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Staurolite-bearing sillimanite schist cobble from the Upper Jurassic Tetori Group in the Kuzuryu area, Hida Mountains, central Japan

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Abstract

A cobble of staurolite-bearing sillimanite schist is found from a conglomerate boulder on the Itoshiro River floor along which the middle part of the Upper Jurassic-Cretaceous Tetori Group is exposed. This is the first report of a staurolite schist cobble from the Tetori Group, and the rock assemblage of the conglomerate indicates that the staurolite schist has been exposed with quartzite, sandstone, granite, gneiss, and marble in the source area of the Tetori Group in the late Jurassic time.

The cobble is chemically different from the other staurolite-bearing rocks in the Hida Mountains in view of its extremely high Al_2O_3 (25 wt.%), low FeO* (total Fe as FeO) (1.7 wt.%) and low MgO (0.5 wt.%) contents in the bulk rock composition. The absence of cordierite and primary chlorite, and stable sillimanite-staurolite-biotite-quartz-muscovite assemblage in this high-Al metapelite indicate the condition of the upper amphibolite facies ($P<8.5$ kbar, $T<720$℃), which corresponds to the high-grade part of the Unazuki metamorphic belt rather than that of the Hida metamorphic belt.

Key words : staurolite–sillimanite schist, cobble, conglomerate, medium-P/T metamorphic rocks, Tetori Group, Hida Mountains, Fukui Prefecture

Introduction

Staurolite typically occurs in medium-P/T type (kyanite-sillimanite series) metamorphic belts, which are common among the continental collision zones. In Japan, however, the Unazuki belt in the Hida Mountains is the only regional medium-P/T type metamorphic belt (Hiroi, 1983).

The author has found a cobble of staurolite-bearing sillimanite schist from a river boulder probably derived from the Upper Jurassic Yambara conglomerate (Yamada et al., 1989), which is the lowest member of the Itoshiro Subgroup of the Tetori Group in the Kuzuryu area, Hida Mountains. The occurrence of staurolite-bearing rocks in the Hida Mountains has well been known from the Unazuki schists (the Kurobe River area and Katakai River area : Hiroi, 1983), but has also been reported from the dominantly low-P/T type Hida gneisses in the Mt. Arashimadake area, Toga area (Asami and Adachi, 1976), and Momose-Mizunashi area (Kano et al., 1994) (Fig. 1).

Recently, the provenance analysis of the Upper Jurassic-Cretaceous Tetori Group, which is widely distributed as a molasse cover on the Hida gneiss (Saida, 1987 ; Takeuchi et al., 1991), gave some useful data to interpret tectonic evolution of the Hida Mountains. Most of the clasts in the Tetori Group came from the Hida gneisses, the adjacent serpentinite melange (the Hida marginal belt) and the accretionary complex on the south (the Mino belt). The occurrence of the Triassic to early Jurassic radiolarian chert as clasts from the upper horizons of the Itoshiro Subgroup indicates that the Jurassic accretionary complex with the oceanic sediments were accreted and exhumed by the earliest Cretaceous time. However, any clast originated from the Unazuki schists has never been confirmed in the Tetori Group so far.

This report describes petrography and mineralogy of the staurolite-bearing sillimanite schist cobble, and discusses its geologic significance and provenance.

Geologic setting

The Paleozoic rocks in the Hida Mountains comprise three geologic units ; the Hida belt, the Unazuki belt, and the Hida marginal belt (Fig. 1). The Hida belt consists of the poly-metamorphosed low-P/T type orthogneiss, paragneiss, amphibolite and marble of the amphibolite to granulite facies. The Unazuki

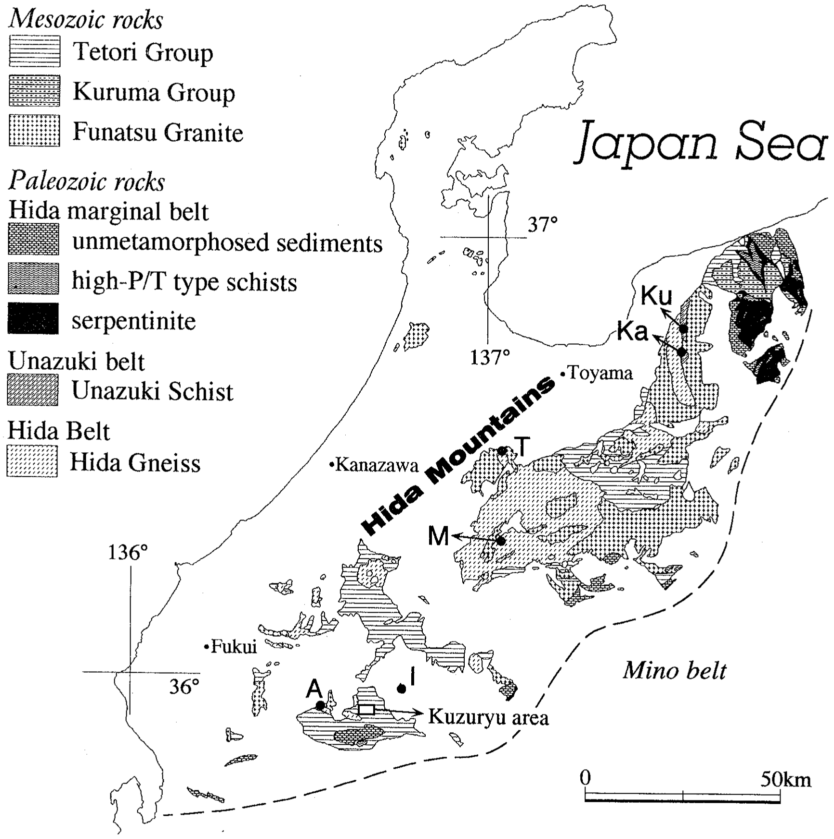

Fig. 1. Simplified geologic map of the Hida Mountains with localities of staurolite-bearing rocks (after Soma and Kunugiza, 1993). (Ka) Katakai River, (Ku) Kurobe River, (I) Itoshiro, (A) Mt. Arashimadake, (T) Toga, (M) Momose-Mizunashi.

belt consists of the medium-P/T type schists originated from the Upper Paleozoic (Carboniferous) ferro-aluminous sediments, limestone and acidic volcanics. The Upper Paleozoic limestone and chloritoid-bearing slate are unconformably overlain by the Tetori Group in the Itoshiro area (Konishi, 1954). It is interpreted as correlatives of the Unazuki schists in the eastern Hida Mountains (Hiroi, 1981). The early Jurassic Funatsu granite is intruded into both the Hida and Unazuki belts. The Hida marginal belt is characterized by the serpentinite melange with high-P/T type schists and various fragments of Paleozoic accretionary complexes (greenstones, limestones, cherts, mudstones, etc.), which are widely developed in the Inner Zone of southwestern Japan. On its east and south, the Hida marginal belt is in contact with the Mino belt, the Jurassic accretionary complex composed mainly of greenstones, radiolarian cherts, limestones, shales and sandstones of Carboniferous to late Jurassic ages.

The upper Kuzuryu River area is located in the eastern part of Fukui Prefecture, and is situated in the western Hida Mountains (Fig. 1). The geologic map of this area is shown in Fig. 2. The Tetori Group is widely exposed in this area, and is divided into the Kuzuryu (about 1.7 km thick), Itoshiro (about 1.6 km thick) and Akaiwa Subgroups in ascending order (Yamada et al., 1989). The marine Kuzuryu Subgroup is unconformably covered by the non-marine Itoshiro Subgroup, which in turn is overlain by the non-marine Akaiwa Subgroup. The olistostromal conglomerate bed called the Yambara conglomerate is situated about 1.2 kilometers above the base of the Itoshiro Subgroup, and the cobbles consist mainly of granite, rhyolite, gneiss, sandstone and shale with minor amounts of chert, high-P/T type schists and serpentinite (Soma and Kunugiza, 1993). They were probably derived from the Hida belt, Hida marginal belt, and Mino belt. Any cobble derived from the Unazuki belt has never been reported from the Tetori Group.

The staurolite-bearing sillimanite schist cobble was discovered in a float (2 m in size) of the Yambara conglomerate on the floor of the Itoshiro River at 100 meters to the downstream of the type locality of the Yambara conglomerate. Pebbles and cobbles in the conglomerate float includes quartzite (35%), granite (22.5%), gneiss (10%), sandostone (17.5%), marble (12.5 %), and schist (2.5 %) (40 samples in a 1 m^2 area were examined).

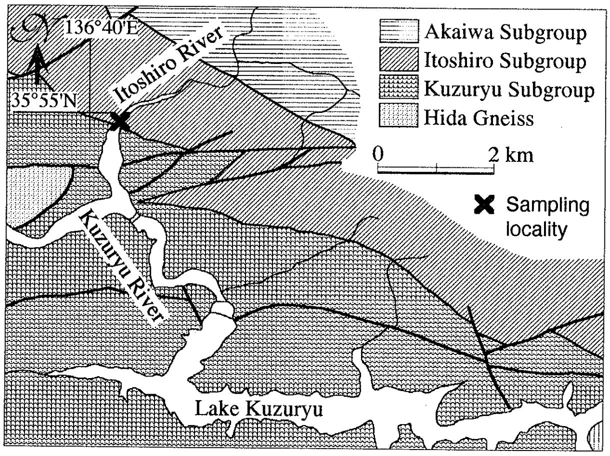

Fig. 2. Geologic map of the Kuzuryu area (after Yamada et al., 1989).

Petrography

The staurolite-bearing sillimanite schist occurs as a rounded cobble (10×5 cm) of a bluish gray, medium-grained, well-foliated rock. The schistosity is defined by the preferred orientation of sillimanite, which occurs as clusters of fibrolite. The cobble consists mainly of quartz (41%), sillimanite (34%), plagioclase (12%), staurolite (5%) and biotite (5%) with minor amounts of primary muscovite (2%), ilmenite (1%) and rutile. Quartz occurs as fine-grained anhedral crystals (<0.3 mm) in the matrix and as tiny inclusions within staurolite porphyroblasts. Plagioclase occurs as anhedral crystals (<0.8 mm) containing opaque minerals and tiny staurolite. Most staurolite forms anhedral or subhedral poikilitic porphyroblasts (0.5–1.2 mm in length and 0.3 mm in maximum width) intergrown with biotite. It contains many tiny inclusions of quartz. Staurolite is closely associated with biotite and sillimanite (Fig. 3). Biotite is often partly replaced by chlorite. The observed mineral assemblage is expressed in Thompson (1957)'s AFM diagram (Fig. 4).

Bulk rock and mineral chemistry

The bulk rock composition of the staurolite-sillimanite schist was analyzed by the Rigaku System 3270 X-ray fluorescence spectrometer at Kanazawa University, using quenched glass bead made of 0.5 g rock powder and 5 g $LiBO_4$. The result is given in Table 1 and Fig. 4. The staurolite-bearing sillimanite schist is very high in Al_2O_3 (25 wt.%) but low in K_2O (2 wt.%), total iron oxide as FeO* (2 wt.%), Na_2O (1 wt.%), CaO and MgO (<0.5 wt.%). This extremely peraluminous bulk rock composition suggests that the rock has originated in a special supracrustal sediment such as aluminous evaporite, hydrolyzate or bauxite.

Mineral analyses were carried out with an AKASHI ALPHA-30 A scanning electron microscope equipped with a Philips EDAX-9100 energy-dispersive analytical system (EDS) at Kanazawa University. Zinc content of staurolite was determined by a JOEL JXM-

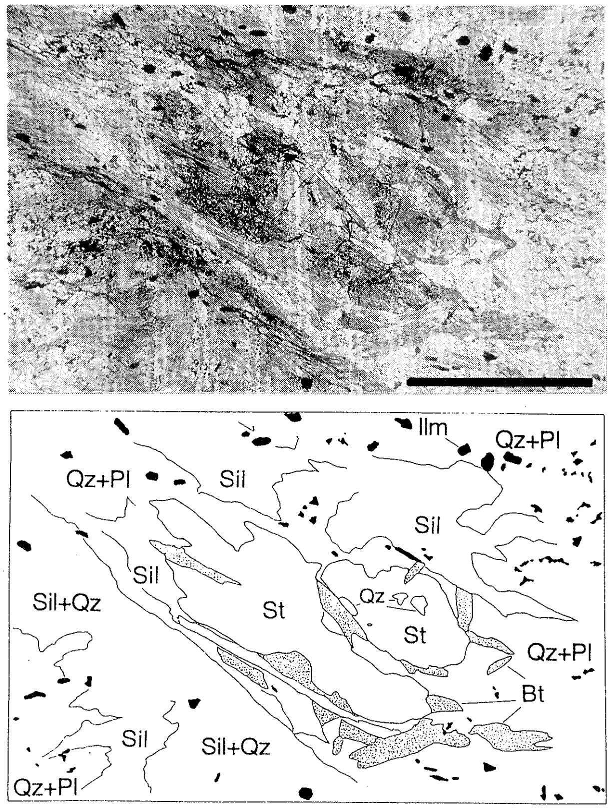

Fig. 3. Photomicrograph and its sketch of the sillimanite-staurolite schist cobble. (Sil) sillimanite, (St) staurolite, (Bt) biotite, (Qz) quartz, (Pl) plagioclase, and (Ilm) ilmenite. Plain polarized light. The scale bar is 1 mm.

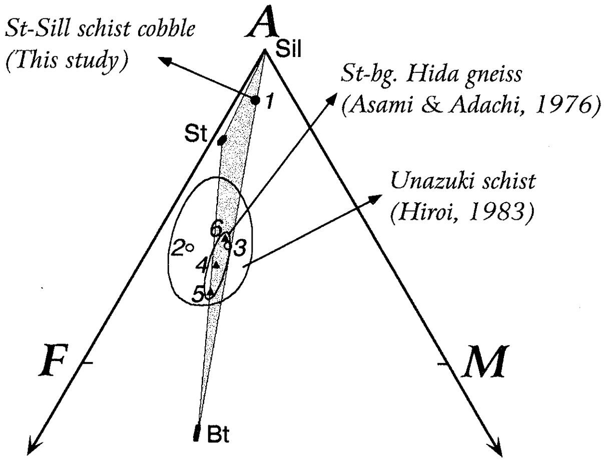

Fig. 4. AFM diagram for the bulk rock composition and coexisting minerals of the sillimanite-staurolite schist cobble. The compositional fields of the Unazuki schists and staurolite-bearing Hida gneisses are also shown. See Table 1 for numerical data.

Table 1. Bulk rock compositions of staurolite-bearing rocks from the Hida Mountains.

	Tetori Group	*Unazuki Schist*		*Hida Gneiss*		
reference	*This study*	*Hiroi (1983, 1984)*		*Asami & Adachi (1976)*		
locality	*Kuzuryu (cobble)*	*Katakai River (Zone IV)*		*Toga*		
assemblage	*1*	*2*	*3*	*4*	*5*	*6*
wt.%						
SiO_2	67.13	63.52	58.70	58.16	59.01	56.57
TiO_2	1.11	0.89	1.20	1.09	1.16	0.96
Al_2O_3	24.51	18.01	24.90	18.26	17.23	19.93
Fe_2O_3	0.42	1.48	1.86	2.10	2.06	0.94
FeO	1.27	4.47	5.59	6.31	6.20	2.83
MnO	0.02	0.14	0.09	0.26	0.23	0.06
MgO	0.46	1.66	0.87	2.08	2.06	0.98
CaO	0.39	1.46	0.04	1.82	2.29	3.22
Na_2O	1.15	1.53	0.65	2.89	3.74	5.60
K_2O	1.98	2.50	5.06	1.78	1.94	1.74
P_2O_5	0.02	0.26	0.00	0.05	0.05	0.05
Total	98.46	95.92	98.96	94.80	95.97	92.87
Mg/(Mg+Fe)*	*0.33*	*0.34*	*0.18*	*0.31*	*0.31*	*0.32*
A	*0.85*	*0.41*	*0.42*	*0.35*	*0.25*	*0.44*

$Fe^{2+}/(Fe^{2+}+Fe^{3+})=0.77$

$A=(Al_2O_3-3K_2O-Na_2O)/(Al_2O_3-3K_2O-Na_2O+FeO+MgO)$

assemblage:
1. Sil-St°-Bt-Ms-Qtz-Pl-Il-Rt
2. Sil-St*-Grt-Bt-Ms-Pl-Qtz-Il-pyrrhotite-graphite
3. Sil-St*-Grt-Bt-Ms-Pl-Qtz-Il-Rt
4. Sil-And-Crd-St**-Grt-Bt-Pl-Qtz
5. Sil-Crd-St**-Grt-Bt-Ms-Pl-Qtz
6. Sil-Crd-St**-Bt-Pl-Qtz

° occurs abundantly as porphyroblasts.
* occurs only as inclusions in garnet or plagioclase.
** occurs often as inclusions in biotite or cordierite.

8800 M electron microprobe (WDS) at Shimane University. The analyses were done at 20 kV (accelerating voltage), 1 nA on MgO (specimen current) and $<10\mu m$ (beam diameter) for the EDS, and at 15 kV, 20 nA and $10\mu m$ for the WDS. Representative chemical analyses are listed in Table 2.

Mg/(Mg+Fe) of staurolite is 0.09–0.11. ZnO content of our staurolite is about 0.6 wt.%, which is less than that of staurolite from Zone IV of the Unazuki metamorphic belt (Hiroi, 1983). Anorthite content (An) of plagioclase is about 11 mole%. Plagioclase is less calcic than that of the Unazuki staurolite schist. Mg/(Mg+Fe) of biotite is about 0.35. Muscovite is a solid-solution between muscovite and celadonite, and contains 0.9–1.2 wt.% Fe_2O_3 and 0.5–1.0 wt.% Na_2O. The Si content of the muscovite is about 6.2 p.f.u. for O=22.

Comparison with the other staurolite-bearing rocks in the Hida Mountains

The occurrence of staurolite-bearing rocks in the Hida Mountains has been reported not only from the medium-P/T type Unazuki schist but also from the dominantly low P/T type Hida gneiss as mentioned above. The bulk rock compositions of these staurolite-bearing rocks reported from the Hida Mountains are given in Table 1. The iron oxides determined by wet chemical analysis were recalculated on the basis of $Fe^{2+}/(Fe^{2+}+Fe^{3+})=0.77$ in mole, which is the average ratio of the Unazuki staurolite schist (Hiroi, 1983, 1984). Although some staurolite-bearing Unazuki schists and Hida gneisses are also high in Al_2O_3 content, they are distinctly higher in FeO* than the Kuzuryu cobble. The K_2O content of the Kuzuryu cobble is roughly equivalent to that of the staurolite-bearing Hida gneiss (Asami and Adachi, 1976).

Zone IV of the Unazuki metamorphic belt is defined by the appearance of sillimanite instead of kyanite in the metapelites (Hiroi, 1983). In this zone, staurolite (about 6%) occurs only as inclusions within garnet and plagioclase, and staurolite reacts out with muscovite and quartz to form sillimanite, garnet and biotite (Hiroi, 1980, 1983). In the staurolite-bearing Hida gneiss of the Toga area, a minor amount of staurolite (about 1%) occurs in the matrix or as inclusions in the biotite and cordierite, and staurolite reacts out with muscovite and quartz to form sillimanite, biotite and/or garnet in the rocks with higher manganese content (Asami and Adachi, 1976). However, staurolite seems to form a stable equilibrium assemblage with sillimanite and biotite in the Kuzuryu cobble. The absence of cordierite, garnet and primary chlorite, and stable sillimanite-staurolite-biotite-quartz-muscovite assemblage in the high-Al metapelite indicates the condition of the upper amphibolite facies ($P<8.5$ kbar, T

Table 2. Representative microprobe analysis of staurolite, biotite, muscovite and plagioclase in the staurolite schist cobble from the Tetori Group.

	Staurolite			*Biotite*			*Muscovite*		*Plagioclase*	
wt.%										
SiO_2	27.49	27.90	27.92	33.87	33.96		46.27	46.24	65.65	65.53
TiO_2	0.50	0.54	0.54	1.88	2.12		1.28	1.19	0.11	0.03
Al_2O_3	52.19	53.90	54.23	19.55	19.76		35.90	35.06	21.81	21.87
Cr_2O_3	n.d.	0.10	0.07	0.02	0.01		0.04	0.01	0.06	0.05
FeO*	14.24	13.51	13.38	23.55	23.88	Fe_2O_3*	1.21	1.28	0.20	0.17
MnO	0.32	0.00	0.07	0.03	0.01		0.04	0.09	0.08	0.00
MgO	0.80	0.77	0.96	7.04	7.12		0.18	0.35	0.00	0.00
CaO	n.d.	0.07	0.03	0.07	0.10		0.00	0.00	2.28	2.22
Na_2O	n.d.	0.00	0.00	0.25	0.18		0.79	1.02	10.03	10.17
K_2O	n.d.	0.04	0.00	9.08	8.63		9.07	9.11	0.07	0.05
ZnO	0.66	n.d.	n.d.							
Total	96.19	96.82	97.20	95.36	95.77		94.78	94.35	100.29	100.09
atomic ratio										
O=	*46*	*46*	*46*	*22*	*22*		*22*	*22*	*8*	*8*
Si	7.836	7.800	7.770	5.266	5.246		6.125	6.161	2.877	2.877
Ti	0.107	0.114	0.114	0.220	0.246		0.128	0.119	0.004	0.001
Al	17.535	17.756	17.783	3.583	3.597		5.600	5.505	1.126	1.131
Cr	n.d.	0.022	0.015	0.003	0.001		0.004	0.001	0.002	0.002
Fe^{2+}*	3.394	3.157	3.114	3.062	3.084	Fe^{3+}*	0.121	0.128	0.007	0.006
Mn	0.077	0.000	0.016	0.004	0.001		0.005	0.010	0.003	0.000
Mg	0.341	0.321	0.397	1.632	1.639		0.036	0.070	0.000	0.000
Ca	n.d.	0.021	0.009	0.012	0.017		0.000	0.000	0.107	0.104
Na	n.d.	0.000	0.000	0.075	0.054		0.203	0.264	0.852	0.866
K	n.d.	0.014	0.000	1.801	1.700		1.532	1.548	0.004	0.003
Zn	-	n.d.	n.d.							
Total	29.290	29.204	29.218	15.659	15.586		13.752	13.808	4.982	4.990
$Mg/(Mg+Fe^{2+})$	*0.09*	*0.09*	*0.11*	*0.35*	*0.35*				*An 11.1*	*10.7*
									Ab 88.5	*89.0*
									Or 0.4	*0.3*

** Total Fe.*

n.d.: not determined, An: anorthite, Ab: albite, Or: orthoclase.

<720℃) (Spear and Cheney, 1989) (Fig. 5). This P-T condition corresponds to that of the high-grade part of the Unazuki schist (Hiroi, 1983) rather than the Hida gneisses (Suzuki et al., 1989).

Geologic significance of the staurolite-bearing sillimanite schist cobble

It has been considered that the Unazuki belt represents a geologic unit different from the Hida belt (Suzuki et al., 1989). The fact is that the kyanite-bearing assemblage occurs only in the Unazuki belt, but has never been found from the Hida belt. However, this may be due to the absence of lower grade parts in the Hida belt. According to the model for the tectonic evolution of the Hida Mountains in the Mesozoic time by Soma and Kunugiza (1993), the Hida belt and the Mino belt represents a part of the Sino-Korean craton and an accretionary margin of the Yangtze craton, respectively, and the Unazuki belt was formed by the collision between the Yangtze and the Sino-Korean craton at about 250 Ma. The detrital chloritoid, possibly derived from the Unazuki belt, occurs in the sandstone from the late Jurassic Mino belt (Adachi, 1977). The chloritoid-bearing slate is unconformably overlain by the Tetori Group in the Itoshiro area (Konishi, 1954). Therefore, the Unazuki belt must have already been exposed to the Earth's surface by late Jurassic time, when the Hida and Unazuki belts were covered by the Tetori Group.

The bulk rock composition, mineral assemblage, texture and modal composition of the staurolite-bearing sillimanite schist cobble here studied are completely different from those observed in the Unazuki staurolite schists, and are also different from those of the staurolite-bearing Hida gneiss in the Toga and Arashimadake areas. However, this may be due to the extremely high Al_2O_3 content and very low FeO* and MgO contents in its bulk rock composition. This staurolite-sillimanite schist cobble indicates that a medium-P/T type metamorphic belt analogous to the present Unazuki metamorphic belt was exposed in the source area of the Tetori Group in the late Jurassic Hida Mountains, and the cobble may have been derived from its high-grade part.

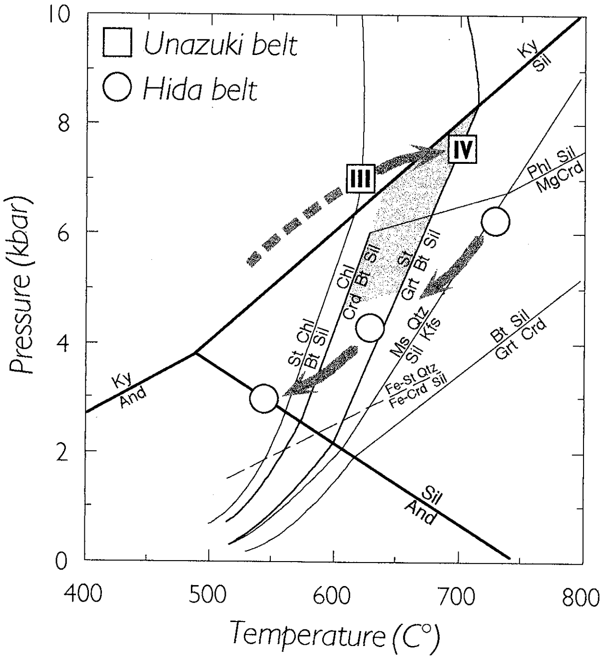

Fig. 5. Estimated P–T condition of the staurolite-bearing sillimanite schist cobble (shaded area). P–T paths of the Unazuki metamorphic belt (Zone III to IV : Hiroi, 1983) and Hida metamorphic belt (Suzuki et al., 1989) are also shown. The petrogenetic grid for the KFMASH system is from Spear and Cheney (1989). The dashed line is low-pressure limit of Fe-staurolite (after Richardson, 1968). The absence of primary chlorite defines the low-temperature limit, and the absence of cordierite in the Fe-bearing system locates an approximate low-pressure limit.

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* : in Japanese with English abstract
** : in Japanese

〈地　名〉

Akaiwa	赤岩
Arashimadake	荒島岳
Fukui	福井
Funatsu	船津
Hida	飛騨
Itoshiro	石徹白
Katakai	片貝
Kanazawa	金沢
Kurobe	黒部
Kuzuryu	九頭竜
Mino	美濃
Mizunashi	水無
Momose	百瀬
Tetori	手取
Toga	利賀
Unazuki	宇奈月
Yambara	山原

（要　旨）

Tsujimori, T., 1995, Staurolite-bearing sillimanite schist cobble from the Upper Jurassic Tetori Group in the Kuzuryu area, Hida Mountains, central Japan. *Jour. Geol. Soc. Japan,* 101, 971-977.（辻森　樹，1995，飛騨山地九頭竜地域，上部ジュラ系手取層群中の十字石-珪線石片岩礫．地質雑，**101**，971-977.）

飛騨山地，福井県九頭竜地域に分布する上部ジュラ系手取層群石徹白亜層群の礫岩転石より十字石-珪線石片岩礫を発見した．礫は極めて特異な全岩組成（$Al_2O_3 = 25$ wt.%, $FeO^* = 2$ wt.%, $MgO = 0.5$ wt.%）のために他の飛騨山地の含十字石岩とはまったく異なった鉱物組み合わせをもつ．菫青石や初成の緑泥石を欠く珪線石-十字石-黒雲母-石英-白雲母の鉱物組み合わせはアルミニウムに富み鉄やマグネシウムに乏しい泥質岩においては角閃岩相程度（$P < 8.5$ kbar, $T < 720$℃）の条件下で安定であり，そのような変成条件は飛騨変成帯の高変成度部よりむしろ宇奈月帯のIV帯に相当する．これは手取層群から十字石片岩礫の初めての報告であり，礫岩の礫組成はジュラ紀後期の手取層群の後背地に中圧型の十字石片岩がコーツァイト，砂岩，花崗岩，片麻岩，大理石とともに分布していたことを示す．