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48. VOLCANIC ASH LAYERS IN THE JAPAN SEA: TEPHROCHRONOLOGY OF SITES 798 AND 799[1]

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ABSTRACT

Exceptional records of explosive volcanic activity were collected at Sites 798 and 799 on Leg 128 in the Japan Sea at the Oki Ridge and Kita-Yamato Trough, respectively. Ash deposition consists of 1-mm- to 20-cm-thick pyroclastic-fall layers dated from mid-Miocene to late Quaternary and of one 27-m-thick pyroclastic-flow sequence dated at about 12.5 Ma. Tephra layers are classified into four sedimentary types: homogeneous, graded, heterogeneous, and turbiditic. They originated from the Japanese volcanic arc (shards, bubble wall fragments, and micropumices of rhyolitic to dacitic composition) or from the volcanic islands of the Japan Sea (micropumices and microscoriae of trachytic to phonolitic composition). The pyroclastic-flow deposit is correlated with the Onnagawa Formation in northern Japan.

A total of nine volcano-tectonic phases are distinguished: four in the Miocene, two in the Pliocene, and three in the Quaternary. The tephra record may aid in determining the precise timing of the Yamato Basin backarc evolution.

INTRODUCTION

Leg 128 of the Ocean Drilling Program (ODP) was devoted to probing the history and structure of the Japan Sea and particularly to assessing the timing and dynamics of the opening of the marginal basin (Ingle, Suyehiro, von Breymann, et al., 1990). The record of the explosive activity can be read, with certain limitations, in the distribution of ash in deep-sea sediments (Donnelly, 1974; Hein and Scholl, 1978; Pouclet et al., 1990). Exceptional records of volcanic activity from the neighboring volcanic arcs and islands were collected in the central and south Japan Sea at Sites 798 and 799 (Fig. 1).

LEG 128 ASH RECORD

At Site 798 on Oki Ridge in the southern Yamato Basin, an almost complete representation was acquired from the Quaternary to the middle Pliocene, by combining data from different holes. This was possible because of the continuous sedimentation without any severe turbation or repetitions by slumping, the excellent preservation of ash, and the fairly good recovery. At Site 799, in the Kita-Yamato Trough, a very satisfying record was recovered from the Quaternary to the lower Pliocene in Hole 799A, in spite of some slumping disturbance. In the Pliocene strata, nonrecovered tephra layers were accurately recognized and enumerated by means of the formation microscanner (FMS) logging tool. Upper and middle Miocene strata were retrieved in Hole 799B with a less satisfactory recovery. In this latter hole, the ashes are highly altered but still recognizable.

Most of the volcaniclastic material consists of pyroclastic-fall layers produced by subaerial explosive activities (fine shards and micropumices). Epiclastic debris in the form of reworked and corroded fragments of glass and minerals are found. No hyaloclastites were observed at either Site 798 or 799. At present, upper atmospheric wind directions are north to south in the winter, south to north in the summer, and are variable during the spring and fall. The wide distribution of late-Quaternary marker tephras of known origin in and around Japan (Machida, 1981; Furuta et al., 1986; Machida and Arai, 1988) indicates that significant quantities of tephra may have arrived at Sites 798 and 799 from a large number of explosive eruptions in many directions up to distances of at least 500 km. The most likely sources are the larger acidic volcanoes of the Japan arc (e.g., Kikai, Aira, Unzen, Aso, Toya), the nearby volcanic islands (e.g., Ulleung, Oki-Dogo), and the explosive volcanoes of North Korea (e. g., Baegdusan).

A prominent 27-m-thick sequence of pyroclastic flows of rhyolitic composition was recovered near the bottom of Hole 799B. The ash deposits consist mainly of micropumices. They originated from a nearby explosive volcano that may have been as close as the Yamato Bank.

PETROGRAPHIC ASPECTS

The petrography of individual ash layers is detailed in Ingle, Suyehiro, von Breymann, et al., 1990). Results are summarized here.

Ash-fall Layers

A total of 113 ash layers was encountered at Site 798 from the Quaternary to the middle Pliocene, and as many as 256 layers were found at Site 799 from the Quaternary to the middle Miocene.

Lithology

Layers range from 1 mm to 20 cm in thickness. At Site 798, 65% of the layers are less than 0.4 cm thick, and 10% are more than 5 cm thick. At Site 799, the proportion is 47% thinner layers and 6% thicker layers. The higher frequency of the medium-thick layers may indicate the proximity of island volcanoes of moderate explosive activity. The average grain size of the volcanic layers is silt to very fine sand (<125 μm). Coarser grain sizes of fine sand (>125 μm) characterize some medium and thick layers.

By definition, a tephra layer contains at least 60% volcaniclastic material (lithic, vitric, crystal) (Explanatory Notes, Ingle, Syehiro, von Breymann, et al., 1990). No lithic fragments were recognized. The glass fractions consist of shards, bubble wall fragments, micropumices, and microscoriae. Many shards exhibit characteristic U- and Y-shapes (tricuspate) that have resulted from disruption of highly vesicular pumices. Vesicles are elongated to tubular in the micropumices; they are spherical or irregular in the microscoriae and correlate with a lower vesicularity and the presence of enclosed magmatic phenocrysts. The crystal fractions consist of fragments or euhedral grains of quartz, alkali feldspar, plagioclase, biotite, amphibole, pyroxene, and scarce oxides. The proportion of crystals ranges from 2% to 10% in the glass-rich beds and from 10% to 30% in the crystal-rich beds.

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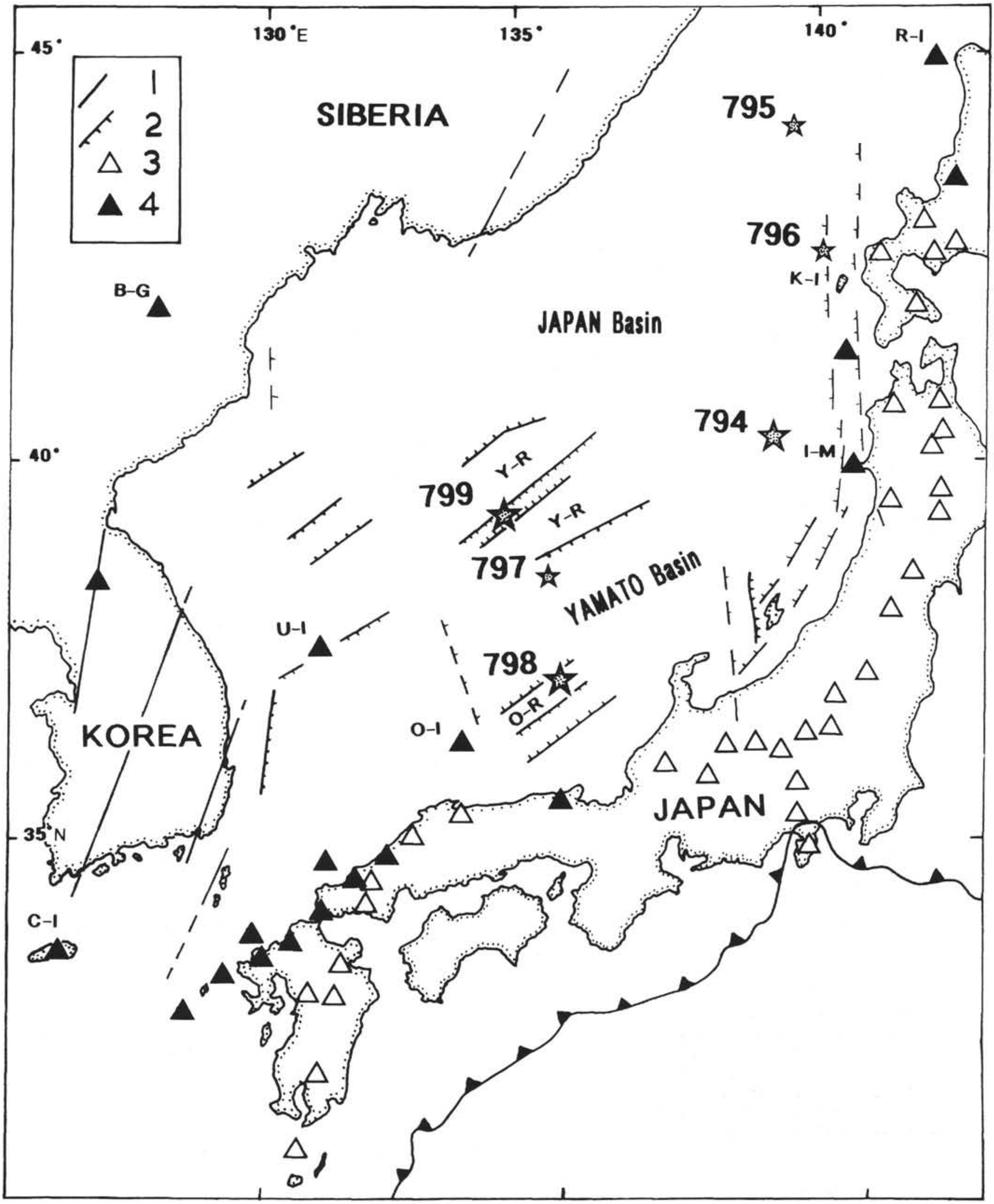

Figure 1. Geographic and structural setting of Sites 798 and 799 and the other Sites drilled during Legs 127 and 128 in the Japan Sea. 1, strike-slip faults; 2, normal faults; 3, calc-alkaline volcanoes; 4, alkaline volcanoes; B–G, Baegdusan volcano; C-I, Cheju Island; I-M, Ichinome-Gata volcano; K-I, Okushiri Island; O-I, Oki Islands; O-R, Oki Ridge; R-I, Rishiri Island; Y-R, Yamato Bank.

Sedimentary Types

The tephra layers are classified into three types of normal sedimentation, given as H (homogeneous), G (graded), and T (heterogeneous), and into one type of reworked sedimentation, given as TT (turbidity flow).

1. Type H. The volcanic material is homogeneous in grain size and composition. The ash beds are typically thin (1–5 mm), although exceptionally thick (> 3 cm) homogeneous ash layers were recovered in Section 128-798C-7H-4 (Pl. 1). The homogeneous layers are products of either a single volcanic event lasting a short period of time or very distant eruptions (fine grain sizes). In the latter case, the homogeneity is produced by winnowing during aerial transport.

2. Type G. Normal graded bedding is a consequence of sorting of the volcanic material as it sinks from the sea surface. This sorting is distinguished by variations in grain size, as well as by variations in color related to the glass/crystal ratio. The lower part is coarser, darker, and crystal-rich. The upper part is finer, lighter, and glass-rich. Thickness ranges from 0.5 to 5 cm, with some rare thicker beds (Pl. 2). Graded layers are related to single- or closely-spaced eruptions from the same volcanic source (e.g., Sample 128-798B-4H-6, 19–24 cm).

3. Type T. In heterogeneous layers, different parts have different compositions (glasses and minerals) that exhibit different colors and ranges in grain size with or without graded bedding. Thicknesses are from 4 to 10 cm. No sedimentary reworking is observed. The heterogeneity is a consequence of either a compositionally complex eruption from a single volcano or cluster of volcanoes or of the superposition of products of closely-spaced eruptions from different volcanoes (e.g., Sample 128-798C-7H-3, 23–28 cm, Pl. 2).

4. Type TT. Unusual thick layers (up to 20 cm) have resulted from turbidity flows as recognized by their sedimentary structures (Ingle, Suyehiro, von Breymann et al., 1990). These flows have reworked tephra from primary ash layers that likely were originally thinner. Some complete turbidite sequences were observed with the coarse bed load at the base, laminated beds in the middle, and the upper, fine-grained suspension material at the top (e.g., Sample 128-798B-44X-2, 58–82 cm).

Magmatic Compositions

Three magmatic groups were distinguished during shipboard preliminary observations: "acidic" (colorless glass shards and micropumices), "intermediate" (colorless glass shards, rare micropumices, fairly abundant biotite, and/or amphibole), and "basic" (pale brown glass shards and abundant microscoriae). Shore-based chemical investigations (Pouclet et al., this volume) indicate that

1. The "acidic" layers are either rhyolitic in composition and characterized by U- and Y-shaped shards and tubular micropumices or are trachytic in composition and characterized by abundant pumices.

2. The "intermediate" layers are dacitic in composition.

3. The "basic" layers are either andesitic (shards and microscoriae) or phonolitic (abundant microscoriae) in composition, so are not really basic.

Alkaline compositions (phonolite, trachyte) are limited to strata of late Pliocene and Quaternary age. They are scarce in the Pliocene and abundant in the Quaternary at both Sites 798 and 799 where they constitute about 50% of the middle and late Pleistocene ash deposits. Alkaline glasses belong to layers of H and G type, or may be mixed with calc-alkaline glasses in some T and TT layers (e.g., Sample 128-798C-7H-3, 25–28 cm). Some thick alkaline layers of G and TT types characterize Site 799 (Samples 128-799A-3H-3, 134–144 cm, -4H-6, 54–65 cm, -4H-6, 69–73 cm). Calc-alkaline compositions (dacite, rhyolite) are found in all strata. Numerous layers of H and G types are encountered in the Pliocene to Quaternary cores at Site 798 and in the mid-Miocene to Quaternary cores at Site 799. The proportion of H-type layers is about 65%. The thickest T and TT layers are found in the lower Pliocene strata at Site 798 and in the mid-Miocene, uppermost Miocene, and Pleistocene strata at Site 799.

Ash-flow Tuff

A thick, white to pale blue tuff was recovered from Sections 128-799B-57R-1, 19 cm, to 128-799B-59R-2, 41 cm. A sharp increase in the natural gamma-ray (NGR) log record accurately places the stratigraphic position of this tuff between 982 and 1009 m below seafloor (mbsf) (Ingle, Suyehiro, von Breymann, et al., 1990). The NGR log is effective because it measures the high-thorium content of the tephra (25.3 ppm, Pouclet et al., this volume) compared to that of the enclosing sediment (5 to 10 ppm). This major volcanic bed is overlain by siliceous claystone formed in a marine basin. It is underlain by interbedded claystone and immature sand, indicating proximity of the source terrane. No more tephra layers were observed to the total depth of the hole (1084 mbsf). The oblique seismic record locates the basement of the sedimentary pile at 1200 mbsf, about 200 m below the tuff (Ingle, Suyehiro, von Breymann, et al., 1990).

Four units can be distinguished in the 27-m-thick tuff sequence based on variations in the NGR log combined with the FMS log. The latter produces high-resolution images of the microresistivity character of the borehole wall. The units are separated by thin intervals of siliceous claystone and/or carbonate (high-resistivity, positive anomaly of Ca, and negative anomaly of Si in the geochemical log). The units, labeled A to D from bottom to top, range in thickness from 4 to 8 m.

1. Unit A (1009–1005 mbsf) is a fine-silt-sized tuff. It includes a 13-cm-thick calcitized zone in its middle part. Coarse layers are located at the uppermost part and have a scoured top.

2. Unit B (104.5–996.5 mbsf) is a massive fine-silt-sized tuff atop an intervening 50-cm-thick carbonate bed.

3. A 1-m-thick sedimentary intercalation, not recovered, moderately resistive, appears from the logs to be a clayey silt with carbonate. The overlying Unit C (995.5–990 mbsf) is a heterogeneous tuff with mixed sediments. The upper 53 cm is a tuff breccia with a scoured top that includes reworked clayey sediment fragments and has been locally replaced by calcite.

4. Following a 2-m-thick intercalation of clayey silt and carbonate, Unit D (988–982 mbsf) is another massive, fine-silt-sized tuff. Some sedimentary fragments are admixed at the upper contact with the siliceous claystone of the overlying sedimentary section.

Microscope and scanning electron microprobe investigations show that the volcanic material of the four units consists of micropumices and rare vitric shards (Pl. 3). Fragments of alkaline feldspar are common. Pumices have been cemented during diagenesis. Glass dissolution and zeolite crystallization were prevalent. The glass is calc-alkaline and rhyolitic in composition (Pouclet et al., this volume). The relatively great thickness of this sequence and the lack of apparent graded bedding in the recovered sections, which are as thick as 2 m, lead us to conclude that this is a pyroclastic-flow deposit. For the same reasons, the micropumice flows probably erupted from a nearby volcano.

TEPHROCHRONOLOGY

Reliable ages for the latest Miocene to Quaternary ash layers for Site 798 and Hole 799A were estimated with good accuracy by combining paleomagnetic dates, cyclical variation in sediments as revealed in the gamma-ray logs, and microfossil data. The methodology is discussed in Ingle, Suyehiro, von Breymann, et al. (1990). The number and thicknesses of the discrete ash layers are plotted vs. time at intervals of 0.1 Ma in Figure 2.

A

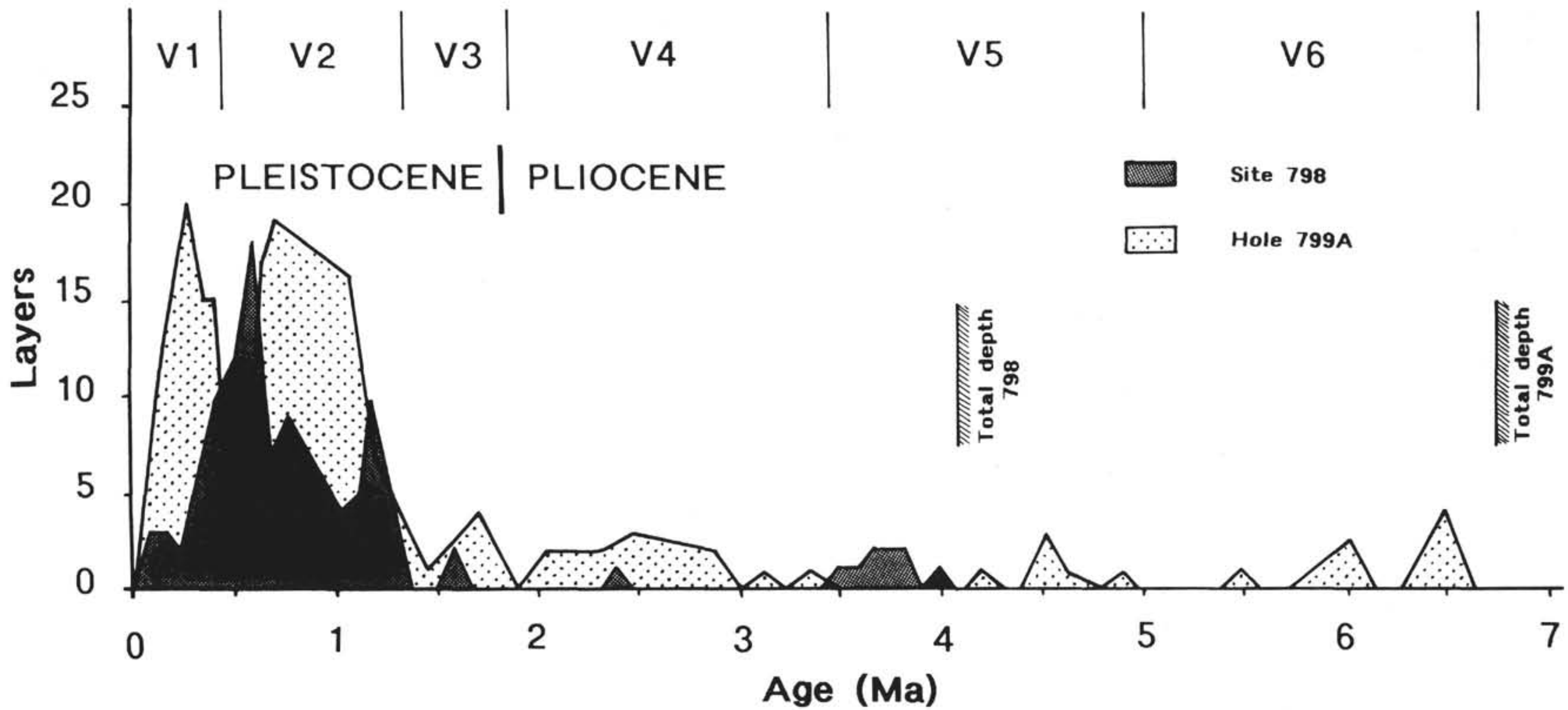

Figure 2. Tephrochronology diagrams, Site 798 and Hole 799A. **A.** Number of ash layers vs. time. **B.** Thickness of ash layers vs. time. See text for an explanation of the "V" volcanic phases.

B

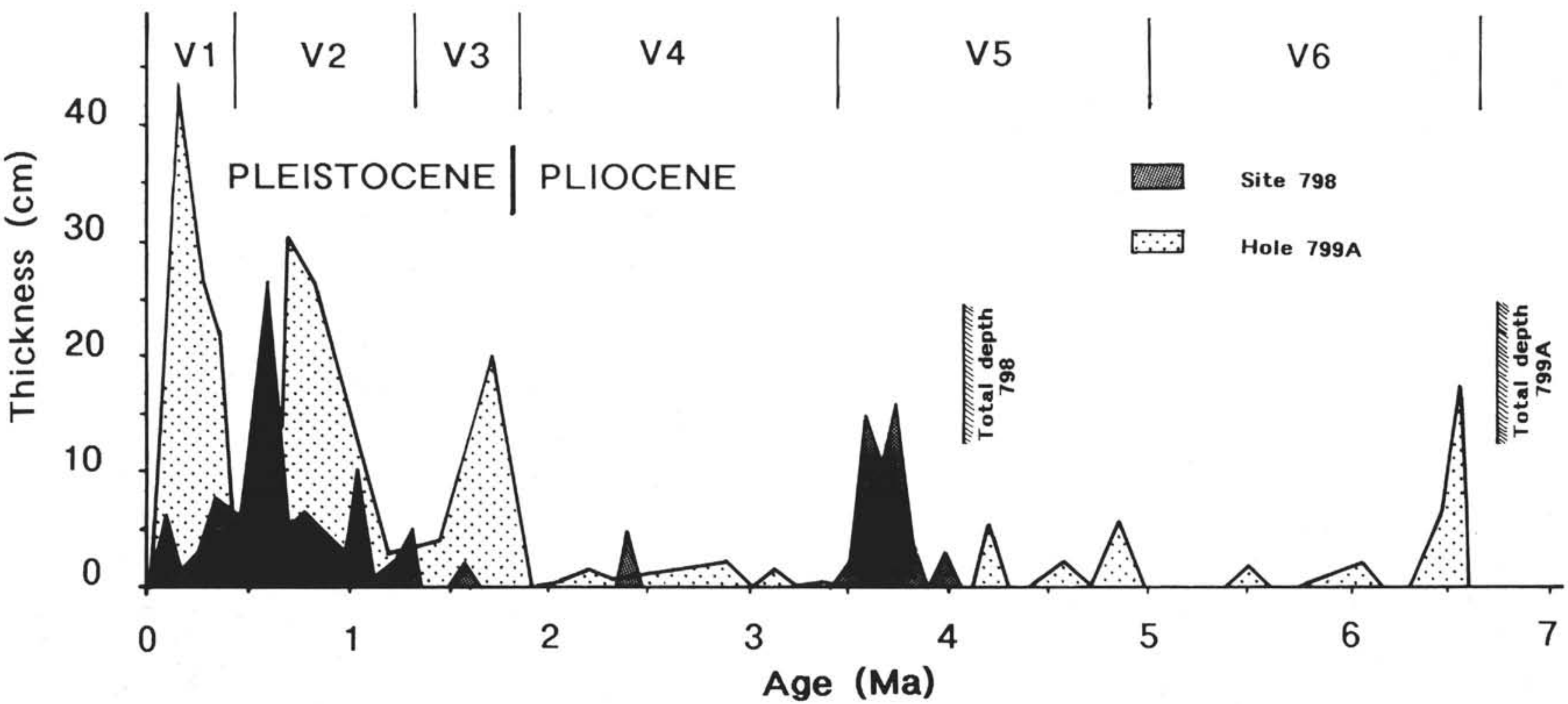

Figure 2 (continued).

Ages for Hole 799B could not be determined precisely from paleontologic and paleomagnetic data. Post-cruise review of the magnetic record (K.A.O. Krumsiek, pers. comm., 1990) showed that the middle/late Miocene Boundary (late Chron 11) is located at about 600 mbsf and that the drilling ended in the lower middle Miocene at 1084 mbsf (late Chron 15). Thus, the prominent rhyolite tuff located between 982 and 1009 mbsf is dated at about 12.5 $\pm$1 Ma (late middle Chron 14). In Figure 3, the number and thickness of ash layers are plotted vs. depth in 10-m increments. Figure 4 presents the number of ash layers within each volcanic phase and also shows (hatched) the volcanic hiatuses in the stratigraphic summary columns.

Phases of Volcanic Activity

Figures 2, 3, and 4 show the volumetric importance and the stratigraphic records of explosive activity. Major changes in both the number and thickness of ash layers (gaps and sharp variations in the amount of volcanic material) led us to identify nine different volcanic phases, which we have numbered from youngest to oldest as V1 to V9 (to allow for the late addition of older records). The following description is in chronological order.

V9 (middle Miocene)

The oldest recorded activity corresponds mainly to the pyroclastic-flow sequence and associated ash-fall layers. The flows are intercalated near the base of hemipelagic sediments that overlie immature terrigeneous deposits just above the basement. This activity is related to a magmatic event linked to the formation of the marine basin. According to the estimated age (12.5 Ma) and the rhyolitic composition, the ash-flow tuff can be correlated with the rhyolitic tuff (blue tuff) of the Onnagawa Formation, this being the acidic volcanism that postdates formation of the Kuroko sulfide ores in the Green Tuff Belt of northeastern Japan (Oshima et al., 1974; Tanimura et al., 1983). Thus, the same acidic explosive activity may have occurred on both edges of the Yamato Rift, after the opening of the marine basin, in the Japan mainland to the east (Onnagawa) and in the Yamato Bank to the west (Site 799), which are presently 900 km apart.

V8 (late middle Miocene)

After a short volcanic gap, another phase of activity is characterized by thick ash deposits that have been reworked by turbidity currents. Sedimentation of siliceous hemipelagites indicates a phase of rapid basin subsidence.

V7 (late middle to late Miocene)

The reduced volcanic activity registered (thinner ash layers) is explained partly by submersion below sea level of certain parts of the Japan volcanic arc and by effective decreasing activity (Iijima et al., 1988; Taira et al., 1989).

A lengthy volcanic hiatus occurred from 9 to 7 Ma. The same gap in time is observed in the occurrences of volcanic ashes at Leg 127, northwestern Japan Basin (Tamaki, Pisciotto, Allan, et al., 1990; Jolivet and Tamaki, this volume), as well as at Legs 57 and 87, Pacific Sea side of Japan (Cadet and Fujioka, 1980; Fujioka, 1985; Fujioka et al., 1985; Pouclet et al., 1985). It indicates that a major pause of the Japan Volcanic Arc activity linked to an important change in magnitude and orientation of the regional stress field may be due to a rotational motion of the Pacific Plate (Takeuchi, 1986).

V6 (late late Miocene, 6.7–5.3 Ma)

Renewal of activity supplying tephra-rich turbidity flows was accompanied by a drastic change in the sedimentary input with an increasing flux of terrigenous sediments (silty clays) (Fig. 4). This activity is correlated with deepening of the basinal area and uplift of the Japan arc (Fujioka, 1985).

V5 (early Pliocene, 5–3.4 Ma)

After a short volcanic hiatus, moderate activity is registered at Site 799. However, some thick turbidite tephra deposits were recovered at the base of Site 798 (4–3.5 Ma). Their coarse grain sizes indicate the proximity of sources.

V4 (late Pliocene, 3.4–1.9 Ma)

At Site 798, rare ash deposition in the late Pliocene seems to indicate a pause in the activity of the volcanic arc. At Site 799, a fraction of the tephra was derived from volcanic islands (microscoriae and pumice layers of alkaline composition).

V3 (early Pleistocene, 1.9–1.4 Ma)

At Site 798, moderate activity of calc-alkaline composition is recorded, together with alkaline tephra that may have come from nearby volcanic islands (Pouclet et al., this volume). At Site 799, alkaline tephra is more common in the thickest layers, which originated from proximal sources. An increase in the flux of terrigenous sediments may be explained either by uplift of land or by a eustatic decrease in sea level (Burkle and Akiba, 1978).

V2 (early to mid-Pleistocene, 1.4–0.5 Ma)

A strong increase in activity is registered at both sites, with the most abundant layers dated between 0.7 and 0.6 Ma. Judging from their magmatic compositions, the tephra appear to have been supplied by the Japan volcanic arc as well as volcanic islands in the Japan Sea. This obviously indicates a major regional volcanic phase.

V1 (middle to late Pleistocene, 0.5–0 Ma)

At Site 798, a less-important volcanic activity is recorded, indicating a decrease in activity of the nearby volcanic arc. However, Site 799, after a short pause, records a renewal of volcanism on the Japan Sea islands, with the thickest and alkaline layers occurring between 0.3 and 0.2 Ma.

Tephra markers of late Quaternary age have been identified in the Sea of Japan (Machida and Arai, 1983, 1988; Arai et al., 1986). Three of these were recognized: Aso-4 (70 Ka) from the Aso volcano (Section 128-799A-3H-1, 6-cm-thick turbiditic layer), Yamato ash (30 Ka ?) from an undetermined source (Sections 128-798A-2H-2 and -799A-2H-4, 0.2-cm and 0.5-cm-thick homogeneous layers), and Aira-Tn (22 Ka) from the Aira volcano (Section 128-798C-1H-3, 5-cm-thick graded layer and Section 128-799A-2H-2, 18-cm-thick turbiditic layer). Determinations are based on the characteristic petrographic and geochemical features (Pouclet et al., this volume). Younger markers were not recorded because, first, at Site 798, the upper portion of the sediment column was entirely sealed for microbiological study and no lithological identification was done, and second, at Site 799, the youngest Holocene strata were not recovered.

CONCLUSIONS

Volcanic ash layers at Sites 798 and 799 provide an unusually detailed record of late Miocene through Pleistocene explosive volcanism. The number and thicknesses of tephra layers can be used to estimate the chronologic evolution of nearby volcanic activity at a time interval of 0.1 Ma. Tephra originated both from the Japan volcanic arc and from the volcanic islands in the Japan Sea. In the middle to late Miocene, the record is less complete because of poorer core recovery and alteration of the ashes.

Nine volcanic pulses are distinguished. They are divided by volcanic hiatuses or by sharp variations in the volume of activity. In the Miocene, four volcano-tectonic phases may be related to the formation and subsidence of the Yamato Basin and to the uplift or sinking of the Japan volcanic arc. The oldest recorded activity is a 27-m-thick pyroclastic-flow sequence that was supplied by explosive eruptions of a proximal volcano. This tephra is tentatively correlated with the blue tuff of the Onnagawa formation that postdated Kuroko sulfide ore formation in northeastern Japan. A major volcanic hiatus is observed between 9 and 7 Ma, indicating a regional pause of the Japan arc volcanic activity. In the Pliocene, two phases of moderate activity are observed. The youngest is characterized by the first alkaline material derived from volcanic islands. In the Pleistocene, three important pulses are encountered, including input from both the volcanic arc and the volcanic islands. Two major paroxysmal pulses occurred between 0.7 and 0.6 Ma and between 0.3 and 0.2 Ma. The present-day activity is estimated to be of moderate intensity compared to that of the past as recorded by Sites 798 and 799.

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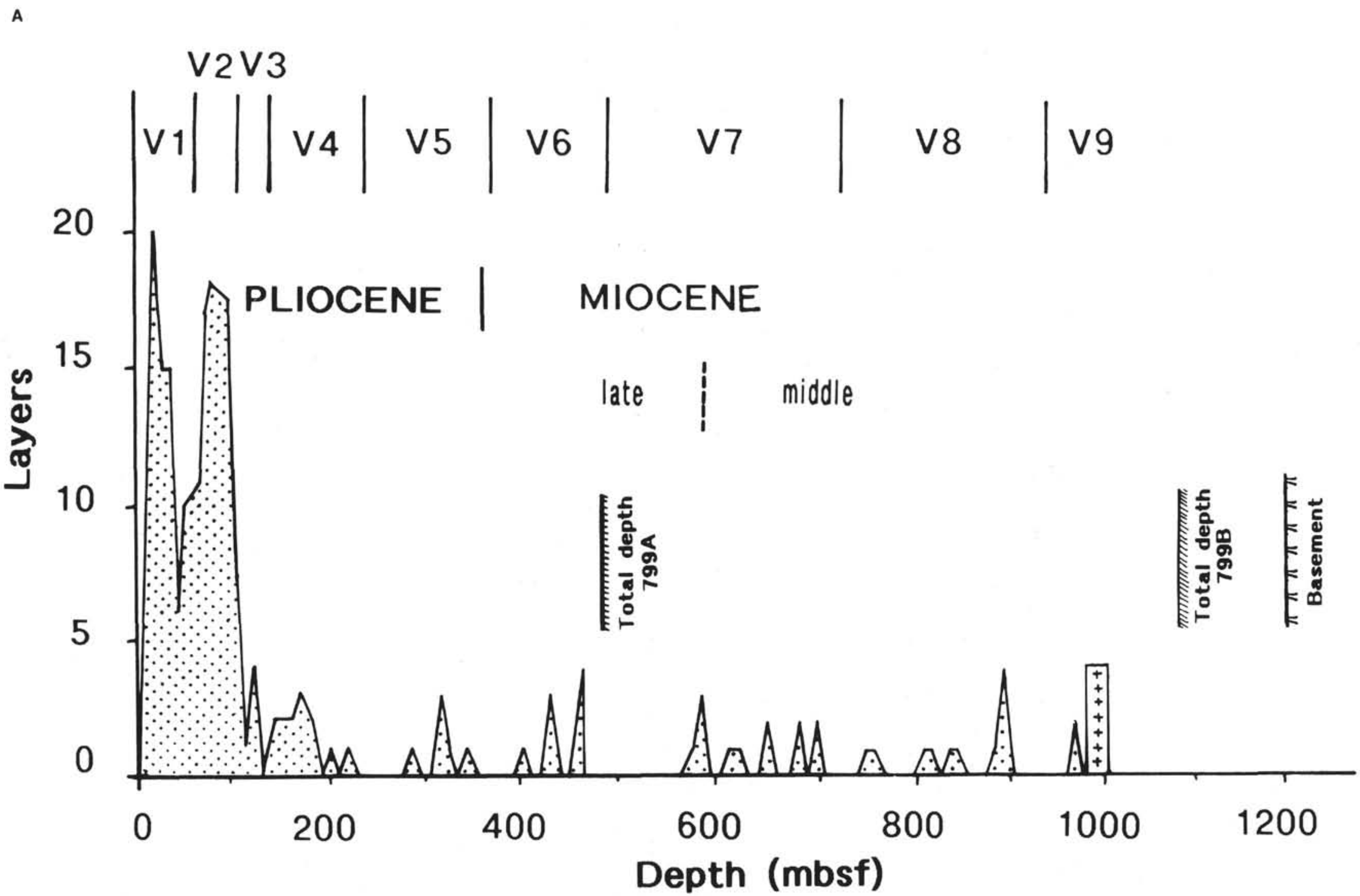

Figure 3. Tephrochronology diagrams, Site 799. **A.** Number of ash layers vs. depth. **B.** Thickness of ash layers vs. depth. Plus sign, pyroclastic flow. See text for an explanation of the "V" volcanic phases.

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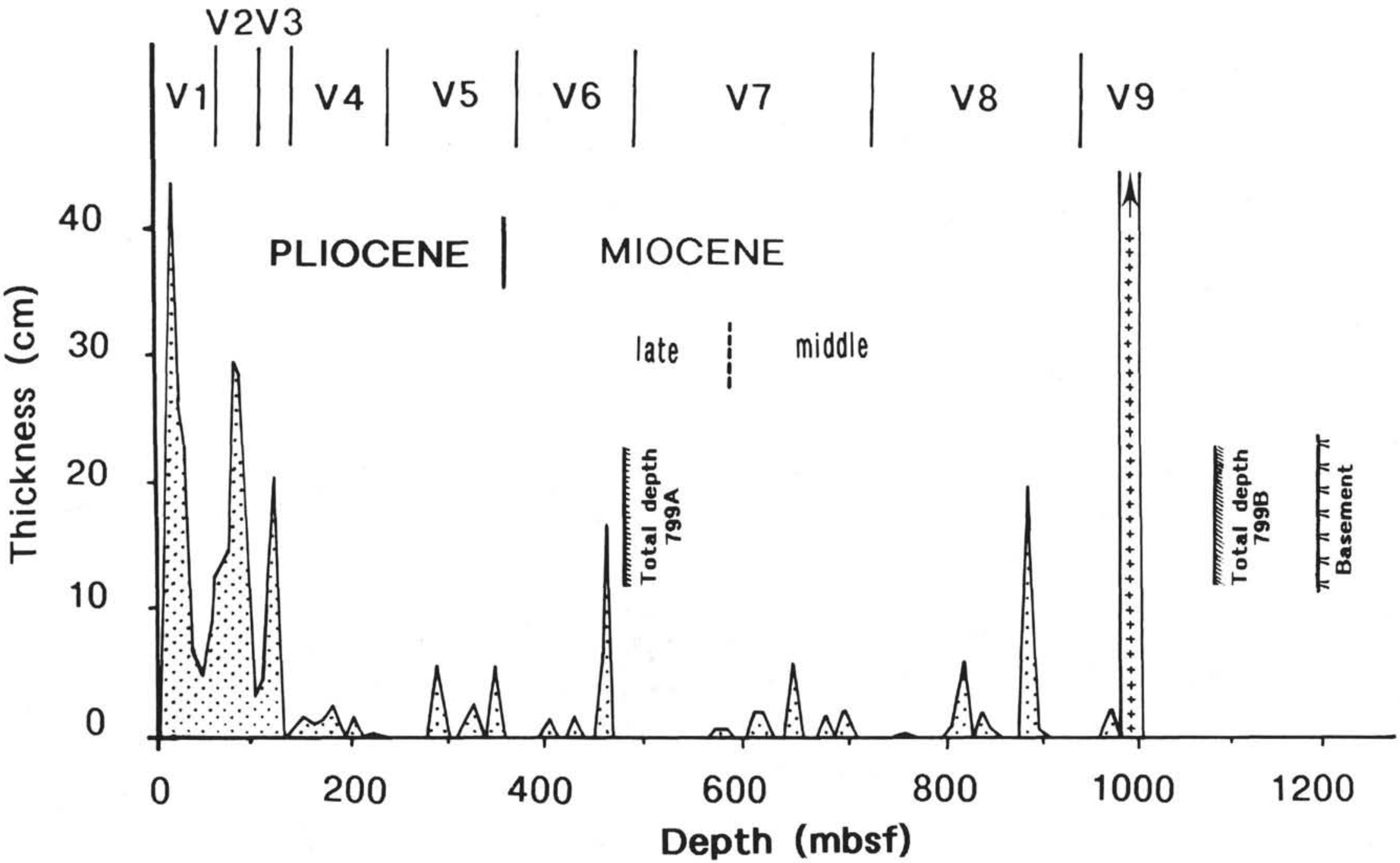

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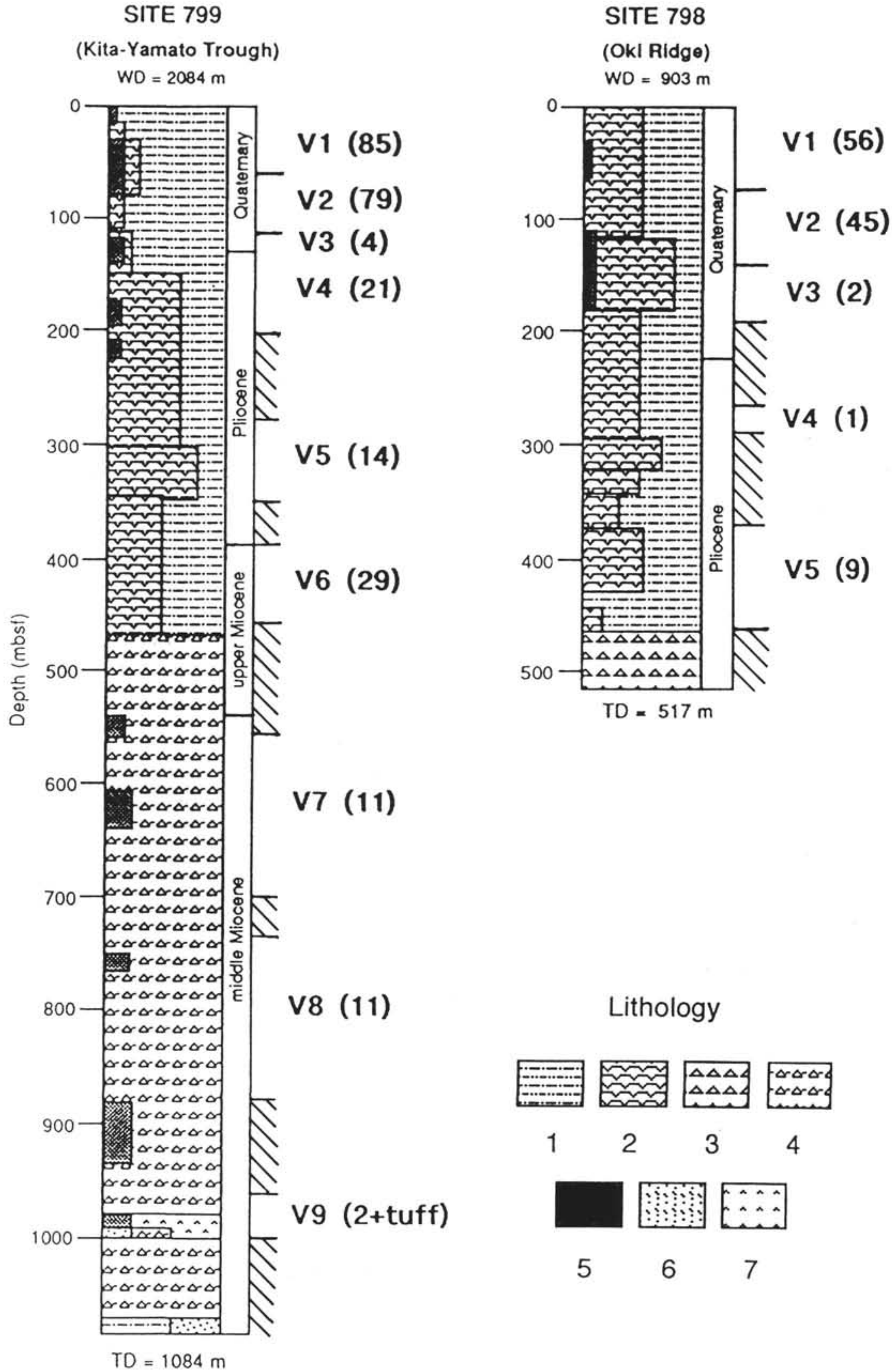


Figure 4. Stratigraphic summary columns for Sites 798 and 799. V1 to V9 = volcanic phases with the number of ash layers in parentheses; hatchured sections = volcanic hiatuses; WD = water depth; TD = total depth below seafloor. Lithology = 1, clay and silty clay; 2, diatom ooze; 3, chert and siliceous clay alternation; 4, siliceous claystone and porcellanite; 5, calcareous ooze; 6, sand and silt; 7, rhyolite tuff.

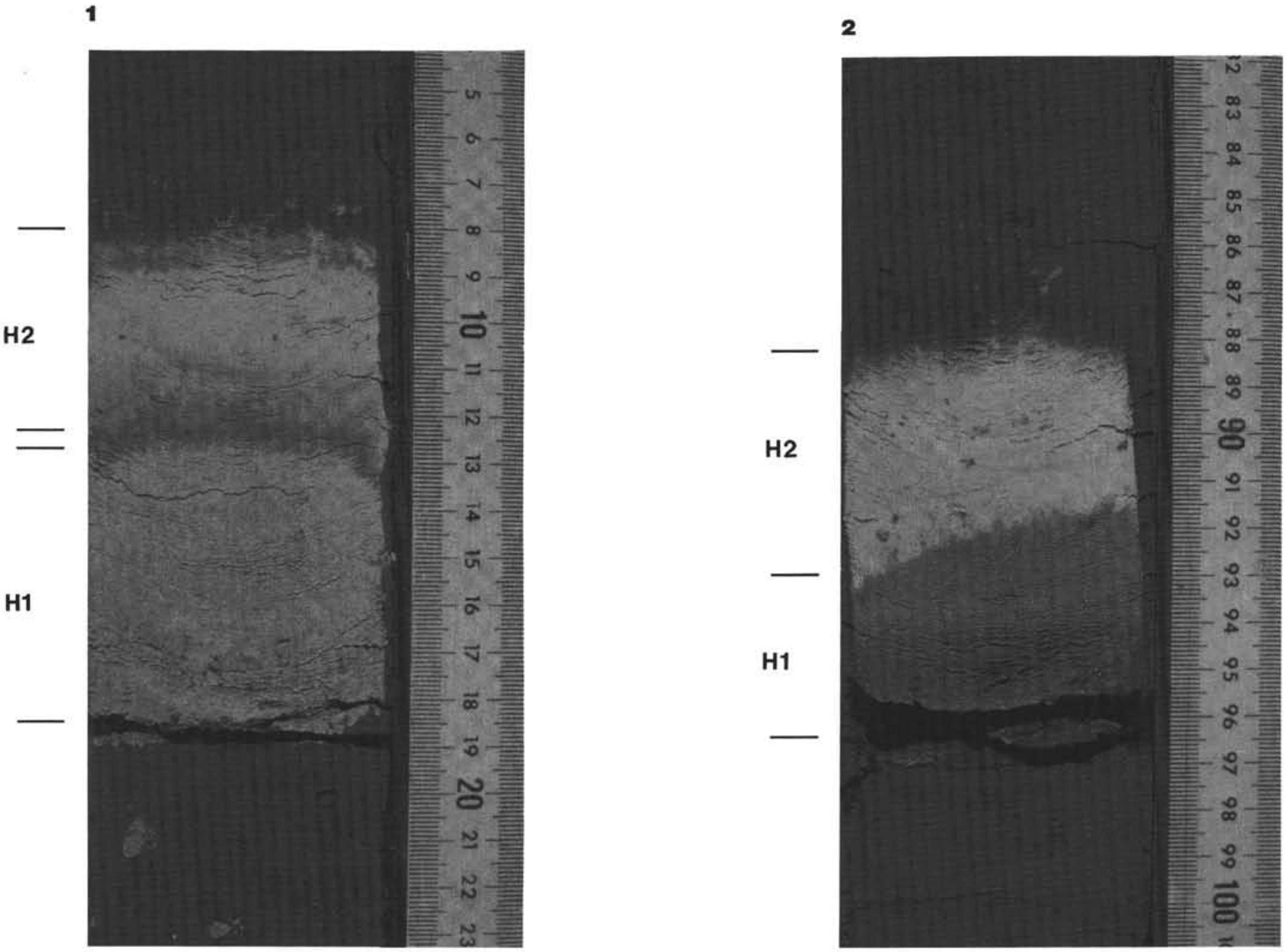


Plate 1. Thick homogeneous ash-fall layers; Samples 128-798C-7H-4, 8–19 cm and 88–96 cm. **1.** Two successive eruptions of rhyolitic composition, H1 (slightly graded) and H2, divided by a short period of sediment deposition. **2.** Two successive eruptions, H1 (dacite) and H2 (rhyolite), separated by a period of erosion (oblique truncation).

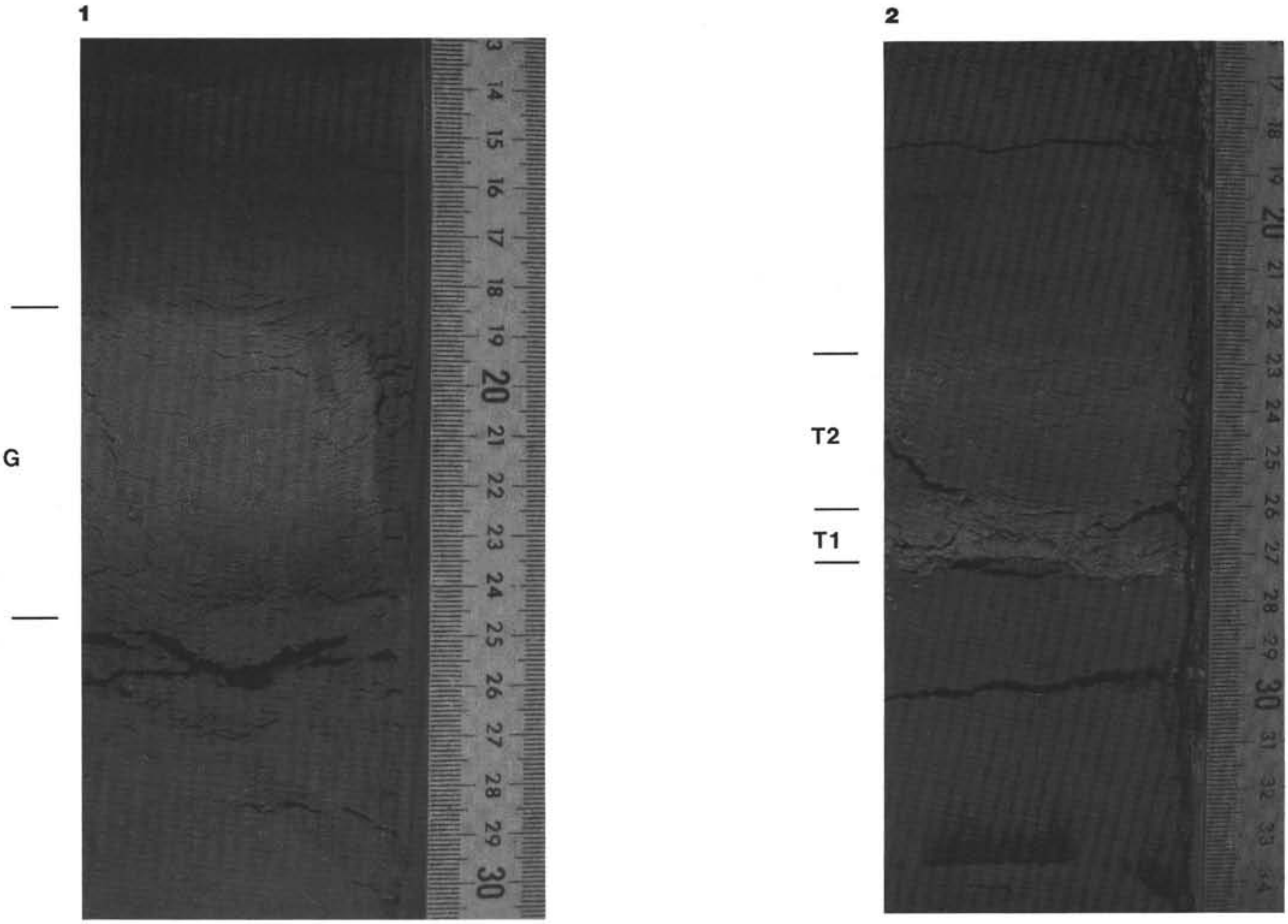
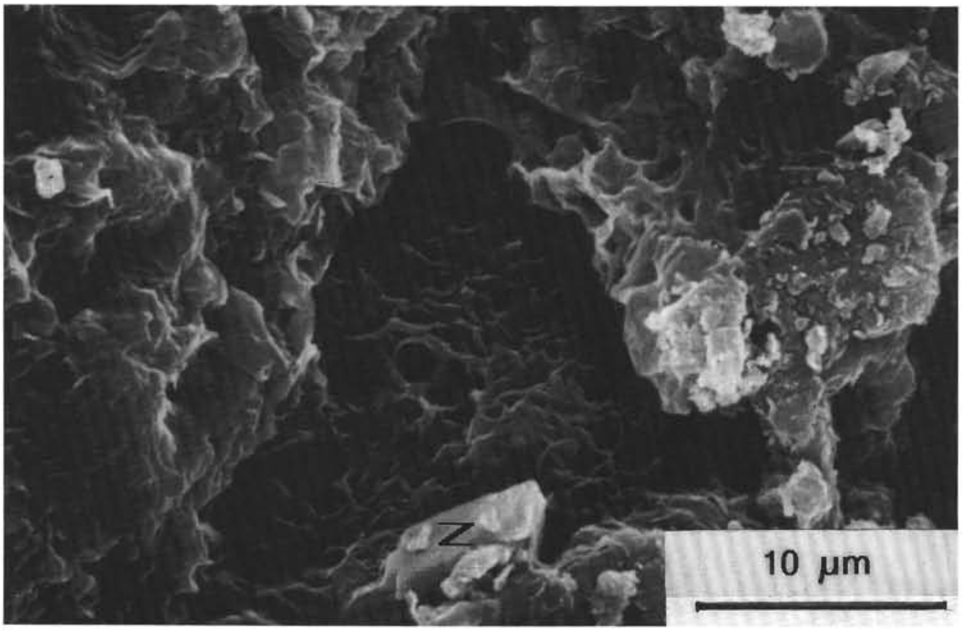
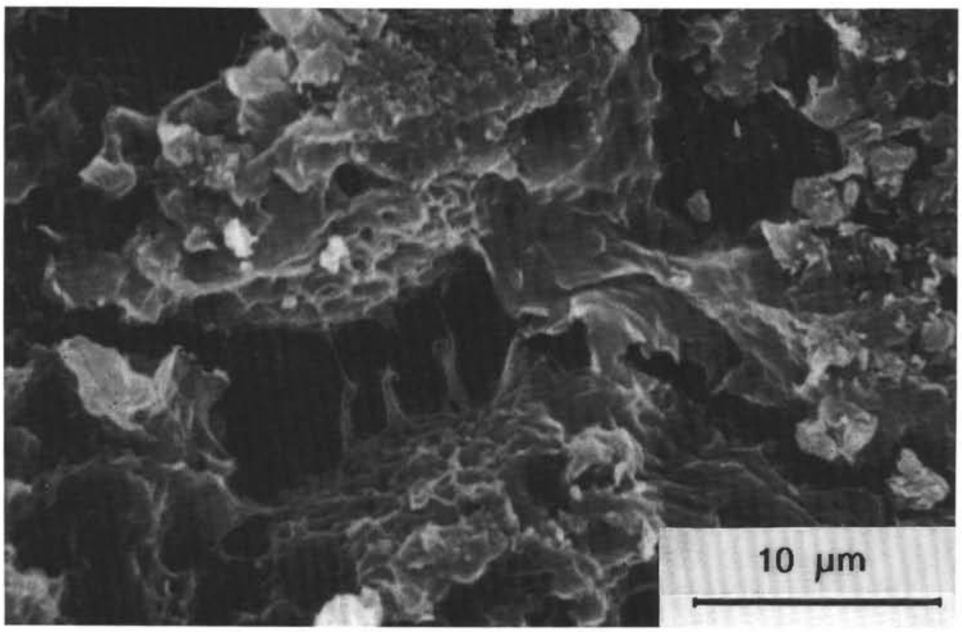


Plate 2. **1.** Graded ash-fall layer of dacitic to rhyolitic composition (G); Sample 128-798B-4H-6, 19–24 cm. **2.** Heterogeneous ash-fall layer of phonolitic (T1) and rhyodacitic (T2) compositions produced by two distinct but closely-timed eruptions; Sample 128-798C-7H-3, 23–28 cm.



1



2

Plate 3. Ash-flow tuff; Sample 128-799B-58R-2, 74–77 cm. **1.** Micropumice aggregate and zeolite (Z) crystallization. **2.** Glass dissolution in the micropumices.