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Folding and related structures of the Maizuru and Ultra-Tamba zones in the Kozuki-Mimasaka area, Southwest Japan

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Abstract

The Inner Zone of Southwest Japan is generally regarded as a pile of accretionary complexes. There are many studies, on the basis of radiolarian biostratigraphic data, of their accretionary processes. Post-accretionary tectonics, however, has not been examined in detail yet. This paper mainly investigates deformation structures observed in the Maizuru and Ultra-Tamba zones, and considers the tectonics of the Inner Zone of Southwest Japan.The study area (Kozuki-Mimasaka area) is located in the southeast Okayama to southwest Hyogo prefectures. The pre-Cretaceous system in the area is divided into the Maizuru Group (Maizuru Zone), the Kozuki Formation (Northern Zone of Ultra-Tamba Zone) and the Yamasakai Formation (Middle Zone of Ultra-Tamba Zone). The geological structures are examined using the relationships of minor structures seen under the microscope as well as the data from field work, such as the interrelation between bedding plane and slaty cleavage. As the result, three stage deformations (D1, D2 and D3) are recognized. D1 produced close to tight folds with slaty cleavage as axial plane cleavage. Although it is thought that D1 structures recognized in each of the zone are almost identical, the development of slaty cleavage is intense in the Middle Zone of the Ultra-Tamba Zone and weak in the Maizuru Zone. D2 formed open folds with crenulation cleavage. The folds formed by D2 bend the low-angle faults of unit boundaries. It is thought that D1 and D2 occurred in Jurassic time and approximately 130 Ma ago.

Key Words: Ultra-Tamba Zone, Maizuru Zone, Kozuki Formation, Slaty cleavage, Structural analysis.

1. Introduction

Many geological units constituting southwest Japan are composed of accretionary complexes which have been formed by subduction of oceanic plates. In the Mino-Tamba Zone, a detailed accretionary process is also shown by Kimura and Hori (1993) and Nakae (1993). On the other hand, Ichikawa (1990) assumed that the A terrane group (pre-Jurassic accretionary complexes) was thrust over the B terrane group (Jurassic accretionary complexes) in late Jurassic to early Cretaceous times. There are, however, few detailed studies about this post-accretionary deformation. This report presents the results of a detailed analysis of deformation structures, especially foliations and folds, in the Maizuru and Ultra-Tamba zones, which belong to the Inner Zone of Southwest Japan.

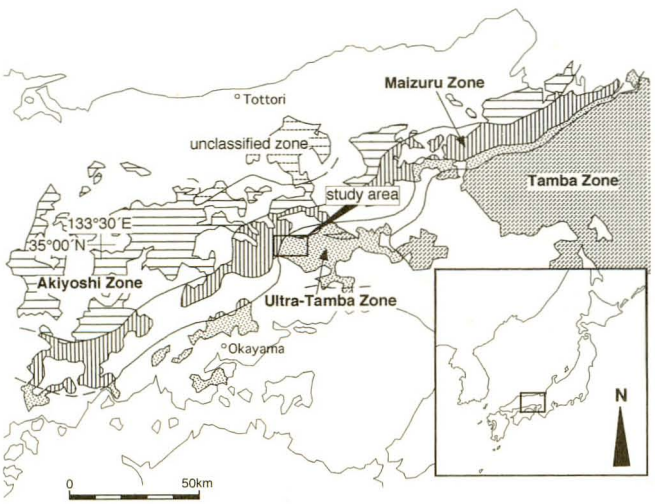

Fig. 1. Location of the study area and simplified map showing tectonic units in the Kinki-Chugoku regions.

2. Outline of geology

Geological units constituting the Inner Zone of Southwest Japan generally trend E-ENE. Some of them, however, are distributed by the WNW strike in southwestern Hyogo and southwestern Okayama prefectures. The study area (Kozuki-Mimasaka area) covers Sayo, Kozuki (Hyogo Prefecture), Sakuto and Mimasaka (Okayama Prefecture) towns. In this area, pre-Cretaceous systems are observed. They are the Maizuru Group (Maizuru Zone: MZ), the Kozuki Formation

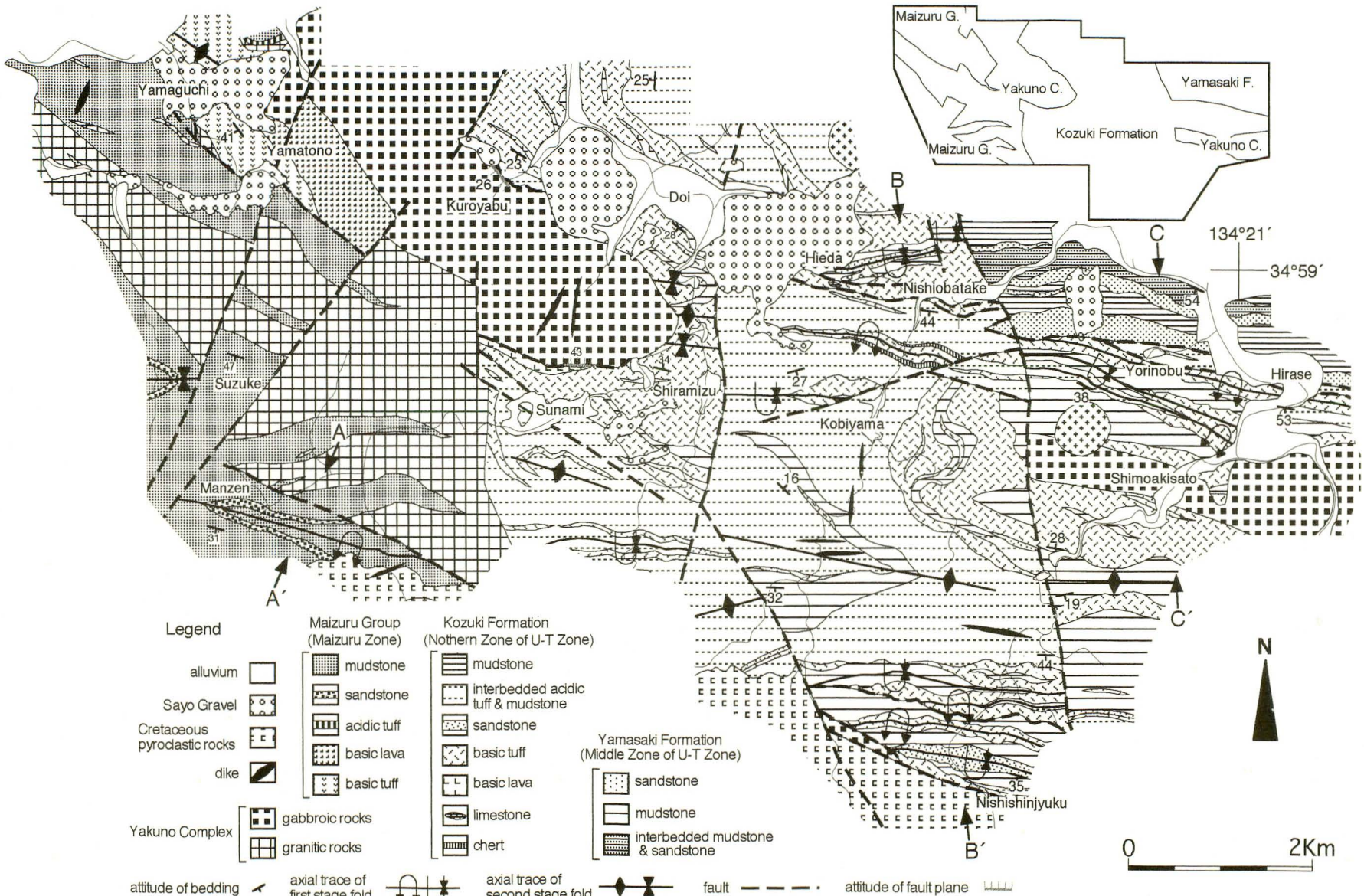

Fig. 2. Geologic map of the study area.

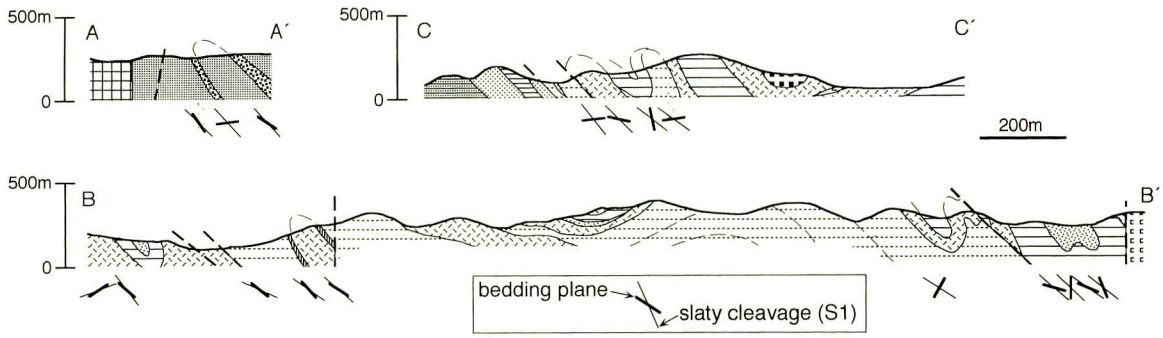

Fig. 3. Structral profiles of the study area. See Fig.2 for locality and legend.

(Northern Zone of Ultra-Tamba Zone: NUT), the Yamasaki Formation (Middle Zone of Ultra-Tamba Zone: MUT) and the Yakuno complex (Fig.2). The Maizuru Group crops out in the western part of this area, and consists mainly of mudstone, sandstone and basic lava. The Kozuki Formation is the largest exposure in the middle part of this area, and is composed mostly of mudstone, acidic tuff and basic tuff. The Yamasaki Formation is distributed in the northeastern part, and consists of mudstone and sandstone. The Yakuno complex is roughly divided into granitic rocks and gabbroic rocks, which are unconformably covered by the Cretaceous Aioi Group and the Tertiary Sayo Gravel (Mitsuno and Omori, 1963 etc.).

3. Lithofacies of the Pre-Cretaceous system

3.1 Kozuki Formation of the Northern Zone of the Ultra-Tamba Zone

The Kozuki Formation was defined by Igi and Wadatsumi (1980). There had not been any detailed report about its lithofacies, stratigraphy and geological structures for a long time, but recently Takemura *et al.* (1993) described them. According to Takemura *et al.* (1993), the Kozuki Formation is a coherent formation (Fig.4) and is divided into four members (Lowermost, Lower, Middle and Upper). But it is necessary to reexamine its stratigraphy in detail, because some new biostratigraphic evidence has been found.

The mudstone is generally siliceous, with intercalations of thin beds of acidic tuff. It is black to dark gray, and has strong fissility. Under the microscope, parallel alignment of white micas and dusty seams accompanied by slaty cleavage are observed (Plate I-1, I-2 and I-7).

The sandstone shows a few centimeters that are stratified or massive. It is classified into lithic wacke and is poorly sorted. Grains of the sandstone are fine to medium, and are composed of quartz, plagioclase, K-feldspar, white mica, mudstone, acidic tuff, sandstone, rhyolite, basic tuff, chert and mylonitic granite. Slaty cleavages are often observed in the matrix.

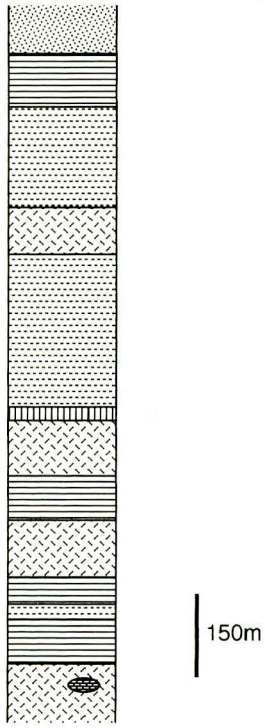

Fig. 4. General columnar section of the Kozuki Formation (after Takemura *et al.*,1993). See Fig. 2 for legend.

The interbedded acidic tuff and mudstone is the most characteristic lithofacies of the Kozuki Formation. Single beds are generally 5 mm to 5 cm thick, and mudstone layers are thicker than the tuff layers. The acidic tuff consists of volcaniclastic sandstone and siltstone. The tuff layers are occasionally discontinuous, and indicate a chaotic lithofacies (Fig.5 and Plate I-5). Slaty cleavages develop in parts of the mudstone.

The basic tuff and lava are gray, green or reddish

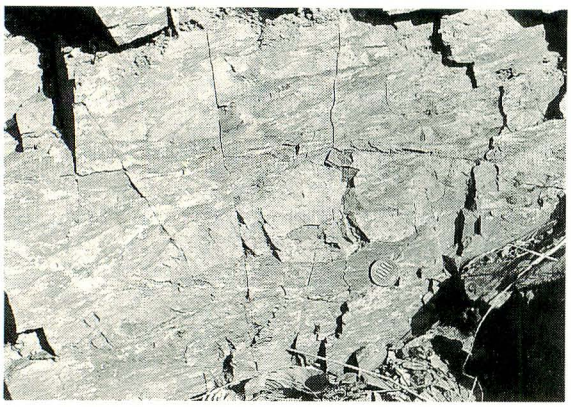

Fig. 5. Photograph of interbedded acidic tuff and mudstone. The lenses of acidic tuff are discontinuous in mudstone. Locality is shown in Fig.7.

brown in outcrops. Graded bedding and cross bedding are infrequently preserved in volcanoclastic sandstones. Lenses or thin beds of limestone infrequently occur in the basic tuff. The basic lava rarely shows pillow structure, and is composed of clinopyroxene, plagioclase and opaque minerals, with chlorite, calcite, quartz, epidote, prehnite and pumpellyite as the secondary minerals. The plagioclase has undergone saussuritization. Variolitic texture and amygdaloidal structure are observed, and sub-ophitic texture is sporadically recognized.

The chert is interbedded with basic tuff and mudstone. The thickness is less than 20 m. It is white and pale yellowish brown, and often shows pale yellowish green and dark brown. It is composed of cryptocrystalline quartz and secondary quartz veins. Radiolarian fossils are observed, but samples with many radiolarian fossils are rarely found.

The siliceous mudstone is present between basic tuff and mudstone, and is sporadically intercalated in basic tuff and mudstone. It is gray to greenish gray, and a few centimeters to 1 m thick.

3.2 Maizuru Group of Maizuru Zone

Mitsuno and Omori (1963) studied the constituents of the Maizuru Zone in this area, and named them the Nigaki and Kose groups. Mitsuno *et al.* (1975) examined the Permian Maizuru Group in Yanahara area, eastern Okayama Prefecture, and divided it into four formations (Lowermost, Lower, Middle and Upper). The Nigaki and Kose groups are correlated with the Lower and Middle formations of the Maizuru Group, respectively. Simplified columnar sections are showed in Fig.6. Judging from the lithology and radiolarian fossils, A, B, C and D can be correlated with the Lower Formation, the upper Lower to lower Middle formations, the lower Middle Formation and the upper Middle Formation, respectively.

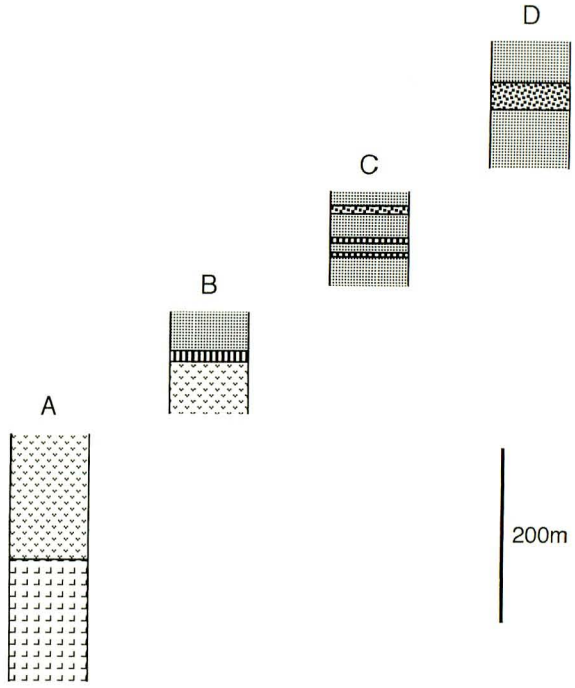

Fig. 6. Simplified columnar sections of the Maizuru Group. The routes of the sections are shown in Fig.7. A,B,C and D are correlative with the Lower Formation, the upper Lower to lower Middle formations, the lower Middle Formation and the upper Middle Formation of the Maizuru Group, respectively.

The basic lava and tuff are reddish brown or dark green. Many vesicles, regarded as the track of bubbling, are occasionally observed in basic lavas. The basic lava is composed of plagioclase and clinopyroxene as phenocrysts, the grandmass being formed by very fine minerals, accompanied by chlorite, quartz, calcite and prehnite as secondary minerals. The basic tuff is generally replaced by chlorite and calcite.

The acidic tuff rests stratigraphically upon basic tuff, and also occurs as thin beds intercalated in mudstone. It is dark gray to yellowish brown. Under the microscope, it consist of quartz, plagioclase and an opaque mineral (magnetite?). Glass shards are occasionally preserved.

The mudstone is massive and silty, and shows hardly any fissility. Many silt patches are found, and thin beds of sandstone are occasionally intercalated. Sponge spicules are characteristically preset.

The sandstone is tuffaceous, and the matrix is frequently replaced by calcite and chlorite. Grains of the sandstone are usually medium in size. The sorting is somewhat poor. Graded bedding, cross bedding and load casts are observed. Clasts in the sandstone are quartz,

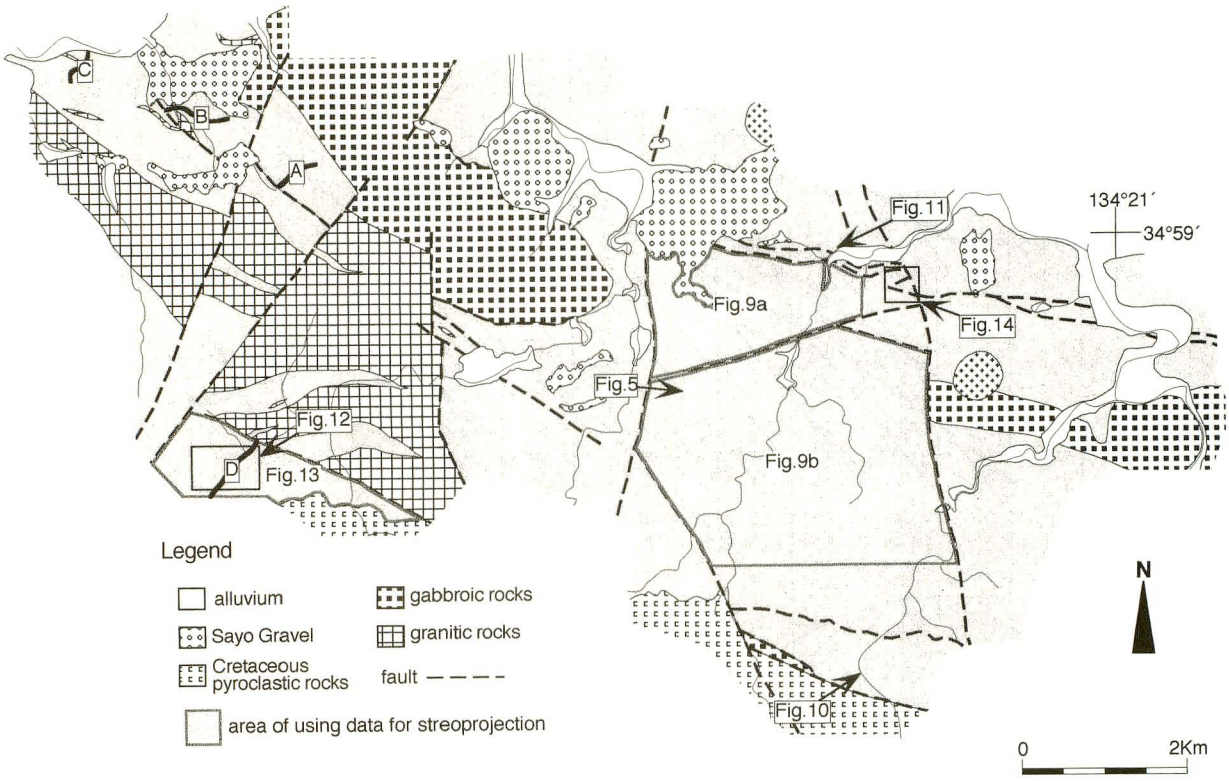

Fig. 7. Map showing localities of figures (with Fig. number), the routes of columnar section (A to D) and the areas in which used data for equal-area projections were obtained.

plagioclase, K-feldspar, white mica, chlorite, mudstone, acidic tuff, rhyolite and quartz andesite.

3.3 Yamasaki Formation of the Middle Zone of the Ultra-Tamba Zone

In the Yamasaki area, northwest of this area, Kanbe and Hirokawa (1963) described the Hijima, Yamasaki and Mikazuki formations. Igi and Wadatsumi (1980) used the name Mikazuki Formation for the strata that are distributed in northeastern part of this area. This report regards the Yamasaki and the Mikazuki formations as the same, and redefines them as the Yamasaki Formation. There has not been any detailed study of the stratigraphy of the Yamasaki Formation, and it is very difficult to know the correct stratigraphy because the Yamasaki Formation yields hardly any fossils, and consists entirely of sandstone and mudstone only. The visible thickness is about 950 m.

The mudstone is dark grayish green to black, and is generally composed of well-laminated claystone and siltstone. It shows strong fissility along bedding planes and slaty cleavage. The rock appears glossy because of the recrystallized planar minerals on the bedding planes and slaty cleavage. Under the microscope, the parallel alignment of relatively weak, dusty seams and very strong recrystallized white micas is observed (Plate II-5 and II-6).

The sandstone is pale green to grayish green, and is usually well stratified. Grains are fine to medium in size, and sorting is relatively good. Clasts of the sandstone are plagioclase, quartz, K-feldspar, white mica, rutile, chlorite, rhyolite, acidic tuff, basic tuff, basalt, mudstone and granite. Slaty cleavage is much in evidence.

4. Geological structure

Geological structures have been determined by observations using the duplication relations of minor structures observed under the microscope, as well as field observations, such as distribution pattern of beds, sedimentary structures and interrelation between bedding plane and slaty cleavage. In particular, the interrelation between bedding plane and slaty cleavage (Fig.8) is very important. As the result, three stage deformations (D1, D2 and D3) are recognized.

4.1 Northern Zone of the Ultra-Tamba Zone (NUT) First stage deformation (D1)

Macroscopic structure

First folds (F1): Major close to isoclinal folds were produced by D1. The axes trend nearly E-W and the

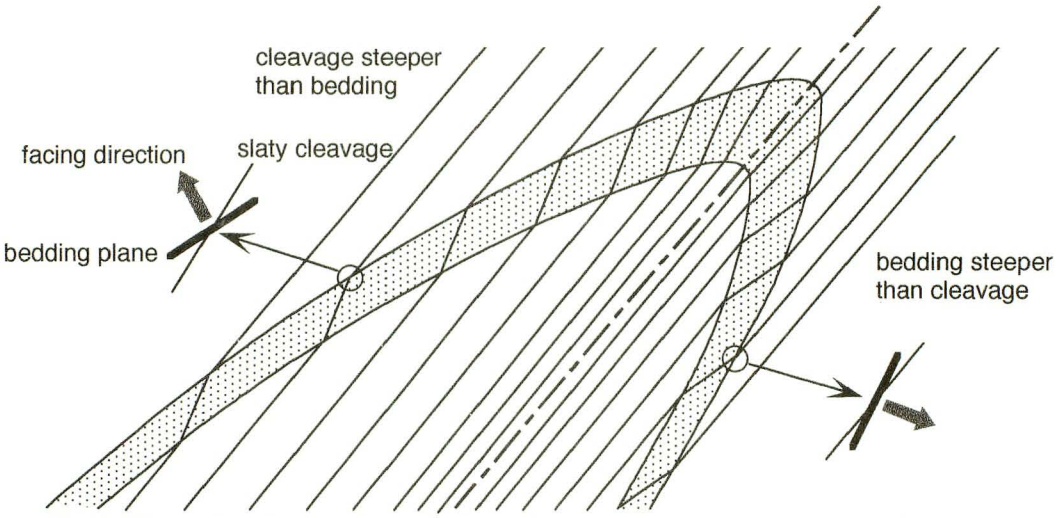

Fig. 8. Illustration showing the interrelation between bedding plane and slaty cleavage.

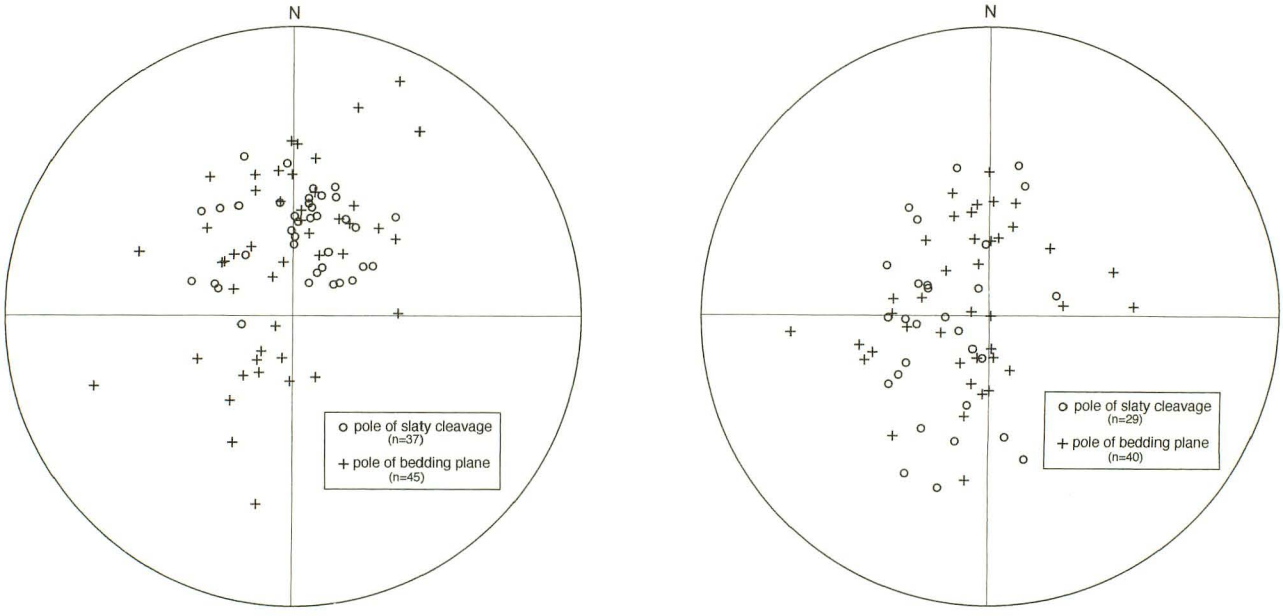

Fig. 9. Equal-area projection (lower hemisphere) of attitude of slaty cleavage and bedding plane in the Kozuki Formation. The used data are from the zones surrounded by a gray line in Fig.7. a:Nishiobatake area. The influence of the F2 folding is weak, and there are the F1 with axial trace trending WNW. b:Kobiyama area. The F2 having axial trace striking WNW bends slaty cleavage as well as bedding plane.

axial planes dip to the south (Fig.2 and 3). Slaty cleavages (S1; described below) are almost parallel to the axial planes of these folds (Fig.9a).

Microscopic structure

Slaty cleavage (S1): Slaty cleavages develop in mudstone, interbedded acidic tuff and mudstone, and in a part of the basic tuff and sandstone. The mudstone breaks easily along the slaty cleavage when hit with a hammer. In stratified mudstone and interbedded acidic tuff and mudstone, intersection lineations between slaty cleavage and bedding plane are observed on the cleavage planes. Parallel and continuous dusty seams and white micas are well developed in the mudstone. In the siliceous mudstone, although dusty seams are not relatively conspicuous, recrystallization of white mica is remarkable. Symmetrical pressure fringes are occasionally observed around opaque minerals in the mudstone (Plate I-1 and I-2), and many pressure shadows exist around detrital grains and tuffaceous lenses (Plate I-3). Some quartz veins are bent and truncated by the slaty cleavages, forming ptygmatic folds. The slaty cleavages develop intensely at the hinges of macroscopic first folds. In the sandstone, dusty seams and white micas are observed in the matrix, but the dusty seams are rough and discontinuous (Plate I-6). In the basic tuff, chlorite as well as dusty seams and white mica, are

recognized. Although the slaty cleavages also develop in the interbedded acidic tuff and mudstone, the dusty seams heterogeneously develop as surrounding tuffaceous lenses in the muddy matrix (Plate I-5). Shearing along the slaty cleavage in rare.

Minor folds (f1): D1 produced minor folds with interlimb angles of 10 to 40°, axial planes with E-W strike and S dip, and half-wave length of 1 mm to 1 m. These folds are accompanied by axial-plane slaty cleavage, and are developed well-in hinges of the macroscopic folds (Fig.10 and 11).

Second stage deformation (D2)

Macroscopic structure

Second folds (F2): D2 formed open folds with almost vertical axial planes, with axis trending NWN to ENE and plunging gently to east or west (Fig.2 and 3). F2 bends slaty cleavage and bedding planes (Fig.9b), and causes large changes in the attitude of strata.

Fig. 10. Photograph of minor first fold in the Kozuki Formation. The slaty cleavage, whichi is shown by fissures, is an axial plane cleavage of the minor fold. The lithology of this outcrop is mudstone accompanied by sandstone. The locality is shown in Fig.7.

Microscopic structure

Crenulation cleavage (S2): Crenulation cleavages develops sporadically in mudstone and interbedded acidic tuff and mudstone. Both the zonal type and the discrete type (Gray, 1979) are recognized. The crenulation cleavage generally trends E-W, dips steeply south, and folds bedding planes and slaty cleavage (Plate I-8).

Minor folds (f2): D2 produced minor folds with interlimb angles of about 160° and with a half wavelength of a few millimeters to 50 cm. These minor folds are considered to be secondary folds because they fold both bedding planes and slaty cleavage. These folds are accompanied by the above-mentioned crenulation cleavage as axial plane cleavage.

Third stage deformation (D3)

Kink bands (f3) are infrequently recognized as the third deformation in mudstone and interbedded acidic tuff and mudstone. They are 0.4 mm to 2 cm in width. They fold bedding planes, slaty cleavage and crenulation cleavage.

4.2 Maizuru Zone (MZ)

First stage deformation (D1)

Macroscopic structure

First folds (F1): D1 produced a close overfold with axial plane dipping approximately 55° south, and with an interlimb angles of about 50° (Fig.2, 3 and 12). The fold axis strikes WNW and plunges slightly west. Slaty cleavages are the axial plane cleavages of this fold (Fig.13).

Microscopic structure

Slaty cleavage (S1): The slaty cleavage in mudstone and a part of basic tuff in the MZ is weaker than that in the NUT (Plate II-1 and II-2). The mudstone hardly breaks in the direction of the slaty cleavage and splits

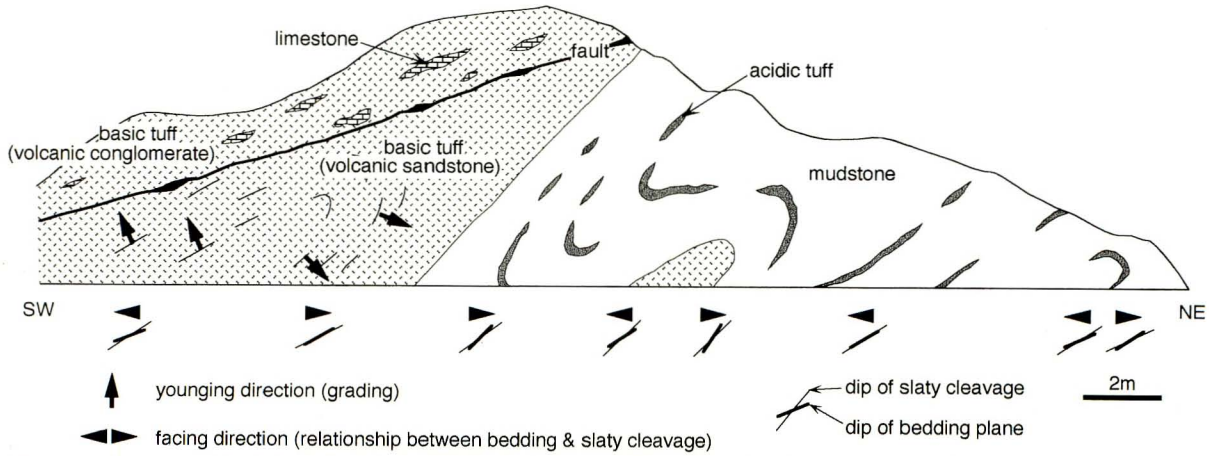

Fig. 11. Outcrop sketch at Nishiobatake. The younging directions (indicated by the graded bedding) completely agree with the facing directions (shown by the interrelation between bedding plane and slaty cleavage). See Fig.7 for location.

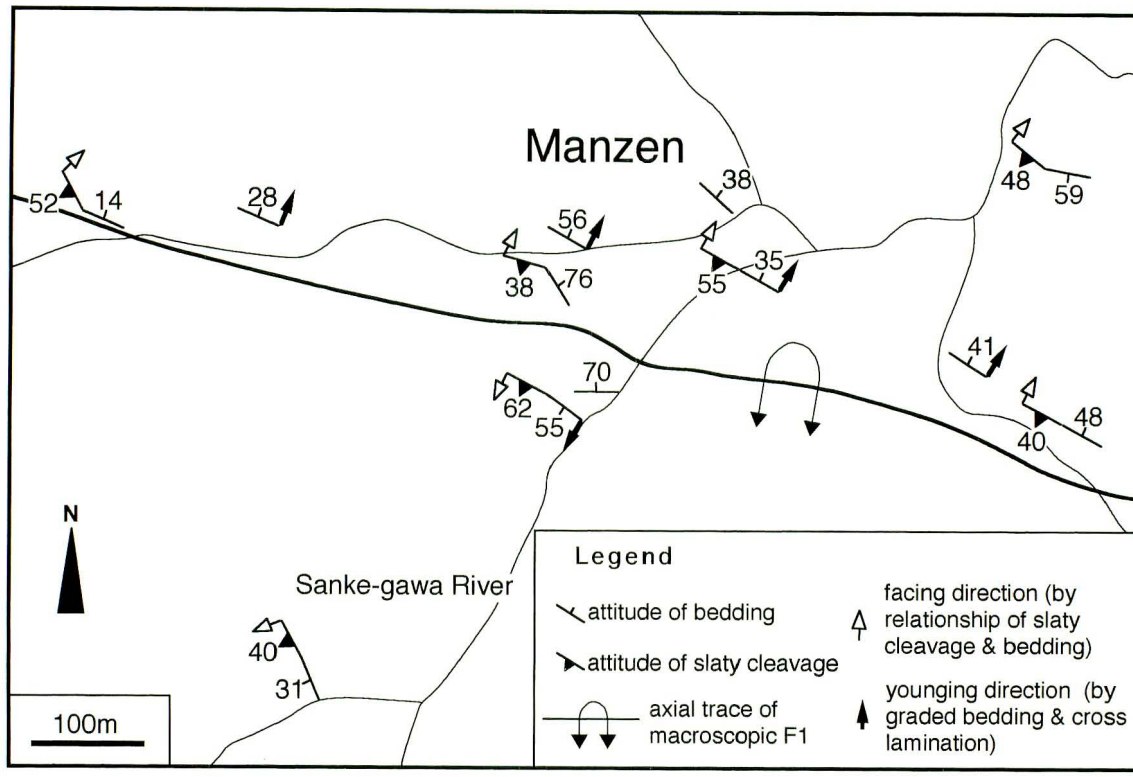

Fig. 12. Structural map of the Maizuru Group in Manzen. In the southern limb of the anticline, the slaty cleavage is steeper than the bedding plane. The interrelation is generally opposite in the northern limb. However, as many parasitic minor folds develop in the hinge of macroscopic anticline. The locality is shown in Fig.7.

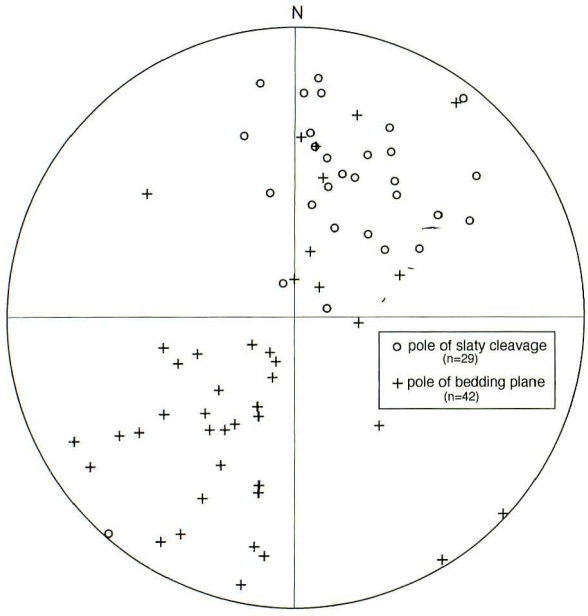

Fig. 13. Equal-area projection (lower hemisphere) of attitude of slaty cleavage and bedding plane in the Maizuru Group. The used data are from the zone surrounded by gray line in Fig.7. In this projection, bedding planes predominantly dip north because the area is located in the hinge of macroscopic fold. As a whole, the bedding plane predominately dips south in the Maizuru Group of this study area.

like a hornfels when hit with a hammer. Although dusty seams are observed under the microscope, their continuity and parallelism are poor. Recrystallization of white mica is very weak. The recrystallized white micas are not recognized until they are observed under the microscope at about 400 magnification. Nevertheless, at Manzen, which is situated at the hinge of the macroscopic anticline, the slaty cleavages are comparatively well developed. Symmetrical pressure fringes are recognized in both directions of the YZ and the XZ planes.

Minor folds (f1): Minor folds with interlimb angles of 10 to 90$_{\circ}$ are recognized in the Maizuru Group. Half wave-lengths of these folds are 1 to 3 mm (Plate II-3). These minor close to tight folds are accompanied by slaty cleavage as axial plane cleavage. They are mainly found in the hinge of the macroscopic fold.

Second stage deformation (D2)

Macroscopic structure

Second folds (F2): D2 formed open folds similar to F2 of the NUT. The axial planes are almost vertical, and the axial traces strike E-W and NW at Suzuke and Yamaguchi, respectively.

4.3 Middle Zone of the Ultra-Tamba Zone (MUT)

First stage deformation (D1)

Macroscopic structure

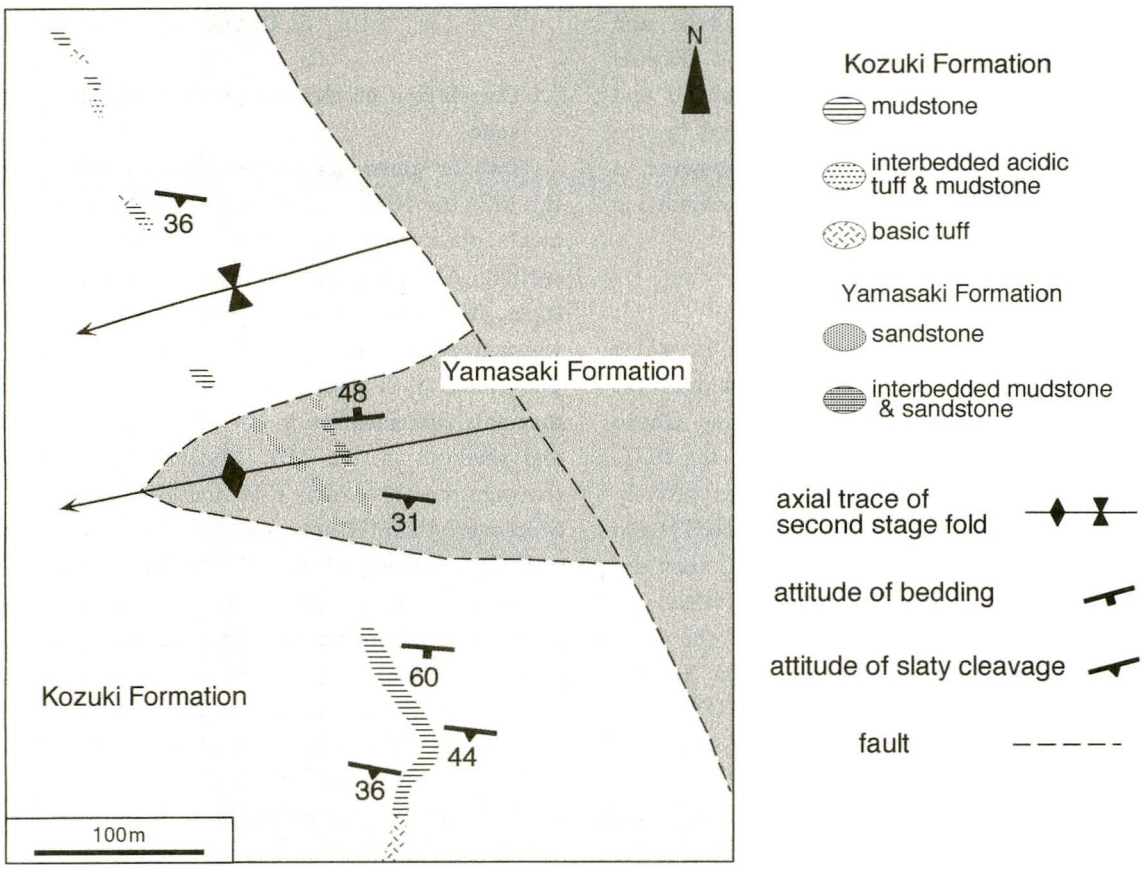

Fig. 14. Structural map of the Kozuki and Yamasaki formations in eastern Nishiobatake. See Fig.7 for locality. The boundary between both formations is folded by the second fold (F2)

In the study area, the rocks of the MUT broadly form a homoclinal structure; the bedding planes and the slaty cleavage dominantly strike EW and dip south. Some sedimentary structures, however, locally indicate overturned bedding, and minor overfolds, which are similar to those of the NUT, are observed occasionally. These show that the MUT in this area corresponds to a normal limb of a large-scale fold.

Microscopic structure

Slaty cleavage (S1): The slaty cleavage develops in all rocks except in a few coarse-grained sandstones. Strong fissility along the cleavage is observed in all mudstones. The most conspicuous lineation is intersection between crenulation cleavage and slaty cleavage or bedding plane. Another intersection lineation, between bedding plane and slaty cleavage, is observed at places where they intersect at a high angle. Dusty seams are not clear, in comparison with those in mudstone of the NUT; on the other hand, white micas develop more intensely (Plate II-5 and II-6). The development of cleavage is generally stronger than in the NUT. Symmetrical pressure fringes are observed very well in both the YZ and XZ planes.

Minor folds (f1): The minor folds in the MUT are similar those in the NUT. The slaty cleavages are the axial plane cleavages of these folds.

Second stage deformation (D2)

Macroscopic structure

Second folds (F2): The only macroscopic second fold exists in Nishiobatake (Fig.14). The antiform folds the Kozuki Formation (NUT) as well as the Yamasaki Formation (MUT).

Microscopic structure

Crenulation cleavage (S2): Crenulation cleavage is developed in mudstone and interbedded mudstone and sandstone (Plate II-7 and II-8). It folds both bedding plane and slaty cleavage. The density and continuity of the crenulation cleavage are generally higher than in the NUT.

Minor folds (f2): The minor folds with half wave length of 0.3 mm to 5 cm are produced by D2. The minor folds bend both bedding planes and slaty cleavage. Although the interlimb angle is generally about 120° (Plate II-8), close folds and box folds are also observed (Plate II-7). These folds are accompanied by the axial plane crenulation cleavage.

Third stage deformation (D3)

Kink bands are found in mudstone and in

interbedded mudstone and sandstone. The shape and scale are almost similar to those of the Kozuki Formation.The local deformation stage between D1 and D2Kink bands found in the MUT were produced by the third deformation. In eastern Nishiobatake, however, a kink band with 0.2 mm width is folded by crenulation cleavages (Plate II-4).

4.4 Relationship between the zones

NUT and MUT: In this study, no outcrop in which the NUT and the MUT are in direct contact has yet been discovered. Igi and Wadatsumi (1981) and Ohoto (1986) thought that the MUT was thrust over the NUT.

NUT and MZ: As the Yakuno complex is extensively distributed between the Kozuki Formation (NUT) and the Maizuru Group (MZ) in this area (Fig.2), they are not in immediately contact. Kuromusya *et al.* (1996) report that the Yakuno complex is thrust over the NUT at Otomi, east of this area. In this area, the Yakuno complex is also in fault contact with the NUT. Both the boundary fault and bedding plane of the NUT dip south at Kuroyabu, but dip north at Sunami (Fig.2). It is supposed that a synform (F2) with E-W axial trace exists in the Yakuno complex and the surrounding NUT. Therefore, the boundary fault between the Yakuno complex and the NUT preceded D2.

Most of the relationship between the Maizuru Group and the Yakuno complex is a fault contact. But they are occasionally in contact without a clear shear zone. When the Yakuno complex is in contact with the Maizuru Group without a clear shear zone, it is difficult to interpret their relationship (Takemura, 1996). The detailed occurrence and interpretation will be discussed in a separate paper.

5. Discussion

5.1 Correlation of the structural elements found in each zone

Two or three deformation stages are recognized in the MZ, the NUT and the MUT, and the structural elements observed in each zone will be compared in this section. Although slaty cleavage develops in the three zones, the greatest difference of geological structure which is recognized in the three zones is in its intensity. The intensity is strongest in the MUT (Yamasaki Formation), intermediate in the NUT (Kozuki Formation), and weakest in the MZ (Maizuru Group). The slaty cleavage mostly strikes E-W and dips south in all zones. Moreover, there is not any difference between the attitude and vergence of the F1. The axial planes of the F1 folds dip south in three zones. In other words, three zones have a similar fold structure with a northward vergence. Thus, the slaty cleavage and F1 in all zones were formed at the same time during D1.

A slight difference is recognized in the deformation structure formed by D2. The crenulation cleavage and the minor folds (f2) developed in the Ultra-Tamba Zone (NUT and MUT), but are not recognized in the MZ (Table1). It possibly shows that D2 affected each zone differently. But the macroscopic F2 obviously exist in the MZ. If the S1 is not intense, the S2 is generally difficult to be recognized. It is thought that the difference of the structure of D2 was caused by the contrast of intensity of S1. Accordingly, the three zones were subjected to the identical D2.

5.2 History of deformation in the Kozuki-Mimasaka area

The deformation structures observed in this area are summarized in Table1. It is not known whether the low-

Table 1 Deformation stage, structure and age

Stage		Maizuru Zone	Northern Zone of UT	Middle Zone of UT	Age
		Maizuru Group	Kozuki Formation	Yamasaki Formation	
D3	microscopic	none	kink band (f3)	kink band (f3)	?
D2	*macroscopic*	*open fold (F2)*	*open fold (F2)*	*open fold (F2)*	130 Ma
	microscopic	none	open fold (f2)	open-close fold (f2)	
			crenulation cleavage (S2)	crenulation cleavage (S2)	
D1	*macroscopic*	*close fold (F1)*	*close-isoclinal fold*	*unknown*	Jurassic
	microscopic	close-tight fold (f1)	close-tight fold	close-tight fold	
		slaty cleavage (S1)	slaty cleavage (S1)	slaty cleavage (S1)	
		(weak)	(intense)	(very intense)	

angle faulting preceded D1 or not, are hence the faulting is included in D1. Suzuki (1987) indicated that the first folding of the MZ occurred in Jurassic time. D1 of this area is identical in the MZ and the Ultra-Tamba Zone (NUT and MUT); hence D1 of the Ultra-Tamba Zone is considered to have occurred in Jurassic time. The open folds produced by D2 clearly bend the slaty cleavages and the low-angle faults formed by D1. It is difficult to determine when D2 occurred, but the attitude and sense of F2 in this area resemble those of one of the fold structures in the lower Cretaceous Sasayama Group, distributed in the eastern Hyogo Prefecture. The folding of the Sasayama Group does not influence the middle to upper Cretaceous Arima Group (Yoshikawa, 1993), and F2 in the study area also does not fold the middle to upper Cretaceous Aioi Group. Yoshikawa (1993) thought that the sedimentation of the Sasayama Group and the folding occurred almost at the same time. It is considered that the folding of the Sasayama Group and D2 took place 130 Ma ago, judging from the fission-track dating of the Sasayama Group (Wadatsumi *et al.* 1983).

6. Conclusion

1. The Pre-Cretaceous system in the Kozuki-Mimasaka area is divided into the Kozuki Formation (Northern Zone of Ultra-Tamba Zone), the Yamasaki Formation (Middle Zone of Ultra-Tamba Zone) and the Maizuru Group (Maizuru Zone). Two or three deformation stages (D1, D2 and D3) are recognized in them.

2. As a result of D1, the overfolds accompanied by slaty cleavage as axial plane cleavage were produced in the pre-Cretaceous system. As the rocks of the three zones were subjected to an almost identical first deformation (D1), they have similar structures with a vergence in the same direction. The intensity of D1 is weak in the Maizuru Zone, intermediate in the Northern Zone of Ultra-Tamba Zone and strong in the Middle Zone of Ultra-Tamba Zone. D1 occurred in Jurassic time.

3. D2 of the three zones is the same, producing open folds and crenulation cleavage. The crenulation cleavage, however, is not observed in the Maizuru Zone. D2 probably took place approximately 130 Ma ago.

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Plate I

Microscopic structures in the Kozuki Formation

1 & 2. Slaty cleavage in mudstone. 1 and 2 are YZ and XZ planes of a same sample, respectively. Symmetrical pressure flinges are observed in both sections.

3. Slaty cleavage and pressure shadow in siliceous mudstone. The pressure shadows develop around radiolarian fossil and detrital clasts.

4. Pressure fringe around opaque minerals in tuffaceous mudstone.

5. Slaty cleavage in interbedded acidic tuff and mudstone. Slaty cleavages are concentrated in muddy parts.

6. Slaty cleavage in sandstone. Dusty seams are rough and discontinuous.

7. Minor fold. The slaty cleavage is an axial plane cleavage of this fold.

8. Crenulation cleavage in interbedded acidic tuff and mudstone. The crenulation cleavage cuts both bedding plane and slaty cleavage.

Plate II

Microscopic structures in the Maizuru Group (1, 2 & 3) and the Yamasaki Formation (4 to 8)

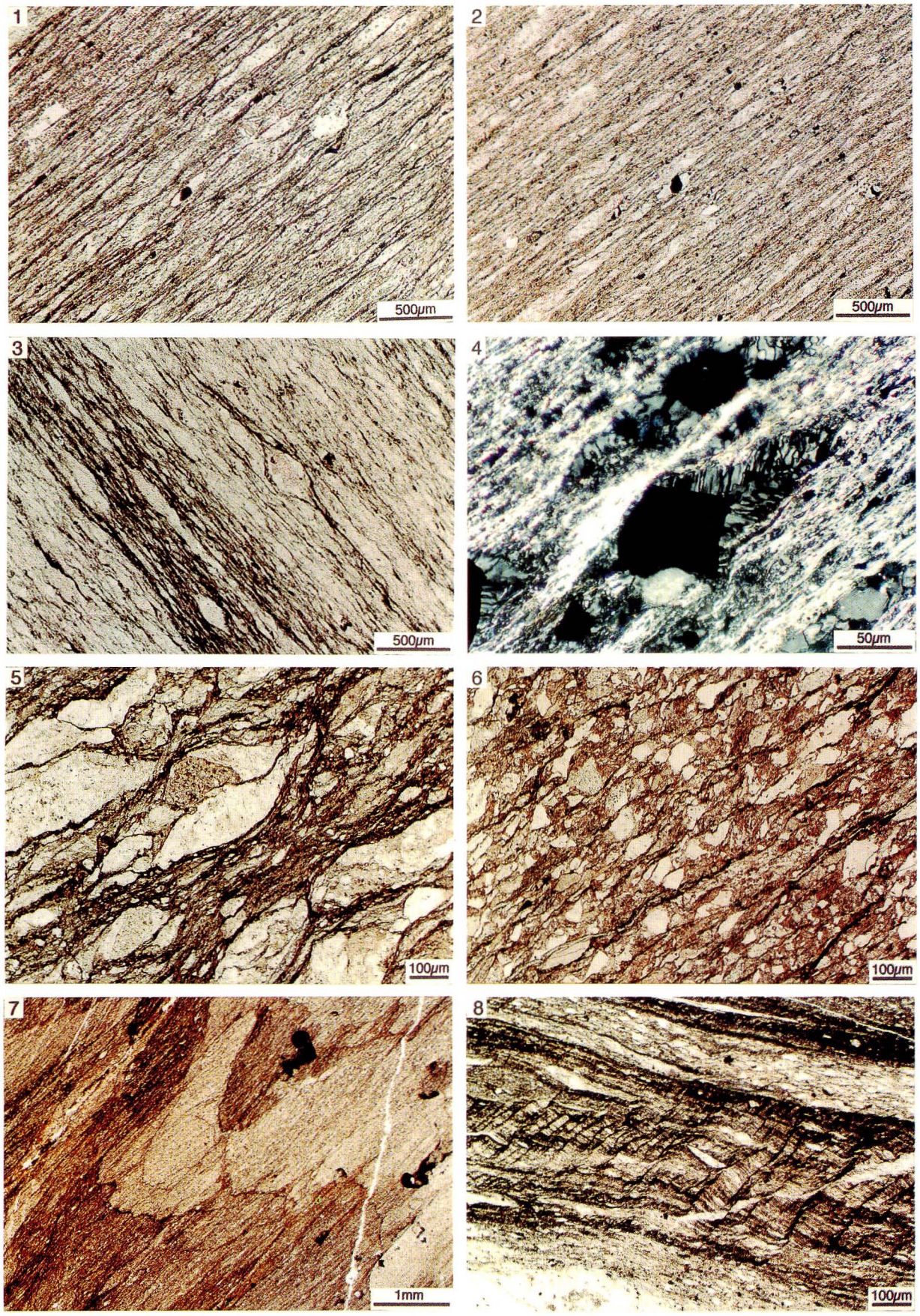
1 & 2. Slaty cleavage in mudstone. 1 and 2 are the same thin section, and x20 and x100, respectively. Slaty cleavage is hardly recognized under the microscope at x20.

3. Minor fold. Thin bed of mudstone is observed in very fine-grained sandstone. Very weak dusty seams which are parallel to the axial plane of the fold are recognized in mudstone.

4. Kink band preceding the D2. BS, K and C show directions of bedding plane & slaty cleavage, kink band and crenulation cleavage, respectively. Kink band is obviously cut by crenulation cleavage.

5 & 6. Slaty cleavage in siltstone. 5 and 6 are parallel and crossed polars, respectively. Although dusty seams are not conspicuous under parallel polar, strongly recrystallized illite is observed under cross polars.

7 & 8. Minor folds. Minor folds bend bedding plane and slaty cleavage, and are accompanied by crenulation cleavage as axial plane cleavage.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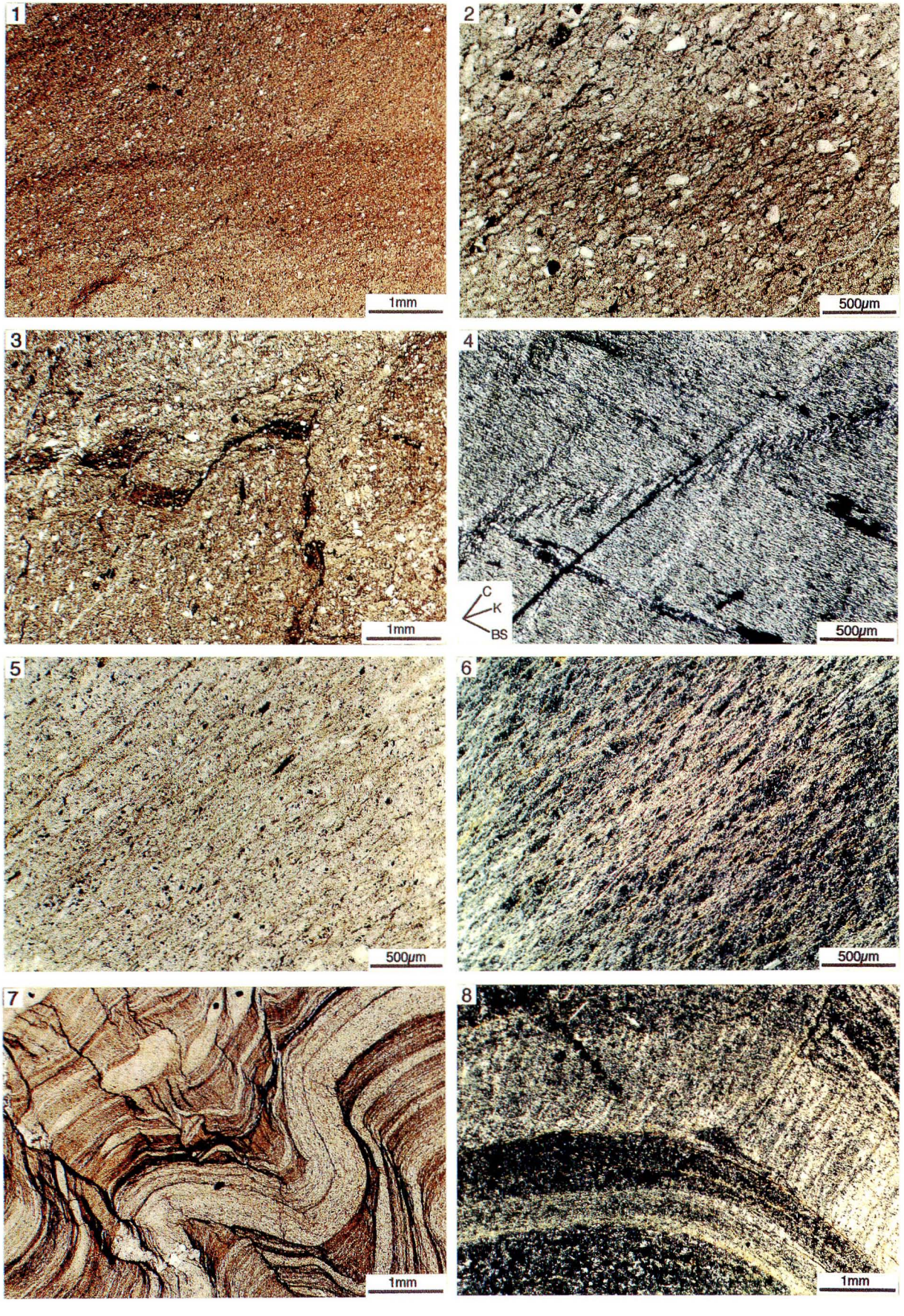
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