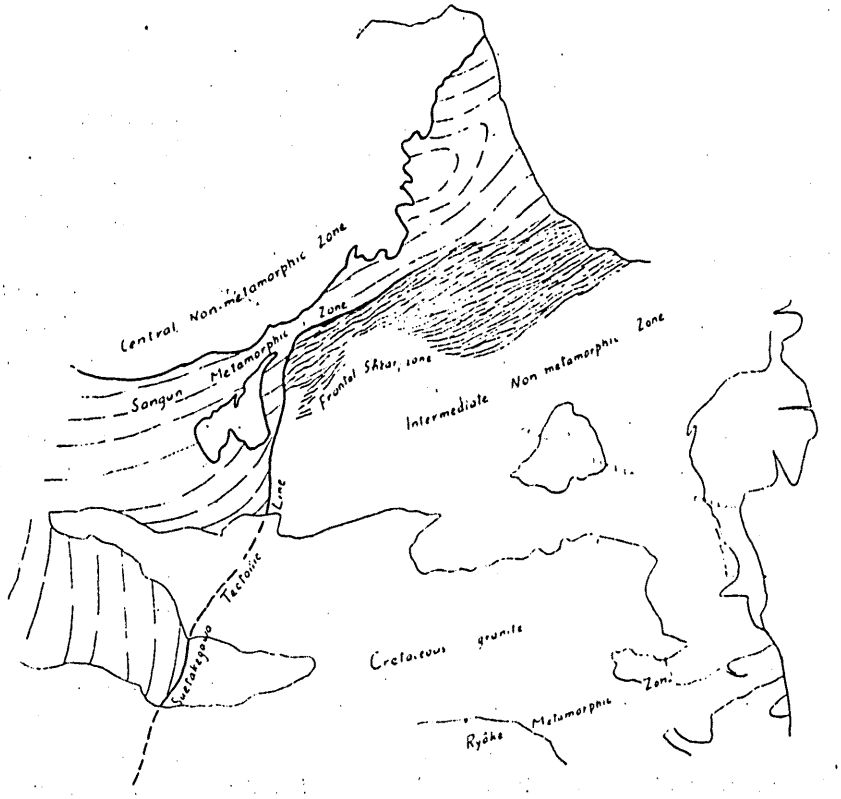

Fig. 4. Geological sketch map, showing the relation between the Sangun and the Ryôké metamorphic zones in the Tokuyama-Yanai-Iwakuni-Kawayama district (1 : 400,000)

1) 岡山縣勝田郡北和氣村百百
2) Recently, Prof. S. Imamura has found Permian fossils at Sasai (廣島縣高田郡川村佐々非) (oral communication).

(B) Relation between the intermediate non-metamorphic zone and the Sangun metamorphic zone

The Sangun metamorphic zone and the intermediate non-metamorphic zone are separated by a zone of discontinuity, which are named the **frontal shear-zone of the Sangun metamorphic zone.** The relation is clearly observable in the area west of Iwakuni (Fig. 4). The nature of the frontal shear-zone is similar to that of the shear-zone, found between non-metamorphic and metamorphic belts in the Sangun metamorphic zone (p. 29), except its scale of occurrence. In the Iwakuni-Kawayama area, the apparent width of the frontal shear-zone attains 4~6 km on the geological map. As the fissility plane of shear-slates or shear-semi-schists is commonly dipping to N at an angle of ca. 50°, the real width of the frontal shear-zone may attain 3~4,5 km.

The frontal shear-zone is mainly composed of shear-slates and black-semi-schists, in which teared blocks of sandstones, cherts, and limestone are included. The teared blocks are mostly lenticular or spindle-shaped, and are arranged parallel to the shear-plane. The grade of metamorphism of shear-rocks is becoming lower from N to S. Near the Sangun zone, the matrix of the shear-rocks is black-semi-schists, while in the southern part of the frontal shear-zone, it is represented by shear-slates.

Judging from various geological and petrographical data, the writer and Okamura (1952) have interpreted the genesis of the frontal shear-zone as that it was formed by the up-thrusting movement of the northern (Sangun) metamorphic zone at the later stage of the Sangun metamorphism.

These types of shear-zone are not confined to the frontal shear-zone. Shear-zones of the similar nature are also found in places in the intermediate non-metamorphic zone and even in the Ryôké metamorphic zone proper, but the width of these subsidiary shear-zones is commonly within a few hundred meters. The formation of these subsidiary shear-zones is believed to be contemporaneous with that of the major shear-zone.

(C) Relation between the Ryoke and the Sangun metamorphic zones

Summing up the above description, the following points are important on interpreting the relation between the Ryôké and the Sangun metamorphic zones.

(1) *Difference in metamorphic character:* The Sangun metamorphic zone is characterized by crystalline schists of the green-schist facies, mainly of

the muscovite-chlorite subfacies, and no granitic intrusions are detected in intimate association with the metamorphism. While, the Ryôké metamorphism is characterized by the prevalence of thermal and metasomatic effects, closely related to the intense granodioritic magmatism, and the normal types of crystalline schists, resulted from dynamo-thermal metamorphism, are almost completely lacking. Judging from these facts, it is concluded that *the Sangun and the Ryoke metamorphic zones have been resulted from the essentially different types of metamorphism.*

(2) *Age of metamorphism*: The age of the Sangun and the Ryôké metamorphisms is believed to be the late-Palaeozoic or the early-Mesozoic, but they are not contemporaneous. The presence of the subsidiary shear-zones in the intermediate non-metamorphic zone and even in the Ryôké metamorphic zone proper, and the overlapping thermal effects of the Ryôké metamorphism to the already deformed rocks, suggest that *the Sangun metamorphism preceded the Ryoke metamorphism.*

(3) *Presence of the intermediate non-metamorphic zone*: In the Chûgoku, Kinki, and Chûbu provinces, the intermediate non-metamorphic zone separates the two metamorphic zones. This fact suggests that *the Ryoke metamorphism occurred in the zone of non-metamorphic Palaeozoic formations, which had been left unaffected by the Sangun metamorphism.*[1]

(D) Suetake-gawa tectonic line

The western margin of the Ryôké metamorphic and the intermediate non-metamorphic zones in the Iwakuni-Yanai district is bounded by a tectonic line (Fig. 4), which has been named the "**Suetake-gawa tectonic line**" by Okamura and Kojima.[2] As to the age of the formation of the Suetake-gawa tectonic line, we can only say that it is post-Ryôké and pre-middle-Cretaceous (probably pre-Kitayama-overthrusting[3]).

On interpreting the meaning of the Suetake-gawa tectonic line, the following facts should be noticed:

(1) The trend of the tectonic line is NNE SSW from Kawayama to Tokuyama, but, in the north of Suô-nada, it turns to WSW or W. The northeastern extension of the tectonic line has not yet been ascertained, but, it

1) The width of the intermediate non-metamorphic zone is not constant, but it becomes narrower to the west. In the Iwakuni-Kawayama area, it is only 10 km. This fact shows the obliquity in trend of the Ryôké and the Sangun metamorphic zones.

2) Y. Okamura & G. Kojima: On the relation between the Sangun and the Ryôké metamorphic rocks, northwest of Tokuyama, Yamaguchi Prefecture (abstract, in Japanese). Journ. Geol. Soc. Japan, 57, (670), p. 342, 1951.

3) Newer movements along the Suetake-gawa tectonic line are almost neglible.

is most probable that it turns the trend to NE or ENE along the northern boundary of the frontal shear-zone.

(2) The frontal shear-zone is cut by the Suetake-gawa tectonic line, but the strike of the shear-plane shows a tendency, harmonic with the trend of the tectonic line: the trend of the shear-plane is generally ENE-WSW, but, near the Suetake-gawa tectonic line, it turns to SW or SSW.

(3) The structural trend of the Sangun metamorphic zone is also harmonic with the trend of the Suetake-gawa tectonic line: in the Kawayama district, it is ENE-WSW, but, in the area, west of the tectonic line, it turns to SW or SSW, subpallel to the tectonic line.

Judging from these facts, the bending of the trend of the Suetake-gawa tectonic line may be interpreted as reflecting the general structural trend in the region.

Sambagawa metamorphic zone

As to the character of geological structure, stratigraphy, and metamophim of the Sambagawa metamorphic zone, the writer has summarized in several papers (Kojima, 1950, 1951A, 1951B, 1951C, 1953). In this paper, the writer intends to recapitulate only those points which seem important in interpreting the mutual relations between metamorphic zones.

(A) Metamorphism

The Sambagawa metamorphic zone consists of two componental subzones; the non-spotted sub-zones and the spotted sub-zones, which are characterized, respectively, by the absence and the presence of albite-porphyroblasts or albite-"spots".

Crystalline schists without albite-spots constitute the bulk of the Sambagawa crystalline schists. The component rock-types of the non-spotted schists are as follows:

Crystalline schists, derived from pelitic sediments: The majn constituents are quartz, sericite, graphite (or carbonaceous matter), and albite, sometimes accompanied by chlorite and calcite.

Crystalline schists, derived from psammitic sediments: — The main constituents are quartz, sericite, albite, and subordinate graphitic matter, occasionally accompanied by chlorite and calcite. Clastic minerals, such as quartz, plagioclase (saussuritized), microcline, orthoclase, augite, hornblende, garnet, tourmaline, zircon, and titanite, are often found almost free from neocrystallization.

Crystalline schists, derived from basic pyroclastic and effusive rocks : — They are represented by green-schists. The main constituents are albite, chlorite, epidote, and leucoxene, often accompanied by quartz, calcite, actinolite, talc, pumpellyite, stilpnomelane, and hematite. Glaucophanic amphiboles are sometimes found. Augite and hornblende, as relict minerals, are rare. Metamorphic differentiation is very remarkable (Kojima, 1951A).

Other members of the non-spotted schists : — Quartz-schists are developed in intimate relation to green-schists, especially of basic pyroclastic origin. They are composed of quartz and subordinate minerals, such as hematite, stilpnomelane, carbonates, piedmontite, spessartite, sericite, chlorite, actinolite, epidote, and alkali-amphiboles. Schistose limestone is also found.

The total thickness of these crystalline schist beds attains to 5,000 m or more.

Judging from the above listed mineral assemblages, the schists of the non-spotted sub-zone may be interpreted as belonging to the muscovite-chlorite subfacies of the green-schist facies after Turner and Verhoogen (1951).

Crystalline schists with albite-spots (*spotted schists*) are developed in narrow zones in the Sambagawa metamorphic zone. They have the following characteristics, compared with those of the non-spotted sub-zone:

(1) The neocrystallization prceeds, and the grain-size increases. Original texture and minerals are totally obliterated by neocryatsllization.

(2) Spotted schists, derived from pelitic and psammitic sediments, are mainly composed of albite, quartz, graphite, chlorite, and muscovite, often accompanied by garnet, tourmaline, epidote, and phlogopitic biotite. It must be noticed that no evidence of reaction: chlorite + muscovite → biotite, corresponding to the biotite isograd in the normal case of regional metamorphism, can not be found.

(3) The mineral assemblage of the spotted green-schists shows no essential differences in comparison with that of non-spotted green-schists, but the increase in grain-size of amphibole is very conspicuous. The composition of plagioclase is albite or acid oligoclase. The amphibole is not rarely alkalic. Zoicite and cyanite are rarely found in spotted oligoclase-amphibolite. Garnet is not uncommon.

The development of spotted schists is intimately related to the ultramafic intrusives, which are believed to be syntectonic.

The spotted schists, having the above listed characteristics, can not be referred to any metamorphic facies of the normal regional type of metamorphism, but have similarities to the Alpine amphibolite facies or the prasinite facies.

(B) Geological structure

The schist beds in the non-spotted sub-zones show, generally, gentle folding. The dip of beds rarely exceeds 60°. The main anticlinal structure of the spotted sub-zones has an order of magnitude of 10+ km in width (one wave-length) and 100 ± km in extension.

The geological structure of the spotted sub-zones is characterized by the presence of recumbent type of folding. This type of geological structure is clearly shown in the Besshi-Shirataki spotted sub-zone, in Shikoku, where the dunite and serpentine mass, from which eclogite was reported, of syntectonic origin is found at the core of a recombent fold.

It must be borne in mind that, in the Sambagawa metamorphic zone, the southerly *Vergenz* prevails.[1)]

Relation between the Ryoke and the Sangun metamorphic zones

(A) Characteristics of the Sambagawa metamorphism

As described in the preceding chapter, the geological structure of spotted sub-zones show a remarkable contrast to that of non-spotted sub-zones. The conditions of metamorphism of the spotted sub-zones may have been characterized by a strong solution effects, as considered from such facts as the development of albite porphyroblast under strong soda addition, as the increase in grain-size, and as the formation of tourmaline and phlogopitic biotite. Under these conditions, the plasticity of rocks must have been highly increased. The highly plastic or pseudoviscous conditions at the time of metamorphism of spotted schists must be attributed to the syntectonic intrusion of ultramafic rocks.

Along with these characteristics of metamorphism, the intimate association of syntectonic ultramafic intrusion, the prevailing southerly *Vergenz*, and

1) This type of geological structure has been analysed by the writer and his collaborators in the following districts, in Shikoku:

Besshi-Shirataki mining district: —— Besshi-Shirataki recumbent fold, with the Higashi-akaishi syntectonic ultramafic mass in the core (K. Hide, G. Kojima, et al.: Preliminary observation of the geological structure of the Shirataki-Besshi-Ehime mining district (abstract, in Japanese). Journ. Geol. Soc. Japan, **58**, (682), p. 350, 1952).

Kotsu mining district, Tokushima Prefecture: —— minor recumbent fold.

Ehime mining district, Ehime Prefecture: —— minor recumbent fold (G. Yoshino & G. Kojima, 1953).

Okuki mining district, Ehime Prefecture; —— minor recumbent fold in the non-spotted sub-zone.

the absence of thermally influenced metamorphic facies show remarkable contrasts to the Ryôké metamorphism, and these facts suggest that the Sambagawa metamorphic zone was formed under the influence of southerly up-thrusting movement, accompanied by the syntectonic intrusion of ultramafic rocks. In other words, the Sambagawa metamorphism is a type of dislocation metamorphism of relatively large scale. The intimate association of ultramafic intrusion and the perfect absence of acidic plutonism at the time of metamorphism are in accordance with the above interpretation.

The fact that the Sambagawa metamorphic zone is traceable from the Saganoseki Peninsula, Kyûshû, to the Kantô mountainland, always fringing the Ryôké metamorphic zone, suggests that the formation of the former was genetically related to the up-thrusting movement of the Ryôké *Kratogen*. The Sambagawa metamorphism must have been related to the later act of orogenesis of the late-Palaeozoic or the early-Mesozoic, subsequent to the Ryôké metamorphism and plutonism.

(B) Bearing of the Mikabu tectonic zone

The Mikabu tectonic zone has been defined by the writer (Kojima, 1950) as a zone characterized by the intense shearing, running nearly along the boundary between the Sambagawa metamorphic zone and the non-metamorphic zone of the Chichibu Palaeozoic groups.

The Mikabu tectonic zone is mainly composed of shear-semi-schists or black-schists, which are characterized by even foliation plane and the absence of micro-corrugation and lineation, The zone of shear-semi-schists or black-schists cuts the geological structure of the Sambagawa metamorphic zone. The width of the zone is ca 2 km in Central Shikoku, but, it decreases to the west, and in the vicinity of the Okuki mine, it is only a few hundred meters.

Judging from these geological facts, the shear-semi-schist or black-schist of the zone must be interpreted not as a formation of schist beds, but as a type of phyllonite of local dislocation metamorphism, which accompanied the southerly up-thrusting movement of relatively crystalline belt of the Sambagawa metamorphic zone at the later act of the Sambagawa metamorphism. It is conceivable that such up-thrusting movement of metamorphic belt was located nearly at the boundary between crystalline and non-crystalline belts.[1]

1) It must be mentioned that the boundary between crystalline and non-crystalline belts also represents the boundary between terrains of different geological structure. As described above, the Sambagawa metamorphic zone is mainly characterized by gentle folding, while the non-metamorphic Chichibu terrain is characterized by isoclinal folding and faulting, near the boundary at least.

(C) Geological meaning of the Median Dislocation Line

In the former geological literature, Southwestern Japan is customarily divided with the Median Dislocation Line into two fundamentary different geological units: — the Inner Zone and the Outer Zone. According to the above described view of the writer, the outermost zone (the Ryôké metamorphic zone) of the Inner Zone and the innermost zone (the Sambagawa metamorphic zone) of the Outer Zone constitute the *Metamorphiden* of the same orogenesis. It seems to the writer meaningless to draw a clear line of demarcation between the Inner and the Outer Zones and to describe each zone independently.

As discussed above, the southerly up-thrusting movement of the Ryôké *Kratogen* influenced the formation of the Sambagawa metamorphic zone, and furthermore, at the later phase of metamorphism, the movement was localized at the Mikabu tectonic zone. Generally speaking, as metamorphic recrystallization and injection of magmatic material progress, the movement is more and more localized at narrow shear-zone or fault. The Sambagawa metamorphic zone → the Mikabu tectonic zone → the Median Dislocation Line may be understood as a successive series of representation of the same movement, i. e. the southerly up-thrusting movement of the Ryôké *Kratogen*.

Table 2

Mutual relations between three metamorphic zones of Chûgoku and Shikoku, Southwestern Japan, and the characteristics of each metamorphic zone

	Stratigrphy *	Geological structure	Metamorphism
Sangun metamorphic zone	Upper formation —Ota group (Pennsylvanian-UpperPermian) Middle formation Lower formation —Tsuno group	In the metamorphic terrain, gentle folding, a wave-length of which is 10 ± km.	1. Mainly, crystalline schists, referred to the muscovite-chlorite subfacies of the green-schist facies. 2. Partly, crystalline schists, referred to the biotite-chlorite subfacies of the green-schist facies. 3. The upper formation mainly consists of semi-schists and non-metamorphic rocks.

Relation between the Sangun and the Ryoke metamorphic zones

1. Between the two metamorphic zones lies the intermediate non-metamophic zone.
2. Between the Sangun metamorphic zone and the intermediate non-metamorphic zone intervenes the frontal shear-zone of the Sangun metamorphic zone, which has been formed by the up-thrusting movement of the northern (Sangun) metamorphic zone at the later stage of the Sangun metamorphism.
3. The Ryôké mesamorphism occurred in the zone of non-metamorphic Palaeozoic formations, which had been left unaffected by the Sangun metamorphism.

Ryôké metamorphic zone	Kuga group (partly, at least, upper- ~ middle-Permian)		1. Mainly composed of schistose hornfels, gneisses, and migmatite, which have been metamorphosed under intense thermal and material addition, associated with intense plutonism. 2. Crystalline schists of normal regional metamorphic type are totally lacking.

Relation between the Ryoke and the Sambagawa metamorphic zones

1. The Sambagawa metamorphism was genetically related to the southerly up-thrusting movement of the Ryôké *Kratogen*, which occurred at the later act of the late-Palaeozoic or the early-Mesozoic orogenesis.
2. After the metamorphic recrystallization of the Sambagawa metamorphic zone was completed, the up-thrusting movement has been localized at the Median Dislocation Line.

Sambagawa metamorphic zone	Yoshinogawa group: Upper sub-group; Middle sub-group: Minawa formation, Koboké formation; Lower sub-group: Kawaguchi formation, Oboké formation Nishiiya group	1. In the non-spotted sub-zone, gentle folding, a wave-length of which is 10+km. 2. In the spotted sub-zone, recumbent type of folding. 3. Southerly *Vergenz*.	1. Crystalline schists of the non-spotted sub-zone are referred to the muscovite-chlorite subfacies. 2. Crystalline schists of the spotted sub-zone have similarities to the rocks, referred to the Alpine amphibolite facies or the prasinite facies. 3. The development of spotted schists is intimately related to syntectonic ultramafic intrusion 4. The Sambagawa metamorphism is a type of dislocation metamorphism of relatively large scale.

Mikabu tectonic zone

1. Mainly composed of phyllonites of local dislocation metamorphism.
2. The Mikabu tectonic zone was genetically related to the southerly up-thrusting movement of relatively crystalline belt of the Sambagawa metamorphic zone at the later act of the Sambagawa metamorphism.

* Formations of each metamorphic zone are tentatively correlated as follows:

Sambagawa met. zone	Sangun met. zone	Ryôké m. zone	
Yoshinogawa group: Upper sub-group; Middle sub-group: Minawa formation, Koboké formation; Lower sub-group: Kawaguchi formation, Oboké formation	Upper formation (Ota group)	Kuga group	Upper Permian ↕ Pennsylvanian
	Tsuno group: Middle formation, Lower formation		
Nishiiya group			

Conclusion

(A) Mutual relation between the three metamorphic zones.

The mutual relations between the three metamorphic zones and the characteristics of each metamorphic zone are summarized in Table 2.

As read from the table, the *Metamorphiden*, related to the late-Palaeozoic or the early-Mesozoic orogenesis, can be divided into three metamorphic zones, which represent, respectively, successive acts of orogenic movement. In short, metamorphism was propagated from the north to the south, and the metamorphic character has been changed, keeping in step with the change of geological conditions. Among the three metamorphic zones, the Sambagawa zone is genetically related to the presence of the Ryôké zone, but, the formation of the Ryôké zone seems unrelated to the presence of the Sangun zone. Except schists of the spotted sub-zone, the metamorphic character of schists of the Sambagawa zone closely resembles that of schists of the Sangun zone, but, the geological situation at the time of formation of each metamorphic zone must have been quite different.[1]

(B) Metamorphism and plutonism

It must not be overlooked that higher-grade metamorphic zones of the normal regional type, such as the almandine-, cyanite-, staurolite-zones, are completely lacking in the *metamorphiden* of the late-Palaeozoic orogenesis in Southwestern Japan.[2] The Ryôké metamophism, which is characterized by intense thermal and material addition, related to plutonism, is not accompanied by dynamic effect, while the Sangun and the Sambagawa metamorphisms, which are characterized by intense dynamic effect, are not accompanied by thermal effect, which may give rise to higher-grade schists. This fact may confirm P. Misch's opinion (Misch, 1949) that dynamic regional metamorphism, occurred in eugeosynclines, may give rise to the uppermost mesozonal schists at the highest, and that higher-grade schists are formed under the effect of additional heat of granitizing agent (also cf. E. Bederke, 1953).

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1) To the north of the Sangun zone, one can imagine the land of Hida gneiss complex, the fragments of which are seen in the Hida region and in the Islands of Oki. It has not been ascertained, whether the land of Hida played the same rôle in the formation of the Sangun metamorphic zone, as played by the Ryôkè zone in the formation of the Sambagawa metamorphic zone.

2) These higher-grade zones have only been found in the Hida gneiss region.

(C) Subjects for consideration

In this paper, metamorphic and structural characteristics and mutual relations of the three metamorphic zones in Southwestern Japan have been described, according to the observations in Chûgoku and Shikoku. The writer wishes that the subjects, discussed in this paper, may be criticized with the observations in the other provinces. Especially, in North and Cental Kyûshû, the situation may be very complicated.

In Kyûshû, the Ryôké metamorphic and intrusive rocks have been reported only in the Peninsula of Kunisaki, Oita Prefecture, and the western extension of the Sambagawa metamorphic zone is tracesble to the west of the Peninsula of Saganoseki, Oita Prefecture. Unfortunately, the main portion of Central Kyûshû is covered with enormous quantity of the Aso lavas. In the western part of Central Kyûshû, the situation is changed. There found several metamorphic units, such as the Ryûhôzan schist zone, the Higo gneiss and schist zone, accompanied by granodioritic intrusives (H. Yamamoto, 1953), the Chikugo metamorphic region, which may not be referred to either the Sambagawa, or the Ryôké, or the Sangun metamorphic zone proper. So, the parallelism of the Ryôké and the Sambagawa metamorphic zones is not traceable over the Aso lava area. The extinction or the change in character of the Ryôké metamorphic zone should correspond to the extinction or the change in character of the Sambagawa metamorphic zone. It is a subject of importance to analyse successive metamorphic history related to the late-Palaeozoic orogenesis in Kyûshû, especially to decipher the plutonism and metamorphism of the Ryôké phase in Chûgoku in the metamorphic regions in North and Central Kyûshû.

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