**87. DATA REPORT: GEOCHEMISTRY AND MINERALOGY OF ASH LAYERS FROM LEGS 127 AND 128 IN THE JAPAN SEA**

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**ABSTRACT**

Deep-sea ash records from Legs 127 and 128 in the Sea of Japan provide reliable data about the nature and composition of explosive volcanic activity of the surrounding area since the middle Miocene. Special attention is given to glass alteration and a determination of initial magmatic compositions. Barium accumulations are responsible for massive crystallization of barite and harmotome in some altered ash layers.

The glasses are assigned to four compositional magmatic groups that correspond to various medium- and high-K andesite suites and to alkaline suites. Analyses of trace elements in selected ash layers distinguish two subgroups in the medium-K andesite suites (unequilibrated and moderately enriched in incompatible elements), one subgroup that corresponds to a K-andesite suite, and two alkaline subgroups of trachytic and phonolitic composition. Some Miocene ash layers exhibit compositions intermediate between the alkaline and calc-alkaline suites. Compositions of coexisting minerals correlate with magmatic signatures: OPX and Al- and Ti-rich CPX, K-rich plagioclases, and Ti-rich biotites occur in the alkaline ash layers.

**INTRODUCTION**

Volcaniclastic material was recovered in lower Miocene to Quaternary sediments of the Japan Sea during Legs 127 and 128 (Fig. 1). Four sites were drilled during Leg 127, two to the east of the Japan Basin (Sites 795 and 796) and two within the Yamato Basin on its northeastern and western margins (Sites 794 and 797) (Tamaki, Pisciotto, Allan, et al., 1990). Two sites were drilled during Leg 128 at the Oki Ridge (Site 798) and at the Kita-Yamato Trough (Site 799). Moreover, Site 794 was revisited to drill deeper in the basement (Ingle, Suyehiro, von Breymann, et al., 1990). Recovery was excellent in Quaternary and Pliocene strata, less excellent, but satisfactory, in Miocene strata. The wide geographic spread of the sites provides an accurate record of the explosive volcanic activity of the Japan Sea region during middle Miocene to Quaternary time, with deposition of ash from the Japanese volcanic arc, from volcanic islands in the Japan Sea, and from the Korean volcanoes.

**VOLCANICLASTIC MATERIAL AT LEGS 127 AND 128**

The volcaniclastic material consists mainly of discrete ash layers (0.1–20 cm thick) and dispersed glass shards of fallout deposition in all of the sedimentary sequences. The thickest deposits were recovered in Miocene strata, including a 27-m-thick pumice flow tuff at Site 799 and ash-fall and gravity-flow tuffs at Sites 794, 795, 796, and 797. Hyaloclastite tuffs were recovered at Sites 794 and 795, near the Oki Ridge (Site 798) and at the Kita-Yamato Trough (Site 799). Initial Reports have been numbered according to the volume's exhaustive list of ash layers (Ingle, Suyehiro, von Breymann, et al., 1990).

Lithological and petrographical aspects of ash layers are described in a parallel note on tephrochronology (Pouclet and Scott, this volume). Detailed investigations at Sites 798 and 799 provide the most accurate frequency of the volcanic activity. A total of nine volcanic pulses are distinguished and numbered from youngest to oldest: V1, V2, and V3 in the Quaternary, V4 and V5 in the Pliocene, V6 in the late Miocene, V7 and V8 in the late middle Miocene, and V9 in the middle Miocene. The distinction of volcanic pulses is based on quiescence of explosive volcanic activity (no ash deposits), and on sharp variations of activities (expressed by number and thickness of ash layers). Similar volcanic phases can be recognized at Sites 794, 795, 796, and 797. Table 1 indicates the number of sampled ash layers per volcanic phases at each site. Information about the distribution of ash layers has been drawn from Legs 127 and 128 Initial Reports volumes (Tamaki, Pisciotto, Allan, et al., 1990; Ingle, Suyehiro, von Breymann, et al., 1990).

Samples selected for petrographic and geochemical studies are shown on the stratigraphic summary columns for the western (Sites 794, 797, and 798) and northeastern (Sites 794, 796, and 795) parts of the Japan Sea (Fig. 2). Table 2 (back-pocket microfiche) presents the list of samples with their location and significant petrographical, chemical, and mineralogical features. Samples from Sites 799 and 798 have been numbered according to the Initial Reports volume's exhaustive list of ash layers (Ingle, Suyehiro, von Breymann, et al., 1990).

**Site 799 (Kita-Yamato Trough)**

Holes were drilled in the southwestern middle part of the Kita-Yamato Trough. The deepest hole ended in lower middle Miocene terrigenous sediments 1084 m below seafloor (mbsf), about 115 m above the acoustic basement. The nine volcanic pulses are well defined and were dated by using paleomagnetic polarity transitions and fossil data. The oldest volcanic event, V9, equated with the prominent 27-m-thick pumice flow tuff, has been dated about 12.5 Ma. It clearly indicates a major volcanic event linked to initial subsidence of the trough (Pouclet and Scott, this volume). A large selection of 90 samples of volcaniclastic material has been analyzed, along with three additional samples of sands from the hole's bottom, to determine their magmatic mineral content.

**Site 797 (Western Yamato Basin)**

Holes were drilled to the west of the Yamato Basin in Quaternary to middle or upper lower Miocene sediments. Drilling entered igneous basement from 554 mbsf to the hole's end (900.1 mbsf). The basement...
Another maximun was observed in middle Miocene sediments having Miocene sediments that correspond to the VI through V6 pulses. The distribution of volcaniclastics in the sediment pile shows distinct peaks of activity in the Quaternary and the Pliocene (V1–V5), in the late Miocene (V6–V7), in the middle Miocene (V8 and V9), and in the middle Miocene above the basalt flows. The latter material is hyaloclastite tuffs related to subaqueous outpouring of basalt flows. We selected 14 samples in the Pliocene and Quaternary strata for analysis. The Miocene ashes were much too altered for analysis.

Site 795 (Northeastern Japan Basin)

The objective of study at this site was to determine the age and the nature of the basement. Basaltic flows were penetrated from 683.5 to 762.2 mbsf, the hole bottom. They have been dated from 24 to 17 Ma (Kaneoka et al., this volume). The distribution of volcaniclastics in the sediment pile shows distinct peaks of activity in the Quaternary and the Pliocene (V1–V5), in the late Miocene (V6–V7), in the middle Miocene (V8 and V9), and in the middle Miocene above the basalt flows. The latter material is hyaloclastite tuffs related to subaqueous outpouring of basalt flows. We selected 14 samples in the Pliocene and Quaternary strata for analysis. The Miocene ashes were much too altered for analysis.

GEOCHEMISTRY OF VOLCANIC GLASSES

Analytical Method

Major Elements

The glass fragments and minerals were analyzed using an electron-probe microanalyzer (EPMA). Samples from Sites 794, 797, 798, and 799 were investigated at the University of Orleans (France), and samples from Sites 795 and 796 at the Ocean Research Institute of Tokyo (Japan). Some of these latter samples were duplicated at Orleans for technical corrections to obtain an internally consistent analytical population. Analytical shifting during determination of major elements from the EPMA method applied to glass material has been corrected by systematic adjustment from reference to high-quality synthetic glasses of known composition.

In each sample, 10 to 30 glass fragments were analyzed, depending on the homogeneity of the glass population. We selected optically unaltered fragments. The total amount of oxide components ranges from 91% to 98%. In the absence of apparent alteration, the deficit comes from the initial volatile content and from seawater hydration. Hydration occurs rapidly to a saturation point during the sedimentation process (Pouclet et al., 1990). Beyond this point, secondary minerals develop in the glass (clay minerals, zeolites, tridymite or cristobalite, and alkaline feldspar). However, hydration of glasses can modify the chemical composition by leaching or concentration of elements (hydrolysis of the large ions: sodium, potassium, calcium, and magnesium, Pouclet et al., 1990), thus the analyses must be corrected for this possibility. This is done by considering the correlation coefficients among oxides and loss on ignition in a population of glasses having the same magmatic affinity, taking into account the differentiation effect. Final corrected data calculated to 100% are presented in Table 3 (back-pocket microfiche). Fe₂O₃ and FeO contents are needed for norm calculations. They have been estimated following Kilinc et al. (1983) and Whitney et al. (1988), given a ferric/ferrous ratio of 0.30 in acidic calc-alkaline glasses.
Minor Elements

A total 25 ash samples were selected from glass-rich and homogeneous ash layers (homogeneous in morphology, size range, and microprobe major-element composition) for trace element and rare earth element (REE) analysis by using an inductively coupled plasma spectrometer (ICP). Table 4 (back-pocket microfiche) presents the ICP data for major (wt%) and trace (ppm) elements. Loss on ignition (LOI, 1000°C) is the total volatile element content and includes H₂O, CO₂, etc. The LOI ranges from 3.80 to 10.10, in agreement with 2O-, CO₂, and sometimes richer in alumina, lime, and alkalies, because of incomplete separation of feldspar.

The Alteration Problem

Frequency of Ash Beds

Alteration is a nagging question when analyzing ash material. Alteration mainly depends on pore-fluid composition and geothermal gradient; it may occur rapidly at shallow depths (150–200 mbsf). With increasing depth in the sediment pile, it becomes more and more difficult to analyze "fresh" (only hydrated) glass, precluding easy recognition of volcanic beds. Tephrochronology records show systematically fewer numbers of ash layers back into mid-Cenozoic time. Obviously, the number of ash layers has been underestimated in the oldest strata because of alteration of ash beds and poorer core recovery. This can be partly corrected by adding the logged ash layers from the formation microscanner (FMS) record, which allows one to recognize resistive ash beds, and from the NGT record, where thicker ash layers were identified by sharp increases in the Th/U ratio. Additionally, only thick tuff beds have been numbered in the Miocene cores. According to Keene (quoted in Kastner, 1979), the transformation of siliceous sediments (opal-A) to porcellanite (opal-CT) and chert (quartz) results in a volume reduction by a factor of 4 to 10. Consequently, a 1-mm-thick ash layer becomes indiscernible, and the thickness and number of ash beds has been underestimated in deeper strata, compared with those in shallower strata. Thus, we cannot assume perfect representation and accuracy of ash sampling in Miocene strata.

Secondary Mineralogy

Silica Diagenetic Evolution

During Legs 127 and 128, alteration of ash layers was conventionally correlated with the opal-A/porcellanite/quartz diagenetic transitions, which are partly controlled by geothermal gradient. High heat-flow values are generally measured in the Sea of Japan, and temperature gradient ranges between 33° and 178°C/km in the holes (Tamaki, Pisciotto, Allan, et al., 1990; Ingle, Suyehiro, von Breymann, et al., 1990). Lower values characterize the Kita-Yamato and Oki Ridge Sites 798 and 799 and may be indicative of thin continental crust underneath. Medium values (121°–133°C/km) were measured at the basinal Sites 794, 975, and 797. An unusually high value (178°C/km) was recorded at the Okushiri Ridge Site 796 (heat source from fluid flow along faults?). Consequently, the opal-A/porcellanite boundary (36°–43°C) is located between 215 (Site 794) and 456 (Site 798) mbsf in the uppermost Miocene to lower Pliocene sediments. The opal-CT/quartz boundary (46°–53°C) is located between 310 (Site 796) and 585 (Site 799) mbsf in upper Miocene to upper middle Miocene sediments.

Above the opal-A/porcellanite transition, glass dissolution features are limited to scattered small pits (Pl. 1). Smectite alteration becomes significant around 200 mbsf (it begins at 90 mbsf at Site 799 and at 175 mbsf at Site 798). In the early Pliocene age strata, some ash beds have been highly affected by leaching of K₂O from glasses and formation of smectites and sparse authigenic illite. Glass alteration and attendant Al-enrichment is responsible for the normative corundum in the norm calculation.

In the opal-CT zone, rare “fresh” (only hydrated) glasses can be analyzed, and their analytical deficits reach 8% to 10%. Glass surfaces are strongly pitted (Pl. 1). Chemical alteration of glasses evolves in two ways, either to alkali loss or to alkali enrichment and increases in the Al/Si ratio. Depending on the behavior of alkali, this may or may not lead to corundum normative composition. Mineralogical evolution seems to be controlled by the formation of celadonite in the glass rim and/or crystallization of zeolites, potassic feldspar (adularia), and silica, because of more or less confined-environment conditions (Hornores, 1990).

Below the opal-CT/quartz transition, “fresh” glass is rare as lithification is complete. Because of high glass dissolution, feldspar and pyroxene laths have weathered out their glass matrix (Pl. 1). Analytical deficits
Figure 2. Stratigraphic summary columns and location of samples. A. Western part, Sites 799, 797, and 798. B. Northeastern part, Sites 794, 796, and 795. V1 through V9 = volcanic phases; Ba = barium anomalies; Opal-A/Opal-CT and Opal-CT/Quartz boundaries; WD = water depth; TD = total depth below seafloor.
exceed 10% and are indicative of a large development of smectite. Zeolites and potassic feldspars are common, as is platy quartz. Abundant authigenic crystals of orthoclase or adularia (Pl. 2) characterize the ash layers 9-200 to 9-209 (Samples 128-799B-15R-2, 81-83 cm, to 128-799B-15R-4, 95-96 cm) just at the opal-CT/quartz boundary. Clinoptilolite is the most common zeolite below this boundary, especially in the pumice flow layer 9-224 (Sample 128-799B-21R-5, 47-51 cm).

The original magmatic composition of altered glass can be approximated from the secondary mineralogy. In the deepest, totally altered, rhyolitic ash beds, smectites have been replaced by illite and silica. In the upper part of two subunits of the Miocene pumice flow tuff at Site 799, 10- to 40-cm-thick intervals of authigenic calcite have recrystallized, indicating strong leaching of Ca and probably K and Na dissolution in pore fluids. At Site 794, in the Miocene hyaloclastite layer, typical palagonitization of blocky glass fragments was observed and is indicative of a former basaltic composition (Pl. 3). Fragments show an outer rim of residual sideromelane coated with a smectite rind. The inner rim consists of successive fibrous and gel-palagonite zones. Smectites and Fe- and Ti-hydroxides are concentrated in the core around a vesicle.

**Barium Anomalies**

Specific secondary mineralogy has been linked to barium anomalies. At Site 799, various barium enrichments in ash layers are responsible for barite precipitation and for replacement of volcanic glass by authigenic harmotome. A positive barium anomaly was detected between 180 and 287 mbsf in ash layers 9-179 and 9-182 (Samples 128-799A-20H-4, 84-86 cm, and 128-799A-32X-6, 102-104 cm) with, 2649 and 2054 ppm Ba, respectively (average Ba content in rhyolite tephra is 500-1000 ppm; Table 4). The first massive precipitation of barite was detected at 323 mbsf at Section 128-799A-36X-5, 23-26 cm, in a 2-cm-thick, light gray tan layer that
was suspected to be altered ash. Analysis indicates an astonishing barium enrichment of 7.64 wt% (and 3089 ppm of Sr) that consisted of tiny (2–10 µm) barite crystals in a biogenic clay. Calculated barium sulfate content reaches as high as 13%. No recognizably volcanic material was found. However, barium again has been concentrated in altered ash layers between 344 and 700 mbsf, as in the layer 9-187 (Sample 128-799A-38X-6, 77–79 cm) with 2023 ppm Ba. In layer 9-199 (Sample 128-799B-14R-2, 32–34 cm, 60% glass), barite aggregates have crystallized with pyrite framboids, and some pyrite has been included in barite crystals (Pl. 4, Fig. 3). Similar barium enrichments occur in ashy layers 9-203 (Sample 128-799B-18R-4, 19–21 cm), 9-209 (Sample 128-799B-27R-5, 47–51 cm), 9-215 (Sample 128-799B-41R-1, 32–34 cm), and 9-217 (Sample 128-799B-46R-3, 148–150 cm). A peculiar alteration of glass was observed in layer 9-209; glass shards have been totally replaced by authigenic assemblage of harmotome crystals (2–6 µm), which grew into a highly dissolved silica framework (Pl. 5; Table 5, back-pocket microfiche). This harmotome alteration is devoid of clay minerals, and the sample has a barium content of an astonishing 9.57 wt%.

**Chemical Composition of Glasses**

**Chemical Nomenclature**

A total 206 glass samples were analyzed (Table 3). Most of the samples (80%) are homogeneous and intermediate to acidic in composition. Some (12%) are heterogeneous with mixed mafic or intermediate to acidic glasses. These compositional types correspond to the sedimentary types H (homogeneous) and G (graded) of Pouclet and Scott (this volume). Other samples (8%) contain detritally mixed glasses of various magmatic compositions (calc-alkaline and alkaline, see below) and correspond to the sedimentary types T (heterogeneous) and TT (turbidite layer).

Examination of the major-element data in variation diagrams (see below) and from norm calculations permitted us to distinguish four chemical groups: (1) a calc-alkaline and moderately alkaline group, (2) a calc-alkaline and peralkaline group, (3) a calc-alkaline and high-K group, and (4) an alkaline group (Table 6, back-pocket microfiche).

**Group 1.** Compositions of glasses were assigned to various andesitic magma series. They account for 57% of the total number of analyses. Their petrochemical nomenclature uses the SiO$_2$ content, as follows: <56% = basaltic andesite (BA), 56%–63% = andesite (AN), 63%–70% = dacite (DC), 70%–74% = rhyodacite (RD), and >74% = rhyolite (RH) (Pecerillo and Taylor, 1976, modified for the acidic series. The analyzed samples were selected to represent the main areas. At Site 799 (Yamato Bank area), alkaline and peralkaline glasses are predominant. At Sites 797 and 798 (Yamato Basin), alkaline glasses are abundant, together with calc-alkaline andesitic products. At Sites 794, 796, and 795 (eastern Japan Basin), calc-alkaline glasses prevail; alkaline glasses seem to be rare, but some shoshonitic products are present.

**Major Element Variation**

The analyses of major elements have been plotted on SiO$_2$ vs. oxides variation diagrams, which show evidence for the four compositional groups (Fig. 4). The calc-alkaline Group 1 shows a compositional range in the medium- to the high-K andesite series (Gill, 1981).

Peralkaline dacites to rhyolites (DCP, RDP, RPH) of Group 2 have been depleted in Al$_2$O$_3$. This is not the case for the potassic and shoshonitic calc-alkaline Group 3.

The alkaline Group 4 exhibits a large range of composition, especially Al$_2$O$_3$ and Na$_2$O in phonolites; this is caused by heterogeneity of glasses. Phonolitic and trachytic glasses are distinguished in the SiO$_2$ vs. K$_2$O diagram. Compared to the calc-alkaline glasses at the same SiO$_2$ contents, the alkaline glasses have higher contents of Al$_2$O$_3$ and lower contents of FeO, MgO, and CaO.

The magmatic groups show a geographic distribution in the three main areas. At Site 799 (Yamato Bank area), alkaline and peralkaline glasses are predominant. At Sites 797 and 798 (Yamato Basin), alkaline glasses are abundant, together with calc-alkaline andesitic products. At Sites 794, 796, and 795 (eastern Japan Basin), calc-alkaline glasses prevail; alkaline glasses seem to be rare, but some shoshonitic products are present.

**Magmatic Distinctions of Trace Elements**

Trace elements are powerful tools for discriminating magmatic series. The analyzed samples were selected to represent the main...
From the image, a page of a document discussing mineralogy, specifically focusing on the compositions of feldspars and pyroxenes in different volcanic ash layers. The text reads: "MINERALOGY Ash-sized mineral fragments are common in selected samples. These are either pyroclastic phenocrysts or xenocrysts, co-genetic with glass shards when they are coated by glass, or epiclastic detrital grains. We analyzed feldspars, pyroxenes, amphiboles, and biotites of magmatic origin (Table 7, back-pocket microfiche), rare pyroclasites or epiclastic oxides, and a few detrital epidotes. Locations of analyzed minerals are given in Table 2.

Feldspars
In mafic to intermediate calc-alkaline ash layers (BA, AN, DC), abundant plagioclase phenocrysts exhibit a large compositional range of An30, with a low- to moderate-K content of Or65-49. In acidic ashes (RD, RH), plagioclases are less abundant and more sodic, and also exhibit a large range of composition (An30, Or65-41) (Fig. 7, Field a). Alkali feldspars are more frequent in acidic layers (PI. 4). Their composition is either sodic (Ab50-43), potassic (Ab35-2), or intermediate (Ab65-35). Sodic and potassic feldspars may coexist; exsolutions of albite were observed in sodic sanidine. Peraluminous and high-K dacitic and rhyolitic ashes contain similar feldspars, but some plagioclases can be more potassic.

In the alkaline trachyte and phonolite ash layers (PH, TP, TR, TQ), plagioclases are less calcic and more potassic (An50, Or60) (Fig. 7, Field b). Alkaline feldspars are sodic or potassic. They are very abundant in the trachyte glass layers. Moreover, glass coating on mineral pyroclasts is frequent.

The compositions of feldspars of the different magmatic groups are shown in Figure 7.

Pyroxenes
Pyroclasts of orthopyroxenes (OPXs) and clinopyroxenes (CPXs) characterize the calc-alkaline ash beds (Fig. 8). They are euhedral and green to light brown in color. OPXs are slightly more magnesium in mafic ashes (Wo50, En30-40, Fs30-20) than in acidic ashes (Wo50, En60-40, Fs30-20). CPXs are scarce in mafic ashes. In acidic ashes, they show little variation in composition (Wo40, En45-50, Fs10-15), and low contents of Al2O3 (<5.0%) and TiO2 (<0.5%), a normal feature of subalkaline pyroxenes (Gill, 1981).

Green to brown pyroxene fragments were found in the alkaline ash beds. Only CPXs were present (Fig. 8). These consist of aluminous and titanium-rich (Al2O3 4%-7%, TiO2 2%) diopside (Wo40, En40, Fs10). In some trachyte ashes, altered brown fragments were determined to be former sodic diopside and aegirine (NaAl2O4 = 2%-8%); these plot near the hedenbergite and clinoferrosilite compositions (Fig. 8).

Amphiboles
Dark green or brown amphibole crystals were analyzed only in calc-alkaline ash layers. They display various compositions, including hornblende, pargasitic hornblende, and tschermakitic hornblende (Leake, 1978). The ferromagnesian ratio (FeO/FeO + MnO) is lower in amphiboles from andesite and rhyodacite ashes (0.30-0.65). In contrast, the amphibole TiO2 content decreases from 1.3%-3.0% to 0.9%-1.7% in andesite and rhyolitic ashes, respectively. Rare actinolite and ferro-edenite were determined in detrital ash beds and are probably epiclastic fragments.

Biotites
Biotite flakes were dispersed in many ash layers having different glass composition, with some being included in microgabbros (PI. 4). In biotites from calc-alkaline ash beds, the ferromagnesian ratio ranges between 0.33 and 0.59; TiO2 contents range between 1% and 4%. In biotites from alkaline ash beds, similar ferromagnesian ratios were found, but TiO2 contents are higher (4%-7%).

Ilmenite and Epidote
Grains of ilmenite were analyzed in four rhyolite and rhyolitic ash layers (ilmenite TiO2 = 44.3%-48.7%). Grains of epidote were determined and analyzed in some detrital ash beds having various glass compositions (Table 2).

Miscellaneous Data
We analyzed the detrital magmatic minerals (except quartz) of the thick sand beds that were recovered at the bottom of Hole 799B, below the pumice flow (Ingle, Suyehiro, von Breymann, et al., 1990) to determine their petrographic origin (Table 2, Samples 9-5). These consist of potassic feldspar in a small range of composition (Or69-79), oligoclase to albite plagioclase that is poor in potassium (Ab35-40, An60-65) and Fe-biotite (ferromagnesian ratio = 0.62).

ACKNOWLEDGMENTS
We greatly appreciate the technical assistance of Michel Tallet for the sample preparation and Simone Casseault for the geochemical data analysis.
analyses, and Dominique Panis for the STEM study. This research was supported by a CNRS grant of ODP-France.

REFERENCES


Date of initial receipt: 24 April 1991
Date of acceptance: 6 January 1992
Ms 127/128B-196

Figure 4. SiO₂ vs. oxides (A-L). 1, 2, 3, and 4 = compositional magmatic groups. BA = basaltic andesite; AN = andesite; DC = dacite; RD = rhyodacite; RH = rhyolite; HW = Hawaitite; PH = phonolite; TP = trachy-phonolite; TR = trachyte; TQ = quartz-trachyte. Boundaries between the low-, medium- and high-K fields after Peccerillo and Taylor (1976).
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Figure 5. Inter-element correlations of incompatible elements. A. Nb vs. Zr. B. Th vs. Zr and La vs. Yb. A, B, C, and D = compositional magmatic subgroups with in addition the Samples 9-127 = alkaline-rich rhyolite, 9-187 = Th- and Nb-rich rhyolite, and 9-224 = Th-rich rhyolite.
Figure 6. Chondrite-normalized patterns (Evensen et al., 1978). A. Calc-alkaline compositions (Subgroups A, B, and C). B. Alkaline compositions (Subgroups D and E) plus Samples 9-127, 9-187, and 9-224.
Figure 7. Or-Ab-An diagram of the feldspars, a = Field of the plagioclases of the calc-alkaline magmatic Groups 1, 2, and 3, b = Field of the plagioclases of the alkaline magmatic Group 4.

Figure 8. Wo-En-Fs diagram of the pyroxenes (CaSiO$_3$-MgSiO$_3$-FeSiO$_3$).
Plate 4.  1, 2. Authigenic barite and pyrite, ash layer 9-199 (Sample 128-799B-14R-2, 32–34 cm).  3, 4. Magmatic minerals; (3) alkaline feldspar in the pumic flow 9-224 (Section 128-799B-58R-2 at 74–77 cm); (4) biotite in ash layer 9-217 (Sample 128-799B-46R-3, 148–150 cm).
Plate 5. Authigenic harmotome in ash layer 9-209 (Section 128-799B-27R-5 at 47–51 cm).