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Picrite sill in the Sado Island, Japan

by

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Abstract Picrite sills occur at the southwestern end of the Sado Island. Picrites are composed of phenocrysts of olivine and spinel with matrix of ophitic texture common to dolerite. Modal proportion of olivine is constantly high, 40 to 60%, in the lower part of the sills and it rapidly decreases to less than 20% in the upper parts. Such variation is similar to the picrites reported from the Skye and shows that the picrites were formed by crystal settling of olivine from olivine basalt magma. There is no evidence to show that they were derived from picrite or picritic parent magma.

Most of olivine grains have chemically homogeneous cores. They have always very narrow Fe-rich rims as a product of rapid cooling after emplacement. Compositions of olivine cores are diverse, ranging from Fo 89 to Fo 79 even in a single thin section. Some olivines have reverse zoning; Mg-rich mantle on Fe-rich core or monotonous increase of Mg towards the rim. The variation of core compositions and reverse zonings may be attributed to heterogeneity of magma composition due to crystallization in a magma chamber with temperature gradient, rather than contamination of peridotite and wall rocks or multiple injection of various-type olivine basalts.

Introduction

Picrites or picritic basalts are rare rock-type as an igneous rock. Presence of picritic primary magma has been advocated by CLARK and O'HARA (1979) and WRIGHT (1984). Many studies on picritic rocks except komatiite, however, show that the liquids produced the picrites were essentially basaltic, and picrites were formed by accumulation of olivine through gravity settling or flow differentiation of olivine basalt (*e.g.* MACDONALD, 1944; SIMKIN, 1967). Komatiite is similar to picrite in bulk composition. But it has high MgO content even in a quenched part, up to 28 wt%, and was formed by primarily high-magnesian magma (*e.g.* ARNDT, 1986).

Picrite sills occur in the Miocene volcaniclastic and sedimentary sequence at the southwestern end of the Sado Island. In this paper we show compositions and compositional profiles of olivine phenocrysts and discuss the origin of the picrite.

Picrite sill

There are two outcrops of picrite sills at the southwestern end of the Sado Island (Fig. 1). They intruded Miocene pyroclastic and sedimentary rocks. As the two sills occur closely each other, it is considered that they were formed originally in a single magmatic event. One of the sills (Fig. 2A) is well exposed with thickness of at least 30 m, and was studied in detail. Upper and lower boundaries between the sill and country rocks have not been recognized. Except for these sills, there are many picritic rocks and olivine basalts in the surrounding Miocene pyroclastics.

Bulk chemical composition of the picrite has MgO content up to 30 wt% (YAMAKAWA and CHIHARA, 1968). Phenocrysts are olivine and spinel. The groundmass consists of plagioclase, clinopyroxene, olivine and Ti-magnetite with ophitic texture. Interstitial glass among the above mentioned minerals is highly altered to clay minerals. Olivine is also often replaced by clay and carbonate minerals, especially along

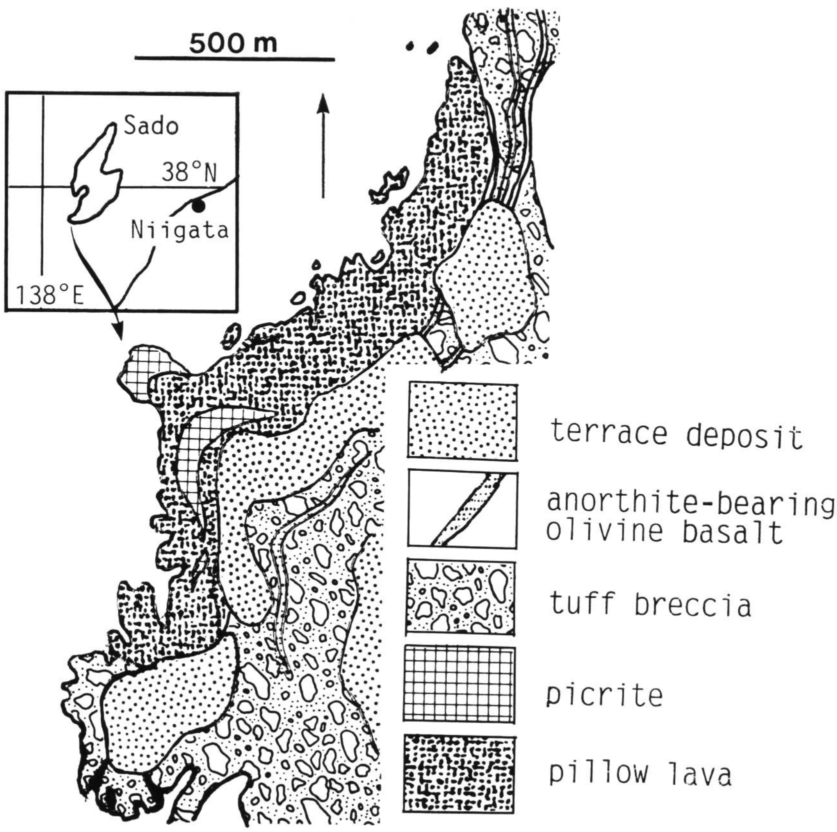

Fig. 1. Geological map of the southwestern end of the Sado Island (after YAMAKAWA and CHIHARA, 1968).

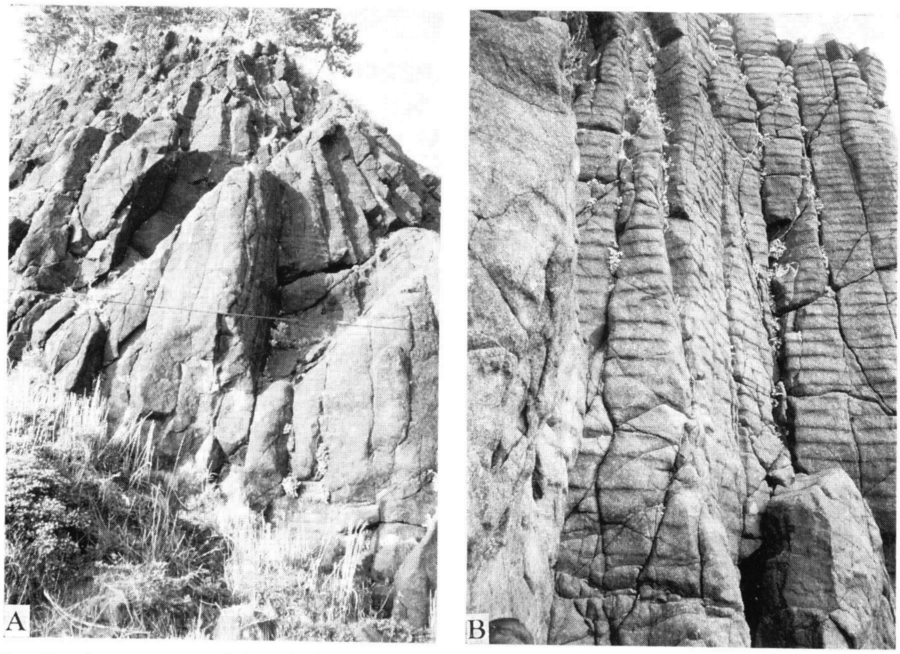

Fig. 2. A: outcrops of the picrite sill studied in detail. Layering is observed faintly in the lower part. B: well-developed layering in the other sill.

cracks. Coarse olivine pseudomorphs are well recognizable even in highly altered samples, whereas it is difficult for fine ones to distinguish from altered glass. Olivine phenocrysts sometimes contain spinel.

The samples were collceted at every 2 m from the base of the outcrop of the picrite sill. The distribution of olivines in each thin section is shown in Fig. 3. And modal variation and grain size distribution are given in Fig. 4. Modal proportions of olivine are constantly high, 40 to 60%, at the lower part of the sill and it rapidly decreases towards the upper part. Although both the lower and upper boundaries between the sill and country rocks have not been recognized at the outcrop, the modal variation of the olivine across the sill resembles those in the picrite sills of North Skye reported by SIMKIN (1967), and is explained well by the crystal settling as discussed later. Enrichment of olivine is also observed in the lower half of pillows close to the sill (Fig. 5). Weak layering, about 20–40 cm thick, is recognizable in a weathered surface of the sill studied. The layering is well developed in the other sill (Fig. 2B). Such layering is observed only in the olivine-rich part of the sill. Although the layering has not been studied in detail yet, olivines in the concave part of the layer are more coarse-grained than those of the convex one.

All the grain sizes shown here are the apparent ones, i. e. the size of olivine grain in thin section. Grain size of olivine is variable in the lower part of the sill as seen

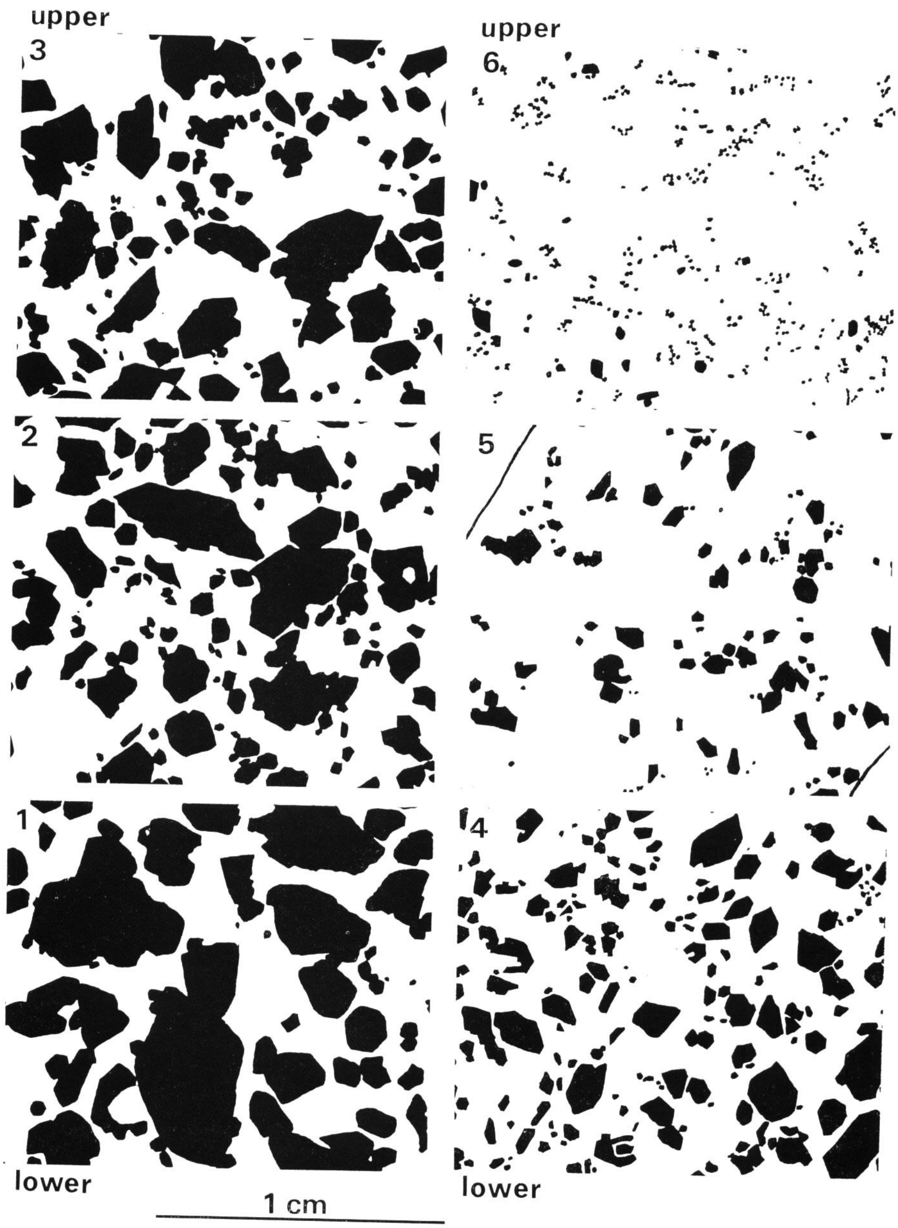

Fig. 3. Distributions of olivine grains in thin sections from the lower to upper parts in the sill.

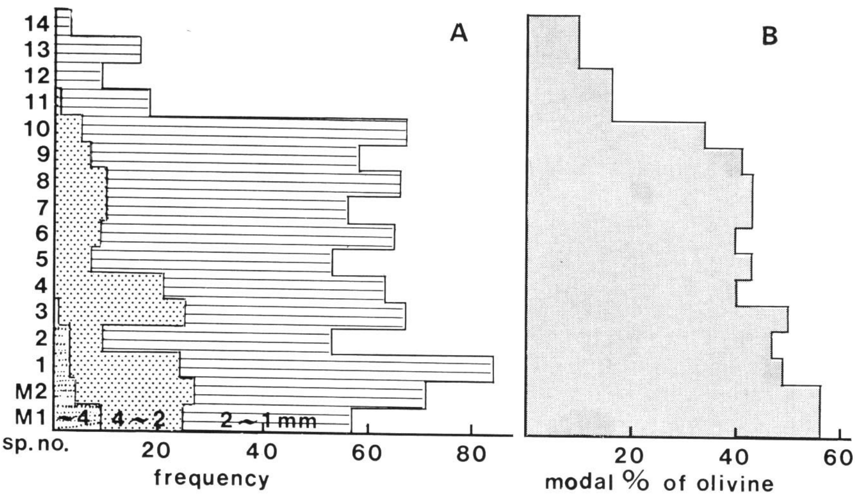

Fig. 4. A: grain size variation in thin sections. B: Modal proportions of olivine.

in Fig. 3. It ranges from 8 mm to 0.2 mm. Coarse olivines (>4 mm) occur only in the lower part (Fig. 4A) and are mostly rounded, subhedral, sometimes corroded. Small olivines are euhedral to subhedral. Number of the coarse-grained olivine larger than 1 mm decreases abruptly at the upper part of the sill and is well corresponding to the modal proportions of total olivines across the sill (Fig. 4). Matrix minerals are mostly constant in grain size from the lower part to the upper part.

Olivine composition

Olivine compositions were analysed by Energy Dispersive Spectrometer at the condition of 100 sec at 15 Kev at each point. Statistical error of the forsterite molecule analysed is less than 0.1. Compositional profiles of olivines were constructed by analyses from core to rim and representative ones are shown in Fig. 6. Distribution of core compositions in an olivine-rich thin section is shown in Fig. 7.

Most of the olivines have homogeneous core with rapidly Fe-enriched rim (Fig. 6). Some coarse olivines show complex zonings: homogeneous Fe-rich core with Mg-rich mantle or Mg increase monotonously towards rim. The homogeneous cores have different in composition from grain to grain (Fig. 7). In the lower part of the sill, any relationship has not been observed between the core composition and grain size.

In most of the volcanic rocks, compositions of mafic phenocrysts have been expected to be almost constant or narrow in range in each thin section. As shown in Fig. 8, Fo value of olivine ranges from 89 to 79 with maximum frequency of around 88. Fo values of coarse-gained olivines (>2 mm) range from 89 to 83 and do not

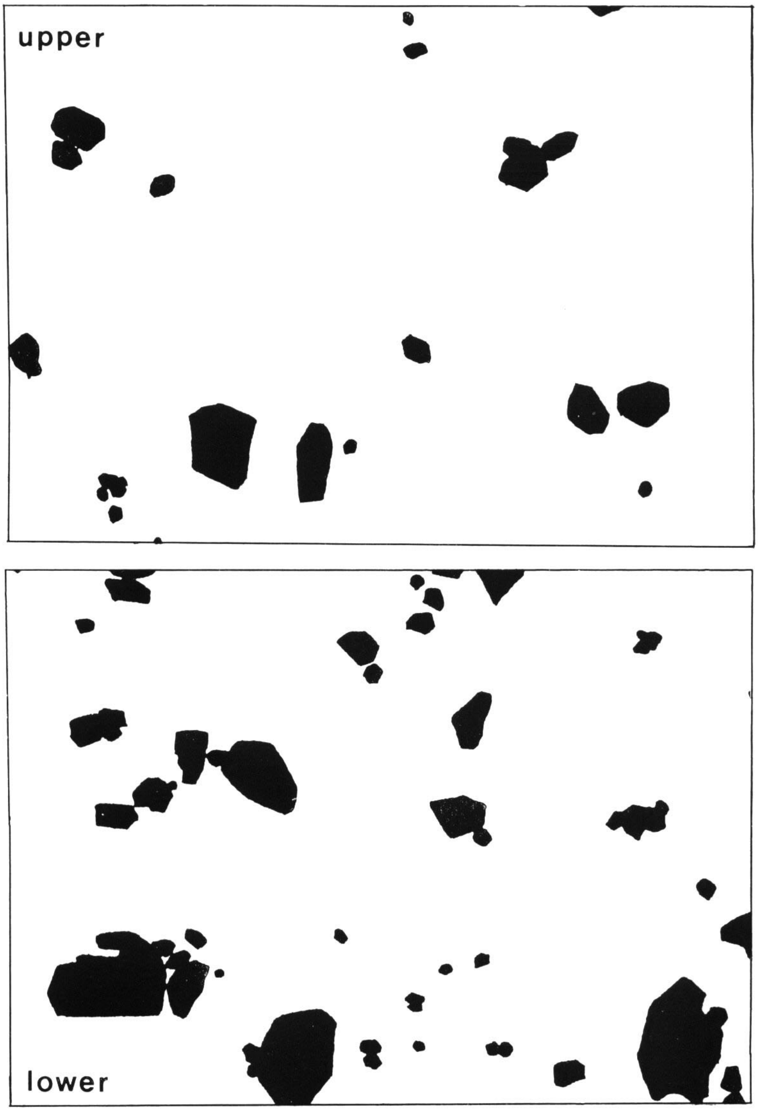

Fig. 5. Distributions of olivines in the lower and upper parts of a pillow.

show a defined maximum in the range (Fig. 8). Such olivines occur randomly in a thin section (Fig. 7) and also do not any distinct tendency against the level at the outcrop. The olivines in picrites are usually large in size compared with olivine phenocrysts in the normal volcanic rocks. Cutting of the normally zoned olivines produces many patterns of the compositional profiles (PEARCE, 1984), however, homogeneous cores in both the coarse- and fine-grained olivines and reverse zonings

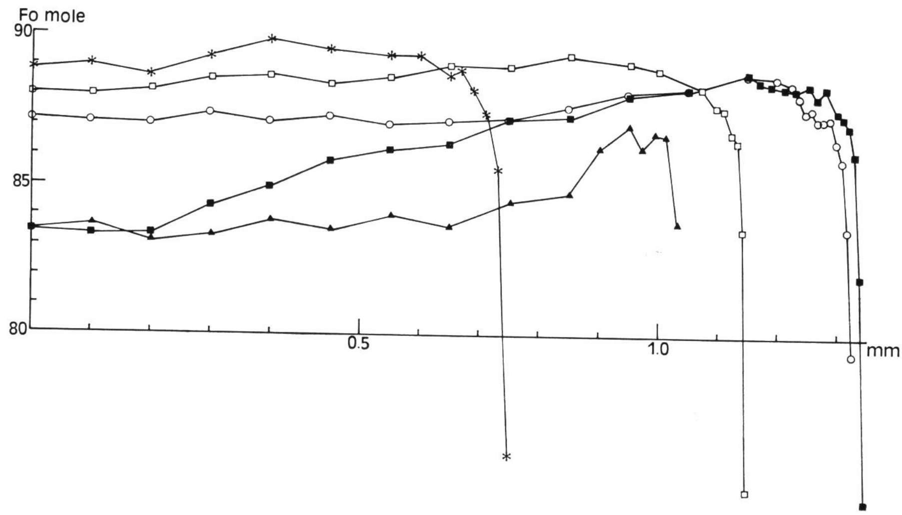

Fig. 6. Compositional profiles of olivine grains from core to rim.

observed cannot be induced from the random cutting of a grain. Olivine grains are constantly small in the upper part of the sill and their compositions have a rather narrow range of Fo mol, as do most olivines of the olivine basalts.

The rapid Fe-enrichments are always observed at the rims. It suggests that the rims, about 50 μm in width, were formed after the emplacement of the picritic rocks. On the other hand, the compositional variation at the cores should be originated in a magma chamber, i. e. before the emplacement. Compositional profiles except for the Fe-rich rim are discussed in the following section.

CaO contents exceed always 0.1 wt%. Most of olivines contain more than 0.2 wt% CaO. Olivines with CaO content from 0.1 to 0.2 wt% are only occasionally present in the scanning profiles. SIMKIN and SMITH (1970) showed that CaO contents of olivines in peridotites are commonly less than 0.1 wt%. Hence the olivines analysed are considered to be primarily magmatic in origin.

Discussions

There are many discussions about the origin of picrites and picritic rocks. Many field observations show that the picrites were formed by crystal settling of olivine phenocrysts in olivine- or picritic basalts. Abundant occurrence of coarse-grained olivines at the lower part of the sill supports that the crystal settling occurred in the Sado picrites. Modal proportion of olivines is up to 60% like that of the Skye picrites. It is constantly high in the lower part and abruptly decreases at the upper part. The maximum proportions and rapid change of the proportions are similar to the gravity settling of the sand grains in the water. Our reconnaissance study gives the result

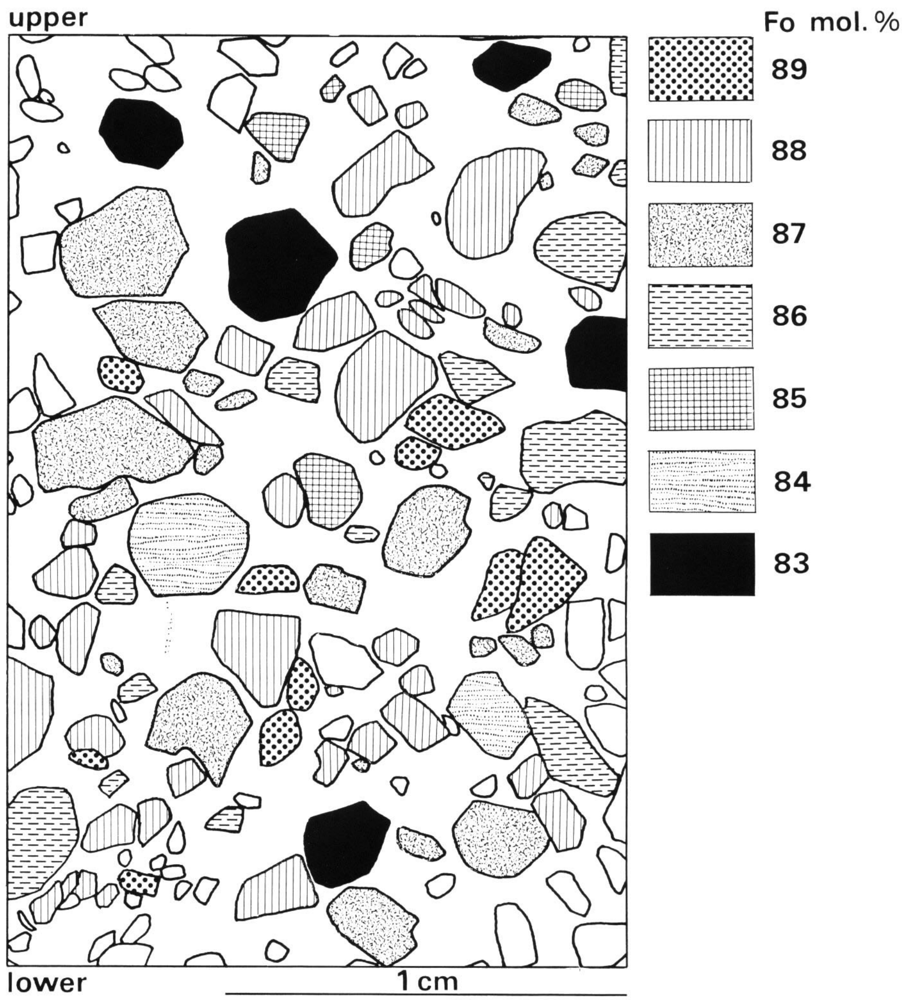

Fig. 7. Variation of core compositions in olivine grains in a thin section.

that the modal proportion of the natural sand grains in water was around 55% and it attains 60% after the vibration of a vessel. In the Skye picrite sill, modal proportions are 50 to 60% at the lower part, whereas in the Sado picirites, proportions are 40 to 60% at the lower part. Rather low values in the latter sill may be due to underestimation by the alteration of olivine grains.

FUJII (1977) developed a quantitative model of settling and obtained satisfactory agreement between the calculated and measured variations of olivine across a dolerite sill. In his calculation, grain size used was 0.8 mm. Olivines in the picrites are mostly coarser than those in the olivine basalt and olivine dolerites. In Fig. 4, the

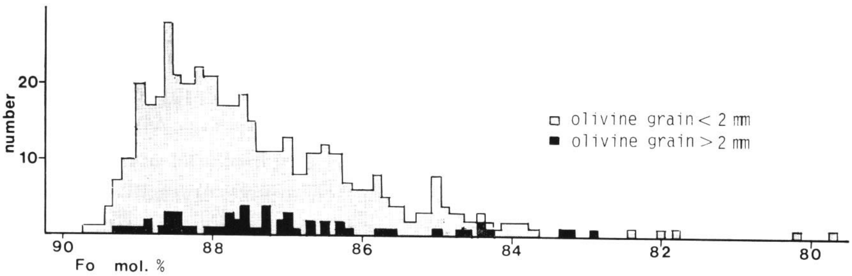

Fig. 8. Histogram of core compositions of olivine grains.

modal variation is well coincident with the number of the olivines larger than 1 mm. Therefore the rather constantly high proportions at the lower part of the picrite sills imply that olivine phenocrysts before the emplacement were larger than 1 mm and they had settled rapidly soon after emplacements as do the sand grains in water. Such rapid olivine settling is supported by an enrichment of olivine in a lower part of pillow lave occurring around the sill (Fig. 5). Rapid changes of modal proportions within the sill (Fig. 4) can be explained by almost complete settling of olivine phenocrysts formed before the emplacement. As layering observed in the olivine-rich lower part of the sill (Fig. 2B) is similar to the sedimentary layering formed by turbidites, the layering might be attributed to cyclic injection of magma into the sill before the crystallization of groundmass.

The present study revealed that the olivine phenocrysts have different core compositions from grain to grain. Such variation was reported by MAALØE *et al.* (1989), KOYAGUCHI (1984) and SATO *et al.* (1991). Compositional profiles reported by them have normal zoning patterns or flat-lying patterns of cores. MAALØE *et al.* (1989) concluded that the composition versus maximum size depends on the growth rate and the rate of decrease in temperature, i. e. the coarse-grained olivines are earlier crystallized Mg-rich ones, whereas fine-grained ones are later Fe-rich olivines.

Present data show that some olivines in the Sado picrites have quite complex compositional variations including reverse zoning and Mg-rich mantle. Such variation might be resulted from a mixing of magmas (EICHERBERGER, 1980; SAKUYAMA, 1981). Wide compositional variation of olivine at the core may be explained by a mixing of various type of basalitc magmas or wall rocks and basaltic magma. Such a mechanism is, however, too much complex to be realistic for the Sado picrites. The variation and zoning should be explained more simply as a common phenomena in a single magma chamber.

Temperature gradient should be maintained in a magma chamber; low temperature near roof and wall and high temperature in the center. Accordingly, the thermal gradient produces local crystallization of olivine, and compositions of olivines depend on the chemical composition and temperature of the surrounding magma. So far we cannot present a realistic phenomena in the chamber, a probable model should be as follows.

In the magma chamber, cooling of the body induces crystallization of olivine at the roof and wall. The first olivine phenocryst crystallizes at such portions and the composition is around Fo 90. As a consequence of coarsening of olivine, crystal settling can occur even in a chamber where magma convects. After settling of the crystal down the lower part of the chamber, more Fe-rich olivine crystallizes near the roof and wall due to further cooling, while Mg-rich olivine crystallizes at high temperature parts of the chamber, i. e. central and lower parts. During settling, the Mg-rich olivine should overgrow on the Fe-rich olivine. In this way, olivines with different core compositions can coexist in the lower part of the chamber. Convecting velocity does not exceed the settling velocities as the olivines in picrites are coarse-grained, or only coarse-grained olivines could have settled in the lower part. Absence of olivines with Mg-rich core and Fe-rich overgrowth support that most of the olivines are settled in the lower part and do not ascent upwards in the convecting magma. Most of magmas, which produced a normal olivine besalts, are brought from the upper part of the chamber, whereas magma formed the picrite was brought from the lower part and most of the olivines are more coarse-grained than those of the normal olivine basalts mentioned above.

In the crystallization sequence, most of the olivines have more or less zoned profiles. The flat-lying patterns and compositional variation of most olivine cores suggest that the olivines may be annealed in a chamber as observed in the olivines in the lower part of a lava lake in Hawaii (MOORE and EVANS, 1967). Some olivines with zonal structure preserve relatively original zoning and are brought to the present positions by less well annealing.

The crystal settling explains enrichment of olivines in the Sado picrites, however, parental magma may not be easily concluded to be an olivine basalt as discussed by CLARKE and O'HARA (1979) and WILKINSON and HENSEL (1988). There are many olivine basalts around the picrite sill and no occurrence of high-magnesian glass has been reported from this area. Hence, as far as the magma just before the emplacement is concerned, it is concluded that its liquid part was an olivine basalt similar to those occurring in this area.

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