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# Geochemistry of Some Miocene to Quaternary Igneous Rocks Bordering an Ensialic Marginal Basin—An Example from Eastern Shimane Prefecture and Oki Dozen Island, Southwest Japan.

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Major element oxide analyses of Miocene to Quaternary igneous rocks from eastern Shimane Prefecture and Oki Dozen Island show that although arc-related volcanism is dominant in this area, alkaline and tholeiitic rocks are also widespread.

The oldest samples (Dolerites and Omori Formation) are a suite of tholeiitic to mildly calc-alkaline eruptives and intrusives, the latter mutually related by low-pressure fractional crystallization. Younger rocks of the Matsue Formation are alkaline to transitional basalts, some containing conspicuous biotite, with accordingly high $K_2O/Na_2O$. Volcanic rocks of Oki Dozen Island are an alkali basalt-trachyte suite, related by low-pressure fractionation. The lowermost Pliocene Wakurayama Andesite is succeeded by alkaline to transitional basalts sampled from south of Yasugi City and from Daikon Jima Island.

The oldest tholeiitic rocks coincide with opening of the Japan Sea, and their chemistry is comparable with that from the initial magmatic stages of other ensialic marginal basins. Younger rocks have source regions variably contaminated either by fluids derived from the downgoing oceanic crust beneath the area, or result from hybridisation of magma with the overlying mantle wedge.

## Introduction

SW Honshu was the sight of intense Miocene volcanic activity (Isshiki, 1972; Sugimura & Uyeda, 1973). K/Ar dating of some samples discussed in this study (Morris *et al.*, in press) show that during the mid-Miocene, volcanism conincided with the opening of the Japan Sea (Hayashida & Ito, 1984; Otofuji & Matsuda, 1983, 1984; Otofuji *et al.*, 1985) by back-arc extension (Karig, 1971; Honza, 1983). Although underthrusting of the Kula and/or Pacific Plate beneath SW Honshu probably accounted for pre-Neogene volcanism, subduction of the Philippine Sea Plate from the Neogene onwards resulted in volcanism in the Kinki and Chugoku districts of southern Honshu (Tatsumi & Yokoyama, 1978). The most recent manifestations of such activity are shown by the volcanoes Aso (Kyushu), and Mts Daisen and Sambe (SW Honshu).

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Although subduction-related volcanism is a persistent feature of the Cenozoic history of SW Japan, this study focuses on tholeiitic and alkaline igneous rocks. The reason for this is to determine why such compositionally diverse rocks of seemingly similar age have been emplaced or erupted in close proximity. Thirty six new XRF major element analyses have been completed for a variety of Miocene to Pleistocene igneous rocks from eastern Shimane prefecture and Oki Dozen Island, SW Honshu. These data complement and extend previous analyses (Miura, 1973, 1974; Uchimizu, 1966; Kano & Yoshida, 1985; Takahasi, unpublished data; Kaneoka *et al.*, 1983), and form part of broader study being undertaken into the petrogenesis of Neogene to Recent igneous rocks of the Chugoku district. Isotopic studies (Morris & Kagami, unpublished data) and trace element abundances (Morris, unpublished data) will be reported elsewhere.

The stratigraphy adopted in this study is summarized in Table 1 (after Kobayashi *et al.*, 1982), which also lists the number of samples analysed from each unit examined. Sample locations, and an abbreviated igneous geology are summarized in Fig. 1. Petrographic descriptions and more precise locations are given in Appendix 1.

*Dolerites.*

Rocks referred to as 'dolerites' in this study comprise middle Miocene 'Dolerite, basalt, and porphyrite' of Kobayashi *et al.* (1982). They are a series of fine (i.e. < 1 mm) to medium (1–5 mm) grain size intrusive and extrusive igneous rocks displaying textures ranging from porphyritic through to various cumulus types. Grain size and texture are the basis for their thin section classification as gabbro, dolerite, and

Table 1. XRF analyses of the two Geological Survey of Japan rock standards JB–1 (basalt) and JG–1 (granodiorite) made during analysis of Shimane-Oki samples. X=mean; SD=1 standard deviation. Tabular values (TAB) from Ando *et al.* (1974).

Basalt Standard JB - 1.

| | $\bar{X}$ | SD | TAB |
|---|---|---|---|
| $SiO_2$ | 52.48 | 0.30 | 52.17 |
| $TiO_2$ | 1.36 | 0.01 | 1.34 |
| $Al_2O_3$ | 14.36 | 0.07 | 14.53 |
| $Fe_2O_3$ | 8.85 | 0.03 | 8.97 |
| MnO | 0.15 | 0.00 | 0.16 |
| MgO | 7.89 | 0.13 | 7.73 |
| CaO | 9.26 | 0.02 | 9.29 |
| $Na_2O$ | 2.74 | 0.11 | 2.79 |
| $K_2O$ | 1.38 | 0.01 | 1.42 |
| $P_2O_5$ | 0.25 | 0.00 | 0.26 |

n = 15

Granodiorite standard JG - 1.

| | $\bar{X}$ | SD | TAB |
|---|---|---|---|
| $SiO_2$ | 72.22 | 0.03 | 72.30 |
| $TiO_2$ | 0.25 | 0.01 | 0.27 |
| $Al_2O_3$ | 14.42 | 0.38 | 14.20 |
| $Fe_2O_3$ | 2.15 | 0.04 | 2.14 |
| MnO | 0.06 | 0.00 | 0.06 |
| MgO | 0.75 | 0.04 | 0.74 |
| CaO | 2.16 | 0.03 | 2.18 |
| $K_2O$ | 3.91 | 0.07 | 3.95 |

n = 4

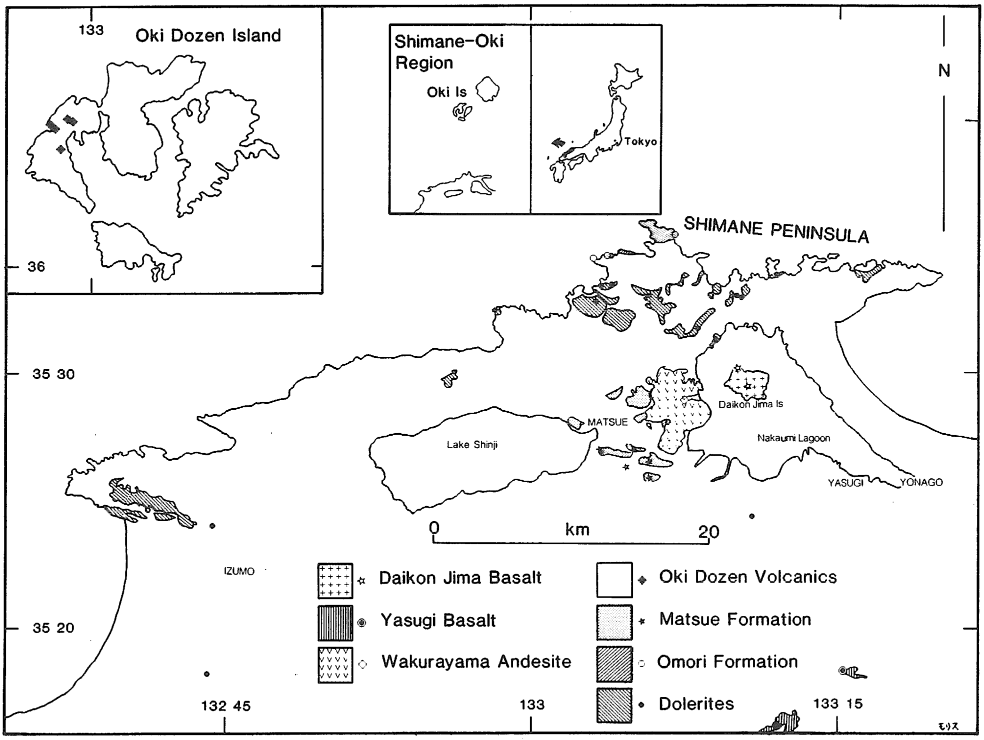


Figure 1. Location map and simplified geology of the Shimane-Oki region (after Kobayashi *et al.*, 1982). Sample locations are also shown.

basalt.

Thirty three samples were examined petrographically. They comprise varying proportions of clinopyroxene, opaque oxide, olivine (party altered), plagioclase, and occasional orthopyroxene, with accessory apatite. Although most samples are holocrystaline and show some degree of poikilitic texture (e.g. 64 (Tai) and 31 (Kitagaki-hama)), some samples are porphyritic ((69 (Asayama), 6 (Kitaura)), and one sample has flow-banded plagioclase in the groundmass (66 (Yokan)). Thus, there is textural evidence for both intrusive and extrusive rocks.

Clinopyroxene is the most common mafic mineral, comprising colourless to very pale green grains up to 0.4 mm, usually fresh and unzoned, although some grains have biotite alteration on the margin. Rare orthopyroxene occurs as colourless to pale green unzoned grains in 1 (Kitaura) and possibly in the groundmass of 28 (Owashi). Olivine is invariably altered to a fibrous green mineral, possibly of the serpentine group. The most common phase is plagioclase, with blocky unzoned grains up to 4.5 mm (28 (Owashi), 66 (Yokan)), although zoned laths are present in finer grained rocks. Some grains are cloudy, spongy (6 (Kitaura)), or resorbed (69 (Asayama)). Plagioclase in 31 (Kitagaki-hama) and 64 (Tai) contains skeletal opaque oxide. Apatite is a common accessory phase enclosed in feldspar. Opaque oxide grains are usually equant and altered on the margin.

Most dolerites contain secondary minerals including various layer silicates, principally chlorite, and clay minerals (saponite), calcite, and occasionally zeolites.

*Omori Formation*

Of the six samples collected from the Omori Formation, five are from the $O_3$ member on Shimane Peninsula, and the sixth is from the lower $O_1$ member at Shingu River near Izumo City. All samples are hypocrysralline, although 47 (Katsurajima) contains about 80% perlitic glass. Rare phenocrysts are euhedral colourless to pale green clinopyroxene, faintly pleochroic orthopyroxene (only in more siliceous rocks-e.g. 46 and 47 (Katsurajima)), and weakly zoned plagioclase. All three phases also occur as phyric aggregates. In more crystalline rocks, the groundmass is dominated by flow-banded plagioclase blades, colourless clinopyroxene and rare orthopyroxene, with minor opaque oxide. In the more siliceous samples, clinopyroxene is noticeably greener, and feldspar is more albitic, than in more mafic rocks.

*Matsue Formation*

Five of the six basalt members of the Matsue Formation recognised by Miyajima *et al.* (1972) have been collected. Particular emphasis was placed on sampling from the two basalt types comprising this formation-those carrying hornblende phenocrysts and conspicuous groundmass biotite, and those with olivine phenocrysts and rare biotite. Samples 17 and 19 are both weakly porphyritic and contain acicular phenocrysts of brown amphibole (up to 3.5 mm) often completely replaced by opaque oxide. The groundmass is a felted mass of plagioclase with opaque oxide, biotite flakes and rare amphibole.

Samples 18, 20, 21, and 22 have rare groundmass biotite (conspicuous in 18), but the phenocrysts are (occasionally spongy) plagioclase and partly resorbed olivine (up to 3.5 mm) with rare pale pink to colourless clinopyroxene, that are set in a coarse-grained groundmass of plagioclase laths, rare olivine (frequently altered), clinopyroxene and opaque oxide.

*Volcanics of Oki Dozen Island.*

Although igneous rocks from Oki Dogo Island have been extensively studied (Tomita, 1935; Uchimizu, 1966; Takahashi, 1978) there have been comparitively few studies of Oki Dozen Island (but see Kaneko *et al.,* 1983). Four basaltic flows and one dike (from the Ab unit) and one trachyte dike (from the Tr unit) have been examined in detail. The flows and basaltic dike are all porphyritic and holocrystalline, comprising phenocrysts of pale pink, unzoned clinopyroxene (occasionary enclosing opaque oxide), oscillatory-zoned plagioclase (up to 3 mm), and rare olivine (partly replaced by a brown alteration product). Feldspar laths dominate the groundmass, partly enclosed by biotite flakes (rare in 55 (Hongo-Kuniga)), and accompanied by granular pale pink to colourless clinopyroxene. The dike from the Tr member (50 (Hongo-Tsutenkyo)) is trachytic, comprising single-twinned alkali feldspar laths (occasionally with partly resorbed plagioclase cores), commonly aggregated with green, subhedral and unzoned clinopyroxene. The groundmass is a flow-banded mass of feldspar with granular green clinopyroxene.

*Wakurayama Andesite*

This weakly porphyritic rocks has flow-banded, simple twinned laths of feldspar occasionally enclosing subhedral clinopyroxene (?rare orthopyroxene) with accessory biotite and opaque oxide. Based on form, rare aggregates of opaque oxide are the result of replacement of amphibole phenocrysts.

*Yasugi Basalts*

This term refers to Pleistocene basalt ($B_1$) south of Yasugi. Two samples have been analysed. Sample 36A (S of Ijiri) carries the only ultramafic inclusions recovered in this study, which comprise metamorphic-textured clinopyroxene/orthopyroxene/olivine (up to 1 cm diameter), and are thus not cognate. The host comprises phenocrysts of olivine and clinopyroxene (some large and partly resorbed grains are treated as fragments of disaggregated inclusions) set in a groundmass of feldspar, with opaque oxide, grains of amphibole and occasional biotite flakes. Elongate cavities in the rock (up to 6 cm long) frequently contain biotite flakes up to 3 mm long. Sample 37 (SE of Suminowa) is similar, but lacks inclusions and has less clinopyroxene.

*Daikon Jima Basalt*

Pleistocene basalt on Daikon Jima Island in Nakaumi Lagoon ($B_3$) is vesicular and infrequentry contains intersertal glass. Phenocrysts are slightly embayed olivine (up to 2.5 mm) and unzoned plagioclase laths (up to 2 mm). These, and rare microphenocrysts of plagioclase are set in a groundmass of plagioclase (enclosing clinopyroxene), opaque oxide and rare olivine. Miura (1974) recorded groundmass pigeonite from basalt on Daikon Jima, but none has been identified in this study.

## Major Element Chemistry

*Sample Selection*

Each sample selected for analysis was examined petrographically prior to crushing, with samples exhibiting excessive alteration (more than 3 volume%) rejected, although these criteria were slightly relaxed for Omori Formation and Dolerite which come from the 'Green Tuff' belt, notorious for its secondary mineral content (Isshiki, 1972; Sugimura & Uyeda, 1973). Samples were mechanically chipped to less than $1 \times 1 \times 1$ cm and inspected for alteration. Chips were ground for 20 minutes at 500 rpm in a Retsch centrifugal ball mill, yielding between 50 and 100g of powder.

Major element oxides were determined on glass discs prepared by fusion of $0.7 \pm 0.0002$ g of rock powder with $3.5 \pm 0.0002$ g of di-lithium tetraborate flux ($Li_2B_4O_7$; MERCK Spectromelt A–10). Fusion was carried out by thermal emission in a Au-Pd crucible. X-ray fluorescence analysis was made on a JEOL JSX–S7 fully automatic spectrometer in the Geology Department, Shimane University. Operating conditions have been described elsewhere (Kobayashi *et al.,* 1981).

Each unknown sample was analysed in duplicate, along with one of the two Geological Survey of Japan rock standards JB–1 (basalt) or JG–1 (granodiorite). JB–1 was most frequently used as it most closely approaches the composition of samples studied. Agreement between duplicates was excellent, as was agreement between analysed and expected values of the two standards (Table 1). Most expected values fall well within $\pm 2$ sd of the mean of results from this study.

Total volatile content was estimated by heating approximately 0.1g of powder at

Table 2. XRF major element oxide analyses made in the Geology Department, Shimane University. CIPW norms calculated on an anhydrous basis recalculated to 100% with $Fe_2O_3$: FeO standardised at 0.3 if the titrated value exceeded this.

| Analysis Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number | 43 | 47 | 9A | 46 | 44 | 68 | 23 | 30 | 28 | 31 | 27A | 26 |
| $SiO_2$ | 52.91 | 71.21 | 58.33 | 73.29 | 58.70 | 62.74 | 50.86 | 49.78 | 49.33 | 50.36 | 59.17 | 53.17 |
| $TiO_2$ | 1.26 | 0.90 | 1.38 | 0.64 | 1.37 | 0.81 | 1.14 | 0.95 | 0.94 | 1.46 | 1.29 | 1.40 |
| $Al_2O_3$ | 18.23 | 13.66 | 16.02 | 12.73 | 15.50 | 14.92 | 17.21 | 19.42 | 19.95 | 18.74 | 14.49 | 15.63 |
| $Fe_2O_3$ | 4.07 | 1.25 | 3.30 | 1.38 | 2.67 | 3.54 | 3.90 | 2.49 | 2.71 | 3.23 | 4.16 | 5.96 |
| FeO | 4.57 | 1.55 | 3.38 | 1.12 | 5.09 | 3.06 | 4.84 | 4.89 | 4.49 | 5.69 | 4.96 | 4.91 |
| MnO | 0.17 | 0.06 | 0.20 | 0.04 | 0.23 | 0.11 | 0.25 | 0.12 | 0.12 | 0.15 | 0.27 | 0.17 |
| MgO | 3.55 | 0.14 | 2.59 | 0.24 | 2.62 | 1.93 | 4.58 | 4.77 | 4.55 | 3.36 | 3.25 | 4.59 |
| CaO | 8.87 | 3.03 | 5.68 | 2.29 | 5.63 | 5.12 | 9.20 | 11.21 | 11.19 | 9.44 | 5.34 | 7.00 |
| $Na_2O$ | 3.58 | 4.32 | 3.78 | 4.22 | 4.01 | 3.70 | 3.30 | 3.05 | 3.10 | 3.50 | 2.96 | 2.84 |
| $K_2O$ | 0.85 | 1.78 | 1.40 | 2.18 | 1.60 | 0.88 | 0.69 | 0.61 | 0.68 | 0.73 | 0.94 | 0.70 |
| $P_2O_5$ | 0.26 | 0.31 | 0.39 | 0.18 | 0.50 | 0.18 | 0.25 | 0.18 | 0.18 | 0.29 | 0.30 | 0.23 |
| LOI | 2.24 | 1.40 | 3.88 | 1.74 | 2.34 | 2.44 | 3.11 | 2.86 | 3.03 | 3.02 | 3.78 | 4.09 |
| TOTAL | 100.56 | 99.61 | 100.33 | 100.05 | 100.26 | 99.43 | 99.33 | 100.33 | 100.27 | 99.97 | 100.91 | 100.69 |
| Q | 3.43 | 33.03 | 14.09 | 35.36 | 12.18 | 22.35 | 1.73 | - | - | 0.99 | 18.94 | 8.75 |
| C | - | - | - | - | - | - | - | - | - | - | - | - |
| Or | 5.08 | 10.69 | 8.54 | 13.09 | 9.60 | 5.34 | 4.21 | 3.68 | 4.11 | 4.42 | 5.69 | 4.26 |
| Ab | 30.65 | 37.16 | 33.03 | 36.28 | 34.45 | 32.17 | 28.86 | 26.33 | 26.84 | 30.35 | 25.64 | 24.74 |
| An | 31.53 | 12.83 | 23.35 | 9.50 | 19.87 | 22.09 | 31.12 | 38.26 | 39.41 | 34.09 | 24.03 | 28.65 |
| Ne | - | - | - | - | - | - | - | - | - | - | - | - |
| Woll (Di) | 4.71 | 0.16 | 1.30 | 0.35 | 2.16 | 1.17 | 6.00 | 7.22 | 6.76 | 4.99 | 0.45 | 2.32 |
| En (Di) | 2.25 | 0.02 | 0.63 | 0.08 | 0.95 | 0.47 | 3.12 | 4.07 | 3.79 | 2.31 | 0.20 | 1.12 |
| Fs (Di) | 2.39 | 0.15 | 0.65 | 0.30 | 1.21 | 0.71 | 2.71 | 2.85 | 2.70 | 2.63 | 0.25 | 1.17 |
| En (Hy) | 6.70 | 0.33 | 6.03 | 0.53 | 5.68 | 4.47 | 8.67 | 5.70 | 3.77 | 6.26 | 8.09 | 10.65 |
| Fs (Hy) | 7.13 | 2.14 | 6.28 | 1.96 | 7.26 | 6.84 | 7.54 | 4.00 | 2.69 | 7.14 | 10.18 | 11.14 |
| Fo (Ol) | - | - | - | - | - | - | - | 1.65 | 2.83 | - | 3.31 | - |
| Fa (Ol) | - | - | - | - | - | - | - | 1.28 | 2.22 | - | 2.51 | - |
| Mt | 3.10 | 1.01 | 2.44 | 0.89 | 2.83 | 2.39 | 3.21 | 2.71 | 2.64 | 3.28 | 3.31 | 3.93 |
| Ilm | 2.42 | 1.74 | 2.71 | 1.23 | 2.64 | 1.58 | 2.24 | 1.84 | 1.83 | 2.84 | 2.51 | 2.74 |
| Ap | 0.61 | 0.73 | 0.93 | 0.42 | 1.18 | 0.43 | 0.60 | 0.43 | 0.43 | 0.69 | 0.71 | 0.55 |
| $Mg^{\#}$ | 47.3 | 9.8 | 46.0 | 17.5 | 42.2 | 39.2 | 53.5 | 58.2 | 57.8 | 44.9 | 43.8 | 48.2 |

| Analysis Number | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number | 1 | 3 | 69 | 64 | 6 | 32 | 66 | 24 | 17 | 18 | 19 |
| $SiO_2$ | 52.51 | 48.03 | 52.50 | 45.78 | 52.41 | 49.46 | 49.08 | 63.21 | 52.77 | 48.17 | 54.82 |
| $TiO_2$ | 1.47 | 0.67 | 1.08 | 0.73 | 1.09 | 1.59 | 1.57 | 0.35 | 1.52 | 1.96 | 1.05 |
| $Al_2O_3$ | 16.57 | 16.55 | 16.44 | 16.87 | 16.67 | 16.77 | 14.75 | 17.49 | 16.46 | 17.46 | 18.00 |
| $Fe_2O_3$ | 5.38 | 3.13 | 6.22 | 4.37 | 5.34 | 4.85 | 5.26 | 1.90 | 4.10 | 4.24 | 3.36 |
| FeO | 4.78 | 5.51 | 4.87 | 4.71 | 3.92 | 5.48 | 8.11 | 2.05 | 2.81 | 3.65 | 2.89 |
| MnO | 0.29 | 0.17 | 0.17 | 0.20 | 0.16 | 0.22 | 0.20 | 0.07 | 0.09 | 0.13 | 0.23 |
| MgO | 3.19 | 8.32 | 4.56 | 8.10 | 4.51 | 4.06 | 5.49 | 1.78 | 3.70 | 5.52 | 3.36 |
| CaO | 7.50 | 10.21 | 8.10 | 11.06 | 8.59 | 9.91 | 6.53 | 5.20 | 7.58 | 8.05 | 7.24 |
| $Na_2O$ | 3.42 | 2.34 | 2.77 | 2.03 | 2.55 | 2.86 | 4.74 | 4.12 | 4.09 | 3.61 | 3.89 |
| $K_2O$ | 0.73 | 0.30 | 0.25 | 0.31 | 0.92 | 0.72 | 0.46 | 1.17 | 3.36 | 2.06 | 1.70 |
| $P_2O_5$ | 0.22 | 0.17 | 0.18 | 0.10 | 0.16 | 0.28 | 0.13 | 0.13 | 1.20 | 0.67 | 0.32 |
| LOI | 3.03 | 4.52 | 3.42 | 4.83 | 4.49 | 3.53 | 4.28 | 1.57 | 2.17 | 4.38 | 3.22 |
| TOTAL | 99.09 | 99.92 | 100.56 | 99.09 | 100.81 | 99.73 | 100.60 | 99.04 | 99.85 | 99.90 | 100.08 |
| Q | 6.49 | - | 7.74 | - | 7.11 | 2.13 | - | 19.67 | - | - | 4.69 |
| C | - | - | - | - | - | - | - | 0.31 | - | - | - |
| Or | 4.47 | 1.85 | 1.51 | 1.93 | 5.62 | 4.40 | 2.80 | 7.08 | 20.26 | 12.69 | 10.34 |
| Ab | 29.96 | 20.62 | 24.00 | 18.12 | 22.30 | 25.00 | 41.25 | 35.68 | 35.32 | 30.23 | 33.87 |
| An | 28.68 | 35.17 | 32.44 | 37.99 | 32.37 | 31.81 | 18.12 | 25.54 | 16.97 | 26.43 | 27.41 |
| Ne | - | - | - | - | - | - | - | - | - | - | - |
| Woll) | 3.49 | 6.86 | 3.13 | 8.02 | 4.42 | 7.13 | 5.98 | - | 5.60 | 4.44 | 3.09 |
| En ) Di | 1.46 | 4.28 | 1.46 | 4.91 | 2.25 | 3.35 | 2.80 | - | 3.15 | 2.75 | 1.66 |
| Fs ) | 2.05 | 2.17 | 1.64 | 2.66 | 2.07 | 3.70 | 3.12 | - | 2.22 | 1.43 | 1.33 |
| En ) | 6.77 | 12.50 | 10.17 | 7.03 | 9.36 | 7.09 | 0.13 | 4.54 | 0.99 | - | 6.95 |
| Fs ) Hy | 9.52 | 6.34 | 11.41 | 3.80 | 8.62 | 7.82 | 0.14 | 4.77 | 0.70 | - | 5.59 |
| Fo ) | - | 3.37 | - | 6.54 | - | - | 7.80 | - | 3.69 | 8.11 | - |
| Fa ) Ol | - | 1.88 | - | 3.90 | - | - | 9.57 | - | 2.86 | 4.65 | - |
| Mt | 3.70 | 3.22 | 3.98 | 3.39 | 3.35 | 3.78 | 4.91 | 1.43 | 2.47 | 2.89 | 2.26 |
| Ilm | 2.89 | 1.33 | 2.10 | 1.46 | 2.14 | 3.12 | 3.07 | 0.68 | 2.95 | 3.88 | 2.05 |
| Ap | 0.53 | 0.41 | 0.43 | 0.24 | 0.38 | 0.67 | 0.31 | 0.31 | 2.84 | 1.62 | 0.76 |
| Mg# | 40.9 | 67.6 | 47.6 | 66.1 | 51.9 | 46.2 | 47.1 | 49.7 | 54.3 | 60.7 | 54.2 |

| Analysis Number | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Number | 20 | 21 | 22 | 51 | 50 | 54 | 55 | 56 | 57 | 14 | 15 | 36A | 37 |
| $SiO_2$ | 51.83 | 49.80 | 48.53 | 52.73 | 65.23 | 53.16 | 46.67 | 49.94 | 48.45 | 50.69 | 48.97 | 50.23 | 50.48 |
| $TiO_2$ | 1.09 | 1.60 | 1.77 | 1.81 | 0.36 | 2.28 | 3.49 | 2.66 | 3.75 | 1.68 | 1.94 | 0.91 | 0.85 |
| $Al_2O_3$ | 16.36 | 16.60 | 17.14 | 19.07 | 16.97 | 16.86 | 16.18 | 18.12 | 15.97 | 16.40 | 15.59 | 16.28 | 16.92 |
| $Fe_2O_3$ | 3.11 | 4.05 | 5.32 | 3.41 | 2.48 | 5.24 | 8.09 | 3.98 | 4.24 | 3.08 | 4.07 | 4.19 | 3.09 |
| FeO | 3.74 | 3.91 | 4.52 | 3.07 | 0.95 | 3.13 | 2.29 | 4.51 | 6.43 | 7.17 | 6.11 | 3.67 | 4.09 |
| MnO | 0.11 | 0.12 | 0.49 | 0.13 | 0.08 | 0.15 | 0.14 | 0.14 | 0.15 | 0.15 | 0.16 | 0.10 | 0.13 |
| MgO | 8.02 | 7.89 | 3.73 | 2.88 | 0.17 | 3.48 | 4.59 | 3.26 | 4.69 | 6.73 | 6.87 | 8.27 | 9.49 |
| CaO | 7.34 | 7.12 | 8.26 | 6.30 | 0.97 | 5.42 | 8.04 | 7.72 | 7.58 | 8.85 | 9.45 | 9.71 | 8.89 |
| $Na_2O$ | 3.55 | 3.74 | 3.75 | 4.19 | 5.54 | 3.96 | 3.20 | 3.80 | 2.91 | 3.55 | 3.07 | 4.33 | 3.61 |
| $K_2O$ | 1.49 | 1.52 | 1.19 | 3.28 | 5.95 | 3.83 | 2.10 | 2.48 | 2.71 | 0.46 | 1.07 | 1.51 | 1.03 |
| $P_2O_5$ | 0.23 | 0.43 | 0.37 | 0.69 | 0.04 | 0.85 | 0.74 | 0.76 | 0.69 | 0.23 | 0.30 | 0.61 | 0.32 |
| LOI | 3.35 | 3.62 | 5.11 | 2.56 | 2.04 | 2.47 | 4.11 | 2.38 | 2.96 | 1.38 | 1.45 | 0.88 | 0.94 |
| TOTAL | 100.22 | 100.40 | 100.18 | 100.12 | 100.78 | 100.83 | 99.64 | 99.75 | 100.53 | 100.37 | 99.05 | 100.69 | 99.84 |
| Q | - | - | - | - | 6.47 | - | - | - | - | - | - | - | - |
| C | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Or | 9.05 | 9.24 | 7.36 | 19.80 | 35.57 | 22.93 | 12.96 | 14.97 | 16.29 | 2.72 | 6.43 | 8.90 | 6.13 |
| Ab | 30.88 | 32.55 | 33.20 | 36.22 | 47.43 | 33.95 | 28.27 | 32.85 | 25.05 | 30.10 | 26.43 | 24.73 | 30.75 |
| An | 24.98 | 24.71 | 27.65 | 24.05 | 3.91 | 17.14 | 24.62 | 25.61 | 22.90 | 27.52 | 26.05 | 20.48 | 27.10 |
| Ne | - | - | - | - | - | - | - | - | - | - | - | 6.41 | - |
| Woll) | 4.55 | 3.65 | 5.30 | 1.37 | 0.29 | 1.87 | 5.00 | 3.53 | 4.50 | 6.25 | 8.21 | 9.86 | 6.34 |
| En ) Di | 3.08 | 2.42 | 2.45 | 0.74 | 0.03 | 0.99 | 2.88 | 1.86 | 2.56 | 3.60 | 4.86 | 6.43 | 4.34 |
| Fs ) | 1.12 | 0.97 | 2.80 | 0.58 | 0.29 | 0.82 | 1.89 | 1.57 | 1.75 | 2.37 | 2.94 | 2.74 | 1.50 |
| En ) | 10.51 | 3.79 | 3.02 | 2.52 | 0.40 | 5.20 | 2.30 | 1.76 | 5.99 | 9.06 | 5.17 | - | 0.24 |
| Fs ) Hy | 3.83 | 1.51 | 3.46 | 1.97 | 3.63 | 4.30 | 1.51 | 1.49 | 4.10 | 5.95 | 3.13 | - | 0.08 |
| Fo ) | 4.87 | 9.82 | 2.98 | 2.85 | - | 1.81 | 4.73 | 3.28 | 2.34 | 2.90 | 5.18 | 9.89 | 13.46 |
| Fa ) Ol | 1.96 | 4.32 | 3.75 | 2.44 | - | 1.65 | 3.42 | 3.05 | 1.76 | 2.10 | 3.46 | 4.65 | 5.13 |
| Mt | 2.50 | 2.89 | 3.62 | 2.33 | 1.20 | 2.96 | 3.71 | 3.07 | 3.88 | 3.70 | 3.70 | 2.76 | 2.57 |
| Ilm | 2.13 | 3.13 | 3.52 | 3.51 | 0.69 | 4.39 | 6.92 | 5.16 | 7.25 | 3.20 | 3.75 | 1.72 | 1.62 |
| Ap | 0.55 | 1.02 | 0.90 | 1.63 | 0.09 | 2.00 | 1.79 | 1.80 | 1.63 | 0.53 | 0.71 | 1.41 | 0.75 |
| Mg# | 71.9 | 68.5 | 45.5 | 49.4 | 10.0 | 48.0 | 50.0 | 45.6 | 48.8 | 58.5 | 59.4 | 69.9 | 74.2 |

>1000°C for 15 minutes in a platinum crucible. This value is expressed as LOI (i.e. loss on ignition). FeO was determined by titration with $KMnO_4$ solution (modified Pratt method; Maxwell, 1968), with frequent checks using JB–1.

## Results

Analyses are presented in Table 2, as hydrous totals (i.e. with LOI) and FeO and $Fe_2O_3$ as measured. In order to partly compensate for the effects of post-magmatic oxidation and to allow rapid visual comparison, CIPW weight percent norms have been calculated on an anhydrous basis, with $Fe_2O_3$: FeO standardised at 0.3 (Gill, 1981; Basaltic Volcanism Study Project, 1981) in those samples in which the measured ratio exceeded this value. The effect of lowering the $Fe_2O_3$: FeO ratio is to reduce *mt*, thereby releasing more $Fe^{2+}$ for *ol*, and eventually producing a more undersaturated norm. The most extreme example of changing this ratio and its effect on the norm is provided by sample 55 (Oki Dozen Volcanics): with $Fe_2O_3$: FeO= 0.3, the norm contains 6.45 wt% *ol* and 4.95 wt% *hy*. Recalculating the norm using the measured $Fe_2O_3$: FeO ratio (3.53) results in no *ol*, 8.67 wt% *hy* and 0.54 wt% *Q*. If high $Fe_2O3$: FeO rations result form post-magmatic alteration, then their should be some correlation between this ratio and LOI. As this is not the case, it is assumed that at least part of the $Fe_2O_3$:FeO values are of magmatic origin.

Dolerites are all silica saturated (i.e. *hy* normative) and eight samples contain

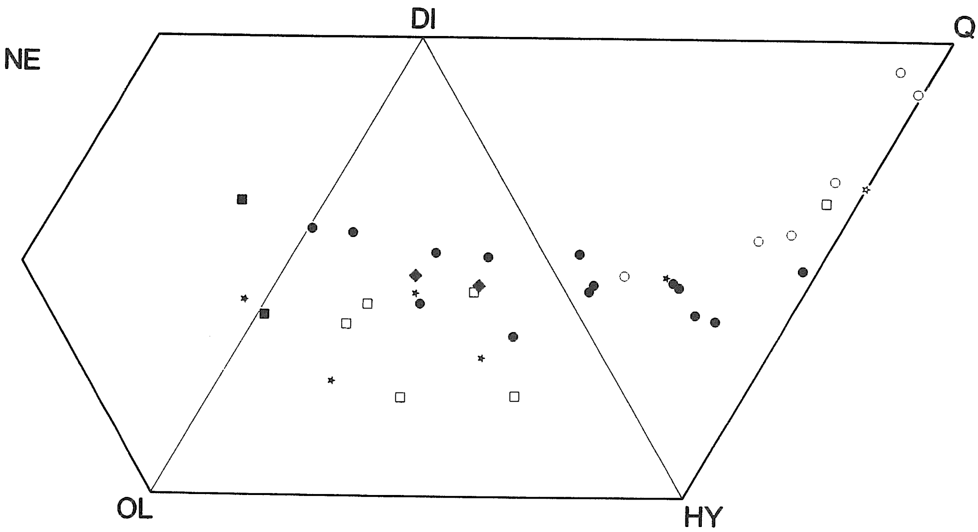


Figure 2. Analysed samples plotted on part of the basalt tetrahedron in terms of CIPW normative components. Symbols; closed circles-Dolerites; open circles-Omori Formation; closed stars-Matsue Formation; open star-Wakurayama Andesite; open squares-Oki Dozen Volcanics; closed diamonds-Daikon jima Basalt; closed squares-Yasugi Basalt.

normative quartz (*Q*) (Fig. 2). The Matsue Formation samples show the widest range in degree of saturation, from nepheline (18) through to quartz normative (19). Oki Dozen volcanics contain *hy*, and trachyte dike 50 contains *Q*. Yasugi Basalts are either undersaturated or only weakly silica saturated, whereas both samples from Daikon Jima contain *hy*.

Petrographic classification of rocks is difficult if groundmass compositions are unresolvable with the microscope (Wilkinson, 1974), hence a chemical classification is employed in this study (but see grain size classification of Dolerites).

In Fig. 3, analyses have been plotted in terms of (anhydrous) total alkalies (i.e. $Na_2O+K_2O$) vs $SiO_2$ (wt%). The alkaline/subalkaline division is after Miyashiro (1978). All Omori Formation samples, the Wakurayama Andesite, and all but one of the Dolerites (66 (Yokan)) are subalkaline. All Oki Dozen Volcanics are clearly alkaline, but samples of the Daikon Jima Basalt and the Yasugi Basalts plot close to the boundary, and are therefore termed 'transitional'. Fig. 4 shows that biotite-rich rocks of the Matsue Formation (notably sample 17) have accordingly high $K_2O/Na_2O$ ratios. With increasing alkalies content, Oki Dozen volcanics trend to more potassic compositions.

The subalkaline rocks have been further divided using the $FeO^*/MgO$ vs $SiO_2$ diagram of Miyashiro (1974) as shown in Fig. 5. Omori Formation samples and Dolerites show a change from tholeiitic to calc-alkaline with increasing $SiO_2$, whereas the Wakurayama Andesite is clearly calc-alkaline. Also plotted are 'subalkaline'

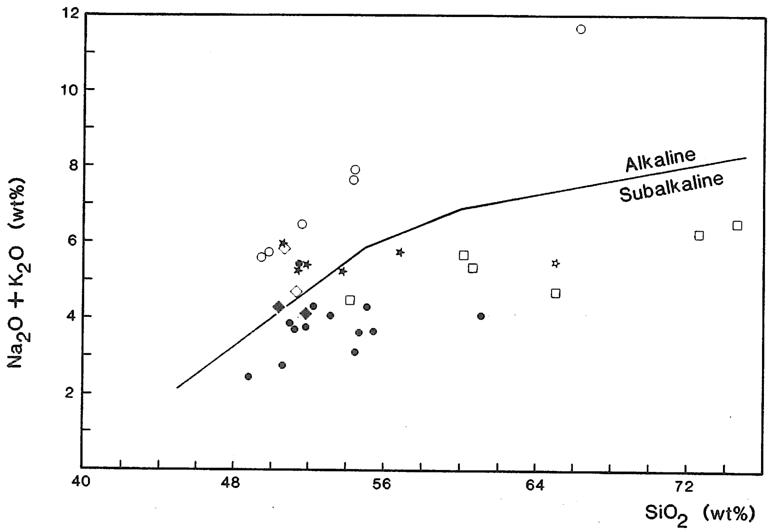


Figure 3. Total Alkalies vs $SiO_2$. Alkaline/subalkaline discriminant line from Miyashiro (1978). Symbols: closed circles-Dolerites; open squares-Omori Formation; open stars-Wakurayama Andesite; open circles-Oki Dozen Volcanics; closed stars-Matsue Formation; open diamonds-Yasugi Basalt; closed diamonds-Daikon Jima Basalt.

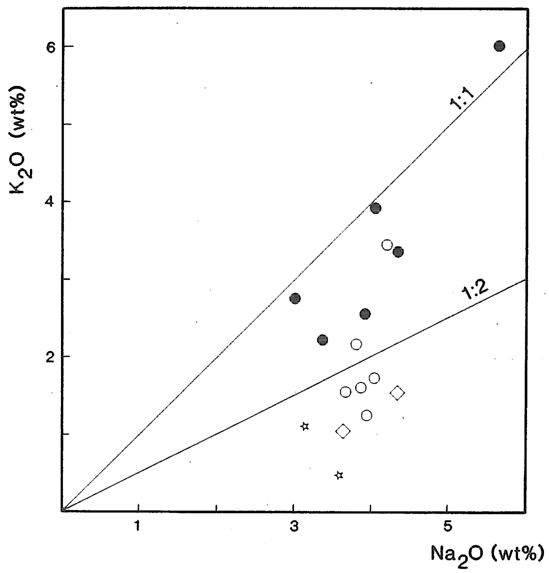


Figure 4. Alkaline volcanics plotted in terms of $K_2O$ and $Na_2O$. Symbols; -closed circles-oki Dozen Volcanics; open circles-Matsue Formation; open stars-Daikon Jima Basalt; open diamonds-Yasugi Basalt.

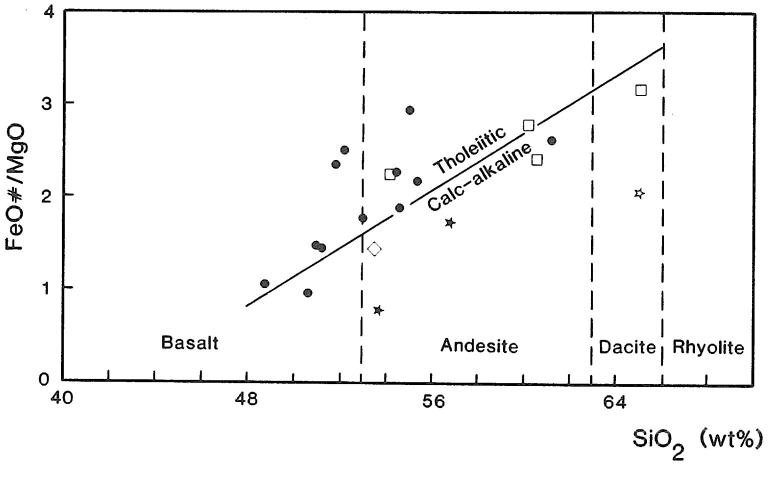


Figure 5. Subalkaline rocks ($SiO_2$<70 wt%) plotted in terms of FeO£/MgO (i.e all Fe as FeO) vs $SiO_2$. Tholeiitic/calc-alkaline discriminant from Miyashiro (1974). Symbols as for Fig. 3.

members of the Matsue Formation, Daikon Jima Basalt, and Yasugi Basalt, all of which plot in the calc-alkaline field.

Chemical variations are further illustrated on the AFM diagram (Fig 6), in which analyses fall into two broad areas: those between Kuno's (1968) hypersthenic and pigeonitic trends (Dolerites, Omori Formation, Oki Dozen Volcanics, Daikon Jima

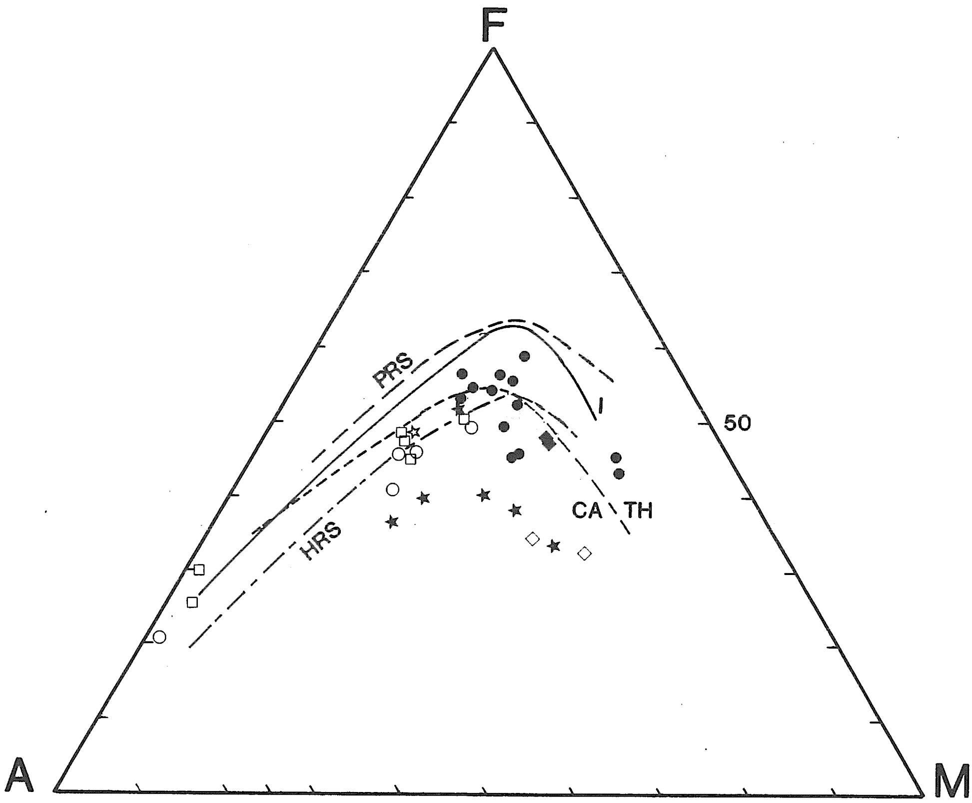


Figure 6. Ternary AFM diagram. Symbols as for Fig. 3. CA/TH-separation of calc-alkaline and tholeiitic rocks (Irvine & Baragar, 1971). PRS and HRS-Pigeonitic and hypersthenic trends from Japan (Kuno, 1968). I-Iceland trend from Thingmuli (Carmichael, 1964).

Basalts) and the remainder plotting well below the hypersthenic trend (Matsue Formation, apart from 17, and the Yasugi Basalts). As Mg (i.e. $100\,Mg/(Mg+Fe^{2+})$) is usually less than 60, few basalts show source chemical characteristics (cf Frey *et al.*, 1978), although the ultramafic xenolith-bearing Yasugi Basalt has a Mg* of 69.9.

$TiO_2$ differs markedly in concentrarion between within-plate alkalic rocks, and volcanics produced at plate margins (Basaltic Volcanism Study Project, 1981), and MgO is a good indicator of fractionation. On Fig. 5, for the alkalic trend (alkalic basalt-trachyte from Hawaii: Basaltic Volcanism Study Project, 1981), $TiO_2$ intially increases with decreasing MgO, then both $TiO_2$ and MgO decrease for intermediate to trachytic rocks. As $TiO_2$ is not an important component in island arc basalts, it shows little change in concentration from basaltic to dacitic rocks. As expected, analyses from the Oki Dozen Volcanics broadly parallel the alkalic trend. However, all other analyses lie between the alkalic and island arc trends (apart from the Wakurayama Andesite), with Dolerites showing weak $TiO_2$ enrichment with initial

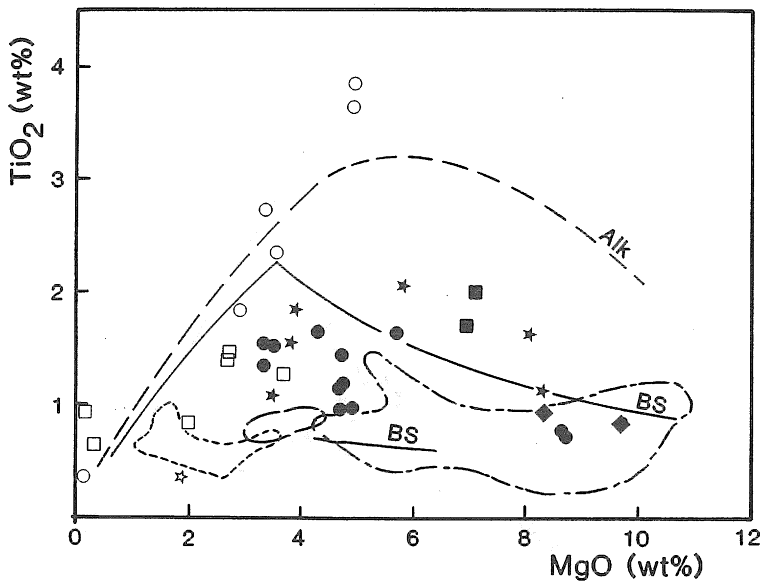


Figure 7. $TiO_2$ vs MgO. Symbols: -closed circles-Dolerites; open squares-Omori Formation; open stars-Wakurayama Andesite; closed stars-Matsue Formation; open circles-Oki Dozen Volcanics; closed diamonds-Yasugi Basalt; closed squares-Daikon Jima Basalt.
Trends: Alk-alkaline intra-plate reference suite (Basaltic Volcanism Study Project, 1981; Table 1, 2, 6, 2.). BS-Quaternary volcanics from Bransfield Strait (Weaver *et al.*, 1979).
Fields: dash-dot-island arc basalt refernce suite (Basaltic Volcanism Study Project, 1981; Table 1, 2, 7, 3.). Long dash-average orogenic andesites (Gill, 1981; Table 5, 1). Short dash line-dacites, Central North Island, New Zealand (Reid & Cole, 1983).

decrease in MgO, a trend broadly parallelled by that of Quaternary alkalic-calc-alkalic rocks from Bransfield Strait (Weaver *et al.*, 1979).

## Discussion

The Oki Dozen Volcanics show a characteristic alkalic mineralogy and chemistry, which can be explained by low-pressure fractional crystallisation of mafic then felsic minerals (cf Morris, 1984). The setting of these volcanics suggests that they are not related to subduction, but probably result from a mantle plume. However Nakamura *et al.* (1985) —with the additional benefit of trace element data— have suggested that the Oki Volcanics show characteristics of a mantle plume contaminated by island-arc-type material. The mineralogy and chemistry of the Wakurayama Andesite points to subduction-related volcanism (Gill, 1981). Although analyses from the Omori Formation and Dolerites are also subalkaline (Fig. 4), they are dominantly tholeiitic, apart from a trend at higher $SiO_2$ levels towards being calc-alkalic (Fig. 4). However, in terms of Fig. 8, these and the more transitional members analysed (i.e. Daikon Jima Basalts, Matsue Formation, Yasugi Basalts) show chemical characteristics of both alkalic and island arc volcanic rocks (cf Bransfield Strait: Weaver *et al.*, 1979). The parallels between Bransfield Strait lavas and those of this study is not surprising, as both Bransfield Strait and the Japan Sea are examples of ensialic back arc basins (Karig, 1971; Honza, 1983) and both periods of volcanic activity coincide with basin opening. Thus it appears that the process of back-arc rifting produces a wide range of volcanic rocks types contemporaneously. Such a spread in compositions is well illustrated by samples analysed from the Matsue Formation, which were erupted contemporaneously (Morris *et al.*, in press) and in close proximity (Miyajima *et al.*, 1972). It is possible that processes such as aqueous fluid transport and magma/periodotite hydridisation above the downgoing oceanic slab beneath the eastern Shimane area can account for the range in composition (cf Wyllie & Sekine, 1983), although such hypothese must wait for trace element and isotopic data to be more rigorously tested.

In a recent paper, Tsunakawa (1986) has assessed the Neogene stress field in SW Japan. He identified 4 periods of stress change (at approximately 15 Ma, 12 Ma, 9 Ma, and 1 Ma) and noted the coincidence of igneous activity with each period. These clearly equate with Omori Formation + Dolerites (15 Ma), Matsue Formation (9 Ma), and eruption of basaltic rocks at Yasugi and Daikon Jima Island (1 Ma). As discussed above, the opening of the Japan Sea coincides with Omori Formation + Dolerite igneous activity, and as Tsunakawa (1986) has noted, stress fields are strongly correlated with such occurrences as back-arc spreading.

Thus, Miocene to Recent igneous activity in the Shimane-Oki region involves the interplay of subduction, back-arc spreading, stress-field chages, and the ongoing compositional modification of the mantle zone from which the magmas were derived.

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## Appendix 1.

Location and Petrography of Analysed Samples.

*Dolerites.*

1. Dolerite. Massive outcrop in road-cutting SE of Kitaura, Shimane Peninsula. Lat: 35°33′5″. Long: 133°9′53″.

Colorless to pale green unzoned clinopyroxene (up to 0.4 mm) enclose anhedral opaque oxide, which is in turn enclosed by oscillatory-zoned plagioclase (up to 2.5 mm), containing acicular apatite. Minor alteration of clinopyroxene to mica, and rare saponite.

3. Gabbro. Massive outcrop on coast W of Sasago, Shimane Peninsula. Lat: 35°33′58″. Long: 133°12′18″.

Anhedral grains of unzoned clinopyroxene (3.5 mm) and rare orthopyroxene enclose intensely-zoned plagioclase and opaque orthopyroxene enclose intensely-zoned plagioclase and opaque oxide. Accessory apatite. Occasional patches of secondary white and green mica. Possible remnants after olivine.

6. Basalt. ?Dike at road intersection, SE of Kitaura, Shimane Peninsula. Lat: 35°32′56″.

Coarsely crystalline, weakly porphyritic rock. Pale green clinopyroxene phenocrysts are rare, unzoned and euhedral. Plagioclase (4 mm) is occasionally spongy and often aggregated with clinopyroxene. Phenocrysts and opaque oxide microphenocrysts are set in a groundmass of plagioclase, clinopyroxene, and opaque oxide. Occasional alteration patches of calcite and brown micaeous material.

23. Basalt. Road cutting SW of Hijira, E of Matsue City. Lat: 35°24′52″. Long: 133°11′12″.

Weakly porphyritic, moderately coarse-grained rock. Phenocrysts of plagioclase (3.5 mm) are euhedral and fresh, although some are strongly resorbed and mantled with spongy feldspar or completely spongy. The groundmass is a coarse admixture of anhedral colorless clinopyroxene,party enclosed by plagioclase and opaque oxide. Saponite alteration occasionally between grains.

26. Dolerite. Corestone of well-jointed outcrop in hill at back of orchard, N of Nobara, W side of Nakaumi Lagoon. Lat: 35°31′25″. Long: 133°9′3″.

Weakly porphyritic, coarse-grained rock. Rare phenocrysts of plagioclase (<1.5 mm) are usually clustered with colorless to very pale green and unzoned clinopyroxene plus some opaque oxide granules. The groundmass is a felted mass of plagioclase laths, partly enclosed by clinopyroxene, which contains opaque oxide granules. Small patches of saponitic alteration.

27A. Basalt. Road cutting at Nagami,W side of Nakaumi Lagoon. Lat: 35°31′43″. Long: 133°8′1″.

Weakly porphyritic rock. Slightly cloudy phenocrysts of plagioclase (euhedral, unzoned and up to 1.5 mm) are often aggregated with clinopyroxene (colorless to pale green and unzoned) in a felsic groundmass. Flowage of plagioclase laths around phenocrysts. Possible intersertal alkali feldspar. Mafics are occasionally altered.

28. Dolerite. Hill above Owashi, Shimane Peninsula. Lat: 35°32′48″. Long: 133°2′58″.

Sub- to euhedral grains of plagioclase (4 mm) are intensely zoned on the rim and set in a coarse-grained mixture of unzoned plagioclase (partly enclosing colorless to pale green clinopyroxene) and rare ?orthopyroxene and opaque oxida. Minor leucoxene, and the feldspars are occasionally cloudy.

30. Gabbro. Stream cutting above Owashi, Shimane Peninsula. Lat: 35°32′40″. Long: 133°3′″.

Grains of continuously-zoned plagioclase (3.5 mm) are cracked and slightly cloudy. They are set in a coarse (maximum grain size is 1.3 mm) mass of clinopyroxene, which partly encloses plagioclase. Both are partly enclosed by opaque oxide. Minor chlorite.

31. Gabbro. Road cutting between Kitagaki and Hama, Shimane Peninsula. Lat: 35°33′26″. Long: 133°3′22″.

Texturally inhomogeneous rock with areas of coarse grain size (up to 4 mm) where unzoned plagioclase partly encloses colorless to pale green clinopyroxene.Finer grain size areas comprise smaller plagioclase laths with some surrounding alteration. Interstitial opaque oxide is occasionally spongy.

32. Gabbro. In bank at school entrance, Hama, Shimane Peninsula. Lat: 35°33′30″. Long: 133°3′50″.

Moderately altered medium grain rock. Plagioclase (4.2 mm) is euhedral with a slightly resorbed core and occasional spongy rim, which shows either continuous or oscillatory zoning. Plagioclase encloses pale green unzoned clinopyroxene, which encloses anhedral opaque oxide. Significant interstitial green brown alteration.

64. Gabbro. Massive outcrop intruding Kuri-Kawai Formation at Tai, Shimane Peninsula. Lat: 35°32′24″. Long: 133°58′14″.

Equigranular rock. Colorless to very pale pink unzoned clinopyroxene partly encloses anhedral, continuously-zoned plagioclase. Possible late stage alkali feldspar. Minor olivine (often replaced by serpentine-group mineral). Skeletal opaque oxide is often intergrown with clinopyroxene. Patches of green alteration, and feldspars are occasionally cloudy. Apatite contained in the feldspar.

66. Basalt. Large block adjacent to outcrop on hill at Yokan, NE of Izumo City. Lat: 35°23′43″. Long: 132°43′28″.

Weakly flow-banded, equigranular rock. ltahs and occasional blocks of slightly cloudy plagioclase partly enclose colorless to pale green anhedral and unzoned clinopyroxene and opaque oxide. Interstitial alteration include patches of chlorite and serpentine-group minerals. Minor zeolite and secondary mica.

69. Basalt. Massive outcrop in quarry Asayama, S of Izumo City. 35°19′18″. Long: 132°47′19″.

Microphenocrysts of single-twinned plagioclase (unzoned and slightly resorbed) are set in a moderately coarse-grained groundmass of oriented plagioclase, clinopyroxene, opauqe oxide and slightly altered clinopyroxene. Minor Fe alteration and calcite veining.

*Omori Formation.*

9A. Basalt. Glassy block in diatreme cross-cutting volcaniclastic sediments N of Sezaki, Shimane Peninsula. Lat: 35°35′25′. Long: 133°6′57″.

Hypocrystalline rock comprising phenocrysts of plagioclase, clinopyroxene and opaque oxide in a fine-grained groundmass of plagioclase laths and devitrified brown glass. Plagioclase phenocrysts (2.5 mm) are fresh, euhedral, oscillatory zoned and often aggregated with clinopyroxene and opaque oxide. Colorless unzoned and cracked clinopyroxene is often aggregated with equant opaque oxide. The groundmass consists of thin plagioclase laths, granular colorless clinopyroxene,opaque oxide and minor brown, weakly-anisotropic glass.

43. Basalt. Glassy flow adjacent to rubbly flows, NW of Sanami, Shimane Peninsula. Lat: 35°34′35″. Long: 133°3′38″.

Moderately coarse-grained rock with phenocrysts of plagioclase (3.5 mm) which are show weak continuous zoning and are occasionally spongy. Clinopyroxene microphenocrysts are colorless to very pale green, anhedral and unzoned. Possible alteration after olivine. The groundmass is a coarse, mixture of clinopyroxene, plagioclase, opaque oxide and rare secondary mica.

44. Basalt. Block in water-worked volcaniclastic sediments, Kukedo, Shimane Peninsula. Lat: 35°34′29″. Long: 133°3′3″.

Hyaline rock. Flow-banded, usually single-twinned laths and groundmass grains of plains of plagioclase (intense oscillatory zoning) and rare granular anhedral grains of colorless clinopyroxene are set in brown vesicular glass. Possible olivine remnants.

46. Rhyolite. Glassy flow (?dike) at Katsurajima, Shimane Peninsula. Lat: 35°33′48″. Long: 133°3′8″.

Weakly porphyritic rock comprising subhedral to euhedral unzoned plagioclase laths (occasionally aggregated) up to 1.5 mm long, with rare green clinopyroxene and rare orthopyroxene, and euhedral opaque oxide. Groundmass is devitrified, perlitic glass with aligned feldspar laths.

47. Rhyolite. Sample adjacent to 46, but less glassy. Katsurajima, Shimane Peninsula. Lat: 35°33′48″. Long: 133°3′8″.

Petrographically similar to 46, but more crystalline. Plagioclase microphenocrysts accompany phenocrysts of plagioclase and clinopyroxene, and the groundmass has little glass and significantly more albitic plagioclase. Rare amygdules are infilled with zeolite.

68. Basalt. ?Flow in quarry, Shingu River S of Izumo City (O). Lat: 35°18′24″. Long: 132°44′23″.

Weakly porphyritic rock comprising microphenocrysts of unzoned and weakly pleochroic orthopyroxene, clinopyroxene,and rare unzoned plagioclase. Often all three are intergrown with opaque oxide. Some phenocrysts are slightly resorbed. The groundmass comprises flow-banded laths of plagioclase and slightly altered clinopyroxene with granular opaque oxide.

*Matsue Formation.*

17. Basalt. Flaggy outcrop in road cutting near Higashi Tsuda-cho, Matsue City. Member BL4. Lat: 35°27′4″. Long: 133°5′4″.

Weakly porphyritic rock consisting of rare phenocrysts of acicular brown amphibole (partly replaced by opaque oxide), and bladed clinopyroxene aligned in a felsic groundmass with opaque oxide, biotite and clinopyroxene.

18. Basalt. Columnar jointed flow near Yamashiro Shrine, Matsue City. Member BL2. Lat: 35°26′15″. Long: 133°4′56″.

Weakly porphyritic rock. Rare Phenocrysts of weakly-zoned and blocky plagioclase (up to 2.5 mm), occasionally spongy and slightly altered, with rare slightly pink clinopyroxene phenocrysts. Groundmass is plagioclase, minor olivine, clinopyroxene, and opaque oxide. Minor intersertal biotite.

19. Hornblende-bearing basalt. Jointed, weakly vesicular flow with occasional amphibole crystals. NW of Yada-cho, Matsue City.

Phenocrysts comprise bladed amphibole, which are unzoned and up to 3.5 mm long often with opaque oxide developed on the rim. Plagioclase is spongy, slightly embayed and up to 3 mm. The fine-grained groundmass contains oriented plagioclase with rare clinopyroxene, granular opaque oxide and occasionally secondary calcite patches.

20. Basalt. Small outcrop at rear of shrine, E of Yamashiro-cho, Matsue City. Member BL1. Lat: 35°25′48″. Long: 133°6′3″.

Weakly porphyritic rock. Olivine phenocrysts are up to 3 mm long, subhedral and unzoned. Plagioclase (2 mm) has an outer spongy area rimmed by solid feldspar. The groundmass comprises microphenocrysts of olivine, clinopyroxene, oriented plagioclase laths, and minor leucoxene.

21. Basalt. Flow exposed in road cutting adjacent to tunnel near Metsuki Shrine, Matsue City. Member BL 3. Lat: 35°27′3″. Long: 133°4′3″.

Coarsely crystalline porphyritic rock. Rare olivine phenocrysts are strongly embayed and up to 3.5 mm. Plagioclase occurs as rare euhedral phenocrysts.

The groundmass is a coarse admixture of oreinted plagioclase laths, rare olivine, pale pink to green clinopyroxene (enclosing plagioclase), and rare intersertal biotite.

22. Basalt. Flow adjacent to pottery, Shougi-san, Matsue City. Member BL3. Lat: 35°27′5″. Long: 133°3′15″.

Weakly porphyritic caorse-grained rock. Rare plagioclase phenocrysts are spongy and anhedral, with rare pale pink clinopyroxene. The coarse groundmass comprises plagioclase laths partly enclosed by clinopyroxene, with rare secondary calcite patches, and leucoxene.

*Oki Dozen Volcanics.*

50. Trachyte. 3 m-wide dike cross-cutting ?basalt in road between Hongo and Tsutenkyo. Unit Tr. Lat: 36°5′30″. Long: 132°58′34″.

Oriented, single-twinned and occasionally cracked laths of alkali feldspar (ooccasionally enclosing green anhedral clinopyroxene) sometimes as aggregates. Cores to alkali feldspar are frequently resorbed plagioclase. Groundmass is a felted mass of oriented alkali feldspar laths with green clinopyroxene granules.

51. Basalt. Flow in lowermost part of sequence on caost S of Tsutenkyo. Lat: 36°5′38″. Long: 132°58′2″.

Euhedral phenocrysts of plagioclase (3 mm) are slightly resorbed and show intense oscillatory zoning, usually with a thin, continuously-zoned rim. Phenocrysts of pink, unzoned clinopyroxene (< 1 mm) occasionally enclose opaque oxide. The groundmass comprises biotite microphenocrysts, plagioclase laths, colorless clinopyroxene rods, apatite, and mesostasis feldspar.

54. Basalt. Dike exposed in road cutting between Hongo and Kuniga. Lat: 36°5′46′. Long: 132°59′13″.

Felsic rock, comprising crudely oriented feldspar laths with microphenocrysts of pinkish clinopyroxene, and biotite which subpoikilitically encloses groundmass feldspar. Minor clay alteration.

55. Basalt. Block from rubbly flow between Hongo and Kuniga. Lat: 36°4′48″. Long: 132°58′59″.

Rare, partly-resorbed phenocrysts of olivine and plagioclase are set in a coarse-grained groundmass of plagioclase, minor olivine, clinopyroxene, opaque oxide, and small amounts of secondary alteration. No discernible biotite.

56. Basalt. From towards the top of the sequence between Hongo and Kuniga. Lat: 36°5′56″.

Long: 132°58′45″.

Weakly porphyritic rock comprising unzoned phenocrysts of plagioclase, occasionally aggregated, with rare pale pink clinopyroxene set in a groundmass dominated by feldspar with opaque oxide and plates of biotite (enclosing feldspar).

57. Basalt. Massive, fine-grained flow,with occasional mica flakes. S of Shakunoe. Lat: 36°4′46″. Long: 132°58′28″.

Crudely aligned plagioclase microphenocysts are dominantly single-twinned. Accompanying clinopyroxene is pale green and colorless, sometimes aggregated with opaque oxide. Rare plutonic and sedimentary rock fragments. Abundant groundmass clinopyroxene is accompanied by plagioclase (partly enclosed by biotite), and opaque oxide.

*Wakurayama Andesite.*

24. Hornblende andesite. Massive outcrop in raod cutting, Hirabayashi, N of Matsue City. Lat: 35°28′57″. Long: 133°7′27″.

Flow-banded rock. Rare acicular brown amphibole is almost completely replaced by opaque oxide. Most of the rock comprises fresh, single-twinned laths of feldspar enclosing subhedral clinopyroxene (and weakly-pleochroic orthopyroxene) and occasional biotite, which encloses plagioclase. Very fing granular opaque oxide.

*Daikon Jima Basalt.*

14. Basalt. Block near vent at centre of Daikon Jima Island, Nakaumi Lagoon. Lat: 35°30′13″. Long: 133°10′3″.

Moderately coarse-grained rock. Olivine phenocrysts are euhedral,and plagioclase phenocrysts are unzoned, often intergrown with olivine. The groundmass comprises clinopyroxene, olivine (occasionally altered), plagioclase and minor glass.

15. Basalt. Block near vent at centre of Daikon Jima Island, Nakaumi Lagoon. Lat: 35°29′31″. Long: 133°10′35″.

Non-vesicular. Olivine phenocrysts (up to 2.5 mm) are euhedral and slightly embayed and unzoned. Plagioclase occasionally enclosing olivine. The groundmass is a mesh of plagioclase laths enclosing clinopyroxene, and rare olivine and opaque oxide.

*Yasugi Basalt.*

36A. Basalt. Columnar-jointed flow in large quarry near Ijiri, S of Yasugi City. Lat: 35°18′35″. Long: 133°14′56″.

Phenocrysts of olivine and rare clinopyroxene (occasionally with spongy core) are set in a fine-grained groundmass of clinopyroxene, plagioclase and opaque oxide. Minor amphibole in the groundmass is partly replaced by opaque oxide. Minor groundmass biotite. Rare ultramafic inclusions comprise metamorphic-textured olivine, clinopyroxene, and orthopyroxene-occasional disaggregated fragments are in reaction rerationship. Cavities in the rock are lined with biotite flakes.

37. Basalt. low exposed on gravel road SE of Sumoniwa, S of Yasugi City. Lat: 35°15′48″. Long: 133°11′53″.

Fresh, weakly-porphyritic rock. Olivine phenocrysts (some possible xenocrysts) contain minor opaque oxide. They are acompanied by microphenocrysts of plagioclase in a groundmass of clinopyroxene. plagioclase, opaque oxide, biotite and rare olivine. No inclusions or lined cavities (cf. 36A).