Jour. Sci. Hiroshima Univ., Ser. C, Vol. 9, No. 4, 671–683 (1993)

Sinistral En Echelon Folding of the Sambagawa Schists and Its Tectonic Implication

By

Tsugio SHIOTA, Ikuo HARA, Sachiyo SEKI, Yukio IKEDA,
Takamoto OKUDAIRA and Kei HIDE

with 12 Text-figures

(Received, March 30, 1993)

Abstract: The folds of the Sambagawa schists, which were produced during the last phase (Hijikawa–Oboke phase = Dh phase) of their folding history, are developed as a series of sinistral en echelon upright folds with half wavelength of less than 20 Km (Hara et al.,1977,1992). The Dh phase folds in Shikoku are accompanied with two culminations, Oboke culmination and Nakashichiban culmination, placed near the MTL. Their movement picture during the formation process of such the Dh phase folds has been analyzed on the basis of orientation pattern of parasitic folds and quartz microtextures. It has been clarified that the Dh phase folds were produced by left–lateral shear under N–S compression, being accompanied by the southward tectonic emplacement of two rigid bodies which gave rise to the Oboke and Nakshichiban culminations. These bodies can be assumed to be granitic and/or high–temperature metamorphic rocks tectonically derived from the Kurosegawa–Koryoke continent, as judged from the seismic refraction data in the Oboke district after Ichikawa (1968).

Contents

I . Introduction

The Sambagawa schists, which were exhumed as several nappes from the depth zone of the subduction zone, were folded in upright fashion and large–scale, though less than 20 Km for half wavelength, during the last phase (Hijikawa–Oboke phase = Dh) of their folding history (Hara et al., 1973, 1977, 1992). The upright folds are developed as a series of sinistral en echelon folds throughout the Sambagawa schists from Kyushu to the Kanto Mountains (Hara et al.,1973,1977,1992). The orientation pattern of the Dh phase folds in Shikoku is

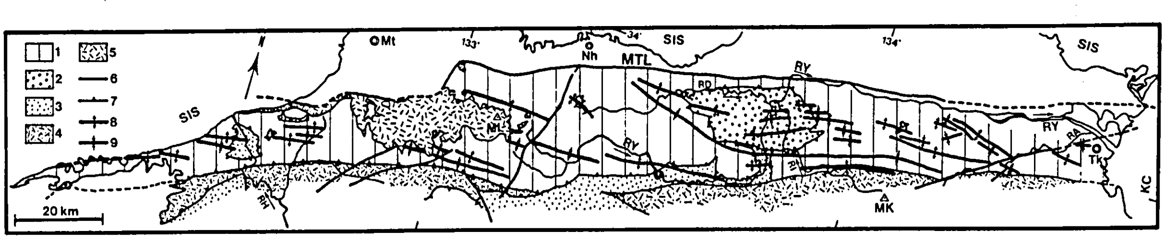

Fig. 1. Diagram showing the axial traces of the Hijikawa–Oboke (Dh) phase folds in Shikoku [simplified from Hara et al.(1992)].
1: Sambagawa megaunit, 2: Oboke unit (Shimanto megaunit), 3: Chichibu megaunit I, 4: Chichibu megaunit II, 5: Ishizuchiyama Tertiary System, 6: fault, 7: nappe boundary, 8: axial traces of the Dh phase folds, MTL: Median Tectonic Line, SIS: Seto Inland Sea, Mt: Matsuyama, Nh: Niihama, RY: River Yoshino, RD: River Dozan, RA: River Akui. RI: River Iya, RH: River Hijikawa, MI: Mt. Ishizuchi, MK: Mt. Tsurugi, TK: Tokushima.

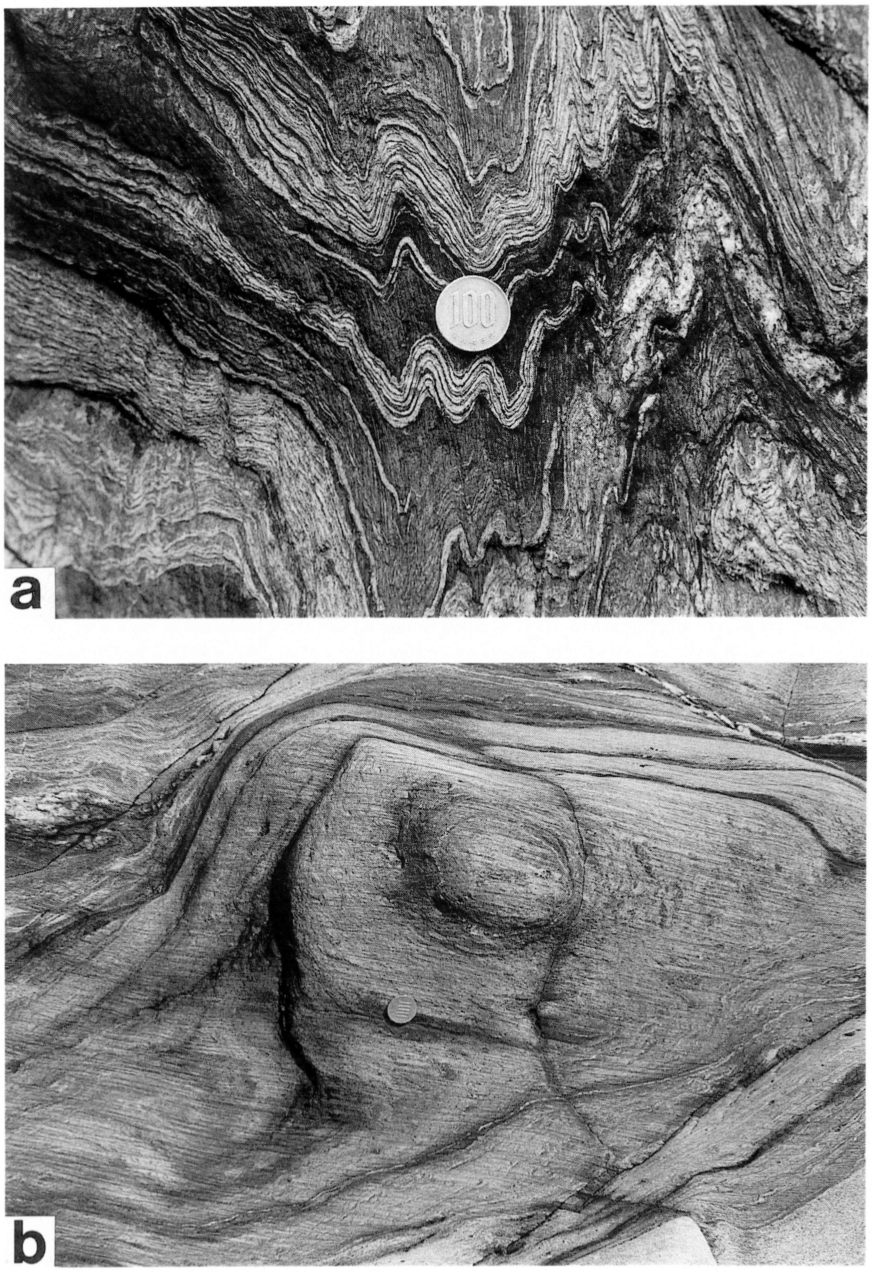

Fig. 2. Dh phase folds. a) Dh phase folds of multilayered rock consisting of pelitic schist layers (black) and siliceous schist layers (white). b) Dh phase folds of crenulation cleavage type in pelitic schist.

illustrated in Fig.1, showing the development of two large−scale culminations, Oboke culmination and Nakashichiban culmination. The movement picture of the Sambagawa schists during the formation process of the sinistral en echelon folds of the Dh phase in Shikoku and its tectonic implication will be analyzed in this paper.

Acknowledgements

The authors' works have been partly supported by the Grant in Aid for Scientific Researches of the Ministry of Education of Japan.

II. Orientation Pattern Analysis of Rock Structures and Microfabrics

A: Parasitic Folds

The Dh phase folds are associated with parasitic folds of various scales from millimeters (crenulation cleavage) to some tens meters (Fig. 2). In order to understand the movement picture of the Sambagawa schists during the formation process of these folds, it is absolutely necessary to analyze the orientation pattern of such parasitic folds. The axial planes of the Dh phase parasitic folds are commonly oriented in upright fashion throughout the Sambagawa schists, except for these in the Oboke and Nakashichiban culminations. The orientation data of the Dh phase parasitic folds in some cross sections for

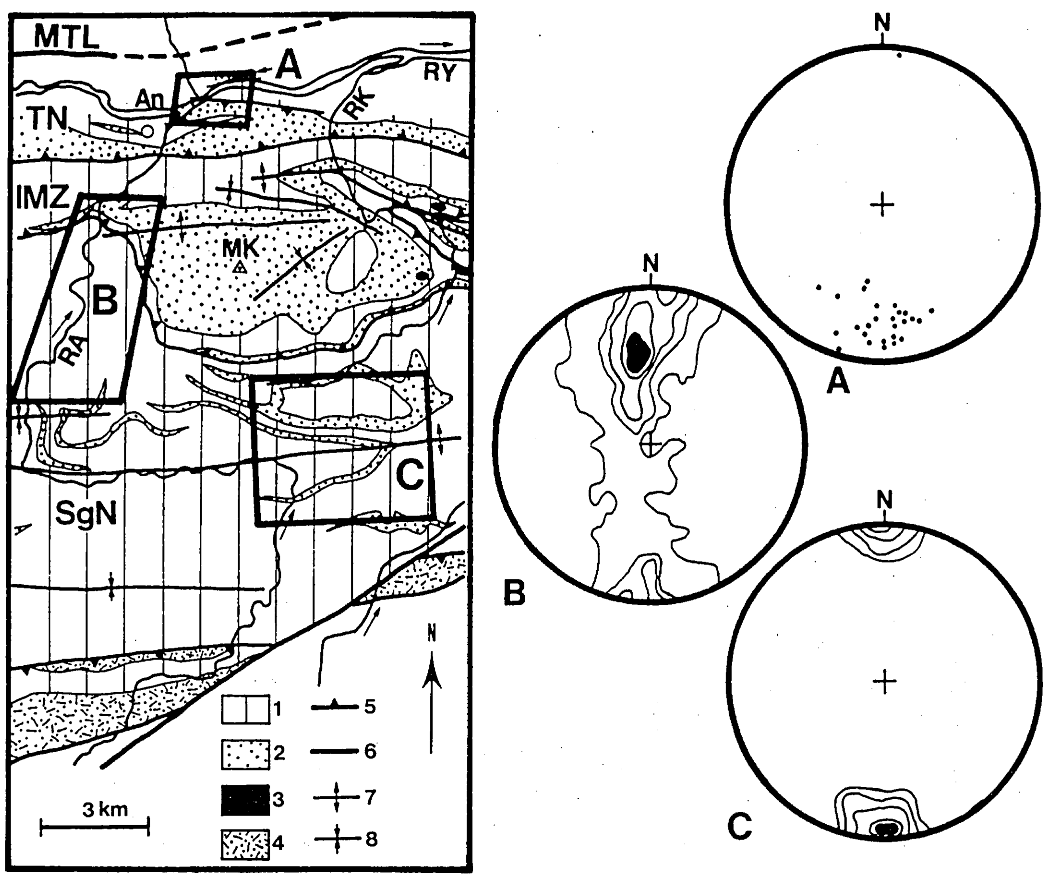

Fig. 3. Orientation data of Sh (axial plane of Dh phase fold) from the selected domains A, B and C in the Nonowaki−Anabuki district.
A: data from the domain A, B: data from the domain B [after Murakami(1970)], C: data from the domain C [after Nakagawa & Kawai (1963)], TN: Tsuji nappe, IMZ: Inouchi melange zone, SgN: Sogauchi nappe, 1: pelitic schist, 2: basic schist, 3: ultrabasic rocks, 4: Mikabu greenstones, An: Anabuki, RY: River Yoshino, RK: River Kawatayama, MK: Mt. Kotsu. The data for Sh dipping with the low−moderate angles in domain B mainly come from the axial zone and northern limb of the Kotsu antiform.

the culminations will be therefore described in the following paragraphs.

The data from the Nonowaki−Anabuki district of eastern Shikoku (Fig. 1), which is placed in the easternmost margin of the Oboke culmination, will be first described. The margin of this culmination appears to be defined by the Kotsu synform with NE−SW trending axial trace. In this district are developed the Dh phase folds such as Nonowaki antiform, Tomouchi synform, Kotsu synform, Kotsu antiform, Hisamune synform and Kawamata antiform from south to north, and just on the north of the Kawamata antiform there are the Tsuji overturned fold and Inouchi melange zone of the pre−Dh phase (Fig.3) (Shiota, 1981; Hara et al.,1992).

The northern limb of the Tsuji fold is as a whole gently dipping toward the south, though its parasitic folds with flat−lying axial planes are found.

The orientation pattern of the axial plane (Sh) of parasitic folds of the Nonowaki antiform around the Nonowaki Mine was analyzed by Nakagawa and Kawai (1963) as reproduced in Fig. 3. Sh is oriented in upright fashion, though many Sh surfaces show a tendency to dip toward the south in the northern limb and toward the north in the southern limb of Nonowaki antiform.

The orientation pattern of Sh in the Tomouchi synform, Kotsu synform and Kotsu antiform in the area along the River Anabuki was analyzed by Murakami (1970) as reproduced in Fig. 3. The axial plane of the Kotsu antiform in this area are inclined at moderate angles toward the south. Therefore, Sh is developed in southward low angles dipping on the northern limb, and it on the southern limb and Tomouchi synform is oriented in upright fashion. While Sh in the Taira synform and the axial part of Kawamata antiform just on the east of the Kotsu Mine tends to show steeply

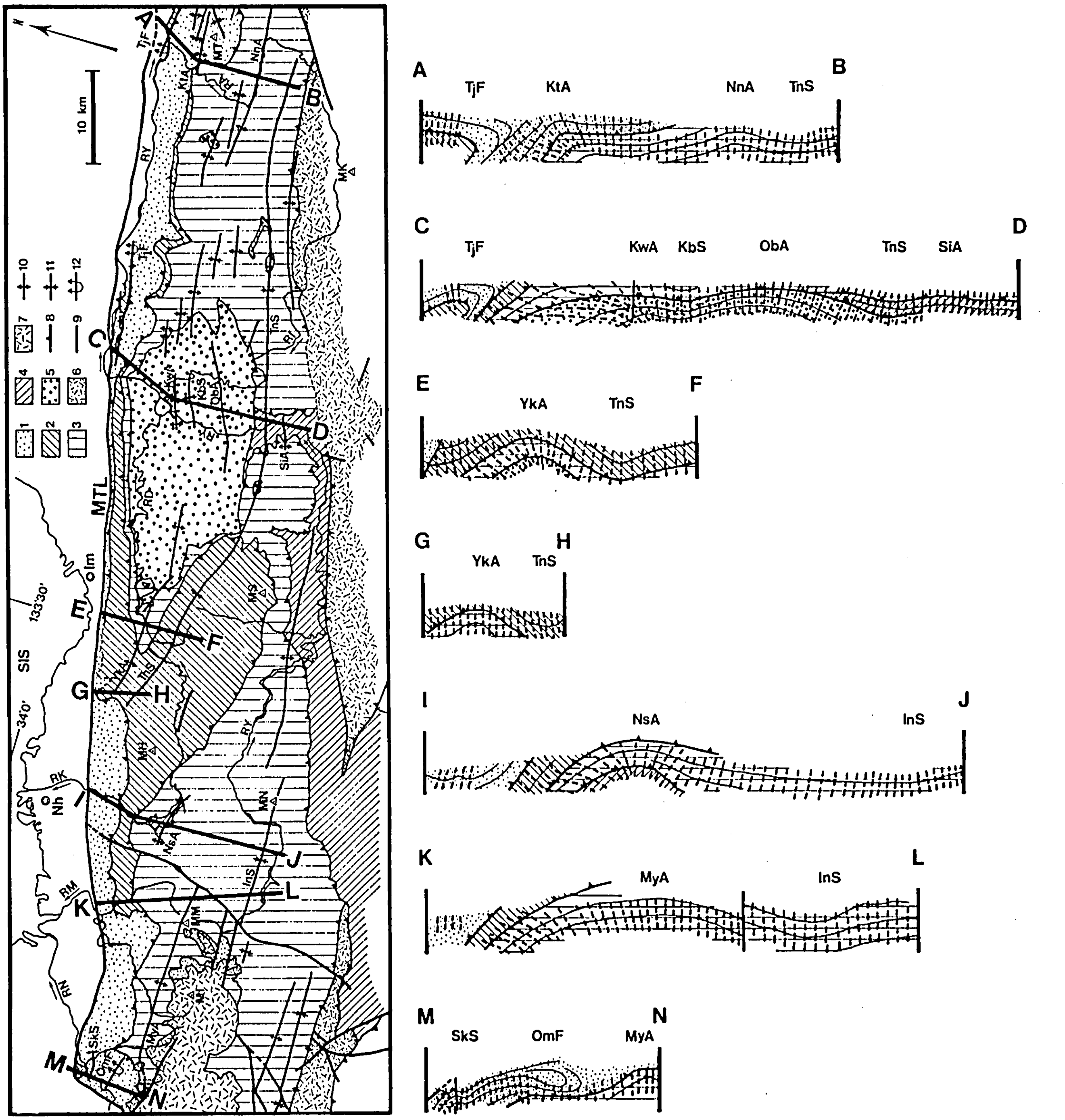

Fig. 4. Schematic diagram showing the orientation pattern of Sh in the large-scale Dh phase folds along seven cross sections.
A–B: Nonowaki–Anabuki section, C–D: Ikeda–Kawaguchi–Oboke–Tosaiwahara section, E–F: Iyomishima–Tomisato section, G–H: River Urayama section, I–J: Besshi–Nakashichiban–Inamurasan section, K–L: Kamo–Sasagamine section, M–N: Sakurasanri section, KtA: Kotsu antiform, NnA: Nonowaki antiform, TnS: Tsuneyama synform, KwA: Kawaguchi antiform, KbS: Koboke synform, ObA: Oboke antiform, SiA: Sakaidani antiform, YkA: Yakushi antiform, NsA: Nakashichiban antiform, InS: Inamurasan synform, MyA: Myoga antiform, SkS: Sakurasanri synform, TjF: Tsuji overturned fold, OmF: Omogiyama recumbent fold, 1: Inouchi–Ojoin melange zone, 2: Saruta nappes and Fuyunose nappe, 3: Sogauchi nappe, 4: Chichibu megaunit I, 5: Oboke nappes, 6: Chichibu megaunit II, 7: Ishizuchiyama Tertiary System, 8: nappe boundary, 9: fault (post–Dh phase), 10: axial trace of Dh antiform, 11: axial trace of Dh synform, 12: axial trace of the Ozu phase overturned fold, MI: Mt. Ishizuchi, MM: Mt. Kamegamori, MN: Mt. Inamurasan, MS: Mt. Shiragayama, MK: Mt. Tsurugi, MT: Mt. Kotsu, RN: River Nakayam, RM: River Kamo, RK: River Kokuryo, RY: River Yoshino, RD: River Dozan, RI: River Iya. SIS: Set Inland Sea, Nh: Niihama, Im: Iyomishima.

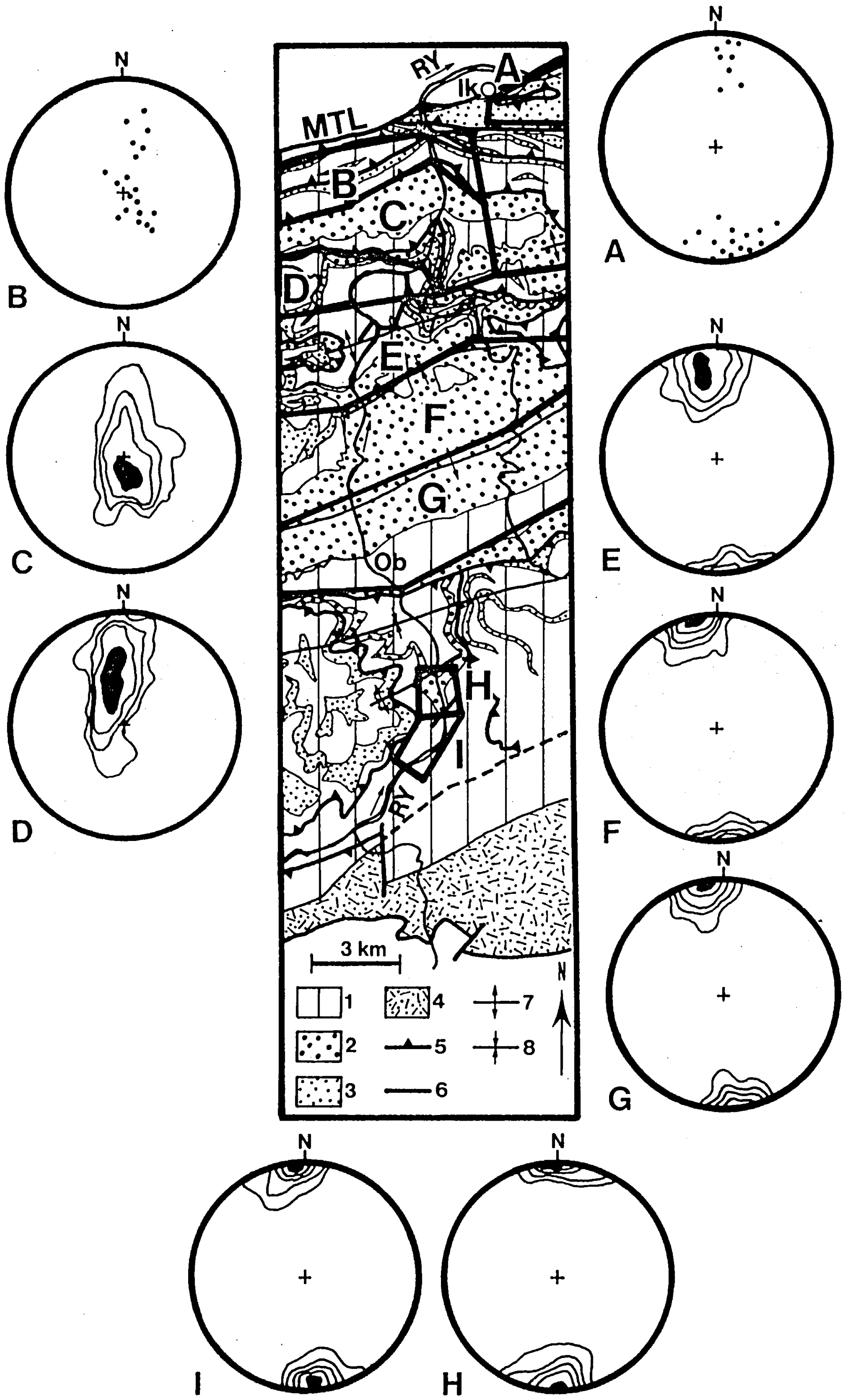

Fig. 5. Orientation data of Sh from the selected domains A – I in the Ikeda–Kawaguchi–Oboke–Tosaiwahara district.
A – G: data from the domains A – G respectively [after Yokota (1969) and Hara et al.(1977)], I and H: data from the domain I and domain H respectively [after Kojima and Suzuki (1958)], 1: pelitic schist, 2: psammitic schist, 3: basic schist, 4: Mikabu greenstones (Chichibu megaunit II), 5: nappe boundary, 6: fault, 7: axial trace of Dh phase antiform, 8: axial trace of Dh phase synform, RY: River Yoshino, IK: Ikeda, Ob: Oboke.

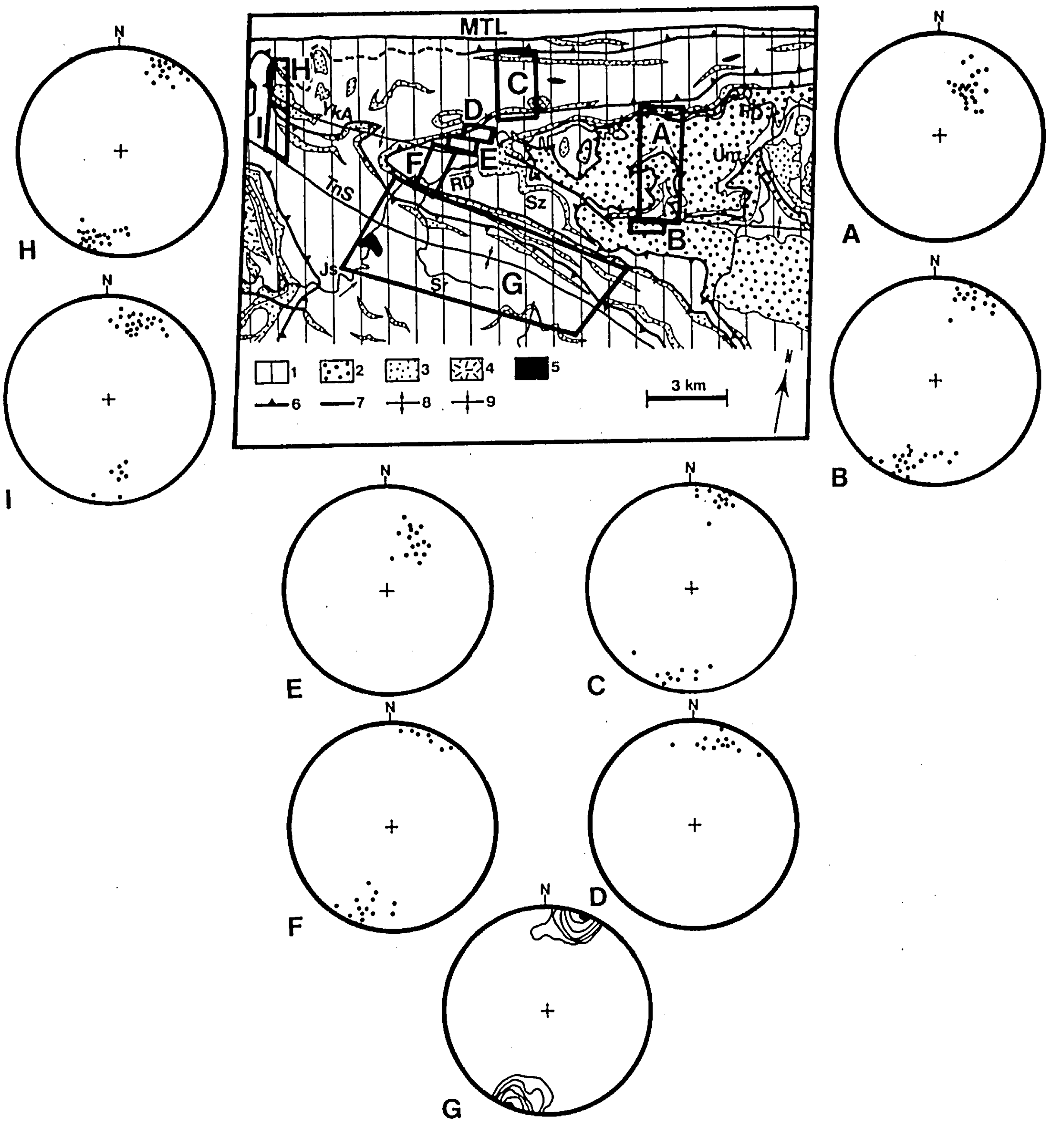

Fig. 6. Orientation data of Sh from the selected domains in the Nakanokawa, the Iyomishima–Tomisato and the River Urayama district.
A and B: data from the Nakanokawa district, C–G: data from the Iyomishima–Tomisato district [data from the domains G is after Oyagi (1964)], H and I: data from the River Urayama district, YkA: Yakushi antiform, TnS: Tsuneyama synform, 1: pelitic schist, 2: psammitic schist, 3: basic schist, 4: Iratsu metagabbros, 5: ultrabasic rocks, 6: nappe boundary, 7: fault, 8: axial trace of Dh phase antiform, 9: axial trace of Dh phase synform, RD: River Dozan, Um: Umadate, Sz: Sazare, Sr: Saruta, Js: Joshi.

dipping orientation, showing disappearance of the southward dipping zone of Sh on the northern limb of the Kotsu antiform. Sh on the northern limb of the Tsuji overturned fold also shows steeply dipping orientation as illustrated in Fig. 3. Thus, the orientation pattern of Sh on a cross section of the Dh phase folds of the Nonowaki–Anabuki district will be schematically illustrated by Fig. 4.

In the Tosaiwahara–Oboke district along the River Yoshino, central Shikoku, there are the Dh folds such

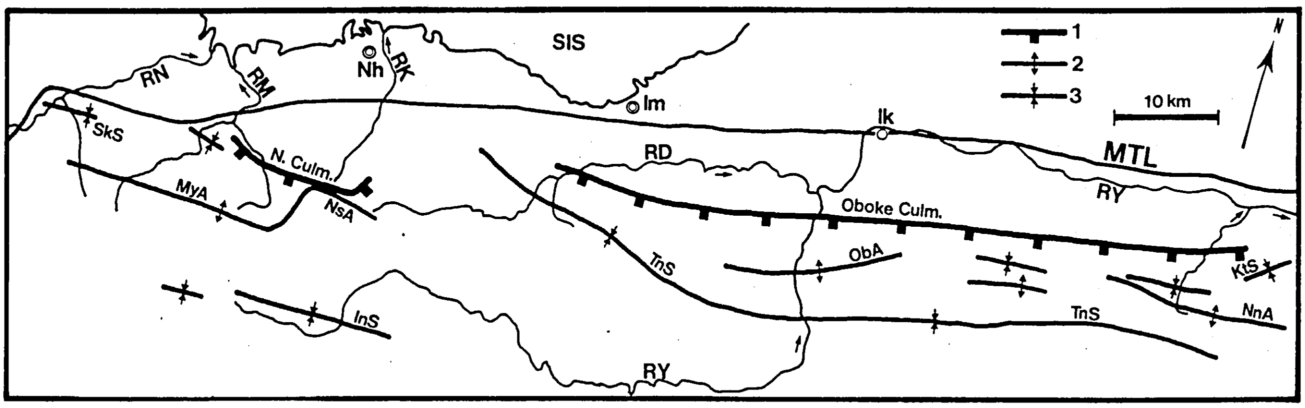

Fig. 7. Schematic diagram illustrating the distribution pattern of the northward vergent zone of minor Dh phase folds in the Oboke culmination (Oboke Culm.) and Nakashichiban culmination (N. Culm) in which Sh dips at low-moderate angles toward the south.
1: trace of the southern margin of the northward vergent zone, 2:crestal trace, 3: trough trace, KtS: Kotsu synform, NnA: Nonowaki antiform, TnS: Tsuneyama synform, ObA: Oboke antiform, Ns: Nakashichiban synform, MyA: Myoga antiform, SkS: Sakurasanri synform, InS: Inamurasan synform, RY: River Yoshino, RA: River Anabuki, RK: River Kokuryo, RM: River Kamo, RN: River Nakayama, SIS: Seto Inland Sea, Nh: Niihama, Im: Iyomishima, IK: Ikeda

as Tsuneyama synform, Oboke antiform, Koboke synform and Kawaguchi antiform from south to north (Fig. 5). Just on the south of the Tsuneyama synform there is the Iwahara overturned fold with axial plane gently dipping toward the north, which is of the Ozu phase (Hara et al.,1977). The orientation pattern of Sh in the Sambagawa schists around the Iwahara overturned fold was analyzed by Kojima and Suzuki (1958) as reproduced in Fig. 5. Sh is oriented in upright fashion in the schists around the Iwahara overturned fold. Analogous orientation pattern of Sh is also found around the Tsuneyama synform. The orientation pattern of Sh in the Oboke antiform, Koboke synform and Kawaguchi antiform, which are developed on the central cross−section of the Oboke culmination, was analyzed by Yokota (1969) and Hara et al.,(1977) as reproduced in Fig. 5. Sh is oriented in upright fashion in the Oboke antiform and southern limb of Koboke synform, though it in psammitic schists appears to show a fan−like arrangement converging toward the fold core. While in the area from the axial zone of the Koboke synform to the northern limb of the Kawaguchi antiform Sh is commonly inclined toward the south, and its inclination angles decrease toward the north being smaller in pelitic schists (incompetent layer) than in psammitic and basic schists (competent layers). Sh in pelitic schists of the northern limb near the axial zone of the Kawaguchi antiform is flat, but in its northernmost part, which consists of the upper member of structural level, Sh shows northward (=upward) increase of southward inclination angles (Fig. 5). It can be thus pointed out that Sh on the northern limb of the Kawaguchi antiform show a sygmoidal arrangement as schematically shown in Fig. 4.

The Yakushi antiform is approximately placed on the line regarded as the western extension of the Kawaguchi antiform and is traced to the River Urayama district (Figs. 1 and 4). In the Tomisato−Iyomishima district between the Oboke−Kawaguchi district and the River Urayama district there are the Yakushi antiform and Tsuneyama synform as the Dh phase folds (Fig. 6). The orientation pattern of Sh in these folds of this district was analyzed by Oyagi (1964). But, he did not distinguish the Dh phase structures from the pre−Dh phase ones. Fig.6 illustrates the orientation pattern of Sh in the Yakushi antiform and Tsuneyama synform. Sh is oriented in upright fashion in the Tsuneyama synform. but it in the Yakushi antiform along the River Nakanokawa is commonly inclined at high to moderate angles toward the south: In the southern limb Sh is oriented in upright fashion, but in the hinge zone and northern limb it is inclined at moderate angles toward the south (Fig. 6).

The Sambagawa schists (Sogauchi and Fuyunose units) involved in the Yakushi antiform of the Tomisato−Iyomishima district (Fig. 6) belong to the structural units just overlying the Oboke unit involved in the Kawaguchi antiform of the Oboke−Kawaguchi district and the Yakushi antiform of the River Nakanokawa. In the hinge and southern limb Sh is oriented in upright fashion. The schists on the northern limb belong to the more upper structural level toward the north, i.e. the Median Tectonic Line (MTL). Within the narrow zone of the northern limb near the hinge, Sh is inclined at moderate angles toward the south and its inclination angles increase toward the north, i. e. with upward migration of structural level. Within the zone near the MTL, Sh is oriented in upright fashion

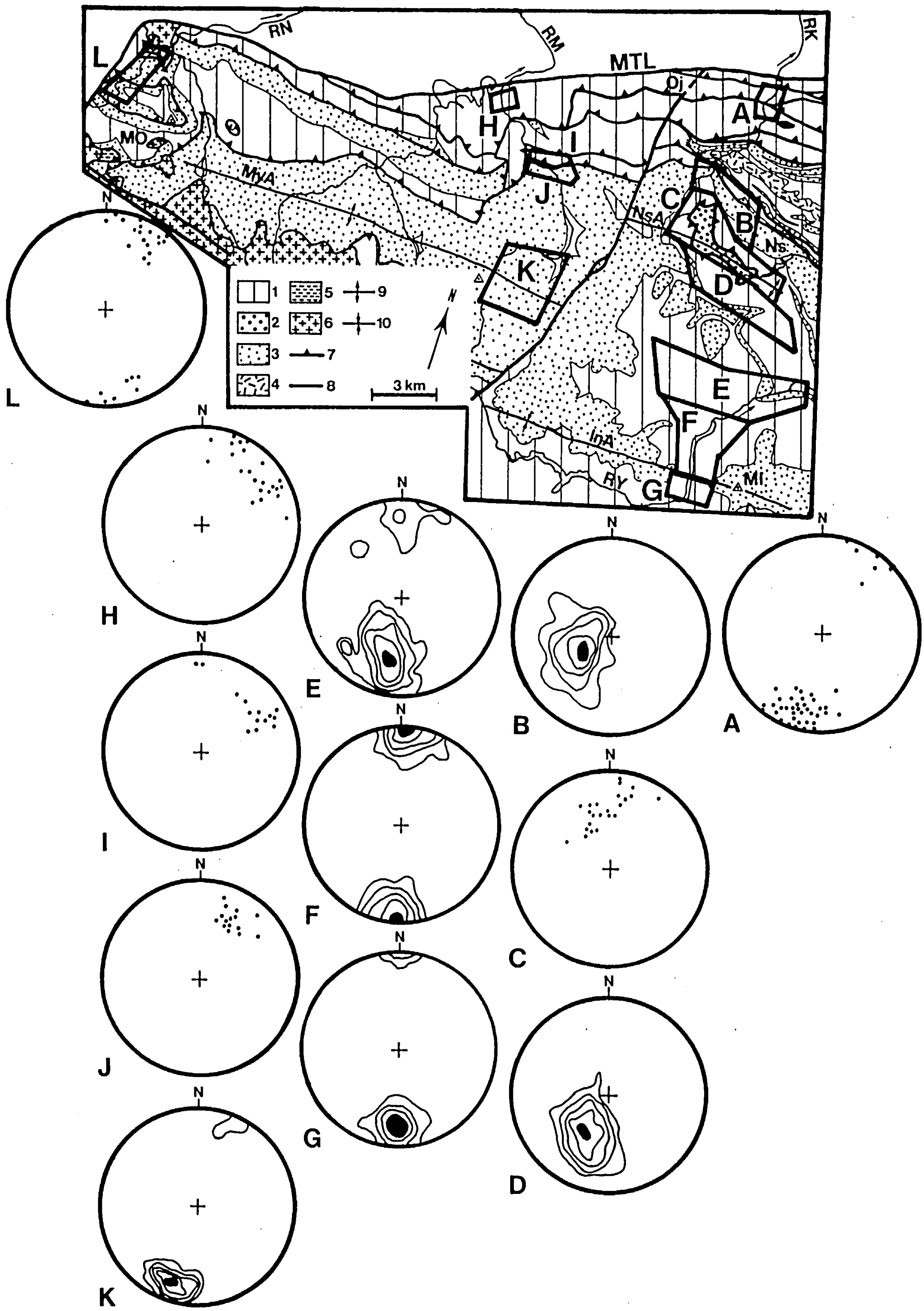

Fig. 8. Orientation data of Sh from the selected domains A–L in and around the Nakashichiban culmination.
A–G: data from the Besshi–Nakashichiban–Inamurasan district [after Ikeda (1972)], H–K: data from the Kamo–Sasagamine district, L: data from the Sakurasanri district, 1: pelitic schist, 2:Chichibu megaunit I, 3: basic schist, 4: Tonaru metagabbros, 5: Chichibu megaunit II, 6: Ishizuchiyama Tertiary System, 7: nappe boundary, 8: fault, 9: axial trace of Dh phase antiform, 10: axial trace of Dh phase synform, NsA: Nakashichiban antiform, MyA: Myoga antiform, InA: Inamurasan synform, Oj: Ojoin, Ns: Nakashichiban, MI: Mt. Inamurasan, MO: Mt. Omogi, RM: River Kamo, RN: River Nakayama, RY: River Yoshino, RK: River Kokuryo.

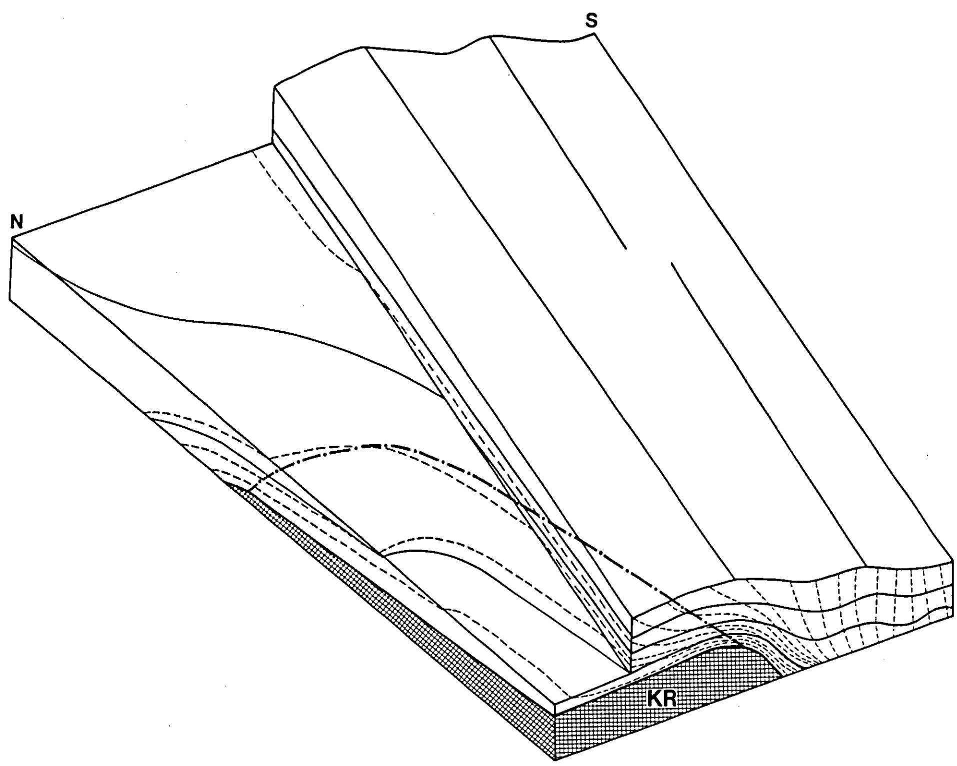

Fig. 9. Schematic diagram showing the orientation pattern of Sh in the large−scale Dh phase folds and of the rigid body tectonically emplaced beneath the Sambagawa schists.
dashed lines: Sh, KR: tectonically emplaced rigid body.

(Fig. 6). It can be thus said that Sh shows a sygmoidal orientation pattern as schematically drawn in Fig. 4.

The schists involved in the Yakushi antiform of the River Urayama district, which is placed in the westernmost margin of the Oboke culmination, belong to the same structural unit as these of the Tomisato−Iyomishima district. The axial trace of the Yakushi antiform in this district is in NW−SE trend. Sh in the Yakushi antiform of the River Urayama district is oriented in upright fashion (Fig. 6). Such the orientation pattern of Sh is also found in the Tsuneyama synform as shown in this figure. It can be thus said that the zone with the low−moderate angles dipping Sh disappears in the River Urayama district, as well as just in the east of the Nonowaki−Anabuki district which is placed in the easternmost margin of the Oboke culmination.

Thus, it would be pointed out that the orientation pattern of Sh on the hinge and northern limb of the Yakushi−Kawaguchi−Kotsu antiform is different between the upper structural level and the lower structural level, in the culminated part showing northward vergence in the lower level and upright fashion in the upper level, but that in the southern limb of Koboke synform, the Oboke antiform and the Tsuneyama synform placed just on the south of the Yakushi−Kawaguchi−Kotsu antiform there is no difference in orientation pattern of Sh between the lower structural level and the upper structural level, as a whole being oriented in upright fashion. The development of the zone with northward vergent Sh in the Oboke culmination would be schematically illustrated in Fig. 7, showing that the zone disappears in its eastern and western margin. The trend of the southern margin of the northward vergent zone shows an arc-like line, which appears to be parallel to the strike of Sh. Fig. 7 illustrates also the trend of dip of Sh.

In the Inamurasan−Nakashichiban−Besshi district there are the Dh phase folds such as the Inamurasan synform and Nakashichiban antiform (Fig. 8). According to Ikeda's (1972) and Hara et al.'s (1977) data (Fig. 8), Sh in the Inamurasan synform and southern limb of the Nakashichiban antiform is oriented in upright fashion, showing a distinct fan−like arrangement converging toward the fold core. Sh in pelitic schists of the lower structural unit (Sogauchi nappe) involved in the northern limb is inclined at low angles: In the domain B of Fig.8 its strike and dip are NS and E respectively, but in the domain C just to the south of the domain B its strike and dip are EW and S repectively. In the domain A where the uppermost structural level [Ojoin melnage zone after Hara et al. (1992)] is developed with the flat−lying bedding schistosity, Sh is steeply inclined with EW strike. Within the area between the domain A and the domain B the bedding schistosity is as a whole steeply inclined toward the north and Sh, if observed,

Fig. 10. En echelon quartz veins developed as conjugate sets in the Sambagawa schist (psammitic schist) of Shimomyo along the River Yoshino.

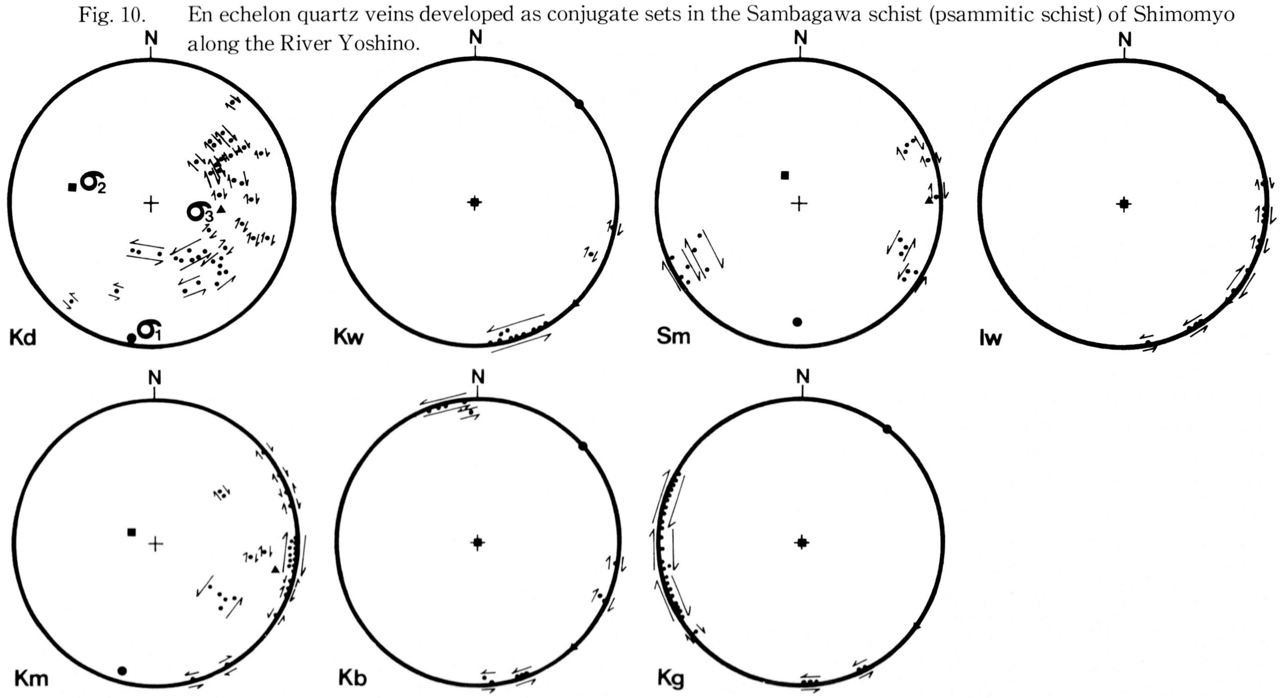

Fig. 11. Diagrams showing the orientation pattern of shear zones consisting of en echelon quartz veins, which were measured from seven outcrops (Fig. 12) in the Sambagawa belt of central Shikoku.

dots: poles to shear zones, arrows: shear sense. Most of dots on the basal line are for shear zones whose dips were not determined. large solid circles (σ_1): compressive stress axis as assumed from en echelon quartz veins, solid squares (σ_2): intermediate axis of stress, solid triangles (σ_3): tensional stress axis, Kd: Kamidoi [data from Tsukuda (1976)], Km: Kawamata, Kw: Kawaguchi, Kb: Koboke, Sm: Shimomyo, Kg: Kuwagara, Iw: Iwazu,

appears to be inclined at moderate angles toward the south. Thus it can be said that Sh on the northern limb of the Nakashichiban culmination as observed on the NS profile is oriented in a sygmoidal fashion as schematically shown in Fig. 4, like the case of the northern half of the Oboke culmination (Fig. 4).

The bedding schistosity in the domains I and J (Fig. 8) of the River Kamo district is oriented in NS strike and westward dip, illustrating the geological structure of the western margin of the Nakashichiban culmination. In the southern margin of this district the culmination joins with the Myoga antiform. Just on the west of this district it abruptly disappears and the northern limb of the Myoga antiform is developed. Fig. 8 illustrates the orientation pattern of Sh in the River Kamo district. In the northern part (domain H) of the Ojoin melange zone which belongs to the uppermost structural level and is placed in the northern margin of the northern limb of the

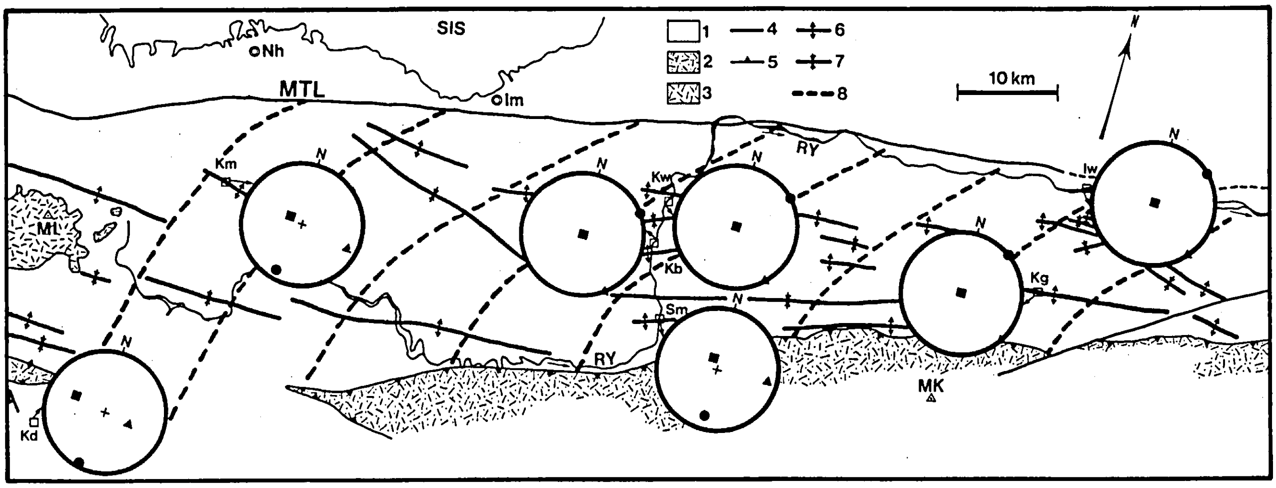

Fig. 12. Diagram showing the localities of the data of Fig. 11 and the orientation directions of the stress axes assumed from Fig. 11.
solid circles: compressive stress axis, solid squares: intermediate axis of stress, solid triangles: tensional stress axis, 1: Sambagawa schists, 2: Mikabu greenstones, 3: Ishizuchiyama Tertiary System, 4: fault, 5: nappe boundary, 6: axial trace of Dh phase antiform, 7: axial trace of Dh phase synform, 8: trajectry of the compressive stress axis, Kd: Kamidoi, Km: Kawamata, Sm: Shimomyo, Kb: Koboke, Kw: Kawaguchi, Kg: Kuwagara, Iw: Iwazu, MTL: Median Tectonic Line, Nh: Niihama, Im: Iyomishima, RY: River Yoshino, MI: Mt. Ishizuchi, MK: Mt. Tsurugi.

Nakashichiban culmination, Sh is oriented in upright fashion. While in the lower structural level (domains I and J) on the northern limb of the Nakashichiban culmination it is developed with southwestward dip at moderate angles, but in the same structural level (domain L) developed in the hinge and northern limb of the Myoga antiform it is oriented in upright fashion. The zone with the moderate angle dipping Sh in the River Kamo district is continuous with that in the Inamurasan – Nakashichiban – Besshi district. This zone disappears with the disappearance of the Nakashichiban culmination, as is obvious in the data of Fig. 8. In the areas (e.g. domain L) where the Nakashichiban culmination disappears, namely, Sh is oriented in upright fashion. Thus it would be pointed out that the orientation pattern of Sh on the northern limb of the Nakashichiban culmination is different between the upper structural level and the lower structural level, showing northward vergence in the lower level and upright fashion in the upper level, that Sh in the northern half of the Nakashichiban culmination shows a sygmoidal orientation pattern as schematically illustrated in Fig. 4 and the northward vergence zone seems to disappear with disappearance of this culmination, like the case of the Oboke culmination, and that the southern margin of the zone shows an arc–like line (Fig. 7) which is parallel to the strike of Sh.

B. Quartz Microfabrics

c–axis fabrics of dynamically recrystallized quartz grains, which, during the Dh phase folding, appeared in quartz veins produced just before the Dh phase, were analysed in the Koboke synform of Oboke culmination of the Koboke district by Hara and Paulitsch (1971).

They may explain the movement and strain pictures of the Sambagawa schists during the Dh phase folding, judging from the previous works (e.g.Tullis et al.,1973; Lister & Price,1978; Lister & Hobbs, 1980; Schmid & Casey, 1986) on the relationship between their pattern and the strain mode. Though some of Hara and Paulitsch's (1971) data indicate that it is not always possible to establish the orientation of the principal axes of bulk strain from the patterns of quartz c–axis fabrics in the cores of Dh phase folds because they strongly remain the characteristics of the pre–Dh phase, many of them are refered to the type I crossed girdle. The orientational relationship between the type I crossed girdle and the principal axes of strain ($X>Y>Z$) is clear from the works of Lister et al (1978), Lister and Hobbs (1980) and Schmid and Casey (1986) etc. From the observed type I crossed girdle it can be said that X is oriented normal to the fold axis. Hara and Paulitsch's specimens were collected from an outcrop placed in the axial zone of the Koboke synform of the Koboke district. The mode of bulk strain of the Sambagawa schists in this outcrop during the Dh phase was also analyzed by Hara et al.(1968), using Flinn's (1962)method based on the analysis of variation in deformation styles of randomly oriented quartz veins. The principal axes X and Y of bulk strain were determined to be normal to and parallel to the fold axis of the Koboke synform respectively. The orientation pattern of X and Y of bulk strain during the Dh phase is harmonic with that assumed from the quartz c–axis fabrics in the cores of

Dh phase folds.

III. Discussion

The Dh phase folds are developed as a series of en echelon sinistral folds in upright fashion (Fig. 1). Thus it has been said by Hara et al.(1973 ,1977) that the folds were produced under left−lateral shear along the general trend of the distribution area of the Sambagawa schists, which is parallel to the MTL. On the basis of the above−cited data after Hara et al.(1968 ,1977), Yokota (1968), Hara and Paulitsch (1971) and Ikeda (1972), further, Hara et al.(1992, Fig. 110) have roughly shown that the Dh phase folding occurred by left−lateral shear under NS compression, accompanied with tectonic emplacement of rigid body from the north.

Further detailed movement picture of the Sambagawa schists during the Dh phase folding will be analyzed in this paper on the basis of the above−described data of the orientation pattern of the axial plane (Sh) of minor parasitic folds.

The Dh phase folds contain the Oboke culmination and Nakashichiban culmination. Sh is commonly oriented in upright fashion throughout the Dh phase folds. In the culminations, however, its orientation pattern is different between their northern half and their southern half. The lower structural level of the former is the zone (northward vergent zone) in which Sh is inclined at low−moderate angles toward the south, though in the upper structural level it is inclined at high angles. While in the latter half Sh is oriented in upright fashion. The orientation pattern of Sh, which is comparable with the XY plane of strain, as observed on the profiles (NS cross sections), shows a sygmoidal fashion within the northward vergent zone. The principal axis X of strain during the Dh phase folding is oriented normal to the fold axis. Thus it would be said that the northern half of the culmination was a shear zone whose center (= highest strain concentration zone) is placed in the lower structural level.

The northward vergent zone disappears in the eastern and western margins of the Oboke and Nakashichiban culminations. The southern margin of the northward vergent zone shows an arc−like line in both culminations, to which the strike of Sh is parallel (Fig. 7). Thus the structure of Sh in both culminations and its related tectonics would be illustrated as schematically shown in Fig. 9. The Dh phase tectonics, which was responsible for the formation of the Oboke and Nakashichiban culminations, would be ascribed to the tectonic emplacement of rigid bodies from the north.

An evidence for the presence of such the rigid bodies appears to be shown in a seismic refraction profile along the NS line running through the Kawaguchi−Oboke−Iwahara district after Ichikawa (1968). The seismic refraction data show two layers, upper layer with 4.8−5.0 km / sec and lower layer with 6.0 km / sec, showing a harmonic structural relation between them. Namely, the Oboke culmination of the Sambagawa schists (= upper layer) is also traced in approximately harmonic relation throughout the lower layer. The top of the culmination of the lower layer is placed at 1.2 km depth below the axis of the Koboke synform of the upper layer. From such a data it would be said that the lower layer was present with the upper layer in the now−observed structural relation during the Dh phase folding. Yoshida et al.(1970) have assumed that the lower layer with 6.0 km / sec is Precambrian rocks, which should mean granitic rocks and/or high−temperature metamorphics. According to the geological characteristics of the Shimanto megaunit in Kii Peninsula which underlies the Sambagawa megaunit (Sogauchi unit) (cf. Hara et al.,1992), the lower layer can not be assumed to be any high−temperature metamorphic equivalent of the Oboke unit and further lower accretionary units of the Shimanto megaunit. Thus it can be assumed that the rigid bodies, which were tectonically emplaced beneath the Oboke and the Nakashichiban culmination from the north, must be the lower layer shown by Ichikawa (1968) and derivatives from the Kurosegawa−Koryoke continent (cf. Hara et al.,1992).

En echelon quartz veins (Fig. 10) were produced after the Dh phase folding. Such veins occur commonly in conjugate sets as shown by Tsukuda (1976). The orientation pattern of the conjugate sets of en echelon quartz veins has been measured in the Sambagawa megaunit and Chichibu megaunit I of some places. The data are shown in Fig. 11. This figure and Fig. 12 illustrate the orientation of the stress axes assumed from such the conjugate vein sets, showing that the compressive stress axis and tensional stress axis both are oriented near the horizontal plane, unlike the case of the Dh phase folding, though the compression axis appears to have been oriented with nearly constant trend throughout both phases. The trend of the compression axis is NE−SW in the zone near the MTL and NNE−SSW in the zone away from that (Fig. 12). It would thus be said that the conjugate sets of en echelon quartz veins were also produced by left−lateral shear under NS compression and that the left−lateral shear component appears to increase toward the north.

References

Flinn,D.,1962: On folding during three−dimensional progressive deformation. Geol. Soc. London, Q.J., 188, 385−433.

Hara,I. and Paulitsch,P.,1971: c−axis fabrics of quartz in bucked quartz veins. N. Jb. Miner. Abh., 115, 31−53.

Hara,I., Uchibayashi,S., Yokota,Y., Umemura,H. and Oda, M.,1968: Geometry and internal structures of flexural folds (I). Folding of a single competent layer enclosed in thick incompetent layer. Jour. Sci. Hiroshima Univ., Ser. C, 6, 51−113.

Hara,I., Hide,K.,Ikeda,Y. and Yokota,Y.,1973: Tectonic movement of the Sambagawa belt and the origin of the Median Tectonic Line. G.D.P. Structural Geology. 1, 29−38.

Hara,I., Hide,K., Takeda,K., Tsukuda,E., Tokuda,M. and Shiota,T.,1977: Tectonic movement in the Sambagawa belt. In Hide, K. ed., The Sambagawa Belt, pp. 309−390. Hiroshima Univ. Press, Hiroshima.

Hara,I., Shiota,T., Hide,K., Kanai,K., Goto,M., Seki,S., Kaikiri,K., Takeda,K.,Hayasaka,Y., Miyamoto,T., Sakurai,Y. and Ohotomo,Y.,1992: Tectonic evolution of the Sambagawa schists and its implications in convergent margin processes. Jour. Sci. Hiroshima Univ. Ser. C, 9, 495−595.

Ichikawa,K.,1968: Seismic prospecting in the Oboke area, Shikoku. Bull. Geol. Surv. Japan, 19, 385−395.

Ikeda,Y.,1972: Study of large−scale folding. Master Th.(MS), Hiroshima Univ.

Kojima,G. and Suzuki,T.,1958: Rock structure and quartz fabric in a thrusting shear zone: the Kiyomizu Tectonic Zone. Jour. Sci. Hiroshima Univ. Ser. C,2, 173−193.

Lister,G.S. and Price,G.P.,1978: Fabric development in quartz−feldspar mylonite. Tectonophysics, 49, 37−78.

Lister,G.S. and Hobbs,B.E.,1980: The simulation fabric development during plastic deformation and its application to quartzite: the influence of deformation history. Jour. Struc. Geol., 2, 355−370.

Murakami, 1970: A study on Geology and structure of the area on the west of Mt.Kotsu, Tokushima Prefecture. Grad. Th.(MS) Hiroshima Univ.

Nkagawa,M. and Kawai,T.,1963: On the geology and ore deposit of the Nonowaki mining district, Tokushima Prefecture, Japan. Geol. Rep. Hiroshima Univ. 12, 149−172.

Oyagi,N.,1964: Structural analysis of the Sambagawa crystalline schists of theSazare mining district, central Shikoku. Jour. Sci. Hiroshima Univ. Ser.C, 4, 271−332.

Shiota,T.,1981: The structural, geological and petrological study of the Sambagawa crystalline schists of the Ikeda−Mikamo district, East Shikoku. Jour. Gakugei, Tokushima Univ.,(Nat. Sci.), 32, 29−65.

Schmid,S. and Casey,M.,1986: Complete fabric analysis of some commonly observed quartz c−axis patterns. In Hobbs B.E. and Heard H.C. eds, Mineral and Rock deformation: Laboratory Studies−Tectonphysics. Paterson Volume. Geophy.Monogr. Ser. 36, 263−286.

Tsukuda,E.,1976: Formation and deformation of en echelon veinlets in shear deformation. Mem. Vol. Prof. G. Kojima. 259−265.

Tullis,J., Christie,J.M. and Griggs, D.T.,1973: Microstructures and preferred orientations of experimentally deformed quartzites. Bull. Geol. Soc. Amer.61, 297−314.

Yokota,Y.,1969: Evolution of the Oboke anticlinorium. Master Th. (MS), Hiroshima Univ.

Yoshida,T., Iizuka,S. and Igi,S.,1973: Reconnaissance survey for Deep Drilling in the JUMP. In The crust and upper mantle of the Japanese area. Geol. Surv. Japan, Kawasaki. 163−176.

Tsugio SHIOTA

Division of Natural Sciences, Faculty of Integrated Arts and Sciences, Tokushima University, Tokushima, 770, Japan.

Ikuo HARA, Sachiyo SEKI and Nobutaka OKUDAIRA

Department of Earth and Planetary Systems Science, Faculty of Science, Hiroshima University, Higashi−hiroshima, 724, Japan.

Yukio IKEDA

Institute of Earth Science, Faculty of Education, Yamaguchi University, Yamaguchi, 753, Japan.