HOKUSATSU BEND AND CLOCKWISE ROTATION OF THE SOUTHWEST JAPAN ARC

By

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Abstract

The Hokusatsu Bend, one of the major bends in South Kyushu, is mapped in detail. The Bend affects the Shimanto Supergroup and the Sambosan Group, and is accompanied by N-S right-lateral and NW-SE left-lateral strike-slip faults. Geometrical analysis has revealed that folds developed within the Hokusatsu Bend are conical style, like those of the Hitoyoshi Bend. They were formed by the flexural-slip folding of formerly inclined strata with vertical fold axes. The vertical cone axes of the conical folds later tilted about 30° toward west-northwest. Thus, the Shimanto Supergroup around the Hokusatsu Bend has a steeper dip than that of the other areas in Kyushu. The conical folds of the Bend were formed associated with the clockwise rotation of the Southwest Japan Arc in Miocene time. The Shimanto and Sambosan Terrains of Kyushu, to the northeast of the Hokusatsu Bend, rotated clockwise about 30°, and those to the south rotated counter-clockwise about 30°-40°.

INTRODUCTION

There are three major bends in South Kyushu, where the NE-SW or ENE-WSW trending Southwest Japan Arc, to the northeast, is connected with the N-S or NNE-SSW trending Nansei-Shoto Arc, to the southwest. They are called the Hokusatsu Bend (HASHIMOTO, 1962a, b), Hitoyoshi Bend (TERAOKA *et al.*, 1981; MURATA, 1987), and Nojiri Bend (TERAOKA *et al.*, 1981). The Sambosan, Shimanto, and Hyuga Terrains of the Outer Zone are affected by the Bends, and extend toward south to the Nansei-Shoto Islands (KONISHI, 1965). These Bends are considered to have been formed by the clockwise rotation of the Southwest Japan Arc, associated with the opening of the Sea of Japan behind it (SHIMAZAKI *et al.*, 1981; MURATA, 1987).

Recent paleomagnetic studies have revealed that the Southwest Japan Arc rotated clockwise about 58° (OTOFUJI & MATSUDA, 1982) or 45° (HAYASHIDA & ITO, 1984). The paleomagnetic data show that the main rotation occurred in the Middle Miocene (about 15 Ma) in a very short period (TORII *et al.*, 1985).

MURATA (1987) recently analysed the geometry of the Hitoyoshi Bend by using attitudes of bedding surfaces; folds developed within the Hitoyoshi Bend are conical style, and they were formed by the flexural-slip folding of formerly inclined strata with vertical axes (MURATA, 1987). The Hokusatsu Bend, however, has been only roughly mapped, and the geologic structure of the

Hokusatsu Bend has little been known. In this paper, I describe that the Hokusatsu Bend consists of three strike swings of smaller scale, and that folds within the Hokusatsu Bend are conical style like those of the Hitoyoshi Bend by using attitudes of bedding surfaces. Furthermore, I discuss the significance of the Bend in relation with the clockwise rotation of the Southwest Japan Arc.

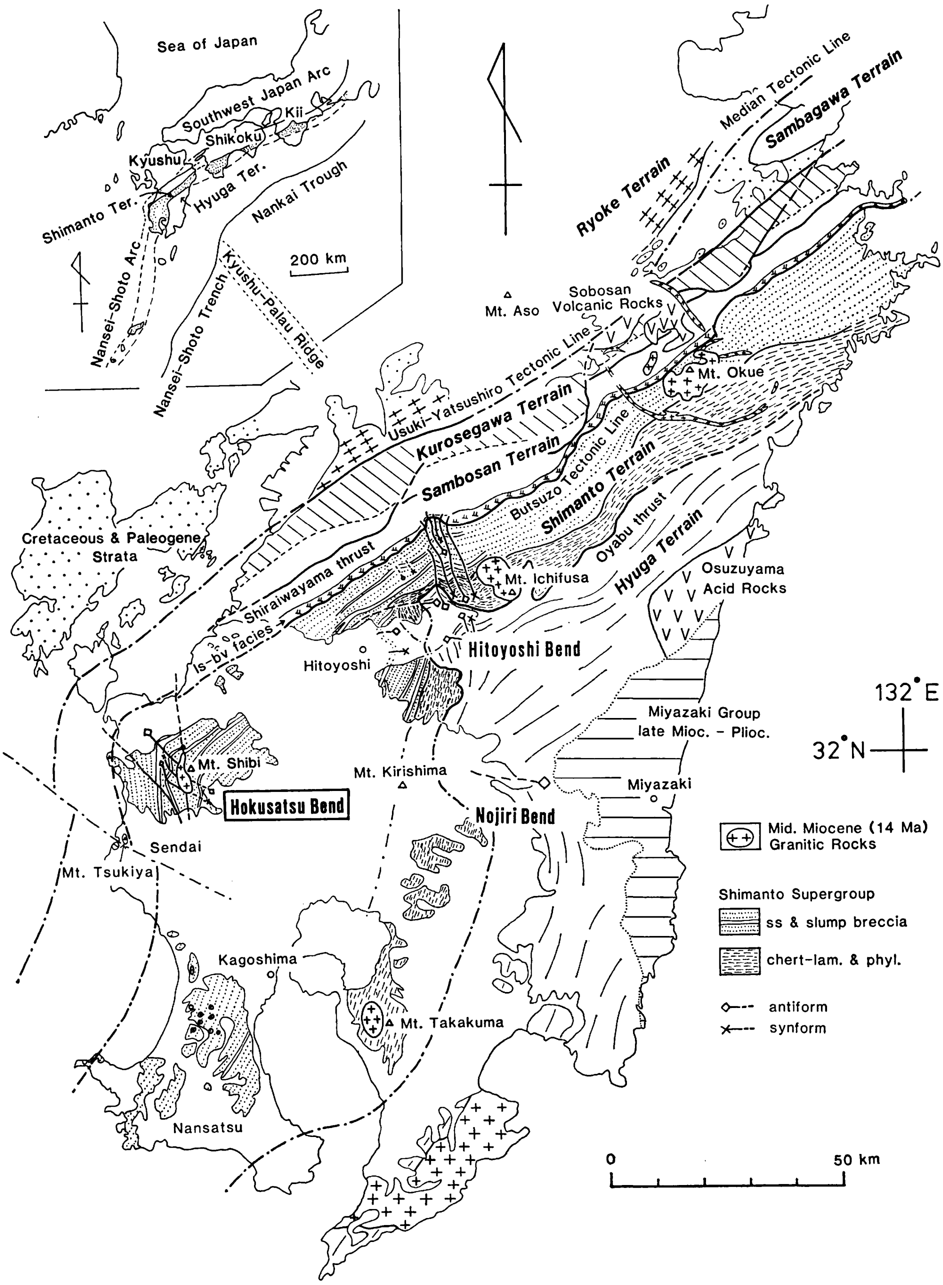

Fig. 1. Geologic map of Kyushu showing major Bends.

GEOLOGIC SETTING

The Shimanto Supergroup and Sambosan Group in the Hokusatsu Area appear to extend toward northeast to the Hitoyoshi Area without sharp bendings, and toward south to the Nansatsu Area with a slight bending, although their continuation is not exposed because of Tertiary and Quaternary volcanic covers (Fig. 1).

The Sambosan Group occurs in the area to the southwest of Akune and at Mt. Tsukiya near Sendai (Figs. 1 & 2). The Group strikes NNW-SSE, steeply dips toward west, and consists mainly of chert, limestone, and slump breccia. The chert yields late Norian conodonts (*Misikella hernsteini*, Loc. 1, west of Akune). The limestone near Mt. Tsukiya yields planktonic bivalves (*Halobia* sp.), which are correlative with those of the Konose Group (KANMERA, 1969) along the Kuma River of West Kyushu. Strata along the Ushinohama coast are probably correlative with the Shimanto Supergroup as described below, although they were believed to belong to the Sambosan Terrain (HASHIMOTO, 1962a).

The Cretaceous Shimanto Supergroup of the Hokusatsu Area was discordantly intruded by the Shibisan Granite of Middle Miocene age (14 Ma) (HASHIMOTO, 1962a; SHIBATA, 1978). Late Tertiary and Quaternary volcanic rocks cover the Shimanto Supergroup and Sambosan Group (HASHIMOTO, 1962a; KAMBE & OZAWA, 1963).

STRATIGRAPHY OF THE SHIMANTO SUPERGROUP

The Shimanto Supergroup of the Hokusatsu Area is divided into slump breccia-dominated and sandstone-dominated strata, which are called the Oganashi and Kurigeno Formations respectively.

Oganashi Formation

The Oganashi Formation which is imbricated and repeatedly distributed by faults forms four zones; Ushinohama, Ikenodan, Torimaru, and Noborio zones from west to east (Figs. 2 & 3). The Formation of the Ushinohama zone occurs from south of Akune to Ushinohama on the east of the Butsuzo Tectonic Line. The Formation of the Ikenodan, Torimaru, and Noborio zones is distributed subparallel to one another. Type locality of the Formation is along the logging road to the southeast of Oganashi. The Oganashi Formation partly corresponds to the lower and middle formations of the Togo Group of HASHIMOTO (1962a).

The Oganashi Formation consists of slump breccia, mudstone, siliceous mudstone, chert, and basic volcanic rocks. The slump breccia is made up of matrix-supported, S-sized (less than 1 m) (KIMURA, 1979) to L-sized (10-100 m) sandstone clasts and mudstone matrix. The mudstone is phyllitic, and rarely shows lamination. The siliceous mudstone is greenish grey or red, locally very fissile, and grades into the mudstone. The siliceous mudstone contains abundant radiolarians occasionally, so that it is called radiolarite in the field. The basic volcanic rocks consist mainly of pillow lava with small amounts of dolerite and

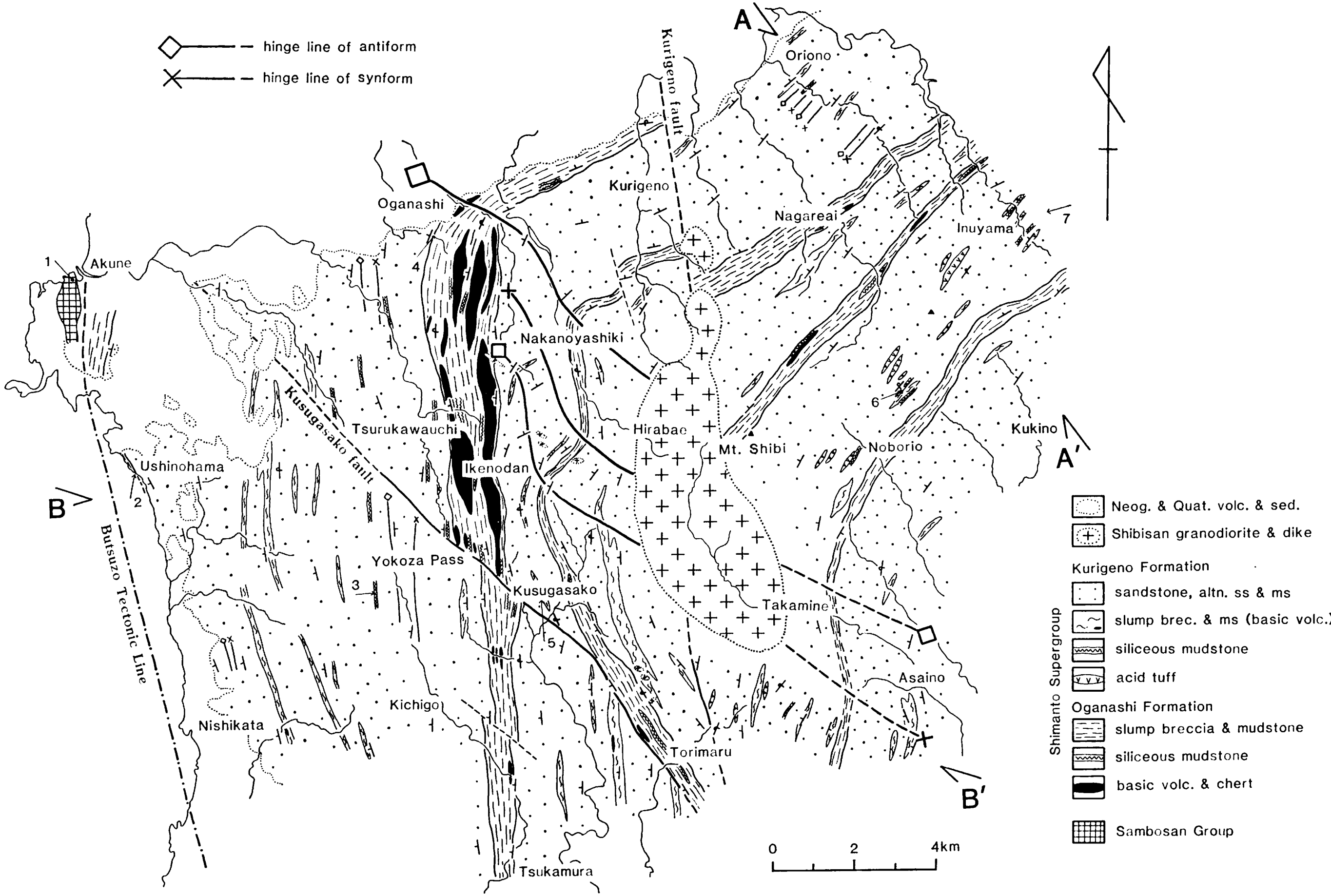

Fig. 2. Geologic map of the Hokusatsu Area.

tuff. The basic volcanic rocks are probably large slump blocks, because they do not occur continuously, and because they are surrounded by the slump breccia and mudstone. The chert is red or grey radiolarian bedded chert.

The Oganashi Formation of each zone has its own characteristics in containing different kinds of slump blocks. The Formation of the Ushinohama zone includes limestone and chert blocks, which are considered to be originated from the Sambosan Group. The Formation is in sedimentary contact with sandstone-dominated strata of the Shimanto Supergroup, to the east (Fig. 5a), and is included in the Supergroup, although the Formation was formerly believed to belong to the Sambosan Group by HASHIMOTO (1962a). The Butsuzo Tectonic Line probably runs N-S on the west of the Ushinohama zone. The Oganashi Formation of the Ikenodan zone is characterized by containing abundant pillow lava blocks. Their amount is the largest in the area between Oganashi and Yokoza Pass, where it attains more than 50% of the Oganashi Formation (Fig. 2). The pillow lava shows westward facing in the area to the north of the Yokoza Pass. The Oganashi Formation of the Torimaru zone contains red siliceous mudstone and bedded chert with a minor amount of pillow lava. The Oganashi Formation of the Noborio zone mainly contains sandstone blocks without basic volcanic rock and chert blocks.

The siliceous mudstone yields radiolarian fossils of *Holocryptocanium barbui*

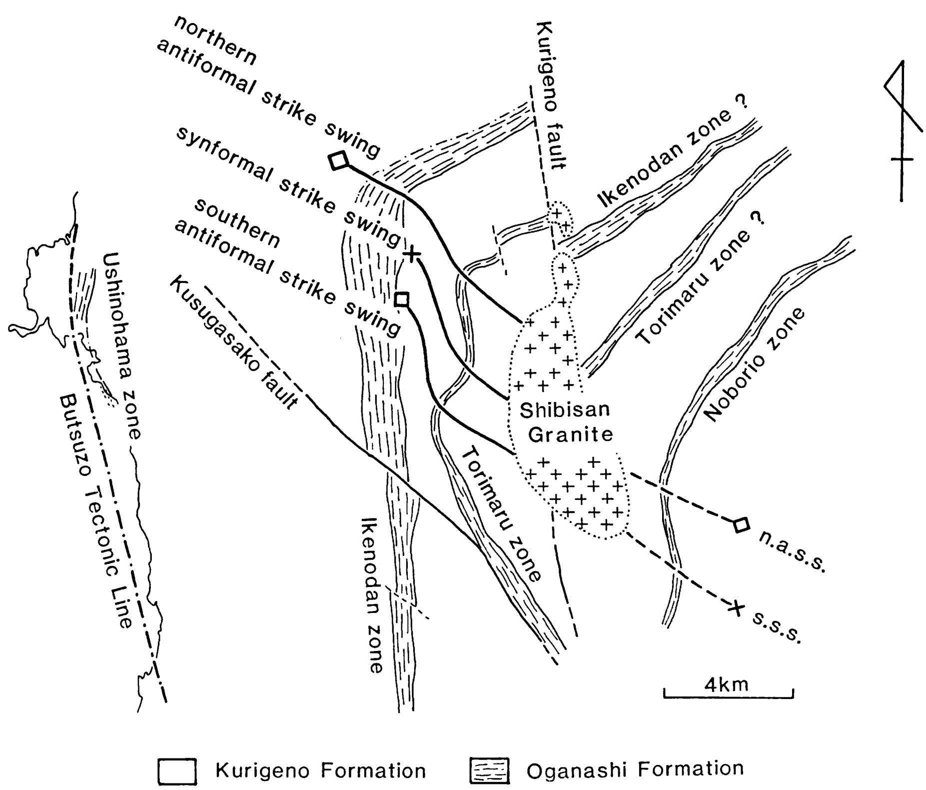

Fig. 3. Outline of the Hokusatsu Bend and strike-slip faults.

—*H. geysersensis* Assemblage of NAKASEKO & NISHIMURA (1981) at some localities (YONEDA & IWAMATSU, 1979; IWAMATSU, oral comm.). The Oganashi Formation is of Albian to Cenomanian.

Kurigeno Formation

The Kurigeno Formation is widely distributed in the Hokusatsu Area. Type locality of the Formation is along the logging road southeast of Kurigeno. The Formation mainly consists of sandstone and alternating bed of sandstone and mudstone with subordinate mudstone, siliceous mudstone, acid tuff, and slump breccia. The Kurigeno Formation corresponds to the upper formation of the Togo Group, the Hokusatsu Group, and the Miyanojo Formation of HASHIMOTO (1962a).

The sandstone is coarse to medium, angular to subangular, and ill-sorted massive wacke. The sandstone is generally quartz-feldspathic, and is lithic occasionally, containing many acid to intermediate volcanic fragments. The alternating bed of sandstone and mudstone is rhythmical one of sandstone bed, 5 cm to 1 m thick, and mudstone bed, 1 cm to 30 cm thick. The sandstone bed in the alternating bed shows graded bedding frequently. The mudstone of the Kurigeno Formation is mainly greyish black siltstone with sandy laminae. The mudstone is less fissile than that in the Oganashi Formation.

The siliceous mudstone is greenish grey or reddish purple and fissile, and grades into the mudstone. It contains abundant radiolarians occasionally, and is not so hard as the bedded chert in the Oganashi Formation. The acid tuff occurs in the area between the Noborio zone and Torimaru zone, and it shows vitroclastic texture occasionally. The slump breccia of the Kurigeno Formation does not continue so laterally as those of the Oganashi Formation. The slump breccia is made up of S- to M-sized sandstone clasts and mudstone matrix. Blocks of chert and basic volcanic rocks are rarely contained in the slump breccia.

The siliceous mudstone of the Kurigeno Formation yields radiolarian fossils of *Holocryptocanium barbui*—*H. geysersensis* Assemblage of Albian to Cenomanian, such as *Pseudodictyomitra pseudomacrocephla*, *Amphipyndax* cf. *stocki*, *Novixitus weyli*, and *Thanarla elegantissima* near Noborio (Loc. 6). The siliceous mudstone at Locs. 3, 4, 5, and 7 yields radiolarians of the same assemblage (NAKASEKO & NISHIMURA, 1981). YONEDA & IWAMATSU (1979) reported Albian—Cenomanian radiolarian fossils from various horizons at some localities. The Kurigeno Formation is of Albian to Cenomanian, and is contemporaneous with the Oganashi Formation.

The Oganashi and Kurigeno Formations of the Hokusatsu Area are correlative with the slump breccia-dominated and sandstone-dominated formations of the Nonowaki Group (MURATA, 1987) of the Hitoyoshi Area respectively, considering their age and lithology. Chert-laminite-dominated strata like the Tashiro Group of the Hitoyoshi Area do not occur in the Hokusatsu Area.

PRE-BENDING STRUCTURES OF THE SHIMANTO SUPERGROUP

Geologic structures of the Shimanto Supergroup before bending are briefly described. In the southwestern part of the Hokusatsu Area, the Kurigeno Formation strikes N-S or NNW-SSE, and mainly dips 60°-90° toward west (KAMBE & OZAWA, 1963). The Formation shows westward facing at many localities, and forms a westerly-dipping homoclinal structure fundamentally (Fig. 4). However, one set of anticline and syncline of mappable scale is detected in the area to the west of Yokoza Pass. In the eastern limb of the anticline, the Formation dips steeply (more than 70°) toward east, or dips toward west and reversed. The axis of the fold trends N-S, and is horizontal. The fold extends toward north to Tsurukawauchi, although it is displaced at Kusugasako by a NW-SE trending strike-slip fault (Fig. 2). The Kurigeno Formation of the northwestern part strikes NE-SW, and dips 40° to 90° towardnorthwest. There occur three sets of anticline and syncline of mappable scale. The fold whose

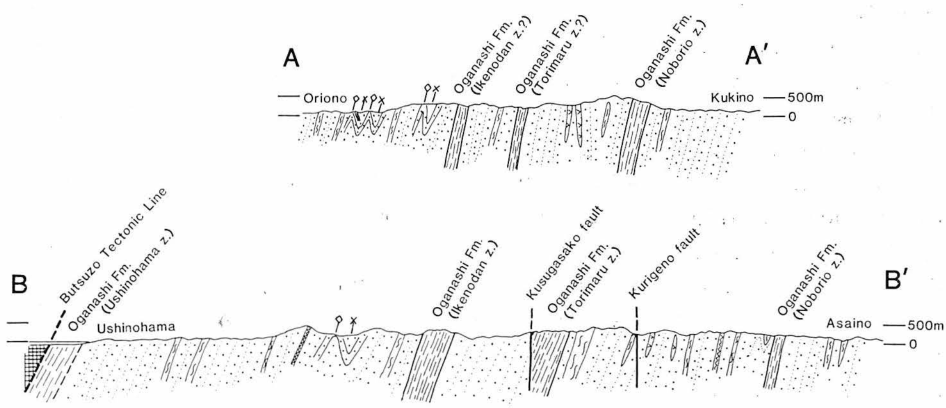

Fig. 4. Geologic profiles of the Hokusatsu Area.

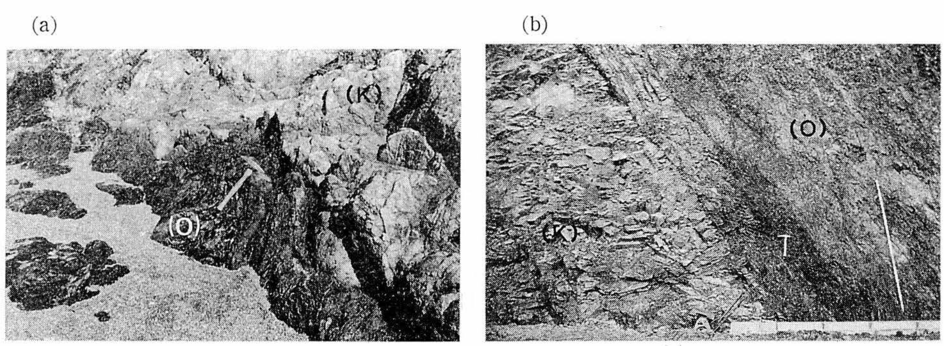

Fig. 5. (a) Sedimentary contact between the Kurigeno Formation (K) (upper right) and Oganashi Formation of the Ushinohama zone (O) (lower left) at Ushinohama coast (Loc. 2). (b) Fault formed before sediment consolidation between the Kurigeno Formation (K) (left) and the Oganashi Formation of the Ikenodan zone (O) (right) near Oganashi (Loc. 4).

half wavelength is 300-500 m is closed in shape, and the axial surface dips steeply toward northwest (Figs. 2 & 3).

The Kurigeno Formation is repeatedly distributed four times, and shows westward or northwestward facing fundamentally. However, the age of the Kurigeno Formation is the same in the whole Area. Therefore, the Kurigeno Formation appears to form an imbricate structure, in which the Formation of the same stratigraphic horizon is repeatedly distributed by faults. The boundary between the Kurigeno and Oganashi Formations is observed at Loc. 4 near Oganashi, where no distinct shear zones are observed (Fig. 5b). The Kurigeno Formation is possibly imbricated by faults, which were probably formed before consolidation.

HOKUSATSU BEND

Strike swings

In the Hokusatsu Area, a remarkable strike swing occurs in the area between Oganashi and Asaino, where the Shimanto Supergroup changes its strike from NE-SW to N-S (Fig. 2). HASHIMOTO (1962a, b) called the major strike swing the Hokusatsu Bend (Hokusatsu Bending). The Hokusatsu Bend, however, comprises three strike swings of smaller scale in the central part of the Bend, like those of the Hitoyoshi Bend (MURATA, 1987). In the northwestern part, the Shimanto Supergroup swings strike from N0°-20°W, to the south of Tsurukawauchi, through N0°-30°E, to the south of Oganashi, to N40°-70°E, to the east of Oganashi (Fig. 2). The Supergroup mostly dips 60°-90° toward west-southwest, west-northwest, and northwest respectively. The strike swing is detected as an antiform which has a NW-SE trending hinge line. The swing is not sharp, but gradual, as shown by the distribution of the Oganashi Formation of the Ikenodan zone (Fig. 2). It is called antiformal strike swing (northern antiformal strike swing in Fig. 3). To the south of this strike swing, the Kurigeno Formation to the west of the Oganashi Formation of the Ikenodan zone extends toward south to Kichigo without changing its strike largely.

On the other hand, in the central part of the Bend, the Supergroup swings strike three times from N20°-30°W, near Enokidan, through N20°-60°E, east of Ikenodan, and N10°E-10°W, west of Hirabae, to N40°-80°E, near Kurigeno (Fig. 2). The Supergroup mostly dips 60°-90° toward west-northwest, northwest, west, and northwest respectively. These strike swings are sharp in places as clearly shown by the curved distribution of the Oganashi Formation of the Torimaru zone (Figs. 2 & 3). They are detected as two antiforms and one synform, which have NNW-SSE to NW-SE trending hinge lines. Among the three strike swings, the northern antiformal one clearly extends to that near Oganashi as described already. However, the synformal and southern antiformal strike swings do not extend toward west, and disappear near the boundary between the Oganashi Formation of the Ikenodan zone and the Kurigeno Formation to the east.

In the southeastern part of the Bend, the Shimanto Supergroup swings strike from N10°-30°E, northeast of Torimaru, through N10°-20°W, near Takamine,

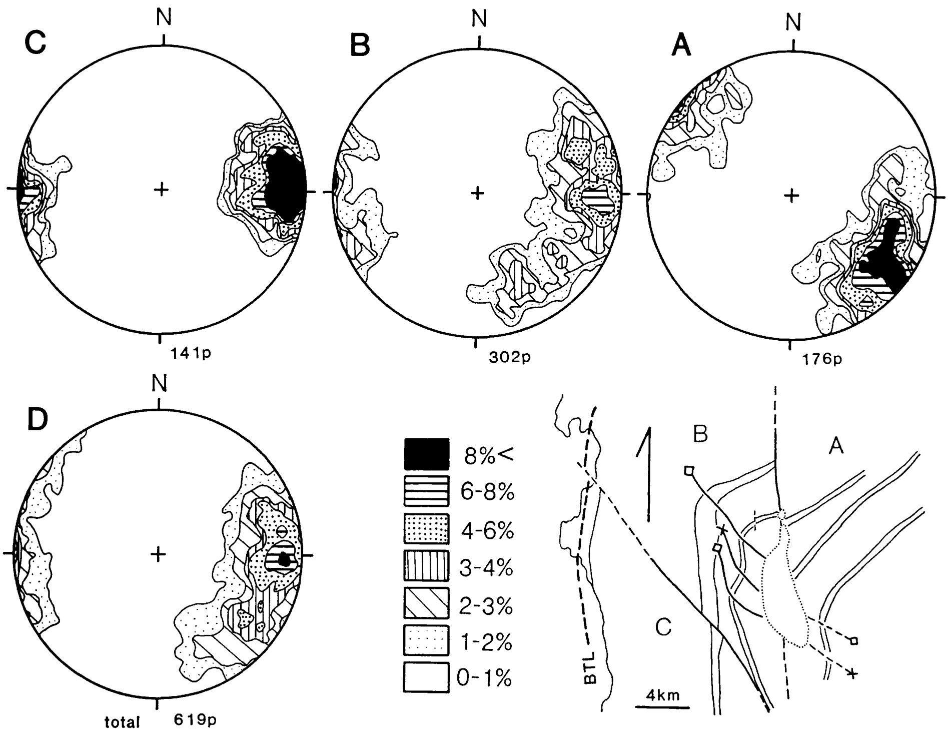

Fig. 6. Contour diagrams of bedding surface poles of the Shimanto Supergroup. Schmidt Net. Lower hemisphere.

to N20°-40°E, near Noborio (Fig. 2). These strike swings are detected as a set of antiform and synform. They extend toward northwest to the northern antiformal and synformal strike swings of the central part respectively, although they are displaced by a N-S trending strike-slip fault.

Conical folds

As the Shimanto Supergroup is considered to have formed the homoclinal structure apparently before bending, geometrical analysis using bedding surfaces is useful for determining fold style created by bending, as shown in the Hitoyoshi Bend Area (MURATA, 1987).

Bedding surface poles of the Shimanto Supergroup of the Hokusatsu Bend are plotted on Net A, B, and C in Fig. 6, which are from three small segments separated by two strike-slip faults described later. Net C is from the southwest of the major strike swings, and shows that the Shimanto Supergroup strikes N10°E-N30°W, and dips 45°-90° toward west or 80°-90° toward east. Net A is mainly from the northeast of the strike swings, but it includes southeastern part of the strike swings. It clearly shows that the Supergroup mainly strikes N40°-70°E, and dips 45°-90° toward northwest or 80°-90° toward southeast. The Supergroup of N-S strikes is also shown in Net A, because the segment

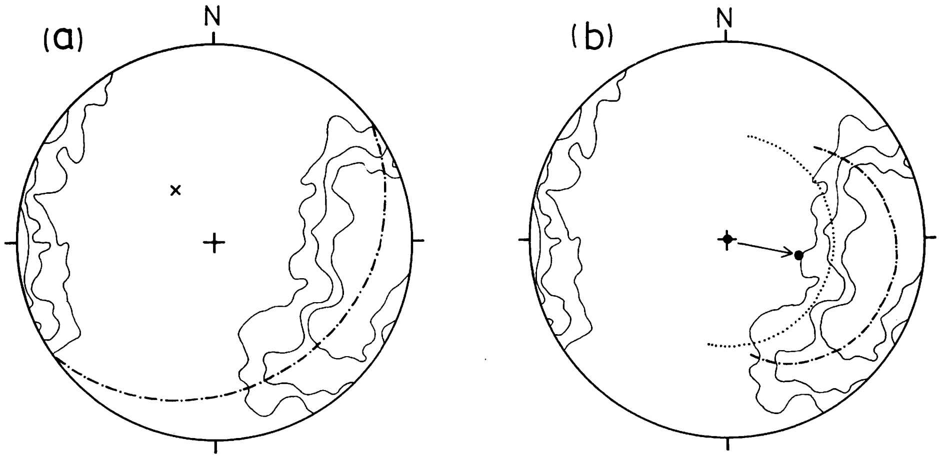

Fig. 7. Analysis of attitudes of bedding surfaces. Schmidt Net. Lower hemisphere. 1, 2, & 3% contour lines of Net D are shown.

of Net A includes a part of the strike swings. Net B includes major strike swings of the Hokusatsu Bend. The Supergroup strikes N40°-60°E to the northeast of strike swings, and N0°-30°W to the south. The strike swings are not abrupt, but nearly gradual.

It is rather difficult to analyse the fold geometry created by the Hokusatsu Bend, because the angle of the Bend, about 60°-70°, is too small. On the other hand, the conical folds created by the Hitoyoshi Bend are well detected, because the angle of the Bend amounts to 135° in places (MURATA, 1987). The conical folds of the Hitoyoshi Bend were formed by the flexural-slip folding of formerly inclined (about 45°) strata with vertical cone axes. The Hokusatsu Bend is very similar to the Hitoyoshi Bend in that they bend the Shimanto Supergroup and that they are situated in the junction area between the Southwest Japan and Nansei-Shoto Arcs. Thus, the result of the Hitoyoshi Bend (MURATA, 1987) can also be used in analysing the folds developed within the Hokusatsu Bend. Net D is a total bedding surface plots of the Area (Fig. 6). The bedding surface poles on Net D might lie on a great circle whose pole plunges at 65° toward N35°W (Fig. 7a), suggesting that the Shimanto Supergroup is cylindrically folded. However, the great circle does not follow the concentration area of more than 2%. The bedding surface poles appear to lie on a small circle (Fig. 7b), just like those of the Hitoyoshi Bend. The small circle represents a cone of apical angle about 45°. Its cone axis trends S80°E, and plunges 60° toward east. The folds in the Hokusatsu Bend are probably conical folds, which were formed by flexural-slip folding of formerly inclined strata.

Steep dipping of the Shimanto Supergroup and tilting of cone axes

Dip of the Shimanto Supergroup is mostly 60°-90°W or NW, and partly 80°-90°E or SE in the Hokusatsu Area. These values are fairly steeper than those of the other areas in Kyushu. For example, the Shimanto Supergroup of the Hitoyoshi Area dips 20°-70° toward west or northwest, where the angles of dip were not changed by the bending. The Supergroup of the Morotsuka Area also dips 20°-70° toward northwest (SAKAI & KANMERA, 1981; IMAI *et al.*, 1982; MURATA, unpublished data). The Shimanto Supergroup of the Nansatsu Area, to the south of the Hokusatsu Bend, dips moderately toward west (MMAJ, 1984). The Sambosan Group of the Hokusatsu Area has also a steeper dip than that of the other areas (MURATA, 1981). These data show that the Shimanto Supergroup and the Sambosan Group in the Hokusatsu Area exceptionally dip steeper about 30° than those in the other whole areas in Kyushu.

It is difficult to consider that the Shimanto Supergroup and the Sambosan Group of the Hokusatsu Area had steeper dips than those of the other areas before bending, because their distributional pattern and pre-bending imbricate structures are the same through the whole areas in Kyushu. Therefore, the steep dipping of the strata of the Hokusatsu Area is regarded to be originated by the formation of the Bend. The present cone axes (S80°E, 60°E) (Fig. 7b) mean that originally formed vertical cone axes tilted toward west-northwest about 30°, the angle of which is concordant with the angle of the steep dipping. The idea of flexural-slip folding creating conical folds and tilting of the cone axes well explains that the Shimanto Supergroup of the Hokusatsu Bend has a steeper dip than that of the other areas in Kyushu.

STRIKE-SLIP FAULTS ASSOCIATED WITH THE BEND

Two major strike-slip faults, the Kurigeno and Kusugasako faults, occur in the Hokusatsu Area.

Kurigeno fault

The Kurigeno fault runs from Kurigeno in the northern marginal part, toward south to Torimaru (Fig. 2). Along the fault, the Oganashi Formation of the Ikenodan zone is displaced at Kurigeno in a right-lateral sense as much as 4.0 km, and the Formation of the Torimaru zone is inferred to be displaced about 4.5 km, although the fault and the surrounding strata do not occur because of the emplacement of the Shibisan Granite (Fig. 2). The fault is probably subvertical or vertical, judging from its straight fault trace, although outcrops of the fault have not been found. Furthermore, strata on the both sides of the fault are diagonal at about 10°-30° to each other near Torimaru. The Kurigeno fault was formed before the intrusion of the Shibisan Granite, because the Granite is not displaced at all.

Kusugasako fault

The Kusugasako fault runs from east of Akune in the northwestern part, toward southwest to Torimaru. The fault is inferred to be subvertical or vertical, judging from its straight fault trace. Along the fault, the Oganashi Formation of the Ikenodan zone is displaced about 0.75 km at Kusugasako in a left-lateral sense, and the Kurigeno Formation is also displaced about 0.75 km in the area near Yokoza Pass. In the southern part of the Area, strata on the both sides of the fault are diagonal to each other; those on the northeastern side of the fault strike N-S, and those of the southwestern side strike N10°-30°W.

Bending and strike-slip faults

The Kurigeno and Kusugasako faults occur on the eastern and western sides of the Hokusatsu Bend respectively. The hinge part of the Bend is situated in the block between two strike-slip faults except for the southeastern part, where it is displaced by the Kurigeno fault. And the block including the Bend is moved toward north-northwest, subparallel to the hinge lines of the bends. These facts suggest that these strike-slip faults were probably formed associated with the bending. The faults were formed after the main bending and tilting of cone axes of the folds, because their fault surfaces are not bent, and because steep dipping of the strata occurs in the whole Area.

A NW-trending left-lateral strike-slip fault occurs near Sendai, to the south of the Hokusatsu Area (HASHIMOTO *et al.*, 1972). There, the Cretaceous Gumizaki Formation and the gabbroic rocks, which belong to the Kurosegawa Terrain, are displaced toward southeast, and are situated near the Sambosan Group in Mt. Tsukiya. The fault was probably formed associated with the formation of the Hokusatsu Bend, because it has the same trend and slip sense with the Kusugasako fault.

HOKUSATSU BEND AND CLOCKWISE ROTATION OF THE SOUTHWEST JAPAN ARC

Clockwise rotation of the Southwest Japan Arc

The Permo-Jurassic Sambosan Group and Cretaceous Shimanto Supergroup are all affected by the Hokusatsu Bend. The Butsuzo Tectonic Line, a large overthrust, along which the Sambosan Group is thrust over the Shimanto Supergroup, is also affected by the Hokusatsu Bend (Figs. 1 & 2). The Oyabu thrust, along which the Cretaceous Shimanto Supergroup is thrust over the Paleogene to earliest Miocene Hyuga Group (Fig. 1), is also affected by the Hitoyoshi Bend, and appears to form conical folds (MURATA, 1987). It is reasonable to assume that the Butsuzo Tectonic Line and the Oyabu thrust were fairly planar and had linear traces originally, because a thrust of fairly large extent is usually formed under the rather stable stress field, even if it is ordinarily slightly curved. All the terrains, the Sambosan, Shimanto, and Hyuga Terrains, were probably zonally arranged with rather linear trends from the Southwest Japan Arc to the Nansei-Shoto Arc, because they have the same structures in both Arcs.

The Southwest Japan Arc is considered to have been rotated clockwise in associated with the opening of the Sea of Japan behind it. This idea is mainly based on that the Hida Terrain was formerly linked to the Chino-Korea Massif.

And the Southwest Japan Arc was situated to the north-northeast of the Nansei-Shoto Arc, forming one linear arc (Fig. 8). The conical folds in the Hokusatsu and Hitoyoshi Bends were probably formed simultaneously associated with the clockwise rotation of the Southwest Japan Arc (MURATA, 1987). Similar conical folds are reported from some foreign areas, where the rotation of geologic terrains with vertical axis occurred (RICKARD, 1963; RAMSAY, 1967, p. 498).

Rotation angle of the Southwest Japan Arc

The Nansei-Shoto Arc trends NNE-SSW from Amami-Ohshima to the Nansatsu Area in Kyushu. This trend is a representative one in the northern half of the Nansei-Shoto Arc. The rotation angle of the Southwest Japan Arc of Kyushu is about 30° clockwise, judging from the strike swing of the terrains against to the northern Nansei-Shoto Arc. The Southwest Japan Arc of Shikoku and Kii Peninsula trends N65°-70°E, and is diagonal to that of Kyushu, to the northeast of the Hokusatsu and Hitoyshi Bends. The difference of trends between two districts is not negligible, because all the terrains are quite linear in both districts. There is another bend near the eastern extreme of the Bungo Strait. Therefore, the rotation angle of the Southwest Japan Arc in Shikoku and Kii Peninsula is expected about 45°, supposing that the terrains of the Outer Zone were nearly linear originally (MURATA, 1987).

The Shimanto Supergroup just to the south of the Hokusatsu Bend strikes N0°-30°W, and is diagonal at 30°-40° to that of the northern half of the Nansei-Shoto Arc. The segment just to the south of the Hokusatsu Bend probably rotated counterclockwise about 30°-40°, resulting the present angle, about 60°-70°, of the Hokusatsu Bend (Figs. 2 & 8). The Shimanto Supergroup of the Hokusatsu Area is moved toward west-northwest by counterclockwise rotation of the southern part of the Hokusatsu Bend. This may be consistent with the fact that the block including the Hokusatsu Bend was displaced toward north-northwest by two strike-slip faults.

NIITSUMA *et al.* (1986) assumed that there should be a right-lateral strike-slip fault between Korean Peninsula and Southwest Japan, because the value of the rotaion angle, about 45°, is too large to fit the Southwest Japan Arc against to the edge of Korean Peninsula without overlap of the continental area. A southward drift of the Southwest Japan Arc was also discussed by KAWAI *et al.* (1969), MURAUCHI (1971), HURLEY *et al.* (1973), and FAURE & LALEVEE (1987). The southward drift should have caused the formation of contractional structures in all the terrains of the Nansei-Shoto Arc. However, no remarkable disturbance large enough to compensate the contraction, which should occur in the Nansei-Shoto Arc (SHIMAZAKI *et al.*, 1981). The rotation angle of the Southwest Japan Arc in Kyushu is only 30°, and the rotation pivot of the Shimanto Terrain should have been situated about 50 km to the northeast of the Hokusatsu Bend, because the Shimanto Supergroup of the Hokusatsu Area had been situated to the southeast of the present position. The restored position of the Southwest Japan Arc is similar to that of SHIMAZAKI *et al.* (1981) (Fig. 8), and it reasonably fits to the edge of Korean Peninsula.

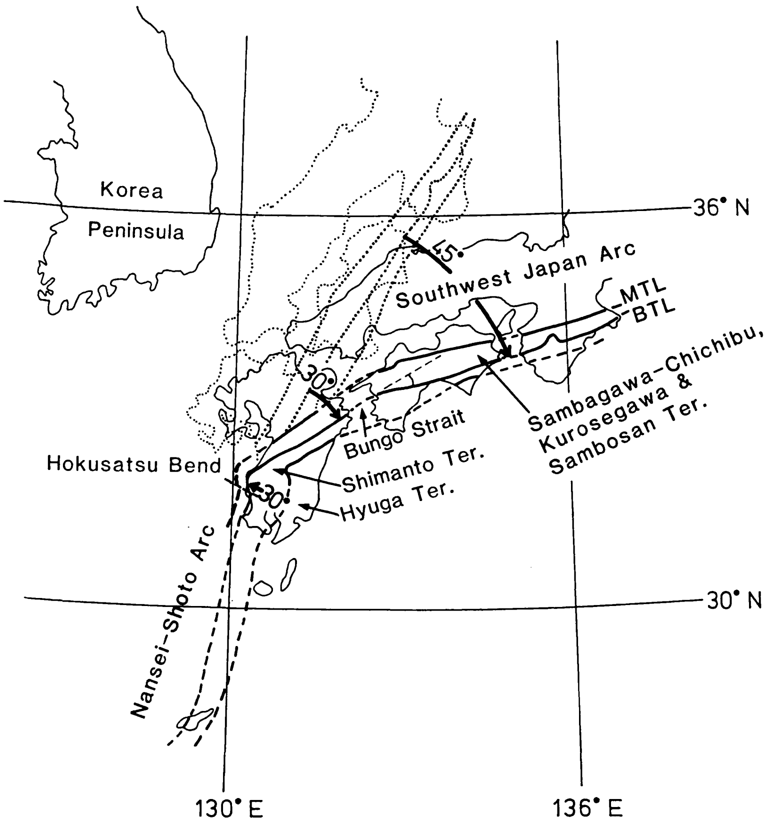

Fig. 8. Clockwise rotation of Southwest Japan Arc in Miocene time.
MTL: Median Tectonic Line, BTL: Butsuzo Tectonic Line.

Age of rotation

The Hokusatsu Bend was formed after the Butsuzo thrusting (probably Paleogene) and before the intrusion of the Shibisan Granite of 14 Ma. The Hokusatsu Bend is very similar to the Hitoyoshi Bend, and they were formed simultaneously. Thus, the Hokusatsu Bend was formed at the period between earliest Miocene (about 20 Ma) and Middle Miocene (14 Ma), because the Hitoyoshi Bend affects earliest Miocene strata of the Hyuga Terrain (MURATA, 1987). Similar bends or strike swings of the same period are reported in the Shimanto Terrain in Shikoku, Kii Peninsula, and Akaishi Mountains (YANAI, 1986; KANO *et al.*, 1987). These data about the rotation age are consistent with the paleomagnetic data (about 15 Ma) of TORII *et al.* (1985).

In North and Middle Kyushu, Cretaceous and Paleogene sedimentary basins are affected by the N-S or NNE-SSW trending disturbances, which are parallel to the Nansei-Shoto Arc. North and Middle Kyushu is considered to have already been affected by the Nansei-Shoto Arc in Cretaceous and Paleogene times (MATSUMOTO, 1976; KIMURA, 1983; TERAOKA *et al.*, 1981). However, the N-S trending disturbances in North and Middle Kyushu, such as Chikusatsu uplift zone (KIMURA, 1983), do not extend to South Kyushu across the Hokusatsu and Hitoyoshi Bends. Strata of the Inner Zone of North and Middle Kyushu were rotated together with the Sambosan and Shimanto Terrains of the Outer Zone in Miocene time. Thus, the present N-S trending faults and uplift zones in North and Middle Kyushu are inferred to have trended NW-SE or NNW-SSE originally.

Horst and graben structures of NE-SW trends were formed across the Hokusatsu Bend in the area to the west of Kyushu (HONZA *et al.*, 1979). They were probably formed after the clockwise rotation of the Southwest Japan Arc, associated with the opening of a part of the Okinawa Trough.

SUMMARY

(1) Folds developed within the Hokusatsu Bend are conical folds like those of the Hitoyoshi Bend. The conical folds were formed by the flexural-slip folding of formerly inclined strata. The cone axes of the conical folds of the Hokusatsu Bend have tilted toward west-northwest. As a result, the Shimanto Supergroup of the Hokusatsu Area has a steeper dip than that of the other areas in Kyushu.

(2) The Shimanto Terrain of Kyushu, which is a segment of the Southwest Japan Arc rotated about 30° clockwise horizontally. In addition, the Terrain just to the south of the Hokusatsu Bend rotated counterclockwise about 30°-40°, resulting the present angle, about 60°-70°, of the Hokusatsu Bend.

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