GEOLOGY OF GEOSYNCLINAL GREENSTONES OF THE CHICHIBU AND SAMBAGAWA BELTS IN CENTRAL SHIKOKU

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I. Introduction

Volcanic and volcanogenic sedimentary rocks, here collectively called the greenstones, are widely distributed in close relation with chert, limestone and other sedimentary rocks in the Sambagawa and Chichibu belts. They are considered to be the products of initial volcanism in the eugeosynclinal domain. They have more or less suffered regional metamorphism. That is why there are no definite correlation between the ages of the original rocks of the distinctly metamorphosed Sambagawa belt and the weakly metamorphosed Chichibu belt, which run parallel to each other in the Outer zone of Southwest Japan. It is, however, very important for understanding the geosynclinal development to make clear the stratigraphic and structural relationships between the two belts.

The Sambagawa and Chichibu belts are widely distributed and contain most of the known stratigraphic units and large bodies of greenstones representing different metamorphic grades in central Shikoku. Thus the two belts of the surveyed area is one of the best field for the study in question.

In this paper, the writer intends to infer the approximate stratigraphic positions of the distinctly metamorphosed rocks of the Sambagawa belt from the comparison of lithological sequences and structural relation with weakly metamorphosed rocks of the Chichibu belt containing fossils. The writer also puts special emphasis on the lithologic nature of greenstones as a basis to carry forward the geochemical study of greenstones distributed in central Shikoku, the chemistry of which will be discussed in another paper.

II. Stratigraphic and Structural Relationships between the Sambagawa and Chichibu Belts

The Sambagawa belt, well known as a typical representative of the circum-Pacific blueschist ter-

rains, and southerly adjacent less or non-metamorphic Paleozoic Chichibu belt are made up primarily of similar eugeosynclinal lithologic assemblage, typified by sandstones of wacke type, mudstones, volcanic and volcanogenic rocks, bedded chert and subordinate lenticular limestones. The metamorphic grade declines towards the south gradually from the northern part of the Sambagawa belt to the Chichibu belt.

Greenstones of the two belts are conformably intercalated in clastic sedimentary rocks. The greenstones and the rock units in which they are contained do not show any particular deformation patterns or sedimentary structures different from those of the overlying and underlying clastic rocks. They are, therefore, regarded as the products of submarine eruptions contemporaneous with the clastic rocks.

The simplified geologic map of central Shikoku with a generalized profile is shown in Fig. 2. Along the boundary area of the two belts in Shikoku there occur fairly large, discontinuous, elongate bodies of green rocks called the Mikabu green rocks. They were once considered as intrusives along a major tectonic line, currently called the Mikabu line (KOJIMA, 1950). Recent researches (SUZUKI, 1964, 1965; IWASAKI, 1969; SUZUKI *et al.*, 1971), however, have clarified that they are

Fig. 1. Index map of the surveyed area.

sa : Sambagawa belt, ch : Chichibu belt, sh : Shimanto belt ; MDL : Median Dislocation Line, B : Butsuzo Line.

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Fig. 2

largely effusive rocks conformable with the surrounding rocks. Detailed mapping of the Ikegawa area (SUZUKI, 1965) and the Odamiyama area (KASHIMA, 1969) have ascertained that the rocks of the northernmost part of the Chichibu belt and those of the Sambagawa southern marginal zone* constitute the southern and northern wings of an anticline respectively, although a fault of small displacement accompanying small acidic intrusive rocks of the Miocene age is found along its axial part. The present writer has also confirmed this anticline and similar lithologic sequences in the northern and southern wings in the Ikegawa area. Therefore, the rocks of the Sambagawa southern marginal zone and the northernmost part of the Chichibu belt can be referred to the same rock unit of stratigraphic and structural continuity. Accordingly, the age of the original rocks of the Sambagawa belt can be deduced from the structural and stratigraphic relationships to the Paleozoic rocks containing fossils of the Chichibu belt, and the greenstones of the two belts and the Mikabu green rocks along their boundary area are regarded as products of successive or contemporaneous submarine volcanism in one and the same sedimentary domain.

In the present area, axial surface of the anticline mentioned above is nearly upright with the northern and southern wings dipping at angles of 40° – 70° . The rocks of the two wings are almost the same not only in the stratigraphic succession and lithology (Fig. 3), but also in the metamorphic grade. The greenstones occur as thin layers of basaltic pyroclastics and gabbro interbedded with black phyllite and chert, and are continuously traced into two wings under consideration. According to SUZUKI (1964, 1965), these greenstones constitute a large body which lies along the axial zone of the anticline to the west and is one of the typical representatives of the Mikabu green rocks.

The formation of the southern wing which occupies the northernmost part of the Chichibu

* after SUZUKI (1965)

Fig. 3. Generalized columnar sections of the Kamiyakawa formation in the boundary area between the Sambagawa and Chichibu belts.

I : Sambagawa southern marginal zone, II : Northern part of the Chichibu belt.

**Neoschwagerina cf. margaritae* (DEPRAT) has been found from the same horizon as this bed at Uchino and Terano by HASHIMOTO (1967).

belt again forms a syncline to the south with a half wave-length of 1 km and thrusts up onto sandstone-rich formations. This thrust, the Nanokawa thrust, is represented by a shear zone of several meters width with a general strike of E-W and moderate to gentle dips to the north.

The Paleozoic strata of the Ōdo area on the south of the Nanokawa thrust consist mainly of massive to thick bedded sandstone with some beds of alternating thin sandstone and shale, and three beds of greenstones accompanying some lenses of limestone with fusulinid fossils. They

Fig. 2. Geologic map of central Shikoku with a generalized profile.

A : Ojoin formation, B-1 : Upper member of Minawa formation, B-2 : Main member of Minawa formation, B-3 : Lower member of Minawa formation, C : Koboake formation, D : Kamiyakawa formation, E : Acidic intrusive rocks, F : Serpentinite, G : Ryoseki formation, H : Torinosu formation, I : Yasuba formation, J : Takaoka formation, K : Kokuzozan formation, L : Shirakidani formation, M : Sima formation, N : Granodiorite, 1 : *Triticites* sp., *Pseudoschwagerina* sp., 2 : *Pseudofusulina vulgaris*, 3 : *Yabeina katoi*, *Yabeina* sp. cf. *Y. globosa*, *Chusenella* sp., 4 : *Fusulina* sp., 5–6 : *Neoschwagerina cf. margaritae* (DEPRAT), 7 a–b : *Neoschwagerina* sp.

strike E-W and dip steeply to the north generally, but locally to the south. They are overturned, becoming young in age from north to south, and range from the Lowest Permian to the Middle Permian so far as has been known. Further to the south they are bounded by a fault and contact with nearly horizontal to gently undulating Paleozoic strata composed mainly of strongly contorted black slate. They are referred to the Middle Permian (*Neoschwagerina* and *Yabeina* zones).

The Sambagawa belt of the present area consists of a thick sequence of psammitic and pelitic schists and mafic volcanogenic schists. They are referred to the upper part of the stratigraphic sequence of the Sambagawa belt established by KOJIMA *et al.* (1956) and HIDE *et al.* (1956) in the Oboke and Besshi, that is, the Kobohe, Minawa and Ojoin formations, in ascending order.

In the central part of the Sambagawa belt, bedding schistosity are nearly horizontally disposed showing gentle undulated structures. Major anticlinal and synclinal axes with symmetrical limbs are disposed with half wave-length of about 8 km. But those of the northern part, where the metamorphic grade is the highest and the Tōnaru epidote amphibolite mass is exposed, show a very complicated structure with general inclination of about 40° to the north and are accompanied with minor recumbent folds and reverse drag folds.

In the Sambagawa southern marginal zone, which has a width of about 5 km, strata incline 40°—70° homoclinally to the north, although minor recumbent folds are also observed. Judging from the normal drag folds, however, the stratigraphic position of the rocks becomes upper from south to north. KOJIMA and SUZUKI (1958) recognized a thrusting shear zone attaining about 1 km in width at about 5 km north of the southern margin of the Sambagawa belt. It runs through a black schist formation in the direction of NEE and steeply dips to the north. The shear structure is represented mainly by closely spaced, nearly vertical to steeply northerly dipping shear cleavages and some thrust faults of the same direction and dip. In the present area, however, no remarkable vertical as well as horizontal displacement is deduced, because one and the same formation are exposed from the south, through this zone, to the north.

III. Age of the Original Rocks of the Sambagawa Belt

The stratigraphic sequences in the boundary area between the Sambagawa and Chichibu belts are, as shown in Fig. 3 (adapted from SUZUKI, 1964), characterized by thick sandstones in the

Fig. 4. Generalized stratigraphic sequences in the northern zone of the Chichibu belt (III) and the Sambagawa belt (I and II) of central Shikoku.

I: Columnar section along the Besshi route, II: Generalized columnar section of the Sambagawa metamorphic rocks (adopted from KOJIMA *et al.*, 1956), III: Columnar section along the Nano-kawa-Mori route. Rock legends are the same as those of Fig. 3.

lower part, black shale with fairly thick chert beds in the middle part and basic tuff accompanied by limestone beds in the upper part. From a limestone bed of the upper part in the northern zone of the Chichibu belt *Neoschwagerina* cf. *margaritae* (DEPRAT) has been found by HASHIMOTO (1967). This indicates that the age of the rock sequences exposed in the boundary area range from the Middle Permian down probably to the Lower Permian.

The Paleozoic rocks of the Ōdo area located at about 15 km south of the boundary area mentioned above consist predominantly of sandstone with two beds of greenstones in the lower part and shale with greenstones, chert and thin sandstones in the upper part. They range, as shown in Fig. 4, from the *Pseudoschwagerina* zone (the lower part) to the *Yabeina globosa* zone (the upper part), although the lowest and uppermost ranges cannot be precisely determined. This stratigraphic se-

Fig. 5. Stratigraphic distribution of greenstones in central Shikoku.

I : Outer zone of Southwest Japan (KANEMERA, 1971), II : Chichibu northern zone, III : Sambagawa belt. The frequency distributions in black indicate the general thickness of greenstone layers, and other figures are the same as in Fig. 2.

quence is closely similar to that of the boundary area: the lower part rich in sandstone in both columnar sections of the northern and southern wings well correspond to each other and the upper part of the Ōdo area can be correlated with the middle and upper part of the columnar sections of the boundary area. Fossils obtained from lenticular limestone at Ōdo indicate that the upper part of both columnar sections at the boundary area is referred to the upper Middle Permian (the *Neoschwagerina margaritae* zone to the *Yabeina globosa* zone), and the sandstone-rich lower part to the Lower Permian (mostly the *Pseudoschwagerina* zone older than the *Pseudofusulina vulgaris* zone).

Regarding the stratigraphic relation between the Sambagawa and Chichibu belts, nowhere else continuous secession has hitherto been obtained. In most areas, the two belts are divided by a fault. In the surveyed area, as mentioned above, the rocks of the Sambagawa southern marginal zone and the northernmost part of the Chichibu belt constitute a structural and stratigraphic continuity, but the Kiyomizu tectonic zone unfortunately prevents us from establishing the

precise stratigraphic relation between the distinctly metamorphosed rocks of the Sambagawa proper and feebly metamorphosed Permian rocks of the Sambagawa southern marginal zone and the Chichibu belt. Accordingly, correlation by means of litho-stratigraphic comparison between them is attempted.

In the generalized stratigraphic sequence established in the Sambagawa proper (KOJIMA *et al.*, 1956), the units characterized by the predominance of sandstone are represented by the Oboke, Koboake and Ojoin formations, as shown in Fig. 4. Of these, the Koboake formation and the overlying Minawa formation well correspond in litho-stratigraphic sequence to the lower part and the upper part respectively of the northern zone of the Chichibu belt and the boundary area; the lower part predominant in sandstone and upper part shale with not a few greenstones and chert. Difference is seen in the thickness of greenstones, but volcanogenic deposits may locally changeable. Approximate ages of the Sambagawa metamorphosed rocks are thus inferred as shown in Fig. 5.

IV. Distribution of Greenstones

Greenstones of the northern zone of the Chichibu belt in the surveyed area are accompanied by lenticular beds of limestone. Fusulinid fossils obtained from these limestones indicate that volcanic activity took place in the Lower Permian (*Pseudoschwagerina* zone, the *Pseudofusulina vulgaris* zone) and the Middle Permian (between the *Pseudofusulina* and *Neoschwagerina* zones). The lithologic sequences of the greenstone beds are summarized as follows in ascending order:

Lower unit (Lowest Permian, ca. 60 m in thickness)

Mainly composed of basaltic rocks and associated thin tuff breccia, red tuff and diabase. Subordinately quenched basaltic rocks accompanied with plumose crystallites and lenticular limestone.

Middle unit (Lower Permian, ca. 80—130 m in thickness)

Predominantly basaltic rocks, which change gradually to diabase or gabbro, associated with lenticular oolitic limestones.

Upper unit (Middle Permian, ca. 250 m in thickness)

Characterized by thick gabbroic rocks associated with diabase and basaltic rocks, tuff breccia and intercalated thin beds of shale.

Fig. 6. Metamorphic zoning of central Shikoku. Solid circles indicate the distribution of alkali amphibole.

The Mikabu green rocks of the present area are composed of thin layers of basic tuff and subordinate gabbro and are intercalated in black schists. Basic tuffs occur at 700 m below the *Neoschwagerina*-limestone at Ikegawa, but thin gabbroic and/or basic tuff layers at 600 m above it at Omoiji, suggesting that the Mikabu green rocks are of the Lower and Middle Permian age.

In the Sambagawa belt, basic schists are contained especially in the main and upper members of the Minawa formation (See Fig. 2 and 3). Their stratigraphic sequence is summarized as follows in ascending order:

Lower member of the Minawa formation (400—900 m in total thickness)

Thin beds of basic tuff rarely intercalated in black schist; their thickness is mostly less than a few meters, but in places (e.g. Negoro-saku) attains more than 50 m.

Main member of the Minawa formation

(600—900 m in total thickness)

Basic schist of less than 10 m in thickness is intercalated in black schist, and dozens of basic schist layers reach the total thickness of 600—900 m, but in places (e.g. the Motoyasu mine, Terakawa) a layer of basic schist attains more than 100 m in thickness.

Upper member of the Minawa formation (1200 m ? in total thickness)

The mode of occurrence of basic schist is similar to that of the main member. In addition, an epidote amphibolite mass is intercalated almost concordantly with the surrounding black schist and basic schist. It is probably derived from basalt, gabbro and basic tuff.

V. Metamorphism of Greenstones

Greenstones of the Sambagawa and Chichibu belts have suffered the high P/T type metamorphism (MIYASHIRO, 1967; BANNO, 1964; SEKI *et al.*, 1964). The two belts in the present area can be divided into the following four zones, showing the changes of mineral assemblages from low to high grade towards the north, the pumpellyite, the pumpellyite-actinolite, the epidote-actinolite and the epidote-common hornblende zones. Exceptionally the metamorphic grade increases again in the Permian strata near the Kurosegawa tectonic line, the southern boundary of the northern zone of the Chichibu belt, where it represents the pumpellyite-actinolite zone or epidote-actinolite zone, as has been reported by BANNO (1964).

(1) Pumpellyite zone: Characterized by the assemblage of pumpellyite and chlorite. Prehnite occurs rarely. Epidote is not common, but increases in quantity with increasing metamorphic grade.

(2) Pumpellyite-actinolite zone: Characterized by the appearance of actinolite in basic schists. Pumpellyite is stable and is not decomposed into epidote or actinolite, although the amount of pumpellyite is decreased.

(3) Epidote-actinolite zone: Characterized by the disappearance of pumpellyite and the abundant occurrence of epidote in basic schists. Alkali-amphibole such as riebeckite or glaucophane rarely occurs in the neighborhood of the Besshi mine.

(4) Epidote-common hornblende zone: Characterized by the appearance of common hornblende. There may be transitional zone characterized by subcalcic hornblende between the

epidote-actinolite and epidote-common hornblende zones (BANNO, 1964). Regarding the mineral assemblage of the epidote-actinolite and epidote-common hornblende zones, more detailed descriptions were given by HIDE (1961) and BANNO (1964).

VI. Lithologic nature of the Original Rocks of Greenstones

(1) Inference of original rocks

The original rocks of greenstones can be deduced to some extent from the field observation and microscopic investigations. In this section the original mineralogical compositions of greenstones of the two belts under consideration and those of the Mikabu green rocks are examined and compared.

A. Greenstones of the northern zone of the Chichibu belt

i) Gabbroic rocks: Rocks with a plutonic texture under the microscope are referred to gabbroic rocks. They occur generally as concordant bodies with surrounding beds such as basalt, tuff breccia, diabase, black slate and chert and their thickness ranges from about 1 m to 80 m. Based on the relic mineralogical composition, they are divided into the followings:

Titaniferous augite gabbro: Composed mainly of purple augite and plagioclase with or without accessory biotite which shows brown or green pleochroism. Soda-pyroxene (?) is observed at the periphery or along the cleavages of pyroxene in some specimens.

Augite gabbro: Composed mainly of plagioclase and colorless augite. Soda-pyroxene (?) and accessory biotite occur in the same manner as in titaniferous augite gabbro. Apatite and opaque minerals are rather abundant.

ii) Diabasic rocks: Rocks with an ophitic texture are referred to diabasic rocks. They occur as thin layers (a few meters in thickness) with gradual change to basaltic or gabbroic rocks, but are, in some cases, in direct contact with black slates above and below. From the relic mineral assemblage, the original rocks are inferred as follows:

Titaniferous augite diabase and olivine (?) - titanite diabase: Composed mainly of the prismatic crystals of plagioclase and moulded augite. Accessory biotite is occasionally found. Apatite and opaque minerals are common. Olivine (?) is almost decomposed to serpentine minerals.

iii) Basaltic rocks: These range in thickness from a few meters of a hundred meters. The original texture and minerals are almost obliterated

by alteration. Most of them represent a reddish tint megascopically. Judging from relic minerals the original rocks can be inferred as follows:

Titanaugite basalt

Olivine (?) basalt

B. Mikabu green rocks

In the surveyed area, the Mikabu green rocks are exposed as thin layer, always associated with black schists. Lava flows or sills are extremely rare. The following rocks are discriminated from relic minerals:

Augite gabbro

Augite-bearing crystal tuff

Hornblende-augite-bearing crystal tuff

C. Greenstones of the Sambagawa belt

Lava flows or sills of basaltic, diabasic and gabbroic rocks are extremely rare in this belt. The apparent scarceness of lavas and sills may be attributable nearly to complete change of the original texture and structure of the rocks by metamorphism. It is practically true that the original textures are hardly detected. But basic schists are frequently interbedded as thin beds with black schists and extend for a long distance. For example, the rocks containing relic hornblende extend for about 15 km from Terakawa through the Motoyasu mine to the Besshi mine. Even in the rocks bearing relic-minerals, relic-minerals are frequently broken and interbedded in fine ash. This fact suggests that basic schists were mostly derived from pyroclastic rocks. A few lava flows and gabbroic layers occur mostly as thin as a few meters in thickness and are always associated with basic tuff. But in a limited places rather thick and coarse-grained rock masses (the Tōnaru and Terakawa masses) are observed. The following rocks are discriminated from the relic minerals:

Pyroxene-bearing rocks

Common hornblende-bearing rocks

Pyroxene-common hornblende-bearing rocks

(2) Difference in the mode of occurrence of greenstones

As shown in Table 1 and Fig. 4, the greenstones of the northern zone of the Chichibu belt and the Sambagawa belt exhibit a remarkable difference in the mode of occurrence, thickness and lithologic nature. Those of the Sambagawa belt are characterized by a large quantity of basic tuff, whereas, those of the northern zone of the Chichibu belt are predominantly basalt flows, diabase and gabbro.

At the boundary area between the Chichibu and Sambagawa belts the Mikabu green rocks are exposed. IWASAKI (1969) and SUZUKI *et al.*

Table 1. Comparison of the nature of original rocks of the greenstones in the Chichibu northern zone and the lower and main member of the Minawa formation of the Sambagawa belt.

	The Chichibu northern zone	The lower and main members of Minawa F. in the Sambagawa belt
thickness of greenstones	(Nanokawa-Mori route) 440m	(Besshi route) 340 (?) m
basalt	} 420m (account for 95%) 20m (account for 5%)	} less than 10m account for more than 90%
gabbro		
basic tuff		
number of thin sections		
basalt	64 (account for 33%)	} 6 (account for 3%) 190 (account for 97%, including crystal tuff)
diabase	29 (account for 15%)	
gabbro	41 (account for 21%)	
basic tuff	62 (account for 31%)	
relic mineral-bearing rocks		38 (account for 19%, including Mikabu green rocks)

(1971) concluded that the Mikabu green rocks were extruded along an oceanic ridge or geanticlinal ridge on the oceanic crust from a close similarity in their occurrence and geochemical nature to oceanic tholeiite. On the other hand the lithologic facies characterized by thick limestone and chert in the boundary area suggests its sedimentary condition much different from the main part of the Sambagawa belt.

Granting that geosyncline was differentiated into several sedimentary basins in Permian age and that Mikabu green rocks were extruded along an oceanic ridge which separate the Sambagawa belt from the Chichibu belt, the difference of the mode of occurrence of greenstones in the two belts may be attributable to the nature of volcanic activity, namely, the explosive eruptions in the Sambagawa and the comparatively non-explosive ones in the Chichibu.

VII. Summary

To sum up the geological data, the following conclusions can be suggested.

1) Main volcanic activity in the Chichibu belt (except for the southern zone), Sambagawa belt and the boundary area characterized by Mikabu green rocks took place in the Lower to Middle Permian.

2) Greenstones of two belts have suffered the Sambagawa metamorphism of fairly high P/T type, showing the changes of mineral assemblages from low to high grade toward the north; the pumpellyite, the pumpellyite-actinolite, the epidote-actinolite and the epidote-common hornblende zones.

3) The rocks are predominantly, if not entirely, of submarine origin as indicated by the close association of limestones containing marine fossils and marine sedimentary rocks and quenched basaltic rocks with dendritic crystallites.

4) Greenstones of the Sambagawa belt are composed mostly of basic tuff and those of the northern zone of the Chichibu belt basaltic flows.

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四国中央部、秩父・三波川帯中の地向斜性緑色岩の地質

沢 田 賢 治

(要 旨)

緑色岩の化学分析を進める前段階として四国中央部において緑色岩の層序・構造的および変成岩的位置づけを行なった。調査地域では三波川・秩父両帯の境界は背斜軸で示されており、変成度から言っても漸移している。したがってフズリナ化石を含む秩父帯との岩相的および構造的比較により三波川帯中の原岩の時代論をも言及した。以下が得られた結論である。1) 秩父帯北帯・三波川帯および両帯の境界部にみられる大量の緑色岩はほぼ同時代に位置づけられ、前期ないし中期二疊紀に大規模な海底火成活動が生じたと思われる。2) 調査地域内の緑色岩は三波川変成作用を受けており南から北に向かって、パンペリ石帯、パンペリ石—緑閃石帯、緑レン石—

緑閃石帯、緑レン石—角閃石帯と累進変成作用を示す。ただし黒瀬川構造帯付近では変成度が南にいくにつれ高くなっており、パンペリ石—緑閃石帯あるいは緑レン石—緑閃石帯を呈する。3) 三波川帯中の緑色岩の大部分は塩基性凝灰岩起原であり秩父帯北帯は大量の玄武岩質溶岩で特徴づけられる。

地 名			
Besshi	別子	Negorosaku	根来佐古
Ikegawa	池川	Ōdo	大渡
Kiyomizu	清水	Omoiji	思地
Motoyasu	基安	Terakawa	寺川
Nanokawa	名野川	Tōnaru	東平