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PETROGRAPHIC STUDY ON SO-CALLED "MADARAISHI" FROM MACHIYA TOWN

– A contribution to the "Koshidai-Takaboyama-Daioh'in Structural Belt", Abukuma Plateau, Japan –

by

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(with 15 text-figures, 4 tables and 1 plate)

Abstract

The ultrabasic rocks in the vicinity of Machiya Town, Ibaragi Prefecture, Japan can be classified into two rock types; massive type and foliated type. The former is mainly composed of olivine-talc and anthophyllite, sometimes enstatite is accompanied. Some of these rocks have been noted as "Madaraishi" because of the presence of peculiar dappled texture. The latter is characterized by formation of pronounced foliated structure in which abundant tremolite and chlorite are present.

Judging from the mode of occurrence, mineral assemblage and bulk chemical composition of the preceding rocks, the massive type including "Madaraishi" is considered to be a product which might have been converted under the heating condition, perhaps related to external system. The foliated type, on the other hand, is concluded that it has undergone shearing stress, an influence of tectonic movement after the formation of the massive type.

As to the "Madaraishi", dappled texture of the rock is not considered as relict of original rock but newly formed rock facies yielded through a metamorphic process. It is conceivable that the olivine is porphyroblast being attributed to a thermo-metamorphic condition.

In this paper, the origin of the "Madaraishi" is discussed in relation to the formative process of the Koshidai-Takaboyama-Daioh'in Structural Belt.

Introduction

Sporadically scattering ultrabasic rock bodies in the Abukuma Plateau are in general strongly serpentinized and/or metamorphosed (Research Group of Peridotite Intrusion, 1967). While, petrographic description of the ultrabasic rocks on each individual mass is scant. Along the Koshidai-Takaboyama-Daioh'in Structural Belt, several ultrabasic rock bodies have been known from Koshidai Village to Hitachiohta City (Watanabe et al., 1978). One of them in the vicinity of Machiya Town, the southern extremity of the structural belt, occurs between the basement complexes (Nishidohira and Tamadare metamorphic complexes) and overlaid Hitachi metamorphic rocks. The Machiya ultrabasic rock is composed mainly of olivine porphyroblast, talc and a minor amount of tremolite widely extended. This peculiar rock has been named "Madaraishi" (Watanabe and Nemoto, 1930) because of its specific dappled texture. Further, in this rock body, anthophyllite and/or enstatite bearing rock facies and the foliated type are observed.

The present paper is aimed at petrographic description of the ultrabasic rocks in the vicinity of Machiya Town in terms of development of the Koshidai-Takaboyama-Daioh'in Structural Belt.

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General geology

The Koshidai-Takaboyama-Daioh'in Structural Belt (Watanabe et al., 1978) is one of major tectonic units in the Abukuma Plateau. Blocky uplifting mass constituted of high grade gneiss, flecky gneiss, aluminosilicate minerals bearing diaphthoritic rock and associated various ore deposits are disposed with conspicuous sheared zone along the structural belt. Moreover, many sorts of igneous activity related to the formation of tonalite, sheared granite and ultrabasics are also characteristic features of the structural belt. Some of blocky uplifting masses and associated ore deposits mentioned above have been described by many authors (Watanabe, 1971, 1974; Shimaoka and Watanabe, 1976; Watanabe and Shimaoka, 1977; Watanabe et al., 1978, 1979). According to them, the high grade metamorphic rocks and related diaphthoritic rocks found out along the structural belt running in the area of low grade metamorphic rocks (Gozaisho and/or Hitachi metamorphic rocks) are not product through a simple progressive metamorphism but by repeated and duplicated metamorphism. This process makes the mode of occurrence of the metamorphic rocks complicated. The activity of tonalitic rock being considered as final product of migmatization is probably related with the formation of the preceding peculiar rocks (Watanabe et al., 1978, 1979).

Geology of the present region, southern extremity of the structural belt described above, is composed of following four geologic units.

(1) Nishidohira and Tamadare metamorphic complexes. Both of them are regarded as uplifting blocks of the basement complex (Watanabe et al., 1978) lying beneath the Hitachi metamorphic rocks and Palaeozoic formations, the Nishidohira metamorphic complex consists of banded biotite gneiss, biotite schist and aluminosilicate minerals bearing biotite schist, and the Tamadare metamorphic complex of amphibole gneiss and schist.

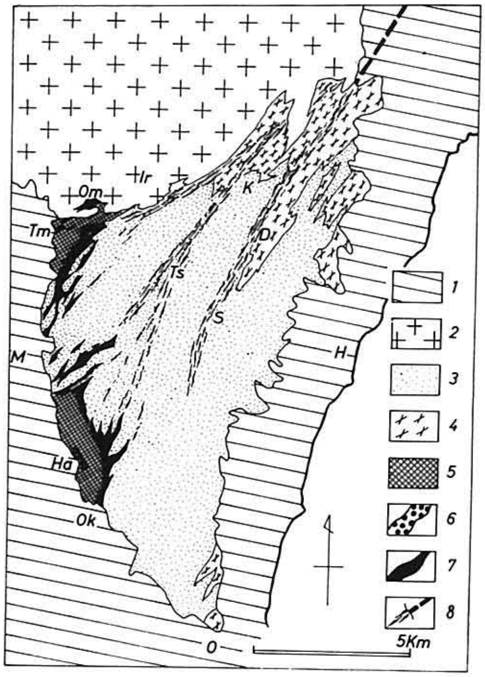
(2) Hitachi metamorphic rocks. They have a NE-SW trend and vertical dip in general, and are predominated by schistose green rock and leptite. In addition, some of these rocks might have been subjected to conspicuous alteration associated with cupriferous sulphide ore mineralization of the Hitachi mine (Watanabe, 1974).

(3) Intrusive rocks. (a) Sheared granite, meta-granophyre, meta-trondhjemite and meta-microdiorite: Sheared granite which is one of the most conspicuous igneous rocks in the structural belt and intruded into the Hitachi metamorphic rocks. For the rest penetrated into the same rocks as very small rock bodies. All of the igneous activity here in the area are probably related to the formation of the structural belt. (b) Irishiken granodiorite: This occurs in the northern part of this area and the Rb-Sr whole rock age of the rock has been believed to be about 158 m.y. (Maruyama, 1979).

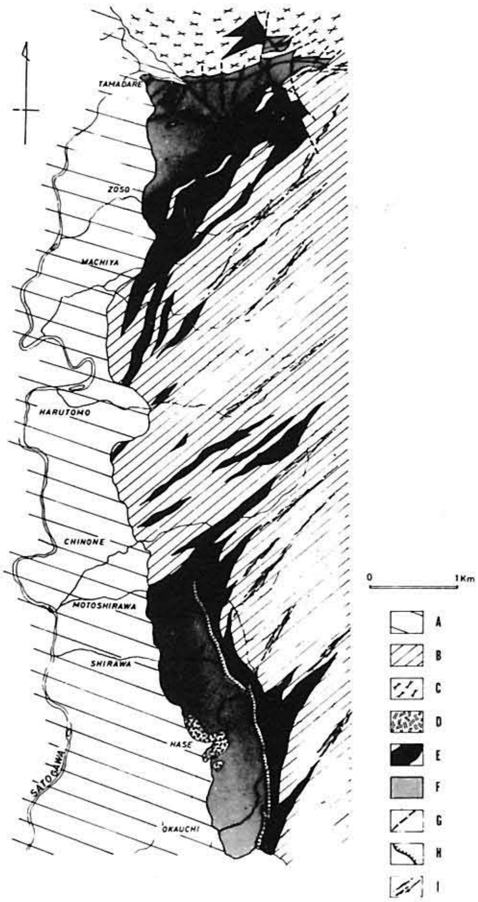
(4) Sedimentary rocks of Tertiary age. These are made up of sandstone and mudstone that overlies directly preceding (1) – (3) groups.

The ultrabasic rocks are exposed between preceding (1) and (2) groups in échelon at the area from Okauchi to Tamadare, and elongated with NE-SW trend which is harmonizing to one of the Hitachi metamorphic rocks and the structural belt. In the Irishiken granodiorite, however, ultrabasic rocks are found out as xenoblocks and xenoliths.

The geological maps illustrating these tectonic units and implication of ultrabasic rocks are given in Text-figs. 1 and 2.



Text-fig. 1 (Left) Geological map showing distribution of the Koshidai-Takaboyama-Daioh'in Structural Belt in the Hitachi district.
1: Tertiary 2: Irishiken granodiorite 3: Hitachi metamorphics and Palaeozoic formations 4: Daioh'in type sheared granite 5: basement complexes (Nishidohira and Tamadare metamorphics) 6: cortlandite 7: ultrabasic rocks 8: sheared zone (southern extremity of the Koshidai-Takaboyama-Daioh'in Structural Belt)
D: Daiyuin H: Hitachi Ha: Hase Ir: Irishiken K: Kamine-san M: Machiya O: Ohmika Ok: Okauchi Om: Ohmuro-yama S: Suwa-mine Tm: Tamadare Ts: Takasuzu-yama



Text-fig. 2 (Right) Map showing the distribution of the ultrabasic rocks in the western Hitachi area.
A: Tertiary B: Hitachi metamorphic rocks C: Irishiken granodiorite D: cortlandite E: ultrabasic rocks F: basement complexes (Nishidohira and Tamadare metamorphics) G: fault H: thrust I: sheared zone

Description of the ultrabasic rocks

Classification of the rock type

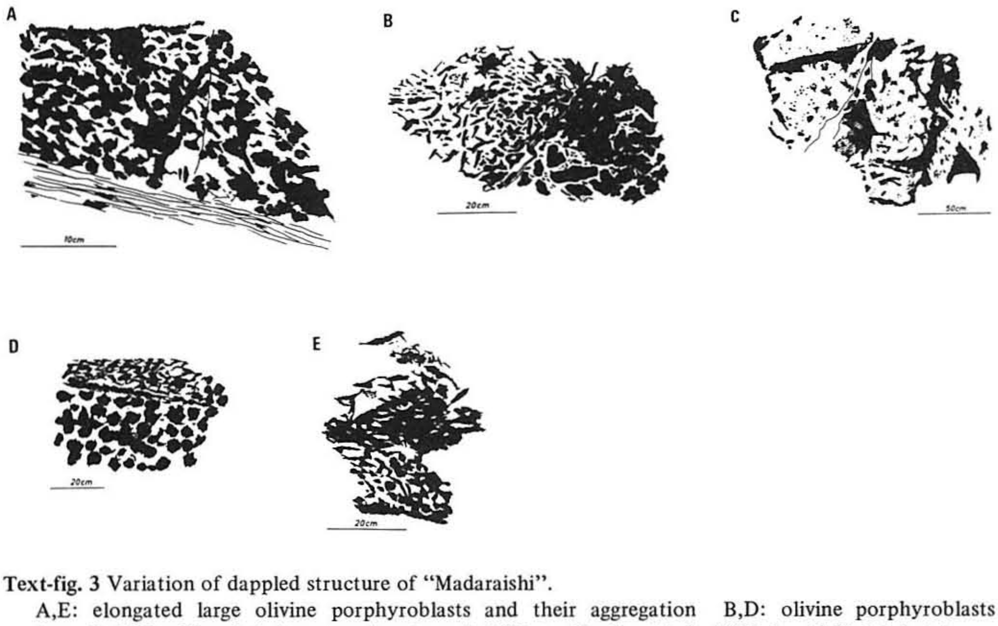
The ultrabasic rocks in the vicinity of Machiya Town can be classified into two rock types based upon the field evidences observed by present author.

Massive type

This type of ultrabasic rocks exhibits irregularly mixtured parts of dark and pale grey in colour, occasionally with greenish tint. In this type of rocks, schistosity or gneissosity caused by parallel arrangement of minerals lacks, and traces of joint system slightly remain. This type of rock is represented by "Madaraishi" which shows various kinds of structure made up of white part mainly consisting of talc with small amounts of tremolite and black part consisting of olivine replaced by veined serpentine in which magnetite dust is attendant. Besides, the massive type is characterized by the presence of anthophyllite and enstatite.

A peculiar structure being full of variety in "Madaraishi" (Text-fig. 3) is owing to diverse texture, size and habit of olivine grains, i.e. these are porphyroblastic tabular, slender prismatic, needle crystals, and aggregation of the preceding olivines makes full of variety. Besides, the relative change of modal composition of talc and other minerals is also important factor of the diverse structure in "Madaraishi". In the massive type, the term "Madaraishi" is restricted by used for the rock facies which shows dappled structure consisting of talc and olivine porphyroblasts. Therefore, massive dark greenish rock which is rich in tremolite or anthophyllite does not belong to the "Madaraishi".

Mineral assemblages of the massive type are summarized in Table 1. Among these, olivine-talc rock facies (typical "Madaraishi") being on occasion accompanied by tremolite and chlorite is the most abundant. In this rock facies, olivine (including serpentine and



Text-fig. 3 Variation of dappled structure of "Madaraishi".
A,E: elongated large olivine porphyroblasts and their aggregation B,D: olivine porphyroblasts (so-called "Sasa") and their aggregation (so-called "Botan") C: a kind of "Madaraishi" rich in talc
Black area: olivine porphyroblasts veined by serpentinization with separation of magnetite dust, White area: talc and small amounts of tremolite

Table 1 Classification of the ultrabasic rocks from Machiya Town and mineral assemblages of the classified rock types

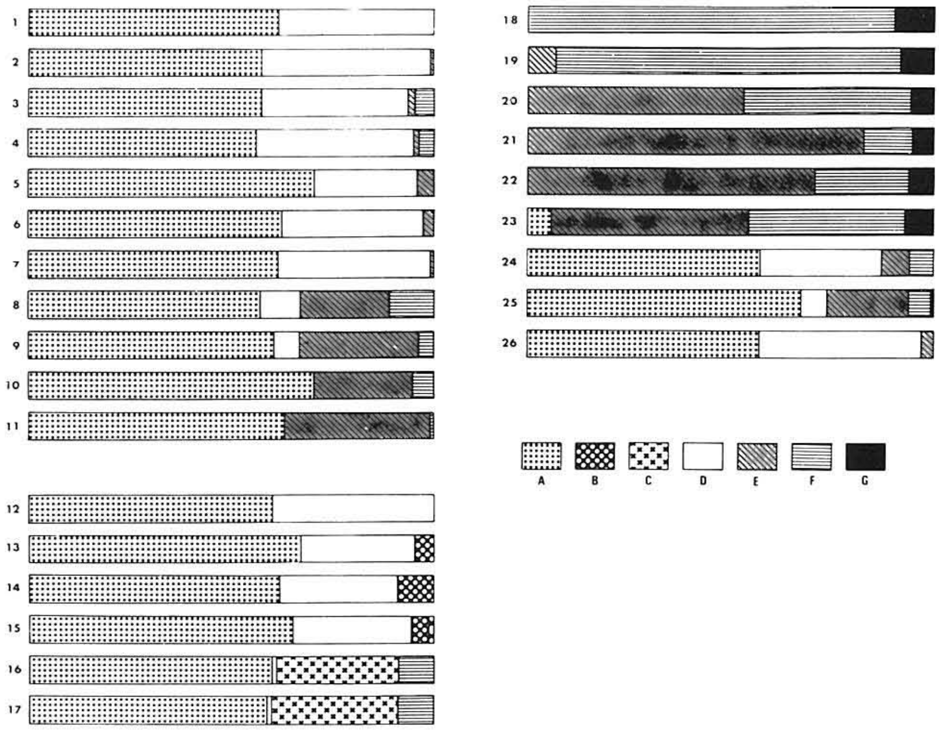
Massive type

olivine*-enstatite-talc	olivine*-talc
olivine*-enstatite-talc-anthophyllte*	olivine*-talc-tremolite*
olivine*-anthophyllite*-chlorite	olvine*-talc-tremolite*-chlorite
olivine*-anthophyllite*-chlorite-talc	olivine*-tremolite*-chlorite

Foliated type

olivine*-tremolite-chlorite-magnetite	chlorite-magnetite
tremolite-chlorite-magnetite	chlorite-magnetite-cummingtonite-garnet-spinel

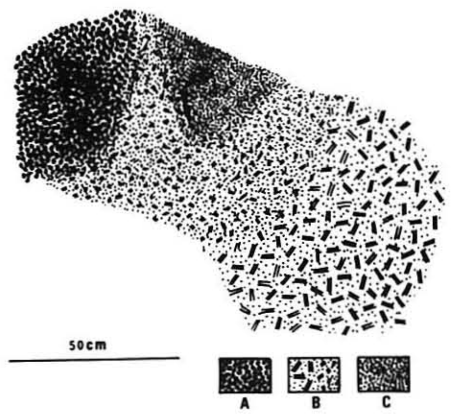
* Serpentinized by lizardite and/or chrysotile.
Serpentine minerals are excluded from the list.



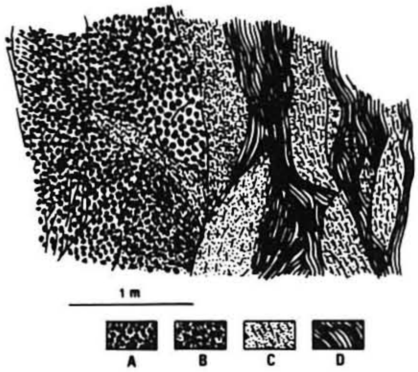
Text-fig. 4 Modal compositions of ultrabasic rocks form near Machiya Town.
1-7: massive type ("Madaraishi") 8-11: massive type rich in tremolite 12: massive type ("Madaraishi") 13-17: massive type (anthophyllite and/or enstatite bearing rock facies) 18-23: foliated type 24-26: massive type 12-17: collected form the outcrop shown in Text-fig. 5 18-26: collected from the outcrop shown in Text-fig. 6
A: olivine (volume of serpentine and magnetite dust after olivine are included in olivine) B: enstatite C: anthophyllite D: talc E: tremolite F: chlorite G: magnetite

magnetite dust after olivine) is in many cases 55–70% and talc is approximately 25–30% in modal composition (Text-fig. 4). Presence of tremolite in the massive type makes the colour of the rock dark green. This change is believed to be caused by increase of tremolite and decrease of talc. In such case, a small amount of chlorite is generally observable. On the other hand, anthophyllite bearing rock facies in the massive type is conspicuous by the greyish green colour and the scattering of large needles of anthophyllite several centimeters long. Enstatite bearing rock facies is characterized by appearance of enstatite associated with rim of talc. Above-stated two rock facies are intergradient one another. The facies change from the anthophyllite bearing rock facies towards the enstatite bearing rock facies makes the rock more fine-grained. On this process, the ratio of anthophyllite/enstatite decreases and chlorite becomes to be disappeared. It is noteworthy that the distribution of anthophyllite or enstatite bearing rock facies is confined to a limited area.

Though all rock facies of the massive type described above are intergradient to each other, the manner of appearance of each rock facies are irregular (Text-fig. 5).



Text-fig. 5 Sketch of an outcrop showing rock facies of massive type.
A: olivine-talc rock facies ("Madaraishi") B: anthophyllite bearing rock facies C: enstatite bearing rock facies



Text-fig. 6 Sketch showing the relation between the massive and foliated types of ultrabasic rocks.
A: massive type (olivine-talc-tremolite rock facies) B: foliated type (olivine-tremolite-chlorite-magnetite rock facies) C: foliated type (tremolite-chlorite-magnetite rock facies) D: foliated type (chlorite-magnetite rock facies)

Foliated type

This type of rock is found in the margin of the ultrabasic rock bodies, in other words, this appears at the contact zone between the massive type and the Hitachi metamorphics or meta-igneous rocks. Besides, this type of rock is frequently observed as small blocks in the massive type. The foliated rock type might have been caused by shearing. The foliation of these rocks shows a NE-SW trend and vertical dip that in parallel with general trend of the

Hitachi metamorphics and of the Koshidai-Takaboyama-Daioh'in Structural Belt in the Hitachi district.

This type of rock is presumed to be derived from the massive type and is characterized by the presence of chlorite. This mineral makes the rock dark green and intensely foliated.

Mineral assemblages of the foliated rock type are showen in Table 1. Among these, tremolite-chlorite-magnetite and chlorite-magnetite assosiations are common. Cummingtonite, garnet and spinel bearing rock facies is rather rare. Olivine or talc bearing rock facies is found at the boundary between typical "Madaraishi" and tremolite-chlorite-magnetite rock facies or chlorite-magnetite rock facies (Text-fig. 6).

A modal composition of this type, compared with one of the massive type, is characterized by enrichment of tremolite, chlorite and idiomorphic magnetite (Text-fig. 4). It is noteworthy that idiomorphic magnetite is present not only in the foliated type in question but spreads over in the Hitachi metamorphics and meta-igneous rocks which contact with the foliated type of the ultrabasic rock.

In the mapped area, small scale talc deposits are found along the boundary between ultrabasic rocks and microdiorite. Some of these talc deposits have been exploited.

Minerals

Description on constituent minerals of the ultrabasic rocks is given as follows.

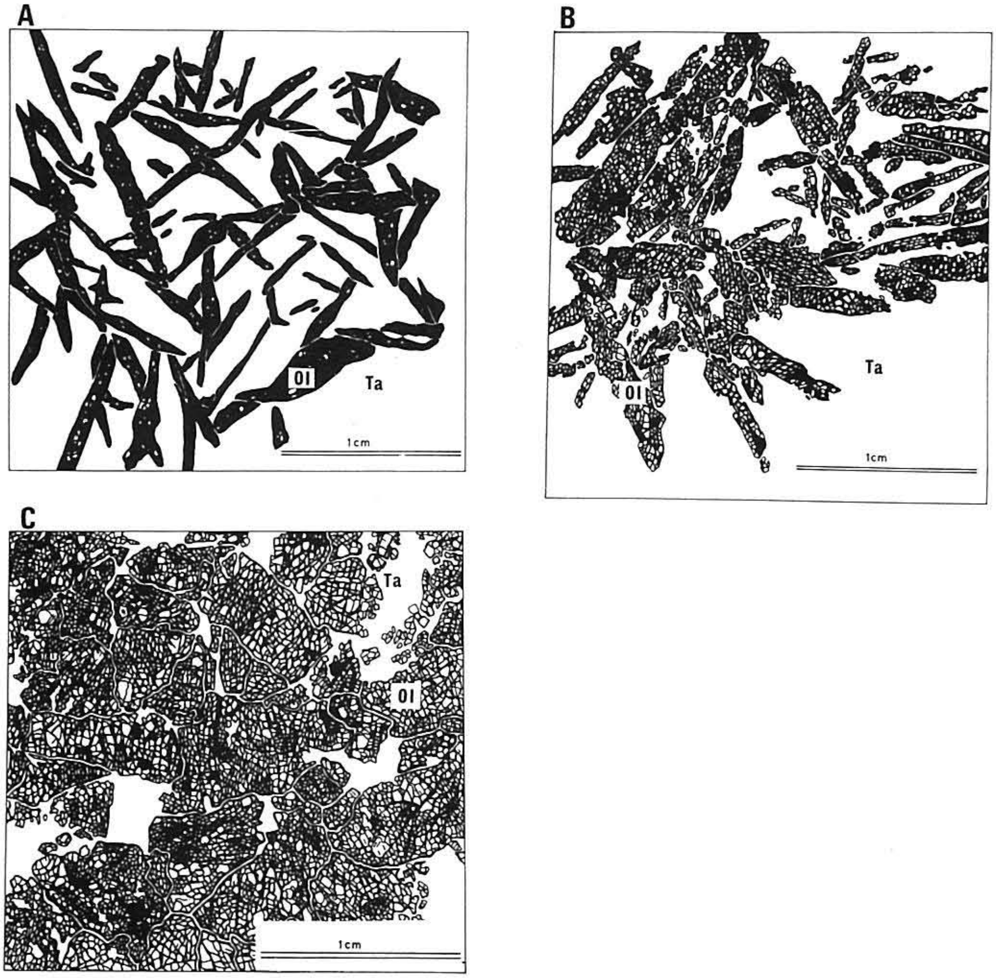
Olivine porphyroblast

In both massive and foliated types, olivine partly replaced by serpentine with separation of magnetite dust shows typical mesh-texture. The degree of serpentinization are variable from 100% to 10%, but the outline and shape of olivine are recognized perfectly by the domain (Text-fig. 7) denoting with same extinction angle under microscope. Olivine grains are mostly idiomorphic tabular-, platy- and needle-shaped crystals and are variable in size ranging from 0.5 mm to 5 cm. Especially, needle-shaped olivine is extremely elongated to (010)-and/or (001)-axes without preferred orientation (Text-fig. 8). Tabular-, and platy-shaped olivine are flat in parallel to [100] and [010]. The characteristic habits of olivine crystals taking two-dimensional elongation seem to have been produced during the formative process of porphyroblasts through a metamorphic condition. Such a feature of olivine described above have been already reported from Alpe di Mea, Switzerland by Evans and Trommsdorff (1974) and from Higo metamorphic belt by Mizuta (1978). While, neither skeletal nor feathery texture and quenched crystal of olivine which forms komatiite and spinifex bearing rock is observed in the "Madaraishi" in question.

Forsterite molecular percent was determined by X-ray diffraction method. The results obtained are plotted in Text-fig. 9.

Talc

Talc is the most abundant mineral as much as olivine in the massive type, and it shows, in general, fine-grained interstitial flake and fills the gap of olivine grains. It is considered that the talc is not originated from the minerals such as olivine, tremolite and anthophyllite



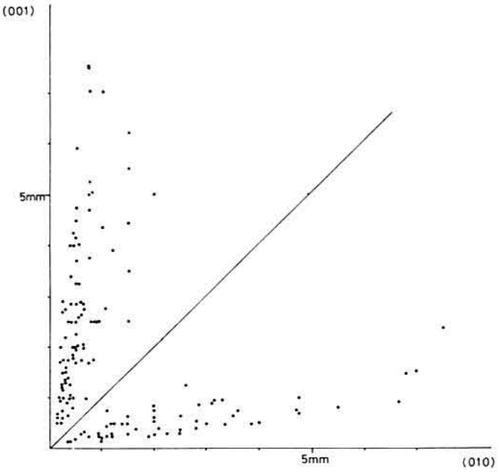
Text-fig. 7 Manner of olivine porphyroblast from the massive type (typical "Madaraishi").
A,B: elongated olivine porphyroblast with serpentinization C: typical mesh-texture in olivine aggregation Ol: olivine Ta: talc

because of the textural evidence of the massive type.

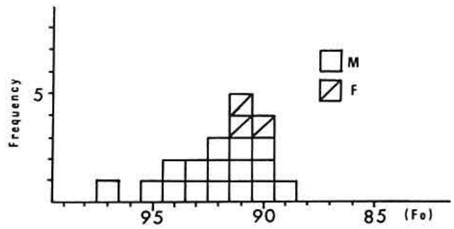
Coexistence of olivine, tremolite, anthophyllite and talc descrived above has been recognized as a typical mineral assemblages indicating the contact or regional metamorphism of ultrabasic rock (Evans and Trommsdorff, 1970, 1974; Trommsdorff and Evans, 1972; Springer, 1974; Frost, 1975; Arai, 1975; Vance and Dungan, 1977). Exceptionally, talc exists to form a rim of enstatite in some of the massive type.

Tremolite

Tremolite is observed in both massive and foliated types, but some distinct differences between tremolite from massive type and that from foliated type exhibit in mode of



Text-fig. 8 Distribution of elongated olivine porphyroblast in terms of the variation of crystal size in (001)-axis versus (010)-axis.



Text-fig. 9 Frequency distribution of forsterite content in olivine.
M: olivine from the massive type F: olivine from the foliated type

occurrence, habit and in some optical properties. In the massive type, needle- and radiated-crystals are general, while, in the foliated type, prismatic one which shows occasionally preferred orientation in strongly foliated part is common. In the former, tremolite has undergone serpentinization, whereas, in the latter, no symptom of serpentinization is observed in it. This fact indicates that the formation of preceding two kinds of tremolite is not contemporaneous. Consequently, two formative stages for tremolite are tentatively distinguishable, i.e. one is the stage related to the formation of olivine and talc, the other is the stage related to the formation of foliated type associated with large amounts of chlorite. Regarding grain size and optical properties, tremolite in the massive type is medium- to coarse-grained and $2Vx = 70^\circ-95^\circ$, $c\hat{}z = 17^\circ-28^\circ$. On the contrary, in the foliated type, the tremolite is fine- to medium-grained and $2Vx = 75^\circ-85^\circ$, $c\hat{}z = 15^\circ-24^\circ$.

Anthophyllite

Anthophyllite is present in greyish green rock that shifts to olivine-enstatite-talc rock facies. Large visible needle-shaped crystal is one of the characteristics of this minerals and radial aggregation is prevailing in the mineral. 2Vx of which is $65^\circ-85^\circ$.

Enstatite

Enstatite rarely occurs in olivine-enstatite-talc rock facies but serpentinization is unobserved. Neither exsolution lamellae nor zoning are found. 2Vz of the enstatite is $67^\circ-88^\circ$.

Serpentine minerals

In most cases, serpentine minerals replace olivine, tremolite and anthophyllite.

Serpentine is classified into two species. One is fine prismatic grain which appears showing typical mesh-texture, and the other is fibrous or tubular grain and shows vein-texture. Judging from the difference of texture as mentioned above, X-ray diffraction analysis and of electron microscopic data, the former is clearly identified to lizardite and the latter chrysotile. It is noteworthy that antigorite has not been found in this ultrabasic rock body. In these, serpentine replaced olivine includes a large amount of magnetite dust but those replaced tremolite or anthophyllite are scant in the dust. These serpentine minerals are frequently replaced by chlorite, especially at the boundary between massive and foliated types.

Chlorite

Generally, chlorite is more abundant in foliated type as compared with the massive type (Text-fig. 4). In the massive type, chlorite is fine-grained and unnoticeable. In the tranditional part between massive and foliated types, chlorite has replaced serpentine minerals after olivine or tremolite. While, in the foliated type, fine-grained chlorites show decussate texture recognized with weak preferred orientation. The chemical composition of typical chlorite from the foliated type is given in Table. 2. From the chemical formula, this mineral can be corresponded to a kind of clinochlore rich in MgO.

SiO_2	31.02	Si	5.897
TiO_2	0.14	Al^{IV}	2.103
Al_2O_3	16.80	Al^{VI}	1.661
Fe_2O_3	1.63	Ti	0.021
FeO	2.97	Fe^{3+}	0.233
MnO	0.05	Fe^{2+}	0.472
MgO	33.82	Mn	0.008
CaO	0.00	Mg	9.585
Na_2O	0.17	Na	0.062
K_2O	0.00		
H_2O^+	12.74	OH	16.149
H_2O^-	0.28	Number of ions on the basis of 36 (O, OH)	
P_2O_5	n.d.		
	Total 99.62		

(Analyst H. Shimaoka)

Table 2 Chemical composition and chemical formula of chlorite from the foliated type of the ultrabasic rock.

Magnetite

Magnetite is classified into two types based upon the mode of occurrence. One is fine dust that might have been separated form olivine through the serpentinization of the massive type, the other shows well developed octahedral that considered to be a product through the recrystallization to form the foliated type. It is true that the magnetite dust is scant in the foliated type and idiomorphic one is rarely found in the massive type. The octahedral crystal of magnetite found in the foliated type is also present in the Hitachi metamorphics and in meta-igneous rocks which contact with the foliated type. However, octahedral magnetite mentioned above is unobservable in the basement complexes which contact with the foliated type of ultrabasic rock.

Chemical composition

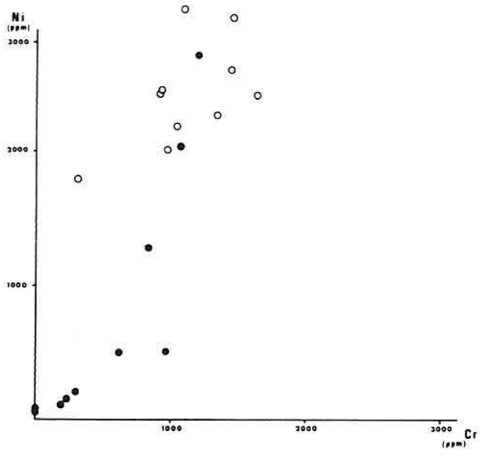
The bulk chemical compositions of the ultrabasic rocks in the vicinity of Machiya Town were examined by gravimetry method for SiO_2, Al_2O_3, CaO and MgO. Colourimetric analysis was used for TiO_2 and P_2O_5, volumetry method for Fe_2O_3, atomic absorption method for MnO, NiO and Cr_2O_3, and flamephotometry method for Na_2O and K_2O. FeO was determined by conventional method. For some samples, chelatemetry method was simultaneously applied to determine Al_2O_3, Fe_2O_3, CaO and MgO. Further, partial analysis was carried out to determine NiO and Cr_2O_3. The results obtained are given in Table 3.

Table 3 Chemical compositions of the ultrabasic rocks and "Madaraishi" from the vicinity of Machiya Town, Ibaragi Prefecture.

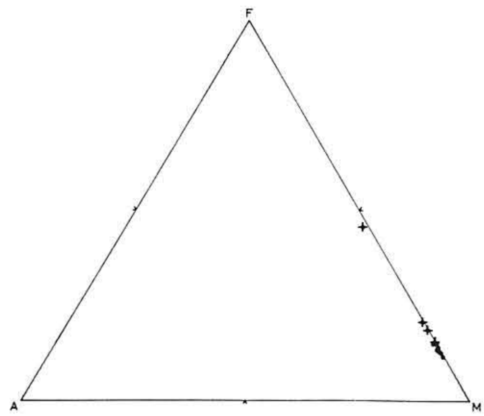
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	42.92	41.06	41.88	43.33	40.97	40.64	45.65	45.96	43.70	30.74	30.41	23.90
TiO_2	.00	.00	.12	.07	.13	.00	.13	.10	.09	.45	.19	.63
Al_2O_3	1.83	.55	1.02	1.83	.61	.72	2.05	5.08	3.66	15.07	16.15	22.68
Fe_2O_3	4.89	4.36	2.71	5.37	4.87	4.91	2.02	4.20	4.88	5.88	2.22	8.68
FeO	.98	3.55	3.69	1.73	2.52	.72	3.41	1.90	2.55	3.66	4.10	10.13
MnO	.10	.12	.12	.09	.07	.08	.13	.07	.11	.12	.06	.39
MgO	37.52	42.20	41.18	37.13	40.13	38.25	29.83	33.61	30.54	32.06	34.12	20.77
CaO	.04	.20	1.72	1.39	1.15	3.07	8.77	.28	5.24	.76	.00	3.15
Na_2O	.24	.16	.22	.07	.10	.12	.20	.12	.13	.11	.09	.50
K_2O	.00	.00	.00	.06	.00	.00	.00	.00	.00	.00	.00	.01
H_2O^+	10.20	6.73	6.63	7.58	8.72	10.60	7.49	8.07	8.12	10.16	11.56	8.85
H_2O^-	.74	.58	.34	.63	.62	.91	.32	.58	.42	.18	.58	.12
P_2O_5	.17	.07	n.d.	.18	n.d.	n.d.	n.d.	.07	.26	.40	n.d.	.33
Total	99.63	99.58	99.63	99.46	99.89	100.00	100.00	100.04	99.70	99.59	99.48	100.14
Cr (ppm)	1344	1039	1627	1438	923	905	358	969	1202	0	230	193
Ni (ppm)	2252	2168	2405	2589	2441	2404	1789	2001	2696	85	150	107

1: enstatite bearing rock facies 2,3: anthophyllite bearing rock facies 4,5,6 and 8: typical "Madaraishi" 7: "Madaraishi" rich in tremolite 9,10,11 and 12: foliated ultrabasic rocks
(Analyst: H. Shimaoka)

In general, the ultrabasic rocks near Machiya Town are always extremely poor in alkalis and rich in MgO. SiO_2 and Al_2O_3 show a remarkable change between massive and foliated types, e.g. in the massive type, SiO_2 content is 40.64% – 45.96%, and Al_2O_3 is 0.55% – 5.08%, while in the foliated type, SiO_2 content is 23.90% – 43.70% and Al_2O_3 is 3.66% – 22.68%. TiO_2 and P_2O_5 are more abundant in the foliated type compared with the massive type. On the whole, CaO is poor except the rock facies rich in tremolite. Fe_2O_3/FeO ratio reflects the episodes of formative process of magnetite dust through serpentinization in the massive type and the formative process of idiomorphic magnetite in the foliated type. It is a matter of course that H_2O content of these ultrabasic rocks is abundant in the rock facies containing large amounts of talc, chlorite and serpentine after olivine. Cr and Ni are extremely poor in the foliated type compared with the massive type (Text-fig. 10).



Text-fig. 10 Ni-Cr diagram of the ultrabasic rocks from Machiya Town.
Open circles: massive type Solid circles: foliated type



Text-fig. 11 AFM triangular plots of the ultrabasic rocks from Machiya Town.
Solid circles: massive type Crosses: foliated type

The ultrabasic rocks in question are plotted on an AFM diagram (Text-fig. 11). In the diagram, the plots of both massive and foliated types are aligned on an area parallel to the F-M side because of extremely low content of alkalis. Therefore, 100·MgO versus MgO + FeO* of the ultrabasic rocks is roughly identical with alignment of the plots on the AFM diagram. As easily read from this diagram, the rocks of the foliated type are rich in FeO* than some of the massive type. This data may support that talc and olivine are rather poor in the foliated type and idiomorphic magnetite may increase in the same type.

In Al_2O_3-CaO-MgO diagram (Text-fig. 12), the rocks of the massive type are plotted nearby the apex MgO, however, the plots of the rock facies rich in tremolite slightly shift towards Al_2O_3 side from the apex MgO. In general, the chemical compositions of the massive type indicate that the rock may belong to of dunite or harzburgite before the serpentinization and metamorphism. On the contrary, the rocks of the foliated type are plotted along Al_2O_3-MgO side. It is noteworthy that the rocks of foliated type are characterized by comparatively high content of Al_2O_3. This result may be attributed to addition of Al_2O_3 to the ultrabasic rock from the surrounding rocks.

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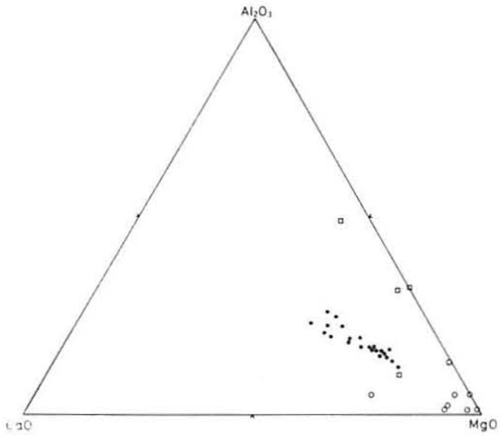
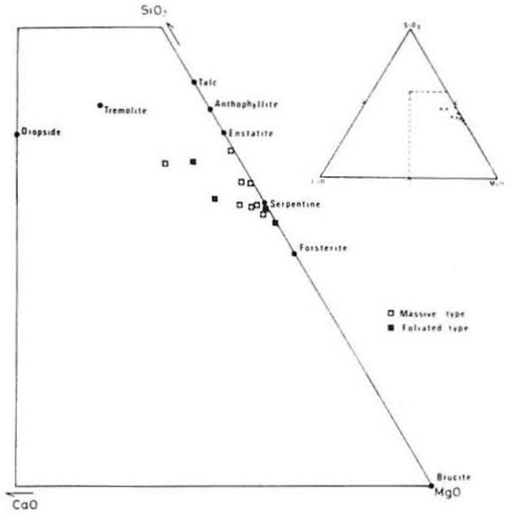
*FeO = Fe_2O_3 + FeO



Text-fig. 12 Al_2O_3-CaO-MgO diagram for the ultrabasic rocks. Open circles: massive type of the ultrabasic rocks near Machiya Town, Squares: foliated type of the ultrabasic rocks near Machiya Town, Solid circles: peridotitic komatiite of Belingwe greenstone belt, Rhodesia (Nisbet et al., 1977) and spinifex bearing rocks of Munro Township, Ontario (Pyke et all, 1973)



Text-fig. 13 CaO-MgO-SiO_2 diagram for the ultrabasic rocks near Machiya Town.
Open squares: massive type, Solid squares: foliated type

The chemical compositions of peridotitic komatiite (Nisbet et al., 1977) and spinifex bearing rocks rich in MgO (Pyke et al., 1973) are also plotted on the same diagram (Text-fig. 12) to compare with the ultrabasic rocks near Machiya Town in question. The quoted rocks show comparatively high content of CaO and low content of MgO in comparison with the rocks of the massive type.

On the other hand, the ultrabasic rocks both massive and foliated types are plotted on a restricted area that included in the subtriangle diopside-forsterite-talc in the CaO-MgO-SiO_2 compositional triangle (Text-fig. 13).

Metamorphism of the ultrabasic rocks

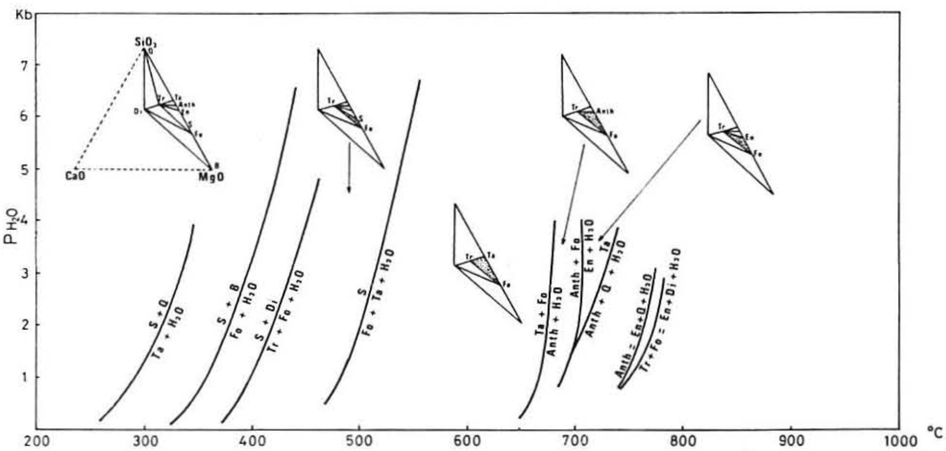
The characteristics of the ultrabasic rocks near Machiya Town mentioned above suggests that the ultrabasic rocks have undergone polymetamorphism. The earlier metamorphism is related to the formation of the massive type and the later one is related to the formation of the foliated type which may be derived from the massive type.

Metamorphism of the massive type

The first thing to be considered is origin of "Madaraishi" which shows dappled texture caused by the presence of olivine and talc. The peculiar texture due to elongated olivine porphyroblast is similar to the texture of elongated olivine interpreted as metamorphic origin by Evans and Trommsdorff (1974), and is also similar to the texture observed in the ultrabasic rocks of Higo metamorphic belt (Mizuta, 1978). However, the texture of "Madaraishi" in question herein differs certainly from those of komatiite (Chii et al., 1975). Because, skeletal and feathery textures which are characteristic feature of olivine grains in komatiite and in spinifex bearing rock are unobserved in the "Madaraishi".

Furthermore, bulk chemical compositions of the massive type are rich in MgO and differ from one of komatiite or spinifex bearing rocks (Text-fig. 12). The formation of the peculiar dappled texture of the "Madaraishi" may be genetically considered to have been formed through the thermal metamorphism related to a certain plutonism within or around the Koshidai-Takaboyama-Daioh'in Structural Belt.

It is well known that talc-olivine rock facies are common in the serpentinite which have undergone contact or regional metamorphism appointed by the following writers: Evans and Trommsdorff (1970), Springer (1974), Arai (1975), Frost (1975), Pinsent and Hirst (1977) and Vance and Dungan (1977). The mineral assemblage of the massive type as given in Table 1 are in accordance with one of the metamorphosed serpentinite. The present author



Text-fig. 14 Sequence of metamorphic reactions in serpentinite (after Evans and Trommsdorff, 1970). Stippled areas: parageneses observed in the massive type of ultrabasic rocks near Machiya Town.

considers that tremolite selectively appears in a part where slightly rich in CaO. From mode of occurrence, mineral assemblages and bulk chemical compositions of the massive type, it has been assumed that talc, olivine, anthophyllite and enstatite are probably formed through the following reactions established by Evans and Trommsdorff (1970):

5 serpentine = 6 forsterite + talc + 9 H_2O

9 talc + 4 forsterite = 5 anthophyllite + 4 H_2O

anthophyllite + forsterite = 9 enstatite + H_2O

These metamorphic conditions are shown in Text-fig. 14 which has been proposed by Evans and Trommsdorff (1970). According to the diagram, the condition that forms the rocks of the massive type near Machiya Town is estimated to be 400°C to 750°C at low pressure. In the massive type, "Madaraishi" is widely spread and anthophyllite or enstatite bearing rock facies is confined within a small area. Therefore, thermal condition formed the "Madaraishi" is considered to be about 500°C to 650°C, and anthophyllite or enstatite bearing rock facies is considered to be formed by a partial rise of temperature reached about 650°C to 750°C.

Metamorphism of the foliated type

The foliated type derived from the massive type shows notable foliated structure and weakly preferred orientation of chlorite or tremolite. The structure and texture of the foliated type are regarded to be formed under the condition of shearing stress. The cause of shearing stress is probably related to the tectonic movement of the Koshidai-Takaboyama-Daioh'in Structural Belt recognized as a major sheared zone.

Through the process of the preceding shearing movement, olivine and talc consisting of massive type might have been replaced by chlorite, tremolite and idiomorphic magnetite. Metamorphism which converts the massive type to the foliated one took place certainly changes of the chemical compositions of the ultrabasic rocks, i.e. the metamorphism yielded a decrease of MgO and an addition of Al_2O_3 in the foliated type. Furthermore, Cr and Ni contents abruptly decrease, and TiO_2 and P_2O_5 slightly increase. The mannar of changes of these elements is similar to the case realized in vein-metasomatized peridotite at Kalskret near Tafjord, South Norway as reported by Kanaris-Sotiriou et al. (1978).

The feature of metamorphism described above suggests that the tectonic movement not only coverted the massive type to the foliated type but yielded some notable chemical changes between the massive type and newly formed foliated one.

Consideration and conclusion

In general, ultrabasic rocks in a structural belt play an important role to clarify the process of development of the structural belt. The study on the ultrabasic rocks in the vicinity of Machiya Town belonging to the Koshidai-Takaboyama-Daioh'in Structural Belt has disclosed the involved some important problemes as follows.

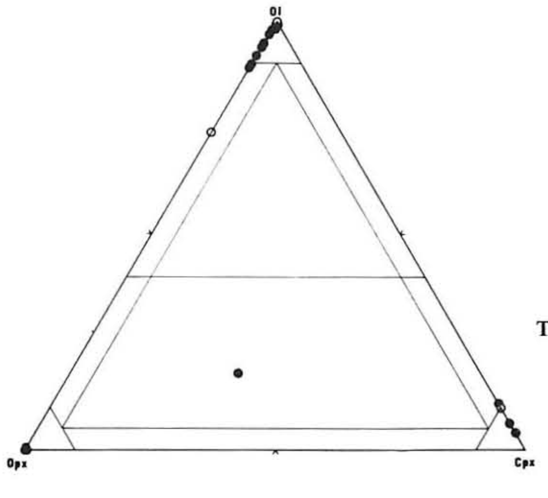
(1) Original rock of the ultrabasic rocks near Machiya Town, especially the massive type is conceivable that it belongs to dunite and harzburgite series. So far as the ultrabasic rocks sporadically scattered in the structural belt is concerned, at present, dunite, harzburgite and minor amounts of pyroxenite have been found from the Hanazono and Koshidai districts.

Bulk chemical compositions of them are given in Table 4 and modal analyses are plotted on an olivine-orthopyroxene-clinopyroxene diagram (Text-fig. 15).

Table 4 Chemical compositions of ultrabasic rocks and related rocks from the "Koshidai-Takaboyama-Daioh'in Structural Belt", Abukuma Mountains.

	1	2	3	4	5	6	7	8
SiO_2	38.60	41.16	42.10	41.28	50.45	47.34	49.58	50.88
TiO_2	.04	tr.	tr.	tr.	.13	.30	.14	.20
Al_2O_3	1.72	1.11	1.60	1.09	3.45	4.95	6.33	9.42
Fe_2O_3	2.66	4.83	6.03	4.91	.90	4.68	2.72	1.99
FeO	4.04	1.18	1.07	1.61	6.39	3.51	7.56	8.46
MnO	.10	.01	.04	.04	.16	.08	.12	.13
MgO	45.80	41.38	39.97	37.11	19.02	20.13	26.45	19.55
CaO	1.07	.54	.43	2.18	18.46	15.76	4.60	6.72
Na_2O	.01	.42	.36	.51	.02	.82	.66	.50
K_2O	.06	.07	.07	.12	.04	.15	.13	.14
H_2O^+	4.90	8.20	7.14	10.04	.57	1.04	.91	1.54
H_2O^-	.38	.87	1.04	.68	.10	.60	.22	.22
P_2O_5	.15	.02	.06	.04	.15	.03	n.d.	n.d.
Total	99.53	99.79	99.91	99.61	99.84	99.39	99.42	99.75
Cr (ppm)	1587	–	–	–	655	–	2990	3009
Ni (ppm)	2715	–	–	–	241	–	632	463

1: dunite from Hanazono district 2,3: dunite from Ohtsube-yama (Kano et al., 1973)
4: tremolite-dunite from Koshidai (Kano et al., 1973)
5: clinopyroxenite from Hanazono district
6: olivine-clinopyroxenite from Inubotoke-yama (Kano et al., 1973)
7: orthopyroxenite from Hanazono district
8: tremolite-chlorite rock from Hanazono district
(1, 5, 7 and 8: analyst: H. Shimaoka)



Text-fig. 15 Modal proportions of olivine, orthopyroxene and clinopyroxene of the ultrabasic rocks from Koshidai and Hanazono districts, Abukuma Plateau.
Open circles: Koshidai district, Solid circles: Hanazono district

Accumulated data suggest that the ultrabasic rocks in the Koshidai-Takaboyama-Daioh'in Structural Belt are generally considered to be consanguineous to dunite and harzburgite series.

(2) The massive type was formed in earliar stage compared with the formation of the foliated type. The former was conceivably formed under the thermal metamorphism uneffected by tectonic movement such as shearing. The source of heat related to the formation of the massive type has not been confirmed yet. Irishiken granodiorite distributed in the northern part of the Hitachi region, is discrete to the formation of the massive type because the granodiorite is younger than the foliated type. Therefore, at present, it may be inferred that the thermal metamorphism formed the massive type may be related to the activity of tonalitic rock which observed in the several parts of the Koshidai-Takaboyama-Daioh'in Structural Belt.

(3) The foliated type derived from the massive type is characterized by well developed foliated structure and metasomatic feature. The tectonic movement produced the foliated type is probably identical with the formation of sheared zone in the Koshidai-Takaboyama-Daioh'in Structural Belt.

Metamorphism of the ultrabasic rocks in the vicinity of Machiya Town may be attributed to both tectonic movement and igneous activity of the Koshidai-Takaboyama-Daioh'in Structural Belt.

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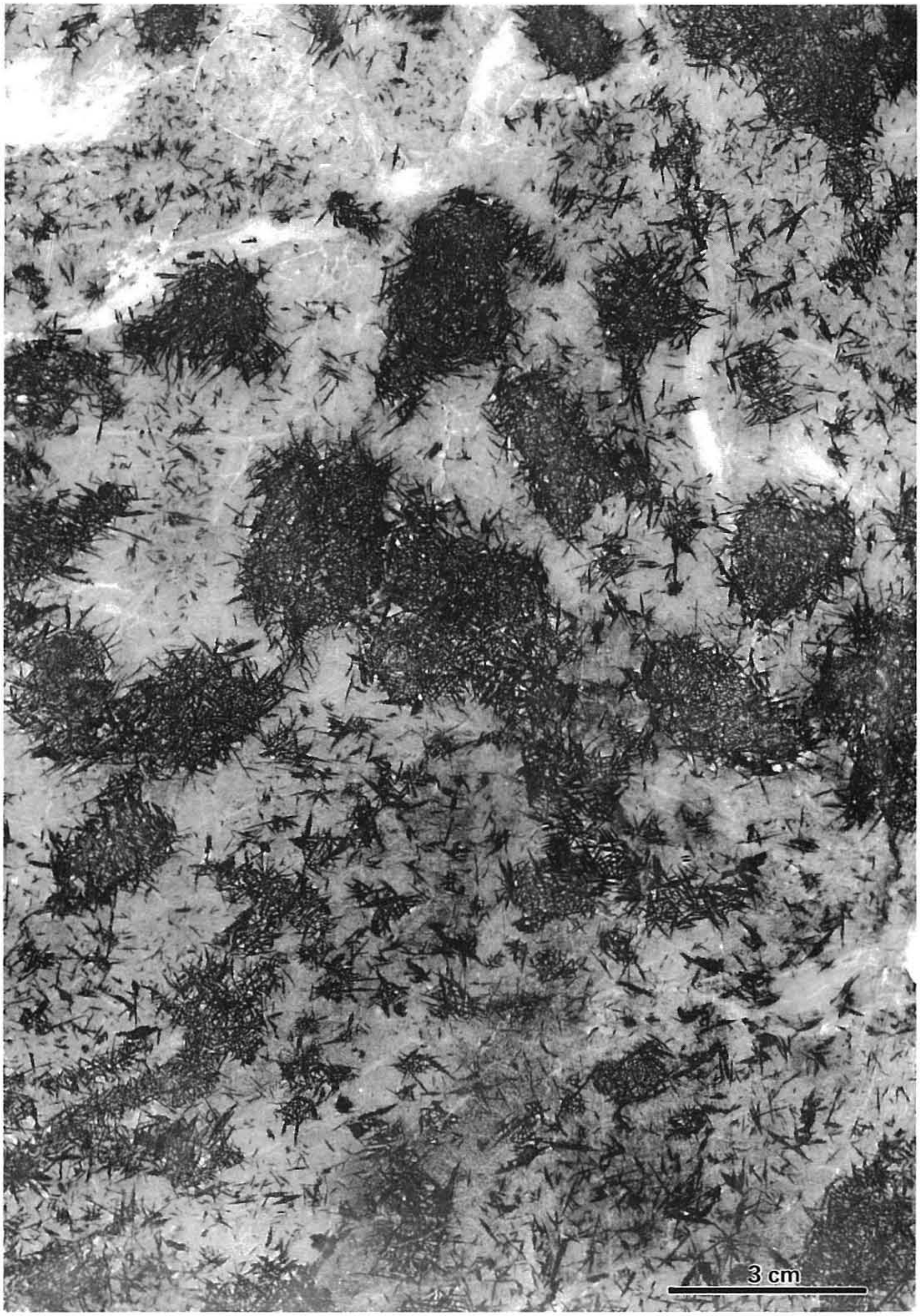
Explanation of plate 1

Polished specimen of the typical "Madaraishi" from Machiya Town, Ibaragi Prefecture, Japan.

Dark coloured area: olivine porphyroblasts veined by serpentinization with separation of magnetite dust.

Light coloured area: talc and minor amounts of tremolite.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