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Synform in the Okutokachi Metamorphic Body, Central Hokkaido

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WATANABE Yasushi and NAKAGAWA Mitsuru (1996) Synform in the Okutokachi Metamorphic Body, Central Hokkaido. *Bull. Geol. Surv. Japan*, vol. 47 (7), p. 365-375 5figs. 2tables. 3plates.

Abstract: The Okutokachi Metamorphic Body, situated in the northern part of central Hokkaido, is composed of amphibolite, pelitic schist and psammitic schist. The metamorphic body forms a N-S trending synform on a mesoscopic scale. The rocks are well foliated and lineated, with the lineations plunging steeply towards the east in the western limb and to the west on the eastern limb of the synform. A K-Ar age obtained from biotite within the psammitic schist is determined to be 18.9 ± 0.9 Ma.

Metamorphic minerals in the rocks exhibit preferred recrystallization parallel to the lineation direction. Asymmetric micro-structures such as pressure shadows around porphyroblasts and porphyroclasts, and the rotation of hornblende porphyroblasts suggest reverse shearing in both of the synform limbs. These micro-structures indicate that flexural flow was involved in the limbs of the synform, which was formed by E-W trending compression. Chemical zoning within hornblende porphyroblasts from the cores to the tails indicates an increase in metamorphic grade during the deformation. Geologic evidence indicates that the formation of the synform occurred before 19 Ma, possibly during the Early Miocene.

The existence of E-W trending folds, including the synform in the Okutokachi Metamorphic Body of central Hokkaido, may have formed during the Early Miocene. This may support a tectonic model in which central Hokkaido was formed by contraction as a result of the collision between the Eurasian and Okhotsk plates during the Miocene.

1. Introduction

Central Hokkaido is regarded as a Cenozoic convergent zone between the Eurasian and Okhotsk plates (Den and Hotta, 1973; Okada, 1982; Kimura *et al.*, 1983). Based on the discovery of N-S trending, right-lateral strike-slip shear zones in central Hokkaido (Kimura *et al.*, 1983; Jolivet and Miyashita, 1985; Watanabe and Kimura, 1987; Watanabe, 1988), the convergent mode between these two plates was interpreted to be due to either an oblique collision (Kimura *et al.*, 1983; Kimura and Tamaki, 1986), or a transform convergence (Lallemand and Jolivet, 1985; Jolivet, 1986; Maeda, 1986, 1990). The time period for the convergence between these plates in central Hokkaido is inferred to be Middle Miocene (Kimura and Tamaki, 1986), Eocene to Middle Miocene (Jolivet and Huchon, 1989) or 17-15 Ma (Maeda, 1986).

In order to clarify the mode and timing of the convergence in detail, structural and geochronological analyses of the shear zones in central Hokkaido are indispensable. In particular, the northern part of central Hokkaido is a suitable area for analysis, as there is evidence that the southern part has been re-deformed by the later collision of the frontal Kuril arc (Kimura *et al.*, 1983) since 13 Ma (Watanabe, in press). In this paper, we describe a synform within the Okutokachi Metamorphic Body in the northern part of central Hokkaido (Fig. 1), and discuss its tectonic background.

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Keywords: central Hokkaido, Early Miocene, Okutokachi Metamorphic Body, synform, structural geology

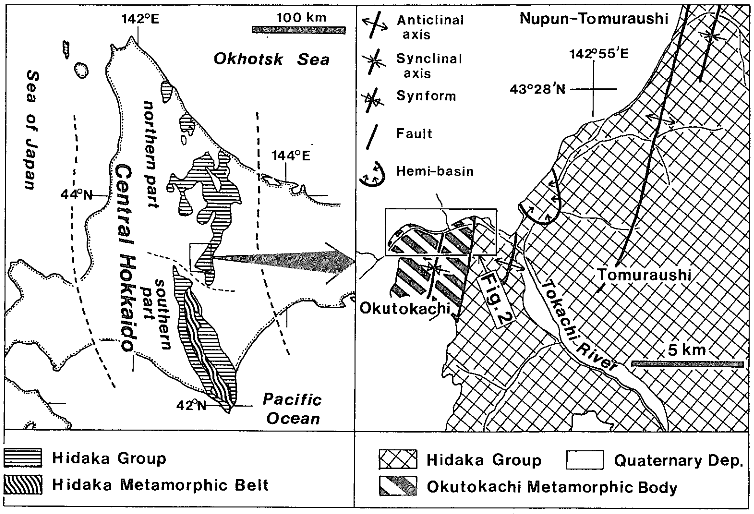

Fig. 1 Index map of the survey area. Folds and faults in the Tokachigawajoryu area are indicated.

2. Okutokachi Metamorphic Body

2.1 Geology

The Okutokachi Metamorphic Body is situated at the upstream of the Tokachi River in central Hokkaido (Fig. 1). The body was first described in the 1 : 50,000 geological sheet map for the Tokachigawajoryu area as metamorphic rocks consisting of greenschists and phyllites (Sako and Hasegawa, 1957), which are discriminated from the non- or less-metamorphosed sedimentary rocks, basalt lavas and dolerite intrusions of the Hidaka Group (Watanabe and Iwata, 1987) of Paleogene age (Kiminami *et al.*, 1990). The body is distributed in an area of 3 km by 4 km, and the eastern side of the body is delineated by a N-S trending faulted contact with the sedimentary strata of the Hidaka Group. There is a gradual change in the strike of the sedimentary strata in the Hidaka Group from ENE-WSW, to N-S through to a NE-SW trend nearest the fault (Fig. 2). This suggests that the change in strike of the sedimentary rocks is due to fault drag which includes a right-lateral strike-slip component. The western side of the synform is covered by Quaternary pyroclastic flow deposits (Fig. 2). Small isolated exposures are also found to the southwest of the metamorphic body overlain by the Quaternary pyroclastic flow deposits. All of the units within the body are well foliated and lineated. Bedding planes are generally parallel to the schistosity, which trends NNE and dips 50°-80° W in the eastern part of the body, whereas gentler dips of 20°-80° E are found in the western part. Thus, the metamorphic body forms a synform structure. Figure 2 shows a whole cross-section of the synform. Although the total thickness of the metamorphic body is unclear, a three kilometer thick section is observed on the western limb of the synform (Fig. 2).

The metamorphic body consists mainly of amphibolite, with intercalated pelitic and psammitic schists (Fig. 2). The amphibolite is originated from basaltic rocks and is composed of hornblende, epidote, chlorite, plagioclase, quartz, biotite, sphene and opaque minerals. It is characterized by the presence of porphyroclasts of plagioclase and porphyroblasts of hornblende. Meta-pelitic fragments composed of chlorite, muscovite, quartz, plagioclase and opaque minerals are also included in the amphibolite. Major constituent minerals in the pelitic schist include quartz, biotite, muscovite, sphene and opaque miner-

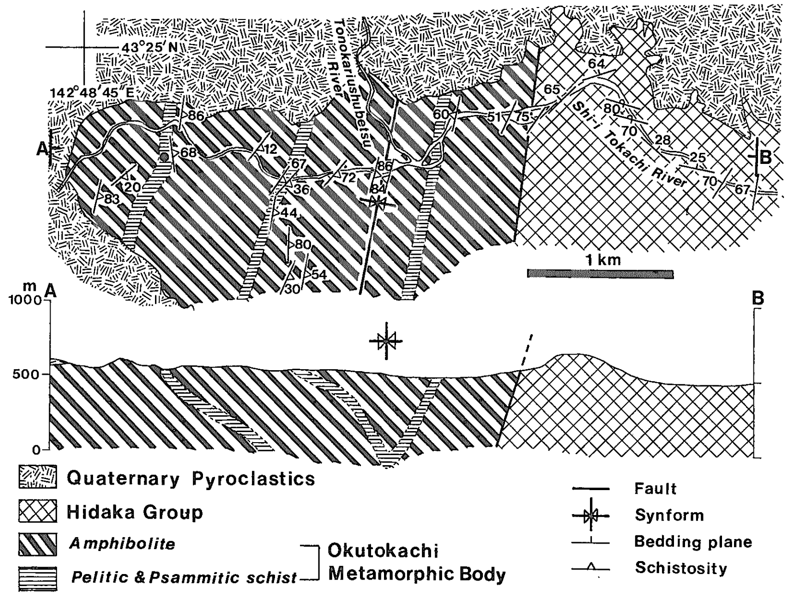

Fig. 2 Geological map and cross-section of the Okutokachi Metamorphic Body. The solid circle denotes the location of the sample used for the measurement of K-Ar age.

als. The psammitic schists consist of quartz and plagioclase grains (0.2–1 mm in size) buried by completely recrystallized matrix minerals of biotite, muscovite, quartz and chlorite. The original combination of basalt, sandstone and mudstone of the metamorphic body is similar to those of the basalt-dominated units in the Hidaka Group (Shimokawa Complex ; Tomuraushi Complex), which occupy a lower position within the group (Miyashita and Watanabe, 1988).

2.2 K-Ar age of biotite

Biotite in the psammitic schist intercalated within the amphibolite units was used in the K-Ar technique. The psammitic schist sample was collected from the western limb of the synform (43°24.6′N, 142°49.8′E ; Fig. 2), and contains plagioclase and quartz porphyroclasts within a matrix of quartz, biotite, chlorite, muscovite and albite. After crushing the sample, biotite crystals less than 0.1 mm in size were separated using a dynamic separator. Use of the X-ray diffractometer revealed that the purified sample consisted mainly of biotite, with small amounts of quartz and albite. The K-Ar measurement of the sample undertaken by Teledyne Isotopes Co. Ltd. yielded an isotopic age of 18.9±0.9 Ma (Table 1).

Table 1 K-Ar age of biotite from the psammitic schist. Constants used for the age calculation are : $\lambda_\beta=4.962\cdot10^{-10}$/y, $\lambda_e=0.581\cdot10^{-10}$/y, $^{40}K/K=1.167\cdot10^{-2}$ atm % (Steiger and Jäger, 1977).

Rock Name	Analysed material	^{40}Ar rad. ($\cdot10^{-6}$ ml / g)	Atmospheric ^{40}Ar (%)	K wt.%	Isotopic Age
Psammitic schist	Biotite (-quartz-albite)	0.157	59.4	2.09	18.9±0.9 Ma
		0.152	46.8	2.09	

3. Structure

3.1 Micro-fabrics

Lineations are common on the schistose planes in the metamorphic rocks, particularly in the amphibolite due to fibrous hornblende crystals oriented in an uniform direction at each outcrop. Fifteen sets of lineation and schistosity measurements were collected ; 12 from the western limb and 3 from the eastern limb (Fig. 3). All of the observed lineations plunge steeply to the dip direction of the

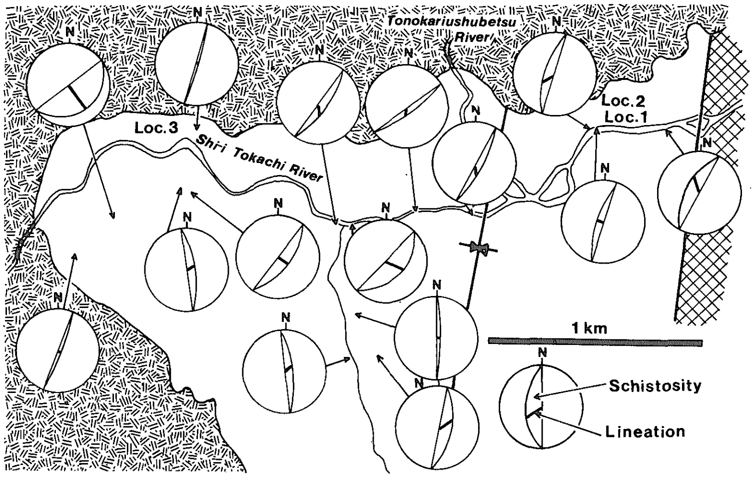

Fig. 3 Schistosity and lineation in the Okutokachi Metamorhic Body projected on to equal-area nets (lower hemisphere).

schistosity.

At several localities where structural measurements were obtained, oriented samples were collected to observe the micro-structures in sets of thin sections cut in three-dimensions, where the cutting planes (XZ, XY and YZ) are perpendicular to each other. The X axis is parallel to the lineation direction, the Z axis is perpendicular to the schistosity, and the Y axis is perpendicular to the X and Z axes.

The fibrous crystals of hornblende are approximately 0.1 mm to 0.5 mm in length along the X axis, 0.03 mm to 0.05 mm along the Y axis, and 0.01 mm to 0.03 mm along the Z axis (Plate 1). *C* axes of hornblende crystals are subparallel to the X axis. The average aspect ratio (X : Y : Z) of the hornblende is approximately 15 : 2 : 1 due to the preferred growth of hornblende along the c axes. Cleavages within the hornblende crystals are generally sub-parallel to the Z axis (Plates 1 a and b). Some hornblende crystals are pulled apart along the X axis to form splits which are infilled with matrix minerals (mainly quartz). The other metamorphic minerals such as plagioclase, quartz and opaque minerals are also elongated in crystal shape along the c axes, subparallel to the X axis (Plate 1a), and their average aspect ratio (X : Y : Z) is approximately 4 : 2 : 1. These micro-fabrics indicate that the amphibolites have been stretched along the X axis, and compressed along the Z axis, associated with preferred crystallization of hornblende and other metamorphic minerals.

3.2 Asymmetric structure

Porphyroblasts of hornblende (Plates 2 a and b), porphyroclasts of plagioclase (Plate 2 c) and meta-pelitic fragments (Plate 2 d) show an asymmetric shape in the XZ plane and accompany the pressure shadows. Porphyroblasts of hornblende frequently have asymmetric 'tails' that have continuously grown towards the pressure shadows along the Z axis (Plates 2 a and b). Cleavages within hornblende porphyroblasts which are oblique in some way to the X axis converge towards the tails (Plates 2 a and b), which is evidence for rotation of the porphyroblasts. Pressure shadows of the porphyroblasts, porphyroclasts and meta-pelitic fragments consist of hornblende, plagioclase, quartz and biotite. The meta-pelitic fragments frequently have a concave shape presented at the roots of the pressure shadows which is the result of dissolution (Plate 2 d).

It is well documented that asymmetric pressure shadows and rotation of porphyroblasts are caused by shear flow, and that the sense of shear can be determined from their shape (Simpson and Schmid, 1983 ; Lister and Snoke, 1984 ; Passchier and Simpson, 1986 ; Choukroune *et al*., 1987). The estimated sense of shear based upon the micro-structures in the

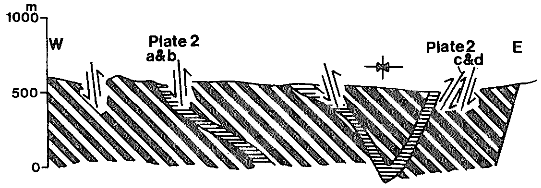

Fig. 4 The sense of shear estimated from asymmetric pressure shadows and rotation of porphyroblasts in the amphibolite. Localities of samples shown in Plate 2 are indicated.

XZ plane (Plate 2) are reverse at both the western and eastern limbs of the synform (Fig. 4). This suggests that the synform was formed by flexural flow folding (Ramsay, 1967).

4. Metamorphic conditions during deformation

The chemistry of hornblende in the amphibolites was examined in order to establish the metamorphic conditions during deformation (Table 2, Plate 3). The chemical compositions listed in Table 2 correspond to those of calcic hornblende (Leake, 1978). Plate 3 shows compositional maps for an area of 1 mm^2, which includes hornblende porphyroblasts within a fine-grained matrix of hornblende, plagioclase, quartz, sphene and opaque minerals. The chemical composition of the hornblende in the pressure shadows is very similar to that in the matrix, whereas a slight change in the chemical composition from the cores of the porphyroblasts to tails in the pressure shadows is detected, with a decrease of Si and Mg, and increase of Al, Fe, Na and Ti contents (Plate 3). The relations between cations of Ti, Na+K and X_{Mg} and Si (Fig. 5) show that the composition of the cores in the porphyroblasts correspond to actinolitic or magnesio hornblende, and that the tails in the pressure shadows and matrix correlate to magnesio hornblende, richer in the Tschermakite components. The outward increase of Ti content from the core of the hornblende, and the Tschermakite substitution suggest a low pressure-type of prograde metamorphism (increasing of temperature) occurred during the deformation.

Table 2 Representative chemical compositions of hornblende in the amphibolite obtained from electoron microprobe analyses.

	10-1	10-4	11-4
	Core	Tail	Matrix
wt.%			
SiO_2	50.11	46.49	45.22
TiO_2	0.24	0.53	0.41
Al_2O_3	6.26	8.77	9.30
Cr_2O_3	0.29	0.03	0.06
FeO*	13.74	15.53	15.75
MnO	0.48	0.40	0.50
MgO	13.50	11.72	12.24
CaO	12.21	12.01	12.63
Na_2O	0.48	0.75	0.97
K_2O	0.16	0.27	0.29
Total	97.47	96.50	97.37
Cations on basis of 23 Oxygens			
Si	7.311	6.949	6.751
Al^{IV}	0.689	1.051	1.249
Al^{VI}	0.387	0.494	0.387
Ti	0.026	0.059	0.046
Cr	0.033	0.003	0.007
Fe	1.677	1.942	1.966
Mn	0.059	0.051	0.063
Mg	2.935	2.611	2.723
Ca	1.909	1.923	2.020
Na	0.165	0.268	0.281
K	0.030	0.051	0.055

* Total iron as FeO

5. Formation of the N-S trending synform and the tectonic significance

The K-Ar age of the biotite implies that the metamorphic body cooled to the closure temperature of biotite (300°±50℃ ; Harrison *et al.*, 1979 ; Baksi and Wilson, 1980) at about 19 Ma. As the biotite is one of the major minerals in the matrix and the pressure shadows of the psammitic schist, it must have been formed and/or recrystallized during the deformation and metamorphism whose maximum temperature must have exceeded the closure temperature of biotite. Thus, the deformation must be older than the K-Ar age. However, the recrystallized metamorphic minerals in the amphibolite, pelitic schist and psammitic schist are small in size (generally less than 0.1 mm)

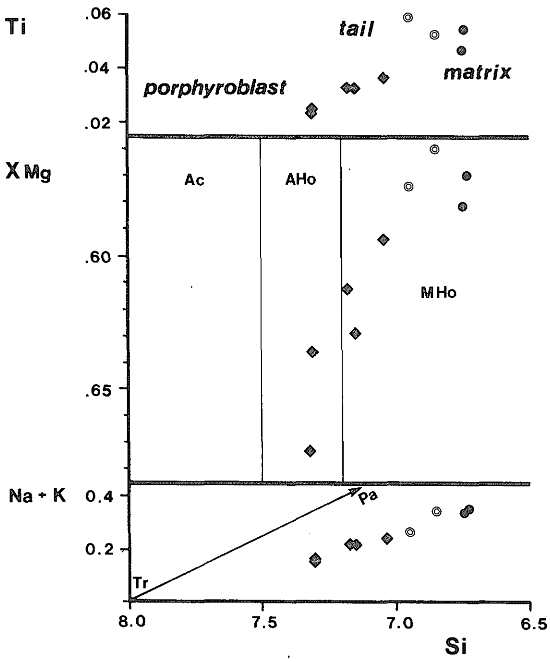

Fig. 5 Relation between Si, Ti Na+K and X_{Mg} of hornblende (Oxygen=23).
Abbreviations ; Tr : Tremolite, Pa : Pargasite, Ac : Actinolite, AHo : Actinolitic hornblende, MHo : Magnesio hornblende. Symbols ; black square : core of porphyroblast, open double circle : tail of porphyroblast in pressure shadow, black circle : matrix hornblende.

and the metamorphic mineral assemblage of the psammitic schists lacks in garnet. These facts suggest that the metamorphism occurred relatively in a short period (Miyashiro, 1965) and the maximum temperature for the metamorphism is lower than approximately 500℃ (Osanai *et al.*, 1991). No record of retrograde metamorphism suggests rapid cooling of the metamorphic body. Therefore, the metamorphic age is inferred not to be far older than the biotite age.

Maeda *et al.* (1986, 1990) compiled geochronological data for plutonic rocks in central Hokkaido and revealed that the climactic activity of felsic plutons was attained during 20–17 Ma. The Tokachigawajoryu area is situated between the plutonic rocks of this period (Pishikachinai and Sahoro Granites), which is compatible with the K–Ar age of the biotite. Thus, a concealed pluton might have been the heat source for the Early Miocene metamorphism (possibly 19–20 Ma) at this area. The prograde metamorphism (increase of temperature) during the deformation suggests the existence of such a heat source. It is likely that the folding and elevation of the Okutokachi Metamorphic Body caused by E–W compression was simultaneous with intrusion of the plutonic rocks during the Early Miocene.

Similar N–S trending mesoscopic folds are recognized in the alternating beds of illite-chlorite-bearing sandstone and mudstone of the Hidaka Group near to the Okutokachi Metamorphic Body (Fig. 1 ; Watanabe and Iwata, 1987 ; Watanabe and Miyashita, 1988). These folds accompany asymmetric micro-folds which were formed by layer-parallel slip (Watanabe and Iwata, 1987) and are classified as flexural slip folds (Ramsay, 1967). Thus, we can ascribe the difference in fold types to variations in rock ductility during the folding ; flexural flow at deeper levels associated with higher-grade metamorphism, and flexural slip at shallower levels related to lower-grade metamorphism. The distribution of such folds at intervals of several kilometers suggests that the Hidaka Group in the Tokachigawajoryu area was compressed in an E–W direction. The contraction is likely to have occurred in the Early Miocene. This folding was followed by N–S trending dextral strike-slip shear in the Tokachigawajoryu area (Watanabe and Iwata, 1987).

Jolivet and Miyashita (1985) stated that the Western Zone of the Hidaka Metamorphic Belt in the southern part of central Hokkaido was subjected to N–S trending right-lateral strike-slip deformation under retrogressive metamorphic conditions at approximately 15 to 17 Ma (Shibata *et al.*, 1984 ; Watanabe, 1990). There is also evidence that right-lateral deformation occurred in the Uenshiri Horst in the northern part of central Hokkaido at 20–24 Ma (Watanabe, 1988, 1990). The co-existence of such N–S trending right-lateral strike-slip deformation with the N–S trending folding which occurred during the Early Miocene favors the oblique collision tectonic model between the Eurasian and Okhotsk plates of Kimura *et al.* (1983), over the pure transform convergence model (Lallemand and Jolivet, 1985 ; Jolivet, 1986 ; Maeda, 1986, 1990).

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中央北海道奥十勝変成岩体中のシンフォーム

渡辺　寧・中川　充

要　旨

中央北海道北部に位置する奥十勝変成岩体は角閃岩と泥質・砂質片岩からなる．この変成岩体には南北方向のシンフォームが認められる．変成岩体を構成する岩石には片理面・リニエーションが発達し，シンフォームの西翼では東に，東翼では西にプランジしている．砂質片岩を構成する黒雲母は 18.9±0.9 Ma の K-Ar 年代を示す．

角閃岩の微細構造はシンフォームの両翼で逆断層のセンスのフレキシュラルフローを示し，このことから，このシンフォームが東西方向の圧縮により形成されたと結論される．角閃石斑状変晶の化学組成の検討から，この変形は変成度が上昇する条件下で起こったと推定される．

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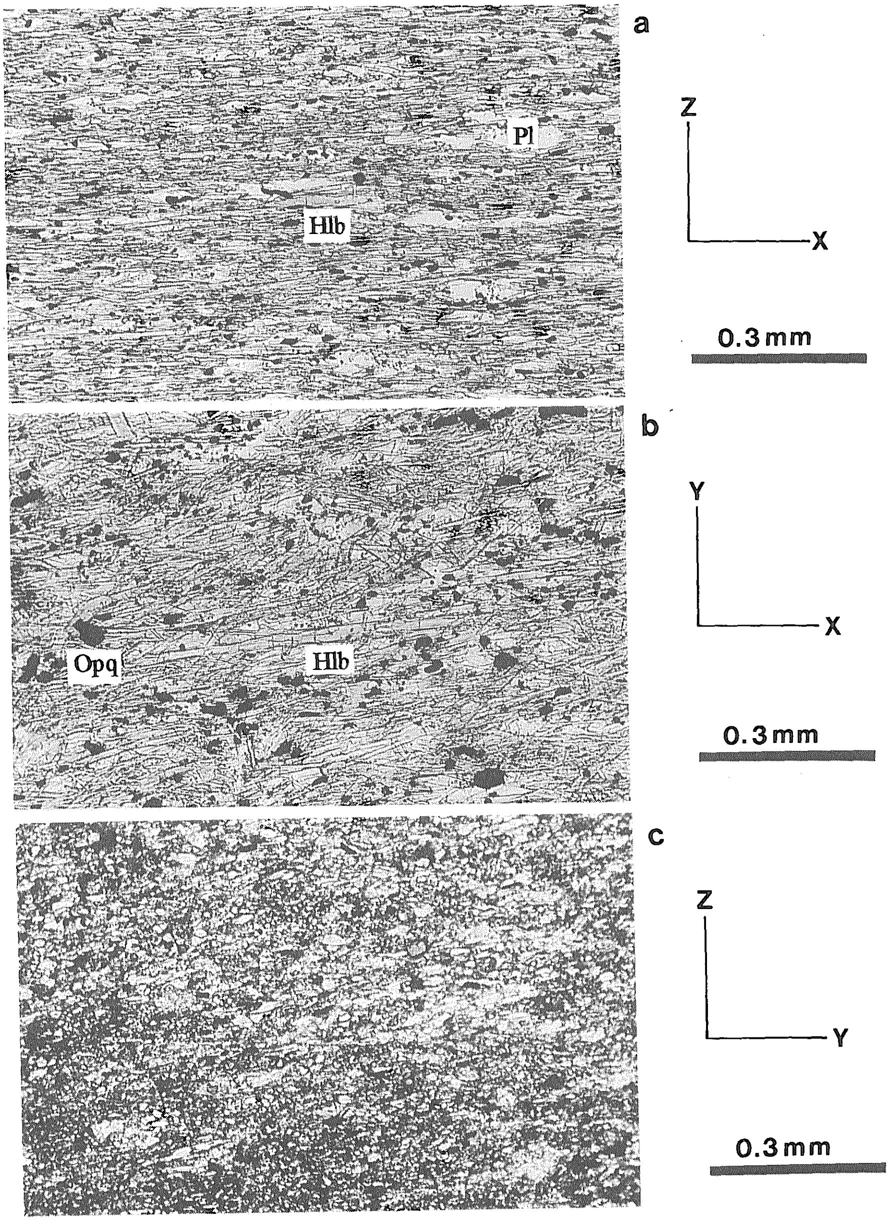

Plate 1 Photomicrographs of three dimensional thin sections of the amphibolite sampled at Loc. 1, shown in Fig. 3. Abbreviations ; Hlb : hornblende, Pl : plagioclase, Opq : opaque minerals.

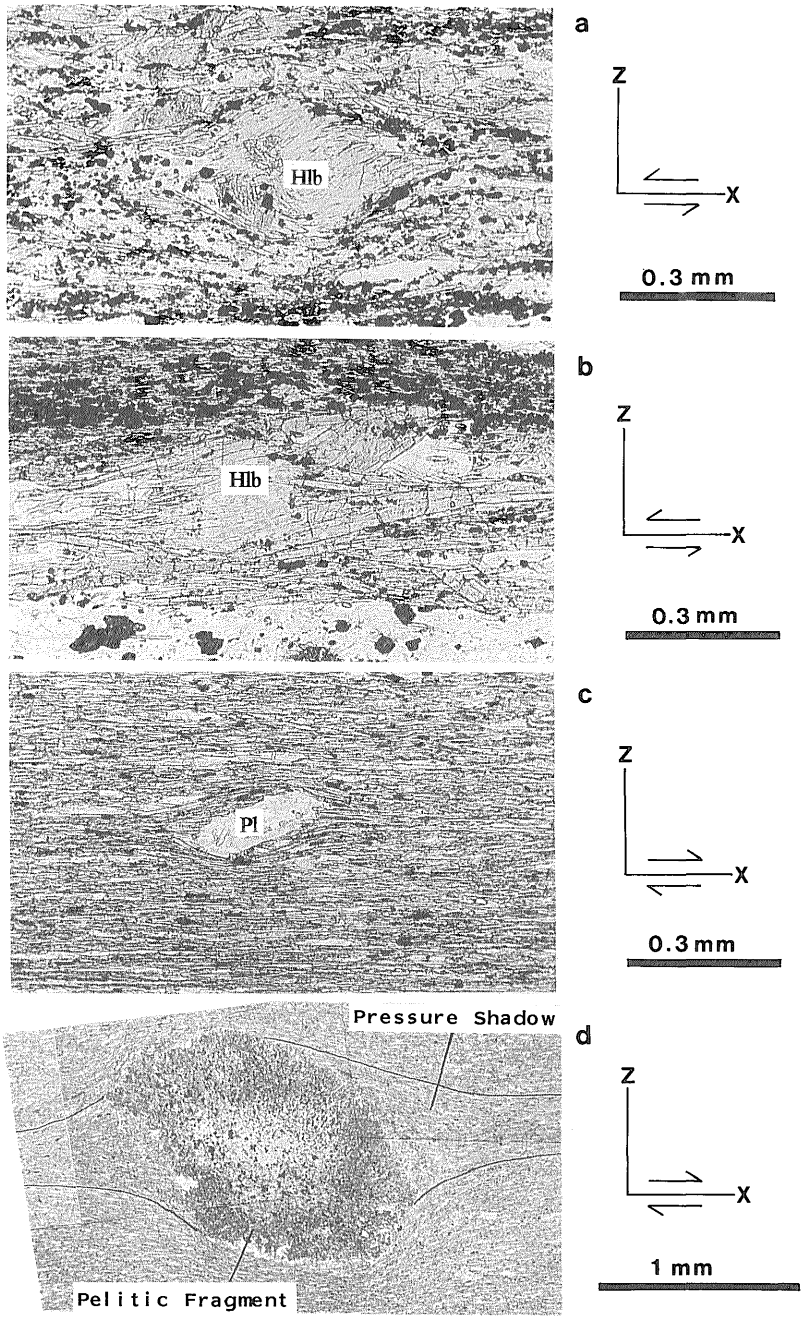

Plate 2 Photomicrographs of asymmetric of asymmetric pressure shadows on the XZ plane within the amphibolite. **a** and **b** : Porphyroblasts of hornblende (Hlb) in a matrix of hornblende, quartz, plagioclase and opaque mimerals. **c** : Porphyroclast of plagioclase (Pl) in the matrix minerals. **d** : Metamorphosed pelitic fragment consisting of chlorite, sericite, quartz and plagioclase. The pair arrows indicate the sense of shear. **a** and **b** are from Loc. 3, and **c** and **d** from Loc. 2, both shown in Fig. 3.

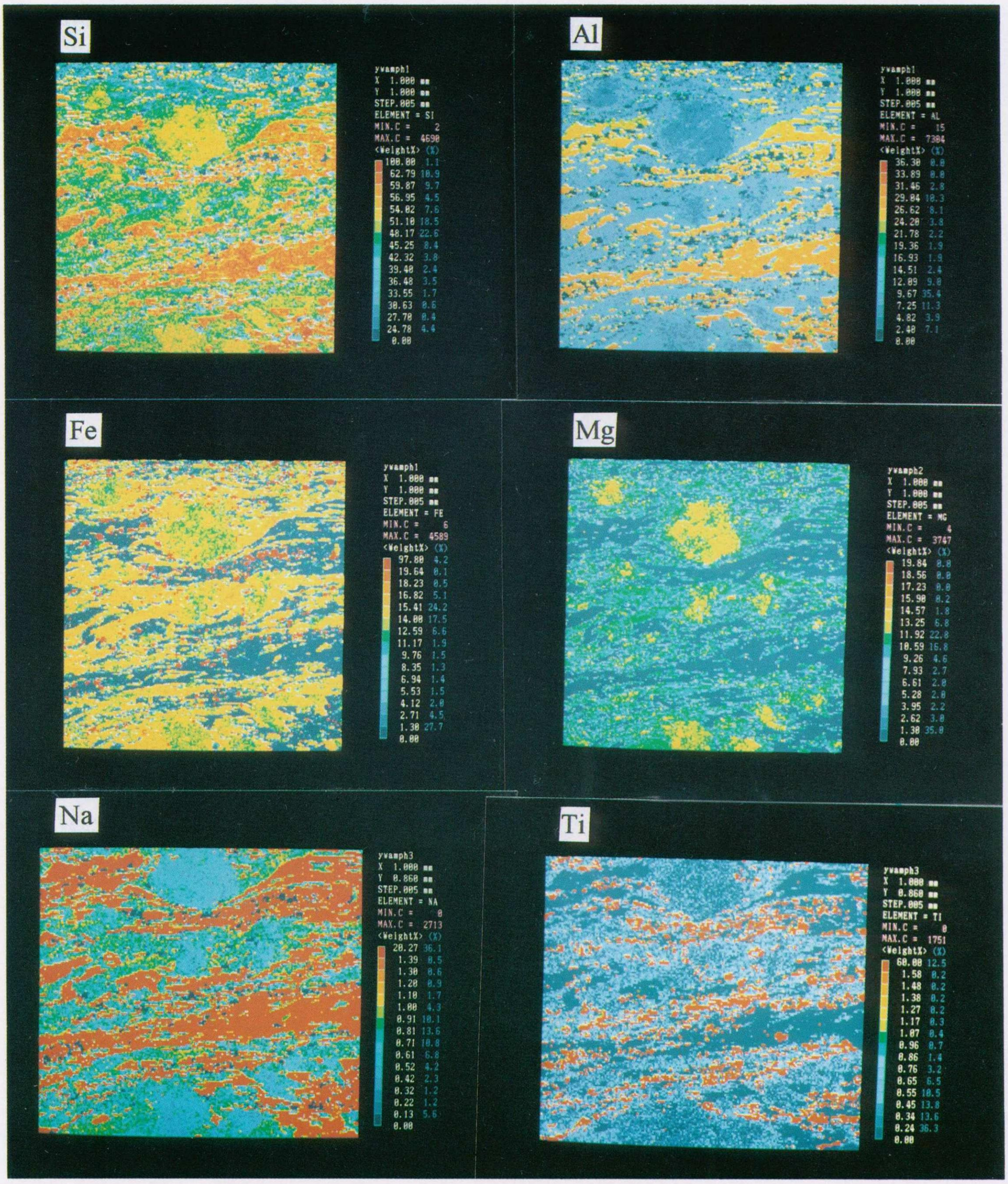

Plate 3 Chemical compositional maps for an are a of 1·1 mm from the XZ plane of the amphibolite analyzed by EPMA. The color-scale bars show the approximate weight percent for each color. Weight percent increases form dark blue to red, through light blue, green, yellow and orage. For example in the Si map, the yellow areas correspond to the cores of the hornblende porphyroblasts, the green parts to horblende in the pressure shadows and matrix, with the orage areas relating to plagioclase in the matrix (mainly albite).