32. RADIOMETRIC AGES OF BASEMENT LAVAS RECOVERED AT LOEN, WODEJEBATO, MIT, AND TAKUYO-DAISAN GUYOTS, NORTHWESTERN PACIFIC OCEAN[1]

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ABSTRACT

The best estimate for the age of the oldest volcanism recovered from the summits of Loen, Wodejebato, MIT, and Takuyo-Daisan guyots, northwestern Pacific Ocean, is 113, 83, 123, and 118 Ma, respectively. All of these sites originated in the central and western regions of the South Pacific Isotopic and Thermal Anomaly (SOPITA). The 113-Ma age for Loen Guyot is significantly different from the 76-Ma age of volcanism under the carbonate platform of its neighbor, the living Anewetak Atoll, and suggests that drowned guyot/living atoll seamount pairs may have no genetically significant relationship other than geographic proximity. Although all of the basalts recovered from the top of Wodejebato Guyot were erupted during polarity Chron 33R (ca. 79–85 Ma), both the occurrence of reworked Cenomanian calcareous nannofossils in one of the summit cores and the existence of a thick Cenomanian volcaniclastic sequence, including 94-Ma basaltic clasts, in the archipelagic apron indicate that there must have been a Cenomanian or older edifice beneath the drilled summit volcanics. AT MIT Guyot, two late-stage periods of volcanism can be recognized: late Aptian (ca. 115 Ma) phreatomagmatic eruptions through the existing volcanic and carbonate platform, and 120-Ma hawaiites seen both as exotic clasts in the 115-Ma tuffs and as lava flows at the top of the basement sequence. Also, the 122.9 ± 0.9 Ma age of two lavas in the basement lava sequence date the upper boundary of the reversed polarity Chron M1R, providing an important calibration point for the Cretaceous Geological Reversal Time Scale. The 118-Ma age of volcanism at Takuyo-Daisan Guyot is best constrained by the age of dredge basalts from its flanks and those of its neighbor to the southwest, Takuyo-Daini Seamount, but agrees well with the oldest sediments recovered at Hole 879A.

INTRODUCTION

Geochronological control through the radiometric dating of seamount basalts provides constraints central to almost all of the scientific objectives of the Guyots and Atolls Drilling Program, Ocean Drilling Program (ODP) Legs 143 and 144: age of principal edifice formation, maximum age of initial reef formation, timing of platform drowning, timing of relative changes in sea level and/or vertical tectonics, timing of seamount paleolatitude changes, and the longevity of the mantle source of SOPITA/Dupal lavas.

Leg 144 reached volcanic basement at the nine sites on the summits of five guyots in the northwestern Pacific Ocean (Fig. 1). Six of these sites had material suitable for $^{40}Ar/^{39}Ar$ dating: Site 872 on Loen Guyot and Sites 873, 874, and 876 on Wodejebato Guyot in the Marshall Islands; Site 878 on MIT Guyot north of the Marcus-Wake Seamount Group; and Site 879 on Takuyo-Daisan Guyot in the Seiko cluster of the Japanese Seamounts. In addition, Leg 143 recovered volcanic material suitable for $^{40}Ar/^{39}Ar$ dating at Site 869 on the archipelagic apron of Wodejebato Guyot and its sister seamount, Pikini Atoll (Pringle and Duncan, 1995). Finally, two dredges recovered during the Aries V expedition of the Scripps Institute of Oceanography from seamounts in the Seiko cluster of the Japanese Seamounts, including Takuyo-Daisan, recovered material with important implications for the timing of volcanism in that seamount group. The purpose of this study is to provide reliable age estimates for each of these sites of volcanism.

[1] Haggerty J.A., Premoli Silva, I., Rack, F., and McNutt, M.K., (Eds.), 1995. *Proc. ODP, Sci. Results*, 144: College Station, TX (Ocean Drilling Program).

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SITE SUMMARIES AND SAMPLES STUDIED

Loen Guyot (Site 872)

Three holes were drilled at Site 872 near the center of Loen Guyot. Hole 872B penetrated about 57 m into basement; Sample 144-872B-9R-2, 115–120 cm, is an aphyric hawaiite from one of the lowermost units. We crushed and leached this sample to dissolve a significant amount of the 10%–15% of green-brown clay in an otherwise fresh, holocrystalline but very fine-grained, trachytic groundmass. Hole 872C recovered about 2 m of titanaugite- and olivine-microphyric differentiated alkalic basalt. Sample 144-872C-18X-1, 88–93 cm, is from one of the freshest pieces, with 10%–15% clay in a nearly holocrystalline, relatively coarse-grained, intergranular groundmass.

The oldest sediments found at Site 872 were Coniacian to early Santonian pelagic limestones filling fractures in the uppermost basalts (Fig. 2; Erba et al., this volume). The normal polarity of the basalts supports a mid Cretaceous eruption age of the volcanic basement, during the long Cretaceous Normal Polarity Superchron (Premoli Silva, Haggerty, Rack, et al., 1993). No evidence for a shallow-water limestone platform at Loen Guyot was recovered at Site 872. However, Lincoln et al. (1993) describe material dredged from the southern slopes of Loen Guyot that suggest that a shallow platform capped the guyot in the early or middle Albian, but that the guyot was already into the pelagic environment by the latest Albian.

Wodejebato Guyot Summit (Sites 873 through 877)

Five sites were drilled on the summit of Wodejebato Guyot: Site 873 near the center of the guyot, Sites 874 and 877 on the inner perimeter ridge, and Sites 875 and 876 on the outer perimeter ridge (Premoli Silva, Haggerty, Rack, et al., 1993). Hole 873A was the only site with significant basement penetration, drilling through a 19-m-thick claystone developed through extensive weathering of the underlying basalts, 29 m of lava flows, and bottoming in 28 m of debris-flow breccias. Samples 144-873A-17R-1, 23–27 cm, and -18R-1,

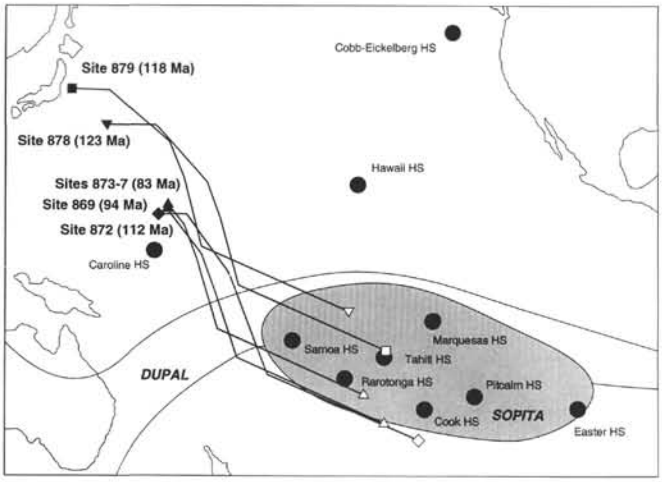

Figure 1. Present-day (solid squares and triangles) and original (open squares and triangles) locations of the volcanism sampled at Sites 869, 872, 873–877, 878, and 879, Legs 143 and 144. Original locations calculated by backtracking the present-day locations using the weighted ages given in Table 1 and the rotation poles of Duncan and Clague (1985). Note that the volcanic source of the 869B apron site was probably about 45 nmi to the northeast, near the summit of Wodejebato Guyot, represented by Sites 873–877. Also shown are locations of the modern SOPITA of Staudigel et al. (1991), the DUPAL anomaly of Hart (1984), and the modern active Pacific hotspots.

14–18 cm, are aphyric, microcrystalline differentiated alkalic basalt or hawaiite flows. Hole 874B penetrated 15 m of claystone before bottoming in 16 m of a single ankaramite flow, Sample 144-874B-24R-4, 106–111 cm, is among the freshest pieces, with 5%–10% green clay and brown glass in an otherwise holocrystalline groundmass (and with relatively fresh olivine phenocrysts). Holes 875C and 876A passed directly from shallow-water limestones into basaltic basement, with little or no indication of an intervening weathering horizon. Hole 875C bottomed in 9 m of altered basalts, whereas Hole 876A bottomed in 14.5 m of at least three distinct basalt flows. Sample 144-876A-17R-1, 91–98 cm, is a sparsely olivine- and clinopyroxene-phyric, fine-grained alkalic basalt, whereas Sample 144-876A-17R-1, 98–104 cm, is a plagioclase-microphyric, medium-grained alkalic basalt; both have 10%–20% green-brown clay in an otherwise holocrystalline groundmass.

All of the sites drilled on the summit of Wodejebato Guyot recovered evidence of a Late Cretaceous shallow-water limestone platform (Premoli Silva, Haggerty, Rack, et al., 1993; Erba, this volume, Premoli Silva et al., this volume). The most age-diagnostic fossil assemblage, nannofossil Zone CC22 of middle Campanian age, was found in a series of carbonaceous clay and argilleous limestone underlying the platform carbonate sequence at Site 877; similar assemblages were found at Holes 873A and 874B (Fig. 2; Erba et al., this volume). The youngest assemblages at Sites 873, 874, and 877 are similar in age to the oldest assemblages found at Sites 875 and 876, from the late Campanian to early Maastrichtian *G. gansseri* planktonic foraminifer zone. All of the basement lavas recovered at Wodejebato Guyot are reversely magnetized and have been attributed to Chron 33R of early Campanian age (Nakanishi and Gee, this volume; Premoli Silva, Haggerty, Rack, et al., 1993). However, the argilleous limestone layers at Site 877 also contain reworked Cenomanian calcareous nannofossils, indicating that only the most recent part of the basement edifice of Wodejebato Guyot has been recovered at Sites 873 through 877.

Wodejebato/Pikini Apron (Site 869, Leg 143)

Site 869 was chosen as an archipelagic apron site, 75 km to the southeast of the Wodejebato/Pikini Guyot/Atoll pair in the northern Marshall Islands. The upper part of Hole 869B penetrated 208 m of an upper Miocene to upper Maastrichtian–lower Campanian pelagic ooze, porcellanite, and chert (Sager, Winterer, Firth, et al., 1993). The lower part of Hole 869B penetrated nearly 600 m of repeated sequences of Late Cretaceous volcaniclastic sandstones and breccias deposited against a background of pelagic nannofossil and radiolarian claystone. The episodic nature of the supply of the volcaniclastic sediments resulted in a distinctly nonuniform rate of deposition (Sager, Winterer, Firth, et al., 1993):

Age	Thickness (m)
late Maastrichtian/early Campanian	29
Campanian	174
late Santonian	19
Turonian–Coniacian	48
late to middle/late Cenomanian	328

In particular, a nearly 50-m-thick subunit of volcaniclastic debris and grain flows in the center of the late Cenomanian section contained angular to subrounded basaltic clasts as much as 8 cm in diameter. We chose three clasts from this subunit for dating: hawaiite (Sample 143-869B-41R-5, 82–85 cm) for whole-rock analysis (fine-grained yet holocrystalline trachytic groundmass), and plagioclase-pyroxene-olivine phyric (Samples 1-869B-41R-2, 84–86 cm, and -41R-4, 70–73 cm) for analysis of plagioclase separates. We have not yet tried to date any volcanic material from the Campanian section, but a dateable sample would probably have to be a bulk plagioclase separate from the volcaniclastic sandstone matrix unless individual crystals of biotite or hornblende could be found.

MIT Guyot (Site 878)

The lowermost sections recovered at Site 878, located just inside the southern perimeter ridge of MIT Guyot, consist of a 187-m-thick basement section of subaerial alkalic lavas flows, overlain by 100 m of platform carbonates and more than 200 m of volcanogenic polymict breccia (Fig. 3; Premoli Silva, Haggerty, Rack, et al., 1993). The basement section itself can be divided into three main compositional groups separated by significant weathering horizons: an upper 10-m-thick sequence of hawaiites, a middle 46-m-thick sequence of titanaugite-rich basanitoids, and a lower 110-m-thick sequence of plagioclase-rich basanitioids and alkalic basalts. An especially well-developed tropical weathering profile, preserved as an 8-m-thick claystone, is present between the middle basanitoids and lower basalts. The polymict breccia is interpreted as the product of a series of phreatomagmatic eruptions through the underlying basalt and platform carbonate succession. We chose five whole-rock samples from the basement section: three of the lower alkali olivine basalts (from Sections 144-878A-98R-3, -91R-3, and -89R-4), a basanite from the middle lavas (Section 144-878A-80R-6), and a plagioclase-phyric hawaiite from the upper lavas (Section 144-878A-79R-3). In addition, we chose two clasts from the polymict breccia: an (originally) olivine-phyric alkalic differentiate or hawaiite from Section 144-878A-46M-1, and a plagioclase-phyric hawaiite from Section 144-878A-46M-2. Both of these clasts appear to be exotic fragments similar to the upper hawaiite flows in the basement section. None of the juvenile material in the polymict breccia was found to be fresh enough for $^{40}Ar/^{39}Ar$ geochronology.

The biostratigraphic constraints on the age of the sediments at Site 878 are summarized in Figure 3. Platform carbonates from Core 144-878A-41M, just above the top of the polymict breccia, are attributable to the late Aptian *N. truittii* Acme of Mutterlose (1991) and the *G. algerianus–H. trocoidea* planktonic foraminifer Zones (Premoli Silva, Haggerty, Rack, et al., 1993; Erba et al., this volume). Platform carbonates from Core 144-878A-75R, 25 m above volcanic basement, are earliest Aptian in age (i.e., above the first occurrence of *R. irregularis*), which defines the base of the *C. litterarius* nannofossil

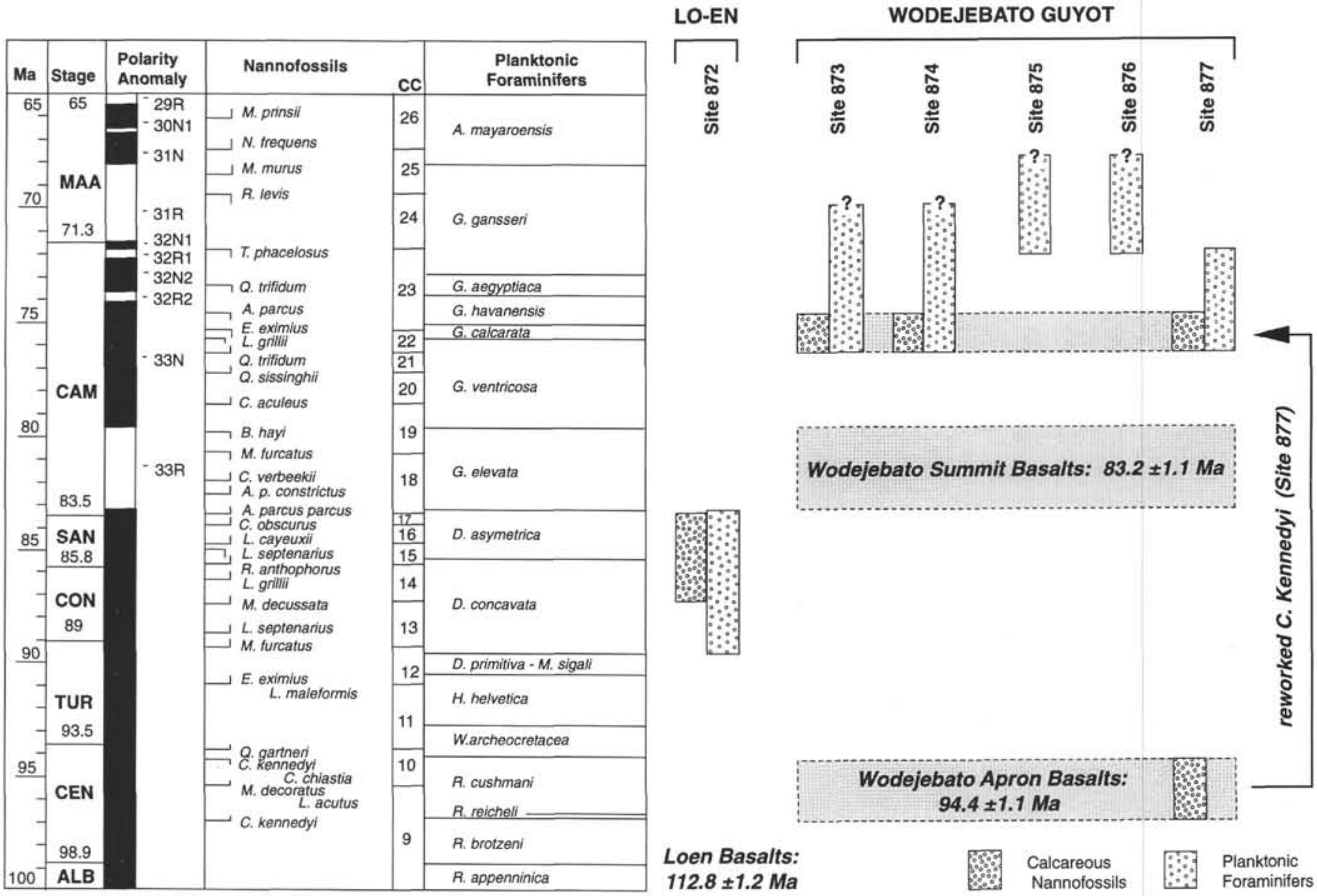

Figure 2. Age of the volcanic basement at the summit of the Wodejebato Guyot (83.2 Ma) and volcanic clasts found in the archipelagic apron 45 nmi to the southwest (94.4 Ma), compared with the oldest sedimentary rocks found at the summit. Note that all of the volcanic basement drilled at Wodejebato, including the undated breccias such as those at the base of Hole 873A, is reversely magnetized and must have been erupted during magnetic Chron 33R. Biostratigraphy from Erba et al. (this volume) and Premoli Silva et al. (this volume); time scale from Gradstein et al. (in press).

zone but below the "nannoconid crisis" (Premoli Silva, Haggerty, Rack, et al., 1993; Erba, 1994; Erba et al., this volume).

The magnetostratigraphy of the sedimentary and volcanic sequences, also shown in Figure 3, has important implications for the age of the basement at MIT Guyot. All of the samples examined from the sedimentary platform sequence, including the polymict breccia, were normally magnetized (Premoli Silva, Haggerty, Rack, et al., 1993). Their biostratigraphic age (see Fig. 3) indicates that all of the sedimentary platform sequence was deposited during the long Cretaceous Normal Polarity Superchron (K-N). Of course, drilling recovery is poor in such sequences, especially in recovering pieces large enough to determine the original orientation of the sample. Thus, it is possible that a reversal has been missed. In fact, although no samples were actually reversed, one sample from the lower limestone section (Premoli Silva, Haggerty, Rack, et al., 1993; Nakanishi and Gee, this volume) did have an anomalously shallow inclination, perhaps suggestive of a reversal just above or below.

A magnetic reversal does, however, occur in the basalt sequence (Premoli Silva, Haggerty, Rack, et al., 1993). According to shore-based measurements on discrete samples (Nakanishi and Gee, this volume), all of the flows from the upper hawaiite and middle basanitoid sequences are normally magnetized, the uppermost lower alkalic basalts (Sections 144-878A-86R-2 to -90R-2) have transitional polarity directions, and all of the flows below Section 144-878A-90R-3 are reversely magnetized. According to the downhole magnetometer logs (Ito and Nogi, this volume), the reversal occurs somewhere between Sections 144-878A-90R-4 and -92R-2. Using the biostratigraphy discussed above and the time scales of Harland et al. (1990) and Gradstein et al. (in press), the reversal seen in the basalts is most likely either M0 or M1 (shown as M1 in Fig. 3; see discussion below).

Takuyo-Daisan Guyot (Site 879 and Dredge Samples)

Hole 879A is located on the perimeter ridge of Takuyo-Daisan Guyot in the Seiko cluster of the Japanese Seamounts (Fig. 1). Drilling bottomed in about 20 m of an intercalated mixture of plagioclase-phyric basalt and volcanic breccia or peperite (i.e., formed by the intrusion of the basaltic lava into a soft, wet sediment). Both the basalt and the volcanic breccia are pervasively altered and variably discolored to various shades of reds and greens (Premoli Silva, Haggerty, Rack, et al., 1993). Apparently fresh plagioclase from two of the fresher pieces of basalt was separated for $^{40}Ar/^{39}Ar$ dating. Also, two samples dredged from Takuyo-Daisan and its southwestern neighbor, Takuyo-Daini, during the Aries V expedition of the Scripps Institute of Oceanography (Heezen et al., 1973; Winterer et al., 1993) were chosen for $^{40}Ar/^{39}Ar$ dating to help elucidate the age of basement volcanism in the Seiko Cluster of the Japanese Seamounts.

The age of the oldest sedimentary rocks above the peperite at Site 879 is similar in to those just above the polymict breccia at MIT Guyot (Fig. 3), with assemblages diagnostic of the *N. truittii* Acme and *G. algerianus–H. trocoidea* Zones, or the late Aptian.

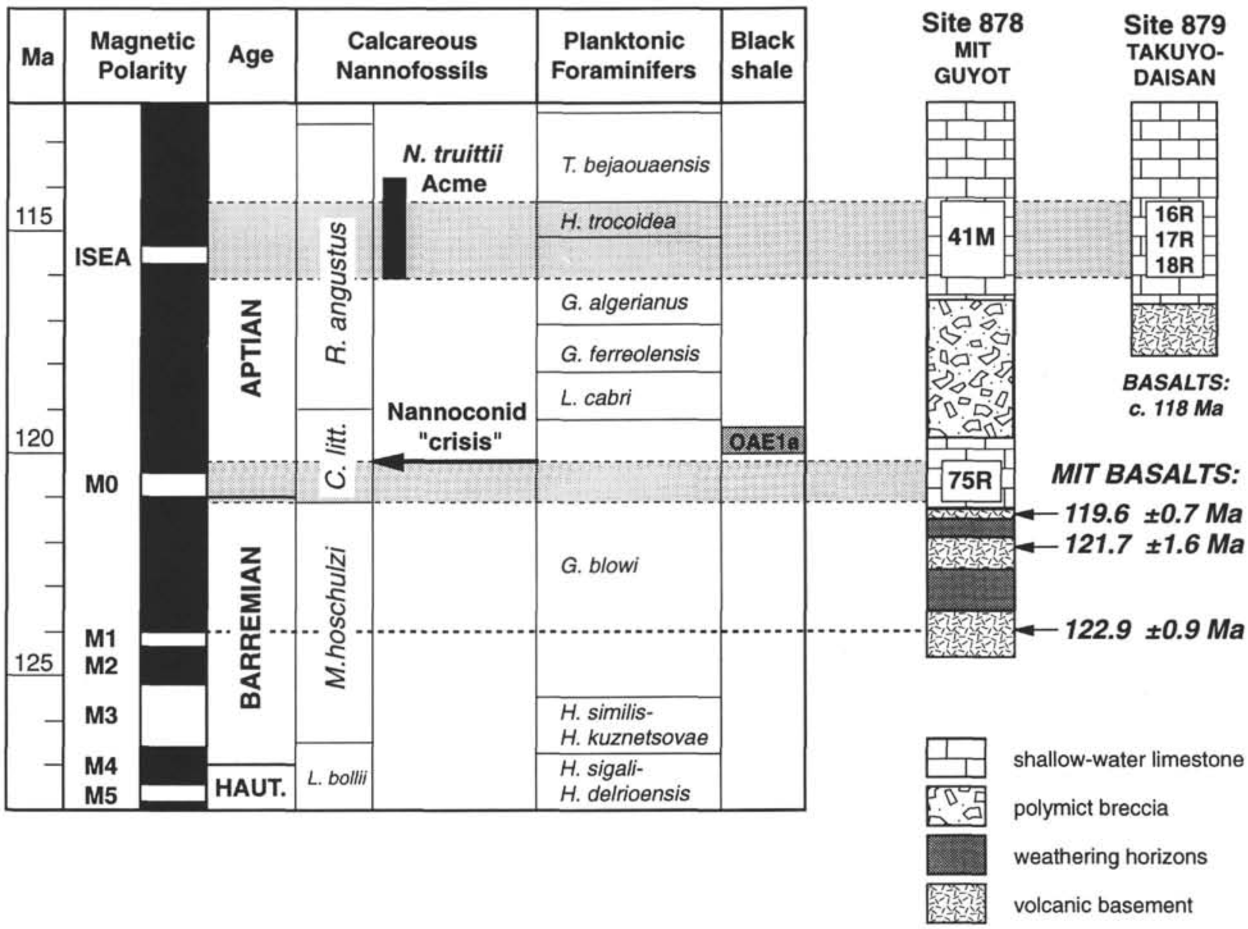

Figure 3. Age of the volcanic basement MIT Guyot and Takuyo-Daisan Guyot, Sites 878 and 879, respectively, compared with the oldest sedimentary rocks found at those sites. Biostratigraphy from Erba et al. (this volume) and Premoli Silva et al. (this volume); time scale from Gradstein et al. (in press).

K-Ar GEOCHRONOLOGY

The K-Ar clock, and especially the $^{40}Ar/^{39}Ar$ technique, has been widely used to date oceanic lavas. However, care must be used in the interpretation of such data because several fundamental assumptions of the technique are almost certainly violated by samples that have been altered in the submarine environment. The advantage of using the $^{40}Ar/^{39}Ar$ method for deciphering the crystallization age of altered rocks is that accurate ages can be differentiated from unreliable dates using a series of *internal* tests for a set of apparent ages from any given sample. It may not be possible to differentiate *why* a particular age from a sample is unreliable, although alteration processes are clearly a contributing factor (see Pringle, 1993, for a more complete discussion). However, one can test *whether* the K-Ar clock of a particular sample is too disturbed to reveal a meaningful age.

Criteria for Interpreting $^{40}Ar/^{39}Ar$ Apparent Ages

To test whether a sample can reveal a reliable $^{40}Ar/^{39}Ar$ age, one must first generate a set of ages upon which to apply the criteria presented below. For relatively low-potassium, moderately to highly altered samples, we have found that step-heating experiments provide the most useful sets of apparent ages. This is principally because low-temperature alteration phases tend to release their gas at lower temperatures, allowing us to examine the higher temperature gas release, presumably from higher temperature igneous phases, for a pattern representative of a concordant crystallization age.

Following Pringle (1993), we modify the conservative criteria of Lanphere and Dalrymple (1978) and Dalrymple et al. (1980) so that each criterion involves the use of a rigorous statistical test. We apply these criteria to a set of apparent ages for a given sample. We accept that this set of apparent ages represents an accurate estimate of the crystallization age of the sample only if:

1. No age difference can be detected between any of the individual ages at the 95% confidence level. For an incremental heating experiment, these ages should represent a well-defined, high-temperature age plateau representing three or more contiguous steps that contain at least 50% of the ^{39}Ar released.
2. A well-defined isochron exists for the set (i.e., the F ratio statistic for the regression is sufficiently small at the 95% confidence level). If this ratio is exceeded, then there is more scatter about the isochron than can be explained by analytical error alone, and some additional geologic or experimental disturbance is significant.
3. The weighted mean plateau age from criterion 1 and the isochron age from criterion 2 are not significantly different at the 95% confidence level.
4. The $^{40}Ar/^{36}Ar$ intercept from the isochron analysis in criterion 2 is not significantly different from the atmospheric value of 295.5 at the 95% confidence level.

Techniques

Samples for whole-rock incremental heating experiments were slabbed and trimmed to obtain the freshest and most holocrystalline material. The Aries V samples were crushed to about 0.5–1 mm in size, hand-picked to remove vesicle and vein alteration, and cleaned in an ultrasonic bath with deionized water; the ODP drill-core sam-

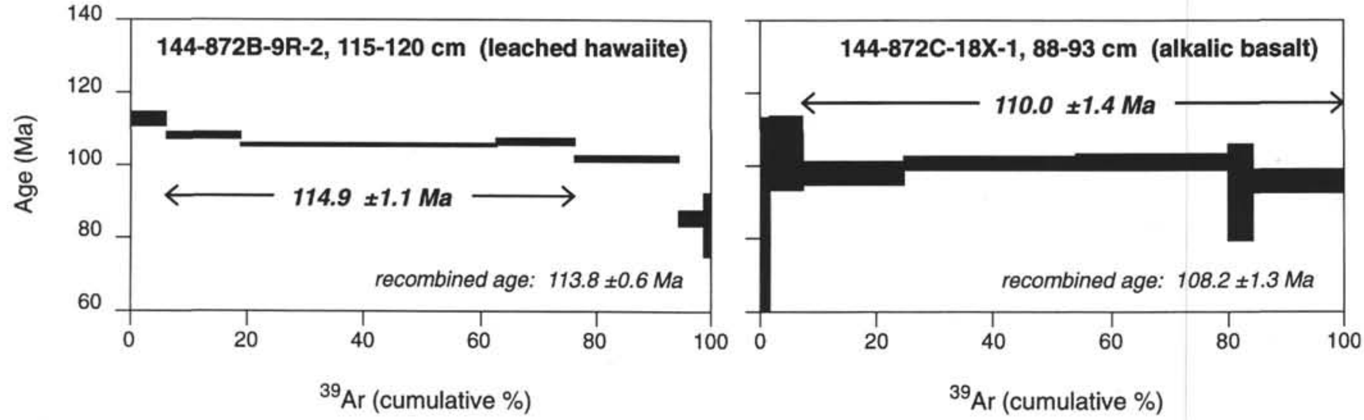

Figure 4. Age spectra of incremental heating experiments on whole-rock samples from Loen Guyot, Site 872. Individual step ages are drawn ±1 standard deviation of the apparent age.

ples were prepared as 6-mm cores drilled from the freshest sections of the 1-cm-thick slabs. Plagioclase mineral separates were prepared using conventional heavy liquid and magnetic techniques, and further cleaned with cold 5%–10% HF, warm 3N HCl, and, finally, distilled water in an ultrasonic bath. One sample was prepared as a groundmass separate by crushing to 125 to 250 μm, cleaning with warm 3N HCl, and rinsing with distilled water in an ultrasonic bath.

The whole-rock samples, about 0.5 g each, and the plagioclase and leached groundmass separates, about 15 mg each encapsulated in Cu foil packets, were sealed in fused-silica vials and irradiated for 6–12 hr in the core of the Oregon State University TRIGA reactor. The efficiency of the conversion of ^{39}K to ^{39}Ar was monitored with 27.92 Ma 85G003 TCR sanidine except for the two Aries V dredge samples, for which 27.7 Ma FCT-3 biotite was used. Corrections for interfering K- and Ca-derived Ar isotopes are those from Dalrymple et al. (1981). ^{40}K decay constants used were $\lambda E = 0.581 \cdot 10^{-10}$ and $\lambda B = 4.962 \cdot 10^{-10}$.

Argon extractions for the whole-rock samples were performed in a conventional high-vacuum glass extraction line using radio-frequency induction heating. The cleanup system consisted of a series of two titanium furnaces held at about 800°C to getter the reactive gases, and subsequently cooled to get hydrogen. Heating steps, each 20 min long, used fixed power levels on the RF generator, determined from previous experience to divide the Ar release into five to seven roughly equal proportions, and ranged from about 600° to 1300°C in roughly 100°C increments. The argon composition of each gas increment was measured with an AEI-MS-10S mass spectrometer using computer-controlled peak switching and data acquisition. The total system blank was better than 2 to $3 \cdot 10^{-14}$ moles ^{40}Ar during the course of these experiments.

Argon extractions for the plagioclase and leached groundmass separates were performed with an all-metal Staudacher-type resistance furnace and a MAP-216 mass spectrometer at Stanford University, or with a defocused argon laser beam laser and a MAP-215/50 mass spectrometer at the Free University (Amsterdam). Both systems use two SAES St172 getters heated to about 250°C for gas cleanup; the Amsterdam extraction procedure also used a glass cold finger cooled with a dry ice/alcohol slurry for some samples. The cold system blank for both systems was better than $2 \cdot 10^{-16}$ moles ^{40}Ar during these experiments.

Argon extractions for the plagioclase and groundmass separates were performed with an all-metal Staudacher-type resistance furnace and MAP-216 mass spectrometer at Stanford University, an all-metal Staudacher-type resistance furnace and a MAP-215/50 mass spectrometer at Oregon State University, or with a defocused argon laser beam laser and a MAP-215/50 mass spectrometer at the Free University (Amsterdam). The Amsterdam and Stanford systems use two Zr-Zr/Fe/V getters heated to about 250°C for gas cleanup; the Amsterdam extraction procedure also uses a glass cold finger cooled with a dry ice/alcohol slurry for some samples. The cold system blank for both systems was better than $2 \cdot 10^{-16}$ ^{40}Ar moles during the course of this study. The Oregon State extraction system is similar but also has a Zr/Al appendage pump heated to about 400°C and subsequently cooled during the extraction; the system blank for this system was about $2 \cdot 10^{-15}$ ^{40}Ar moles during the course of this study.

Incremental heating experiments were reduced as both age spectra and argon-isotope isochron regressions. Errors have been reported as the standard deviation of analytical precision. Plateau ages were calculated as weighted means, where each step was weighted by the inverse of its variance. Isochron ages were calculated for both the $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ and $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ regressions using the York2 least-squares fit with correlated errors (York, 1969); SUMS/N-2 is the F ratio statistic for this regression. We have found no significant difference between the two regressions when proper error estimates and error correlation coefficients are used (Dalrymple et al., 1988).

RESULTS

The $^{40}Ar/^{39}Ar$ age determinations for the basaltic rocks from the four guyots studied are summarized in Table 1; the complete list of incremental heating data is available from the ODP Data Base Group. Age spectrum diagrams with plateau ages are shown in Figures 4 through 8. We prefer to use the isochron age rather than the plateau age as the best estimate of the crystallization age of each sample because it (1) combines an estimate of the degree of the internal discordance (the scatter about the isochron line) and an estimate of the analytical error in the final error estimate, and (2) makes no assumption about the composition of the initial nonradiogenic, or trapped, component. The weighted mean ages of distinguishable phases of volcanism at each site, as discussed below, are shown in boldface type in Table 1.

Loen Guyot, Site 872

Both of the incremental heating experiments (Fig. 4) on the two differentiated alkalic basalt whole-rock samples from Loen Guyot were concordant; the weighted isochron age is 112.8 ± 1.2 Ma. This is significantly older than the Coniacian to early Santonian of the oldest limestones recovered at Site 872, but agrees well with the early to middle Albian shallow-water debris found in the dredge material from the southern slopes of Loen Guyot by Lincoln et al. (1993).

Wodejebato Guyot Summit Sites 873 through 877

Four out of the five whole-rock samples (from Sites 873, 874, and 876) dated from the summit lavas recovered at Wodejebato Guyot yielded concordant incremental heating data (Fig. 5). The weighted

Table 1. Radiometric ages of Leg 144 basalts.

		Age spectrum			Isochron analyses			
Core, section, interval (cm)	Material	^{39}Ar (%)	Age ± 1 SD (Ma)		Age ± 1 SD (Ma)	Intercept ± 1 SD	Sums N–2	N
Loen Guyot:								
144-872B-9R-2, 115–120	Leached hawaiite	70.2	114.9 ± 1.1		113.3 ± 1.4	427.7 ± 66.6	0.47	3
144-872C-18X-1, 88–93	Alkalic basalt	98.0	110.0 ± 1.4		111.3 ± 2.4	289.2 ± 8.7	0.59	6
				Wtd age:	112.8 ± 1.2			
Wodejebato Guyot:								
Summit sites								
144-873A-17R-1, 23–27	Hawaiite	55.1	80.9 ± 0.6		80.3 ± 5.7	283.8 ± 1011	1.24	3
144-873A-18R-1, 14–19	Hawaiite	92.7	81.9 ± 0.7		78.4 ± 2.8	686.8 ± 557.3	0.96	5
144-874B-24R-4, 106–111	Ankaramite	79.3	85.6 ± 0.8		85.0 ± 1.5	309.4 ± 46.8	0.98	5
144-876A-17R-1, 91–98	Alkalic basalt	63.2	78.6 ± 1.2		73.0 ± 3.6*	556.9 ± 150.7	0.69	4
144-876A-17R-1, 98–104	Alkalic basalt	53.7	82.0 ± 0.8		82.8 ± 2.2	258.8 ± 370.4	1.04	4
				Wtd age:	83.2 ± 1.1			
Apron site								
144-869B-41R-2, 84–86	Plagioclase	93.5	94.0 ± 0.3		94.0 ± 0.4	274.3 ± 17.9	1.53	8
	Plagioclase	93.3	94.6 ± 0.3		93.9 ± 0.9	410.3 ± 101.6	1.21	9
144-869B-41R-4, 70–73	Plagioclase	57.3	91.8 ± 0.3		93.5 ± 1.0	220.9 ± 42.3	1.53	4
144-869B-41R-5, 82–85	Hawaiite	49.4	96.0 ± 0.5		96.3 ± 0.7	289.4 ± 10.1	0.34	4
				Wtd age:	94.4 ± 0.3			
MIT Guyot:								
Upper hawaiites								
144-878A-46M-1, 115–119	Hawaiite	90.7	121.2 ± 0.7		120.7 ± 1.4	335.3 ± 89.9	0.07	4
144-878A-46M-2, 51–55	Hawaiite	70.5	119.9 ± 1.3		117.1 ± 2.0	379.3 ± 138.7	0.65	5
144-878A-79R-3, 103–109	Hawaiite	58.6	119.9 ± 0.8		119.7 ± 0.9	295.3 ± 52.2	0.63	4
				Wtd age:	119.6 ± 0.7			
Middle basanites								
144-878A-80R-6, 94–98	Basanite	86.4	118.5 ± 1.0		121.7 ± 1.6	258.6 ± 14.5	0.22	4
Lower alkalic basalts								
144-878A-89R-4, 33–37	Alkalic basalt	66.3	124.4 ± 0.7		123.6 ± 1.4	400.2 ± 195.1	1.00	5
144-878A-91R-3, 100–106	Alkalic basalt	70.3	123.9 ± 0.7		122.3 ± 1.2	341.5 ± 27.8	0.00	3
				Wtd age:	122.9 ± 0.9			
144-878A-98R-3, 48–53	Alkalic basalt	73.2	123.6 ± 0.7		123.3 ± 0.9	306.9 ± 9.4	1.56	5
Seiko Cluster:								
Taikuo-Daisan								
A5-37-3	Alkalic basalt	73.6	118.4 ± 1.8		(Only 2 points, no isochron)			
144-879A-22R-3, 99–104	Plagioclase		Discordant		Recombined total fusion age: 96.1 Ma			
144-879A-21R-2, 82–86	Plagioclase		Discordant		Recombined total fusion age: 90.9 Ma			
Taikuyo-Daini								
A5-39-2	Hawaiite	89.8	118.1 ± 1.0		118.5 ± 1.1	291.5 ± 1.6	1.92	4

Notes: All ages reported relative to 85G003 TCR sanidine at 27.92 Ma except for the A5-37-3 and A5-39-2 dredge samples, which are relative to FCT-3 biotite at 27.7 Ma. SD = standard deviation, and Wtd. = weighted. Single asterisk (*) = discordant, not used in weighted age calculation.

mean age of the concordant isochron analyses is 83.2 ± 1.1 Ma. The 95% confidence interval of both the individual and mean isochron ages confirms that the reversed magnetic polarity of all of the drilled basement sections indicates that all of the basement lavas at Wodejebato Guyot formed during Chron 33R, ca. 79–83 Ma (Fig. 2). The fifth experiment (Sample 144-876A-17R-1, 91–98 cm) is discordant, with a stepwise decreasing age spectrum usually attributed to ^{39}Ar recoil in fine-grained samples (Fig. 5); the lowest and highest temperature steps of the age plateau are significantly different at the 95% confidence level. The apparent age of that fifth sample (73.0 ± 3.6 Ma) is similar to, but significantly younger than, the 83.2-Ma weighted age of the other samples.

Wodejebato/Pikini Apron Site 869, Leg 143

All of the incremental heating experiments of the samples from the volcaniclastic breccia sampled at Hole 869B were concordant (Table 1 and Fig. 6). The weighted age of the four experiments is 94.4 ± 0.3 Ma. Strictly speaking, one of the plagioclase experiments and the whole-rock experiment are significantly different at the 95% confidence level. Thus, it is most correct to consider the ages as two distinct volcanic events: the plagioclase-phyric clasts, with a weighted age of 93.9 ± 0.3 Ma, and the hawaiite, at 96.3 ± 0.7 Ma.

MIT Guyot, Site 878

All of the incremental heating experiments on the seven whole-rock samples from Site 878 on MIT Guyot were concordant (Table 1 and Fig. 7). The three hawaiites, one from the basement upper lava sequence and two from clasts found near the top of the polymict breccia, formed a younger, analytically distinct group. The weighted mean isochron age for these upper hawaiites is 119.6 ± 0.7 Ma (Table 1). The lone basanite, 121.7 ± 0.7 Ma, is intermediate in age between, although not statistically distinct from, the upper hawaiites and lower basalts. The three lower basalts average 123.1 ± 0.6 Ma. The best age for the top of the reversed polarity Chron seen in the lower basalts is the 122.9 ± 0.9 Ma weighted mean of the two flows closest to the transition (Core 144-878A-89R-4 from within the zone of transitional polarity, and Core 144-878A-91R-3, with reversed polarity, from just below the transition).

Takuyo-Daisan Guyot Site 879 and Dredge Samples

The incremental heating experiments on the two plagioclase separates from the peperite at the base of Hole 879A were surprisingly discordant, yielding no plateau in the age spectrum diagram (Fig. 8) and a complicated K/Ca release pattern (not shown). We interpret the

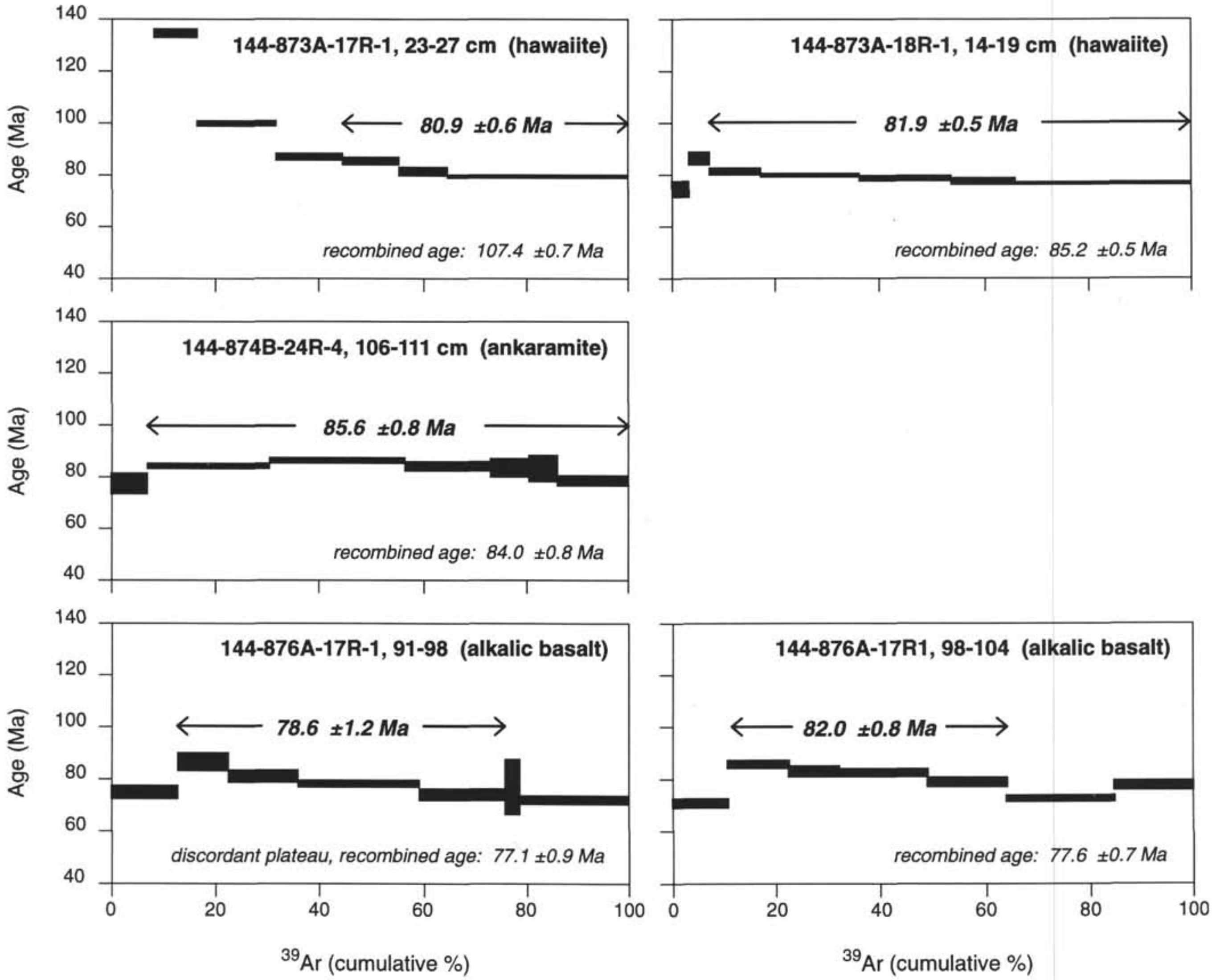

Figure 5. Age spectra of incremental heating experiments on whole-rock samples from the summit of Wodejebato Guyot, Sites 873 through 876. Individual step ages are drawn ±1 standard deviation of the apparent age.

best age estimates from these experiments (90.9 and 96.1 Ma recombined total fusion ages) as minimum age estimates only. We plan further work examining why these apparently clean plagioclase separates did not yield concordant crystallization ages, and we suspect that the red and green discoloration of the basalts may hint at some alteration that we do not yet recognize. However, the two dredge samples did reveal incremental heating experiments concordant with the age of the oldest platform carbonate recovered at Site 879 (Fig. 3). The best result is on the sample from nearby Takuyo-Daini Seamount (A5-37-3); the isochron age of 118.5 ± 1.1 Ma is the best estimate of the age of basaltic volcanism in the Seiko seamount cluster. The two-step, low-temperature plateau age of 118.4 ± 1.8 Ma for Sample A5-39-2 (Fig. 8), containing 73.6% of the ^{39}Ar released, suggests a similar age of volcanism for Takuyo-Daisan.

DISCUSSION AND CONCLUSIONS

Origin in the SOPITA

^{40}Ar/^{39}Ar incremental heating experiments have yielded reliable estimates of the crystallization age of the volcanic rocks sampled from at least four Cretaceous edifices in the northwest Pacific Ocean. Using these ages and stage rotation poles describing Pacific/hotspot motion (such as those of Duncan and Clague, 1985), we can backtrack the current location of these sites to the positions where they formed (Fig. 1). All of these sites had sources in the central and western regions of Staudigel et al.'s (1991) modern South Pacific Isotopic and Thermal Anomaly (SOPITA), a region of extreme isotopic diversity and thermal anomalies in the mantle source of recent South Pacific seamount and ocean island basalts, extending from Easter Island, through French Polynesia, to the Samoan Islands. Volcanism in the Seiko Cluster of the Japanese Seamounts, including Site 879, had an origin near Tahiti in the Society Islands. MIT Guyot, Site 878, had a source in the northwestern SOPITA between the Marquesas and Samoan islands. Volcanism in the Marshall Islands, including Loen and Wodejebato guyots, had an origin near the southern limit of the modern SOPITA, in and south of the Austral-Cook Islands. Possible errors in the original location of these seamounts, principally from errors in the stage poles and an inherent sampling bias because we tend to recover only the uppermost (i.e., youngest) products of volcanism at any given site, prevent a precise comparison between the locations of the Cretaceous and modern hotspots, but the general origin of these Cretaceous seamounts in the SOPITA is clear.

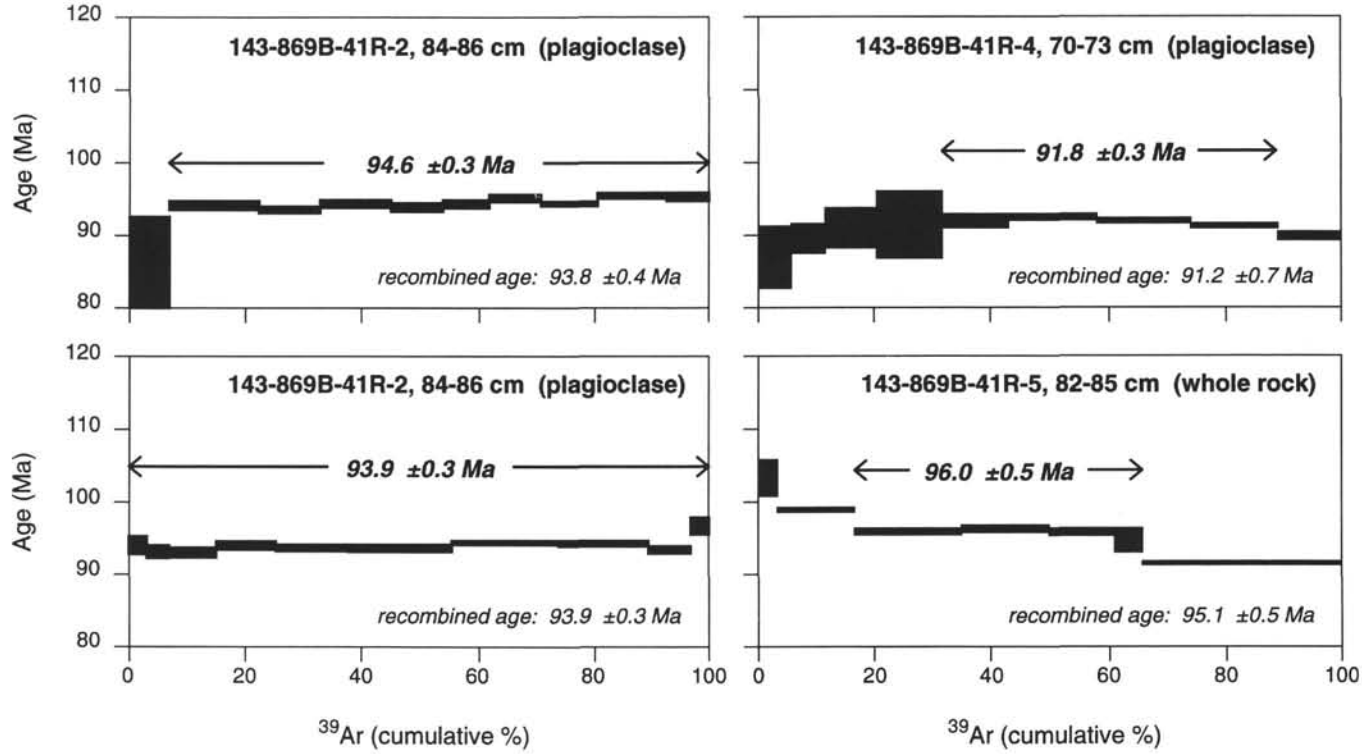

Figure 6. Age spectra of incremental heating experiments on whole-rock samples and plagioclase separates from Hole 869B, drilled on the archipelagic apron southeast of Wodejebato Guyot and Pikini Atoll. Individual step ages are drawn ±1 standard deviation of the apparent age.

Implications for Drowned Guyot/Atoll Pairs

One of the questions to be addressed by the Guyot and Atoll Drilling Program was why some Cretaceous carbonate platforms survive as atolls today, whereas other, "sister" Cretaceous platforms did not. For example, Loen is the "sister" guyot to the living Anewetak Atoll, with whom it shares a common constructional edifice. However, we now know that the age of volcanism at the two volcanoes is significantly different: 113 Ma for Loen Guyot (this study), but 76 Ma for Anewetak (Lincoln et al., 1993). Perhaps at least some guyot/atoll pairs are simply unrelated volcanoes built on the same constructional base. Many of the older of the pairs could have formed in the Early Cretaceous, been affected by the same (as yet unknown) mechanism that seems to have drowned all of the known Cretaceous reefs in the western Pacific by latest Albian/Cenomanian time (e.g., see Winterer et al., 1993), and subsided below the photic zone. A younger, opportunistic volcano could have begun on the existing base of an older edifice, grown to sea level, and established a significantly younger shallow-water carbonate community, but not affected the nearby older edifice enough to bring it back into the photic zone. The Marshall Islands, which seems to have been a literal crossroads of Cretaceous volcanism and hotspot tracks (cf. Lincoln et al., 1993; Bergersen, this volume) would have been an ideal region for such random co-occurrences.

Inherent Bias in Dredged and Drilled Summit Samples

The volcanic basement at the summit of Wodejebato Guyot, including the basal breccias, is all reversely magnetized (Premoli Silva, Haggerty, Rack, et al., 1993). The $^{40}Ar/^{39}Ar$ ages of the lavas reported here, as well as those dredged from the northeast rift zone (M. Pringle and A. Koppers, unpubl. data), are all 85–79 Ma. The only significant reversely magnetized period between 73 and about 120 Ma is Chron 33R. Thus, all of the recovered lavas from near the summit of Wodejebato Guyot must have erupted during magnetic Chron 33R, from 83 to 79 Ma (Fig. 2). This Campanian volcanism most likely provided the source for the thick volcanogenic sands seen in the Campanian section of Site 869. However, these ages are significantly younger than the reworked Cenomanian nannofossils found at Site 877, the Cenomanian to Albian (?) rudists dredged from the southwestern flanks of Wodejebato (Lincoln et al., 1993), and the 96–94 Ma $^{40}Ar/^{39}Ar$ ages of basaltic clasts recovered in the even thicker Cenomanian turbidites at the Site 869 apron hole. Thus, there must have been a Cenomanian or older volcanic edifice at Wodejebato Guyot, even though it was not sampled by the five summit sites drilled during Leg 144.

It is important to note that the only actual samples of this Cenomanian or older volcanism are from the volcaniclastic deposits drilled in the archipelago apron site, 45 nmi away. This suggests that we must be cautious when deciphering the volcanic history of large submarine edifices from limited sample sets, and that drilling through volcaniclastic apron sites may be the best (only?) way to sample the complete volcanic history of large seamounts, guyots, and oceanic plateaus.

Age of the Top of Chron M1R

The 122.9 ± 0.9 Ma age of the top of the reversed-polarity chron seen in the basement lavas of MIT Guyot provides an important calibration point for the mid-Cretaceous Geologic Reversal Time Scale (GRTS), especially if we can unambiguously identify which reversal we are dating. As discussed above, the oldest dated sediments, platform carbonates located approximately 25 m above volcanic basement, are attributable to the lower part of the *C. litterarius* nannofossil Zone (Fig. 3, above the first occurrence of *R. irregularis,* below the nannoconid crisis). The reversed-polarity Chron M0 occurs entirely within this lower part of the *C. litterarius* Zone, but 300–350 ka is represented by the normal polarity interval time between the top of Chron M0 and the nannoconid crisis (Herbert, 1992; Erba, 1994). Thus, the reversal seen in the basement basalts could be the top of

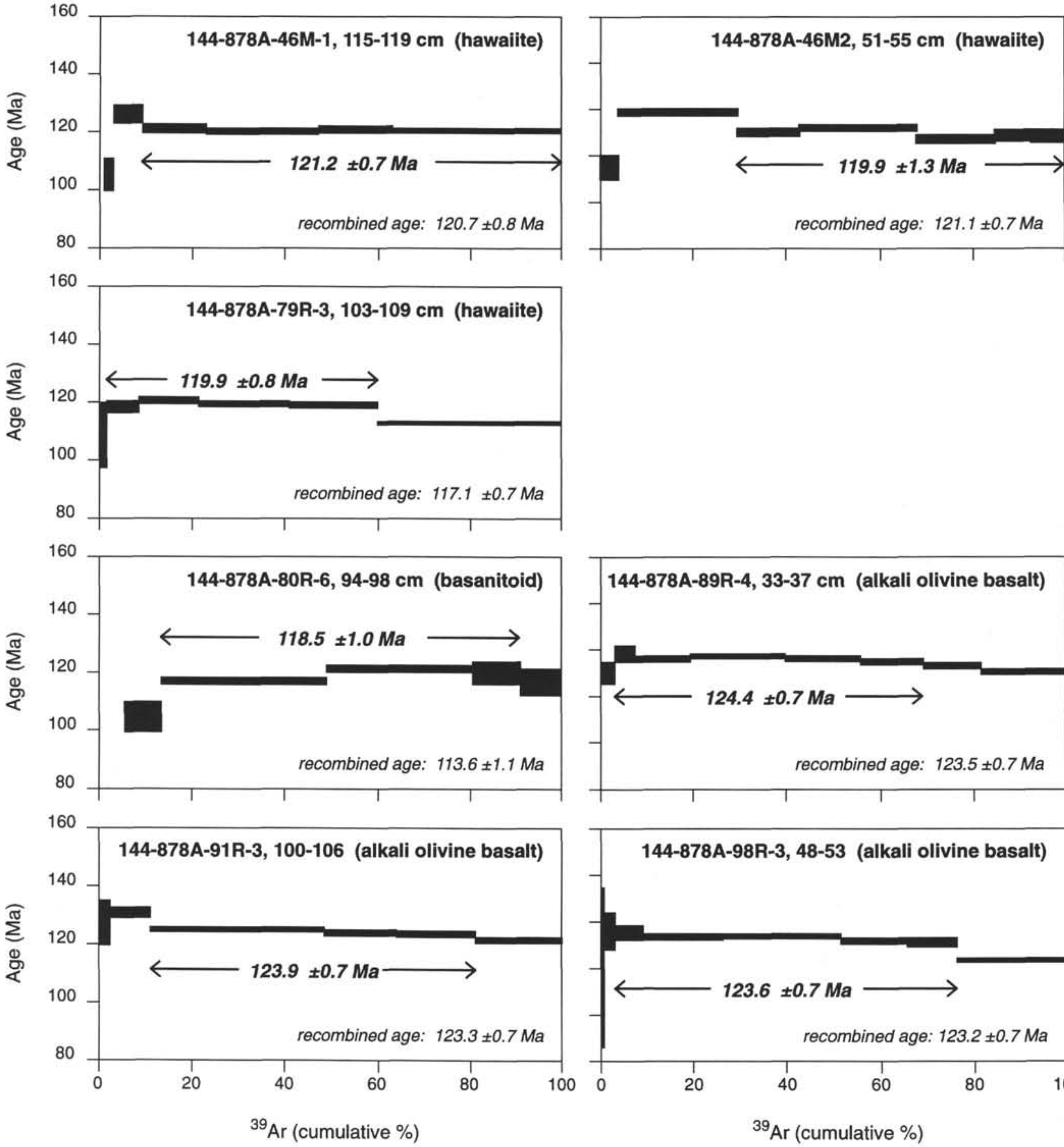

Figure 7. Age spectra of incremental heating experiments on whole-rock samples from Hole 878A, drilled on the summit of MIT Guyot. Individual step ages are drawn ±1 standard deviation of the apparent age.

magnetic polarity Chron M0 if the entire normally magnetized sequence below Core 144-878A-75R was formed in this 300–350 Ka normal polarity interval, that is, (1) if the shallow-water carbonates were deposited significantly faster than about 75 m/m.y., (2) if there was no significant hiatus between the eruption of the top of the reversed basalts and the deposition of the first carbonates, and (3) if the time represented by the weathering horizons and basalt to basanitoid to hawaiite volcanic evolution in the basement sequence is also not significant.

However, given the much more likely occurrence of at least one of (1) slower sedimentation rates, (2) a missed reversal could in the lower sedimentary sequences, (3) a significant hiatus between the youngest lavas and the development of the initial carbonate reef, (4) significant time represented by the two weathering profiles seen in the basalt sequence above the reversal, and (5) significant time represented by the volcanic evolution seen in the basement sequence, the magnetic reversal seen in the basalts must be older than the top of Chron M0, that is, the top of magnetic polarity Chron M1R. From

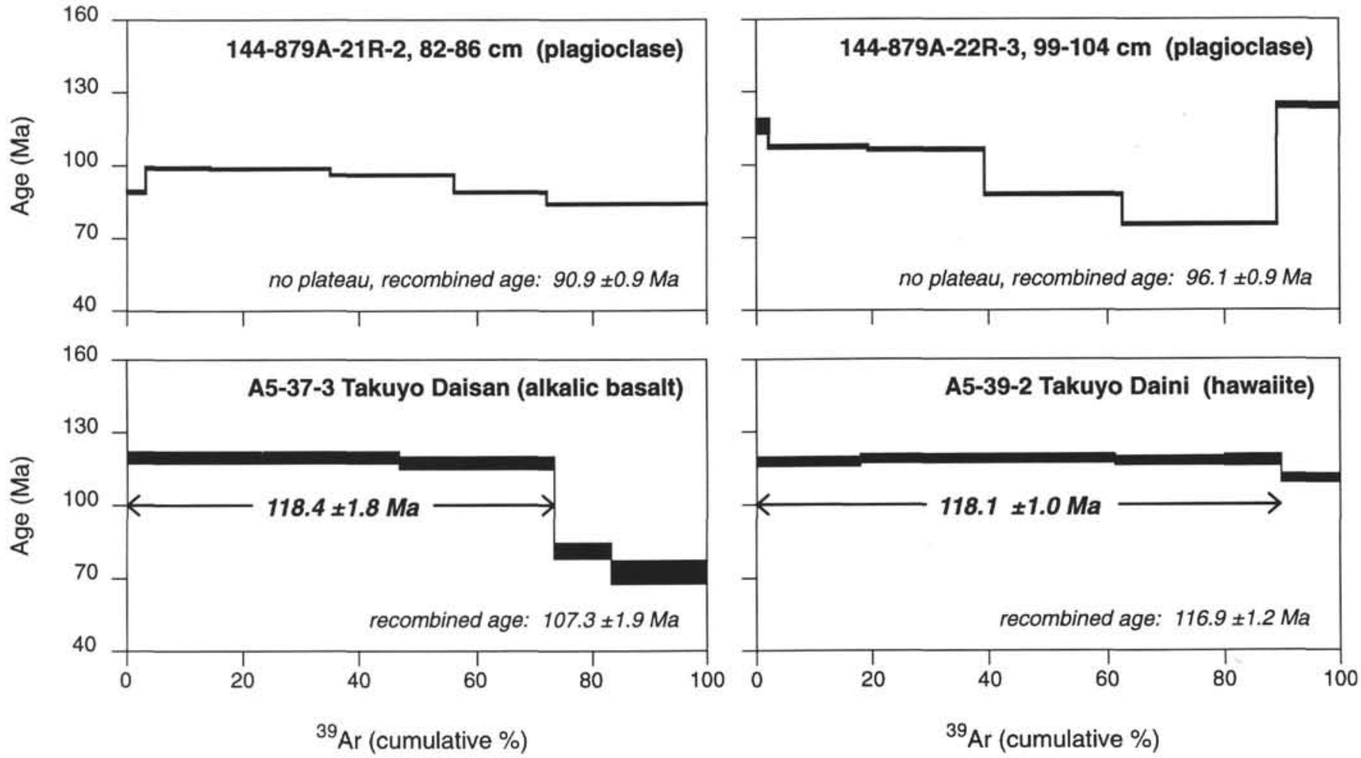

Figure 8. Age spectra of incremental heating experiments on whole-rock samples and plagioclase separates from Hole 879, drilled on the summit of Takuyo-Daisan Guyot. Individual step ages are drawn ±1 standard deviation of the apparent age.

the 122.9-Ma age of the transition basalts and the 2.5-m.y. duration of Chron M1N (Herbert, 1992; Channel et al., in press), we can calculate an age of 120.4 Ma for the base of Chron M0, very near the Barremian/Aptian boundary (Fig. 3), confirming the revised 121-Ma estimate for the age of this stage boundary (Channel et al., in press; Gradstein et al., in press) compared to the older 124.5-Ma estimate of Harland et al. (1990).

Note (added in proof): To confirm the identification of the magnetic polarity transition drilled at Site 878 on MIT Guyot, four incremental heating experiments on plagioclase separates from the same samples from Sections 144-878A-89R-4 and -91R-3 studied above were performed after the initial submission of this manuscript. The weighted mean age obtained from these experiments (122.8 ± 0.2 Ma) is consistent with, but considerably more precise than, the 122.9 ± 0.9 Ma whole-rock ages of the transition reported above. In particular, the new age allows us to state, at the 95% confidence level, that the upper hawaiites at Hole 878A are at least 1.4 Ma younger than the lower basalts marking the polarity transition. Thus, the entire normally magnetized sequence below Core 144-878A-75R cannot possibly have been deposited in the 300- to 350-ka interval above Chron M0 still below the nannoconid crisis, confirming our identification of the reversal as the top of Chron M1R, as shown in Figure 3.

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