Leckie, R.M., Sigurdsson, H., Acton, G.D., and Draper, G. (Eds.), 2000
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 165

13. *DATA REPORT:* DEPTH TO VOLCANIC BASEMENT AT SITE 999, KOGI RISE, COLOMBIAN BASIN[1]

Lewis J. Abrams[2] and Ming Hu[2]

ABSTRACT

Site 999 was positioned near the crest of Kogi Rise based on the images from multichannel seismic (MCS) Line CT1-12a. One of the objectives at Site 999 was to reach volcanic basement and sample oceanic plateau crust in the Colombian Basin for the first time. Although this objective was not obtained, Site 999 is fully cased to ~525 meters below seafloor (mbsf), reaches a total depth of 1066.4 mbsf, and remains a high-priority target for future investigations of large igneous provinces through scientific drilling.

Downhole log-generated synthetic seismograms are used to determine total two-way traveltime (TWT) reached at Site 999 and to estimate total depth to volcanic basement in preparation for future drilling at this Ocean Drilling Program "legacy" site. The results of these depths and TWT estimates are compared to those made using MCS velocity analyses and velocities measured on recovered cores.

Correlations between synthetic seismograms and observed MCS data indicate that volcanic basement at Site 999 lies at ~1420 mbsf, within the range predicted from MCS data and slightly shallower than estimated by laboratory velocity measurements.

INTRODUCTION

Site 999 is located on a small rise in the Colombian Basin that was named the Kogi Rise during Leg 165. The Kogi Rise, ~150 km northeast of Mono Rise, lies nearly 1000 m above the turbidite-filled Colombian Basin (Fig. 1). Before drilling, the Planning Committee of the Ocean Drilling Program designated this site as a "legacy site" because of its strategic location for basement penetration into the still unsampled, westernmost portion of the Caribbean Oceanic Plateau. Site 999 is a reentry site, fully cased to 526.2 meters below seafloor (mbsf). Leg 165 objectives included reaching basement at Site 999; however, coring terminated at 1066.4 mbsf, 16 m below the Cretaceous/Tertiary boundary and at an undetermined level above volcanic basement. Significant (>150 m) basement penetration will be the primary objective when Site 999 is revisited during future drilling legs in the Caribbean (e.g., Duncan et al., 1999). The purpose of this data report is to establish total depth and two-way traveltime (TWT) at Site 999 and then provide an estimate for the depth and TWT to volcanic basement using velocity, depth, and TWT information derived from synthetic seismograms and physical properties data obtained during Leg 165 and multichannel seismic (MCS) velocity analyses. Re-evaluation of correlations between seismic stratigraphy and lithostratigraphy in light of log-generated synthetic seismograms and regional interpretations of seismic stratigraphy based on these correlations are beyond the scope of this data report.

DATA

Seismic Data and Seismic Stratigraphy

Site 999 is located ~800 m east of Shotpoint 4780 of IG2901 MCS Line CT1-12a, which was obtained on 28 and 29 May 1978 aboard the *Ida Green* (Bowland and Rosencrantz, 1988; Bowland, 1993). Line CT1-12 (of which CT1-12a is a short segment) continues for hundreds of kilometers to the southwest of Site 999 crossing the Mono Rise and the Costa Rican Fan and continues to the northeast of Site 999 into the eastern Colombian Basin (Fig. 1). The seismic source consisted of two 1500-in^3 Bolt Inc. air guns fired at ~116-m intervals. Seismic data were received using an array of 24 hydrophone groups, each 100 m in length. Maximum hydrophone group offset ranged from 2405 to 2638 m; thus the length of the receiving array is comparable to the water depth of the Kogi Rise (~2800 m).

IG2901 12-fold stack data were provided by the University of Texas Institute for Geophysics. Processing included demultiplexing, trace editing, common depth point sorting, semblance velocity analysis spaced at 5-km intervals, and 12-fold stacking. Seismic data in this paper are displayed using band-pass filtering (5–50 Hz) and automatic gain control (AGC) with a 500-ms window.

Seismic Stratigraphy and MCS Velocity Analyses

The seismic stratigraphy of portions of the Colombian Basin, including the area of Site 999 on the Kogi Rise, has been discussed by Bowland and Rosencrantz (1988), Bowland (1993), and Sigurdsson, Leckie, Acton, et al., (1997). The seismic stratigraphy of the Site 999 area in particular has been examined by Bowland (1993) and Sigurdsson, Leckie, Acton, et al. (1997) from the analysis of MCS reflection Profile IG2901 CT1-12a (Fig. 2).

The elevated basement of the Kogi Rise is interpreted as the top of thick oceanic plateau crust, which may have experienced subsequent tectonic uplift prior to significant sediment accumulation (Bowland and Rosencrantz, 1988; Sigurdsson, Leckie, Acton, et al., 1997). Prominent, semicontinuous, dipping basement reflections are interpreted as multiple flow units and interbedded sediment representing the later stages of plateau formation and may be comparable in origin and age to the multiple basalt flow units of Campanian age (~77 Ma) recovered at Site 1001 (Sigurdsson, Leckie, Acton, et al., 1997). The maximum age for basement is unlikely to exceed the age of the widespread and contemporaneous igneous activity determined from radiometric dating (88–90 Ma) of on-land, circum-Caribbean igneous sections (Duncan et al., 1994; Sinton et al., 1997) and biostratigraphic ages (Turonian–Coniacian) of Deep Sea Drilling Project (DSDP) Leg 15 basement cores in the Venezuelan Basin and Beata Ridge, Caribbean Sea (Donnelly et al., 1973).

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[1] Leckie, R.M., Sigurdsson, H., Acton, G.D., and Draper, G. (Eds.), 2000. *Proc. ODP, Sci. Results,* 165: College Station, TX (Ocean Drilling Program).

[2] University of North Carolina, 601 South College Road, Wilmington, NC 28403-3297, U.S.A. abrams1@uncwil.edu

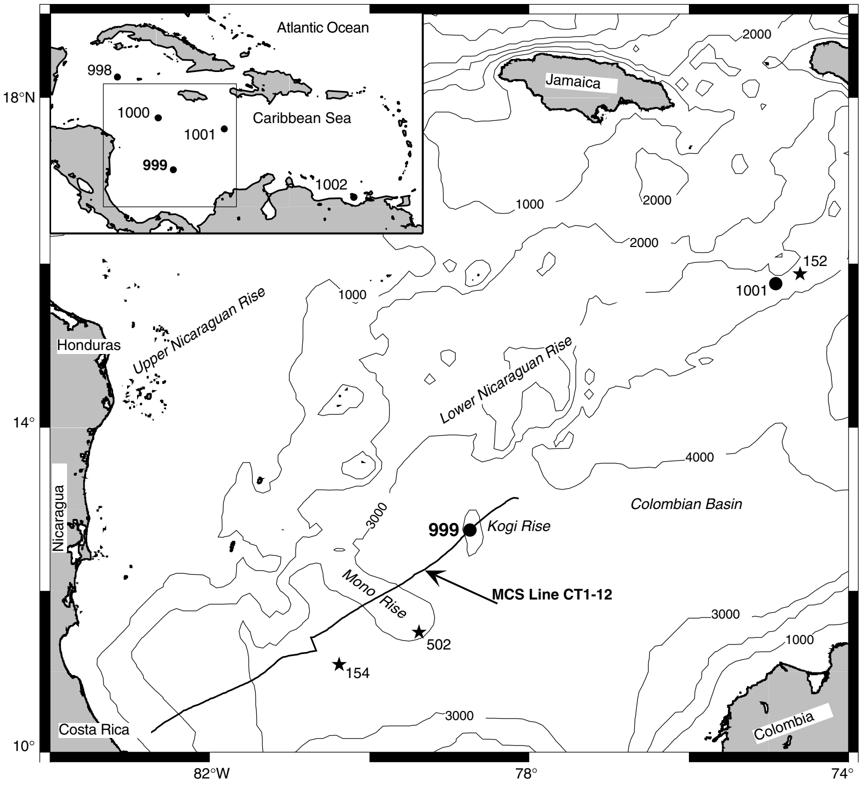

Figure 1. Bathymetric map (1000-m contour interval from ETOPO-5) showing the location of Site 999 on the Kogi Rise and the surrounding physiographic features of the western portion of the Caribbean Sea. Coverage of MCS Line CT1-12 is shown as thick solid line and Deep Sea Drilling Project sites are located with solid stars. Boxed insert shows location of all sites drilled during Leg 165 in the Caribbean Sea (GMT map, Wessel and Smith, 1995).

The bathymetry of volcanic basement strongly controls depositional character in the Colombian Basin, where basement highs such as the Mono Rise and Kogi Rise remained isolated from the large influx of terrestrial turbidites that filled in basement lows with up to 6 km of sediment from Eocene through Miocene time. A complete, almost 1067-m-thick record of largely pelagic/hemipelagic sediments from the Maastrichtian to the Pleistocene was recovered at Site 999 (Sigurdsson, Leckie, Acton, et al., 1997).

Bowland (1993) identified three principal seismic units in the sedimentary section, all of which drape over the presumed oceanic plateau basement of the Kogi Rise. Seismic Unit CB5 overlying volcanic basement extends from 4.556 s TWT to 4.936 s TWT at Site 999 and consists of continuous, high-amplitude reflections concordant with basement.

Seismic Unit CB4 extends from 4.066 s TWT to 4.556 s TWT and consists of two subunits separated at 4.4 s TWT, both of which maintain a uniform thickness in the vicinity of Site 999. Both subunits (CB4A and CB4B) have a hummocky mounded to chaotic and disrupted seismic facies. The upper subunit, CB4A, displays a high-amplitude upper boundary followed by a relatively transparent interval. The thin lower subunit, CB4B, is characterized by chaotic, discontinuous, and relatively high amplitude reflections throughout the interval.

Seismic Units CB3 and CB2 are not present at Site 999 and are restricted to portions of the Colombian Basin west of Mono Rise. These seismic units are interpreted as turbidite deposits that thin by onlap onto Unit CB5 on the western flank of Mono Rise (Bowland, 1993).

Seismic Unit CB1 extends from seafloor (3.776 s TWT) to 4.066 s TWT. This unit has a sheet-drape form, and a relatively reflection free seismic character.

Bowland (1993) reported interval velocities for these seismic units based on the average of 48–50 semblance-type velocity analyses at 5-km intervals along MCS Line CT1-12. We use the reported range of interval velocities to estimate a range of sedimentary thicknesses overlying volcanic basement at Site 999 (Fig. 2). Seismic Unit CB1 with interval velocities of 1.7 ± 0.1 km/s results in an estimated 240–270 m unit thickness. Applying the range of interval velocities of 1.8 ± 0.1 km/s for CB4A results in an estimated 284–317 m unit thickness (524–587 mbsf total). Interval velocities at CB4B are 2.6 ± 0.4 km/s, resulting in a unit thickness of 172–234 m (695–821 mbsf total). Finally, applying the range of interval velocities of 3.0 ± 0.4 km/s results in an estimated 494- to 646-m-thick CB5 section and a depth to volcanic basement ranging from 1190 to 1467 mbsf (Fig. 2).

Physical Properties Data

Compressional velocity data measured on split cores by the Digital Sonic Velocimeter from 0 to 105.93 mbsf and with a Hamilton Frame apparatus from 107.43 to 1066.4 mbsf are available over the entire interval cored at Site 999 (table 18, on CD-ROM, Shipboard Scientific Party, 1997). Corrections to this data for in situ stress by empirical relations described by Urmos et al. (1993) were applied and are available from 0 to 796 mbsf (table 18, on CD-ROM, Shipboard Scientific Party, 1997). Uncorrected laboratory velocity data are used to calculate traveltimes over each depth increment to produce a plot of TWT vs. depth (Fig. 3). The resultant depth vs. TWT data are tied to TWTs picked from MCS data and average velocities are determined (Fig. 2).

Logging Data

Downhole measurements of velocity and density data used in this report were acquired during a single run of the tool string known as the “Quad Combo,” and are available (on the Log and Core Data CD-ROM in Shipboard Scientific Party, 1997). The Quad Combo tool string included, from top to bottom, the telemetry cartridge, natural gamma spectroscopy, long-spaced sonic (LSS), compensated neutron, lithodensity, and dual induction resistivity, creating a tool string 33 m long. The sonic tool, in the middle of the tool string, sampled from 525.8 mbsf to as deep as 1041.65 mbsf (total cored depth =

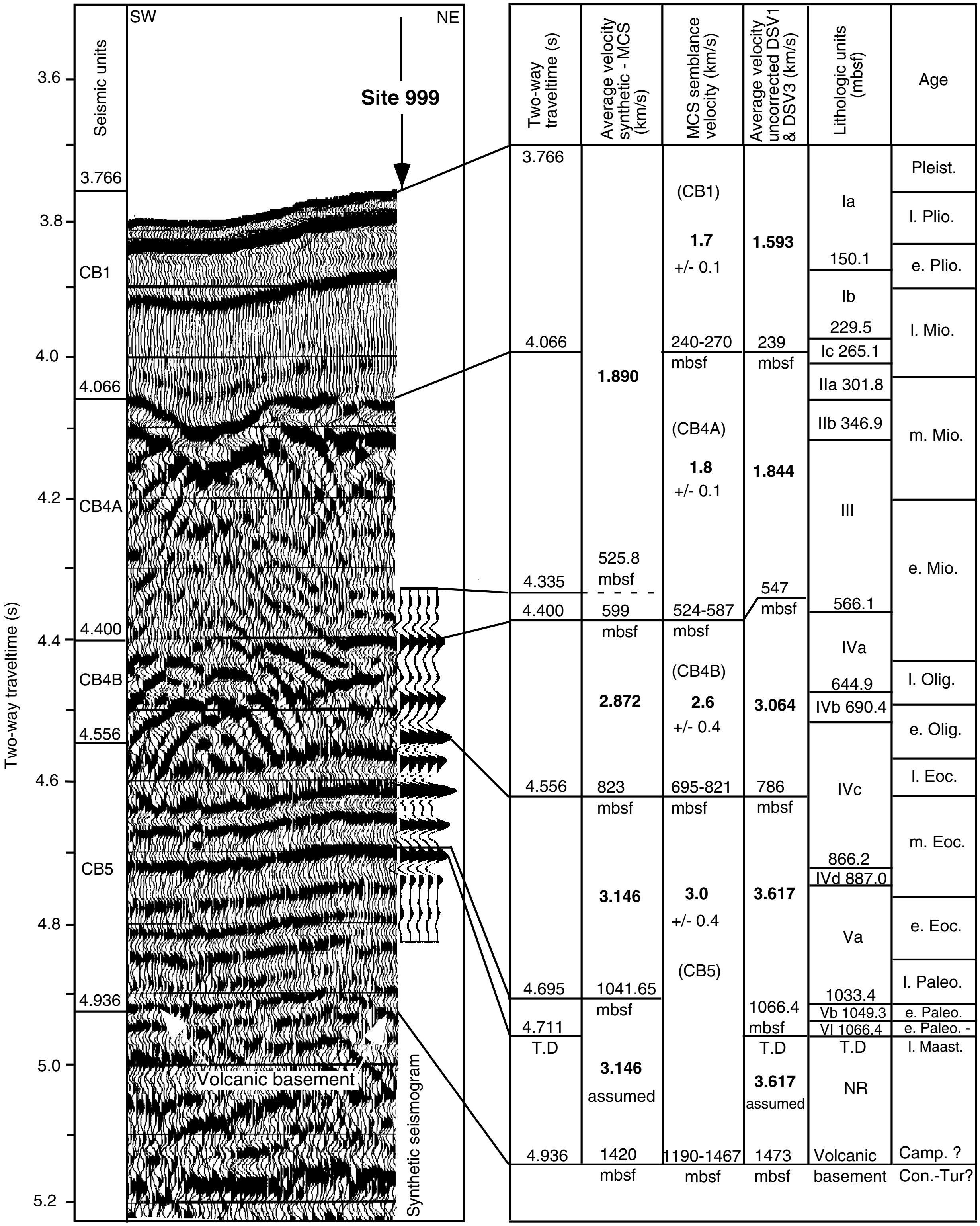

Figure 2. An ~4-km portion of IG2901 MCS Line CT1-12a is displayed with a vertical exaggeration of 15×. Site 999 location marked on this profile is 800 m west of actual site location determined by Global Positioning System. Correlations with the reflection seismic record were constrained by comparison to synthetic seismograms calculated using downhole sonic velocity (DSV) and density data and the far-field source wavelet represented by the seafloor reflection. Two-way traveltimes listed are measured from the MCS record at the Site 999 location and correspond to seismic unit boundaries and the start and end depths of the sonic velocity log. Average velocities and resulting depths shown are derived from three independent data sets: (1) MCS synthetic correlation, (2) average of 50 MCS velocity analyses (Bowland, 1993), and (3) two-way traveltime vs. depth derived from uncorrected compressional velocities measured by *P*-wave logger and Hamilton Frame laboratory instruments. A range of volcanic basement depths are estimated by extending the average velocity derived from physical properties and synthetic seismogram measured within seismic Unit CB5 to 4.936 s TWT and by using velocities from MCS velocity analyses. Ages and lithologic units are from Shipboard Scientific Party (1997; Site 999).

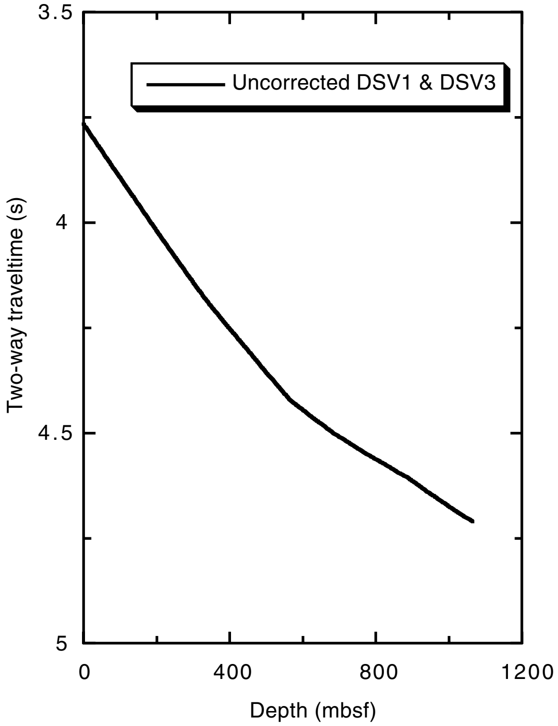

Figure 3. Two-way traveltime vs. depth below seafloor calculated from compressional velocities uncorrected for in situ stress derived from physical properties measurements (0–1066.4 mbsf) in Hole 999B. The resultant two-way traveltime vs. depth below seafloor is used to estimate depths and average velocities of seismic units identified in two-way traveltime on MCS Line CT1-12a in Figure 2.

1066.4 mbsf). The LSS consists of two transmitters spaced 2 ft apart, located 8 ft below two receivers, also spaced 2 ft apart. Velocity is calculated from measured traveltime between transmitter/receiver pairs over a known distance (i.e., 8, 10, 10, and 12 ft). During the downward trip into Hole 999B, the far-spaced transmitter (12-ft spacing between transmitter and receiver) in the LSS tool was determined to be malfunctioning. Postcruise examination of velocity data indicated that only velocities from the 8- and 10-ft spacing traveltime data were valid (see Log and Core Data CD-ROM in Shipboard Scientific Party, 1997). The difference in traveltimes between the 10- and 8-ft receiver/transmitter spacing (known as DTLN) were used to calculate the velocities. The major pitfall of using only some of the transit times to compute velocity, rather than all the possible combinations of transmitter receiver spacings, is the lack of compensation for borehole disturbances, which is achieved by averaging the difference between each pair of transit times. The result is a DELTA-T in µs/ft.

Density data were recorded from 551 to 1055 mbsf and were edited for unrealistic values postcruise (Shipboard Scientific Party, 1997, Site 999). A constant value of 1.9 g/cm^3 (density value at 551 mbsf) was used to extend the density data up to 525.8 mbsf, corresponding to the first sonic velocity measurement. An examination of the velocity and density data vs. resistivity data from three different measurements of varying resolution and borehole penetration reveal a remarkable correlation throughout the entire hole, indicating that borehole effects are not adversely affecting the traveltime or density measurements (Fig. 4).

METHODS

Synthetic Seismograms

Reflections are typically interference patterns caused by the complex interaction between source wavelet and impedance contrasts. These interference patterns are difficult to directly correlate with observed downhole changes in velocity and density (lithology), except in cases such as the sediment/water and sediment/basement interfaces and cases where a homogenous, relatively thick layer lies within a uniform sediment matrix (e.g., thick chert or sill). Downhole logs obtain in situ measurements every 0.1524 m, regardless of core recovery, of velocity and density data used for producing synthetic seismograms. A log-generated synthetic seismogram can accurately tie the cored stratigraphy (depth) to seismic reflection images in seconds TWT if the synthetic seismogram matches the observed seismic character.

Velocity and density data from downhole measurements were used to calculate reflection coefficients that were convolved with a source wavelet to produce synthetic seismograms using software provided by Dr. Sun of the Borehole Research Group, Lamont-Doherty Earth Observatory (LDEO). A 10-trace average of the seafloor reflection, including the bubble pulse at ~0.1 s TWT, which represents the true source wavelet, is used to construct the synthetic seismogram (Fig. 5). Except for the addition of the bubble pulse, this wavelet is nearly identical to a minimum phase Ricker wavelet of 21 Hz. The seismic data and synthetic seismogram are both displayed with a band-pass filter (5–50 Hz) and an AGC with a 500-ms window. The synthetic seismogram, displayed as five adjacent traces, is placed adjacent to observed seismic data at the closest approach to Site 999 and is shifted until the best visual correlation with reflections is achieved. A reasonable match occurs with both amplitudes and traveltimes of reflections between observed and synthetic seismograms within the CB4 and CB5 seismic units.

RESULTS AND DISCUSSION

Depth and traveltime correlations calculated from the synthetic seismogram, MCS velocity analyses, and velocity-depth data on cores are compared and used to estimate a range of depths to volcanic basement. TWTs defining the range of seismic units, including the top of volcanic basement, are picked from the MCS data at the Site 999 location. These traveltimes are fixed and corresponding depths are calculated from the various velocity data. Depths of the top and bottom of the sonic/density log and total hole depth are also fixed, and corresponding TWT and average velocities are calculated. The results are reviewed below and summarized in Figure 2.

1. The CB1/CB4 boundary at 4.066 s TWT corresponds to 239 mbsf and results in an average velocity of 1.593 km/s for this interval using laboratory velocity data. This velocity is just below the range determined by MCS velocity analyses. In unlithified sediment and ooze, sonic velocities measured in the laboratory are typically less than those measured under in situ conditions. The depth to this boundary and average velocity for this interval are 260 mbsf and 1.733 km/s respectively, using velocities corrected to in situ stress by the empirical formula of Urmos et al. (1993) (Shipboard Scientific Party, 1997, Site 999). These velocities, referred to as “corrected velocities,” appear to better match MCS semblance velocities for this depth interval.
2. Correlation of synthetic and observed seismograms indicates the start time of the synthetic seismogram is 4.335 s TWT, which corresponds to the start depth of the sonic/density log at 525.8 mbsf. The CB4A/CB4B boundary at 4.400 s TWT lies only 65 ms below this and corresponds to 599 mbsf, resulting in a calculated average velocity of 1.890 km/s for the interval from seafloor to the CB4A/CB4B boundary.
3. Laboratory velocity-depth data indicate that the start of the sonic log at 525.8 mbsf corresponds to 4.381 s TWT or 4.310 s TWT, using uncorrected or corrected velocities respectively. These values bound that of 4.335 s TWT predicted by the synthetic seismogram correlation to observed seismic data.

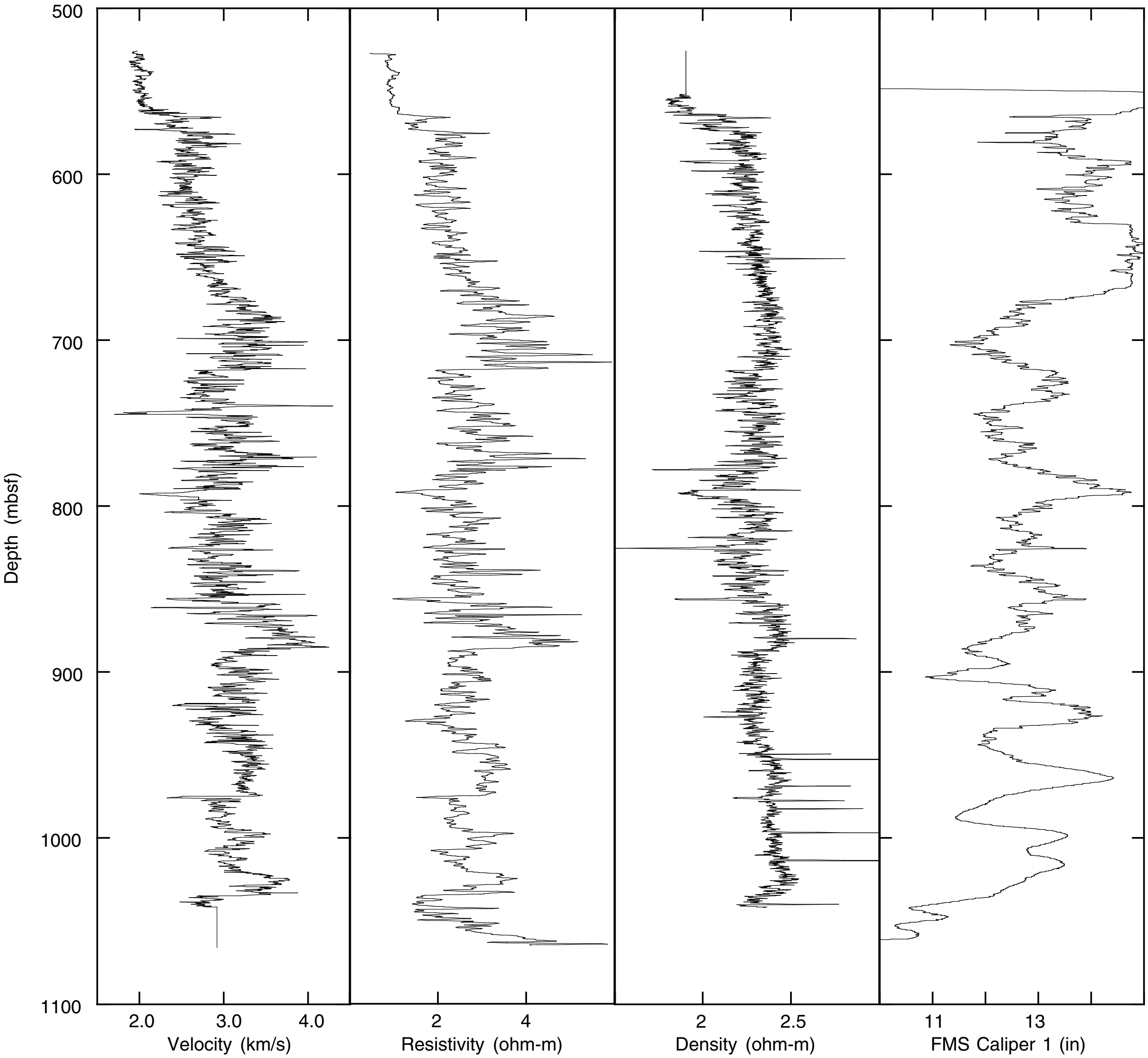

Figure 4. Velocity, density, and resistivity (medium induction resistivity tool) along with caliper 1 from the Formation MicroScanner tool are displayed through the entire logged section of Hole 999B. The closely co-varying velocity, density, and resistivity curves indicate that the variable diameter of the borehole did not adversely effect the data.

4. Correlations with the synthetic seismogram indicate that the CB4B/CB5 boundary at 4.556 s TWT corresponds to 823 mbsf and results in an average velocity of 2.872 km/s for the CB4B interval. This average velocity is within the range determined by MCS velocity analyses (2.6 ± 0.4 km/s) and comparable to that predicted from laboratory measurements (3.046 km/s).
5. Correlations with the synthetic seismogram indicate that the end of the sonic log at 1041.65 mbsf corresponds to 4.695 s TWT, resulting in an average velocity of 3.146 km/s in this portion of CB5. Assuming this average velocity for the entire CB5 seismic unit indicates that the total depth at Site 999 of 1066.4 mbsf corresponds to 4.711 s TWT and that the top of volcanic basement at 4.936 s TWT corresponds to 1420 mbsf.
6. Laboratory data indicate that the total depth of 1066.4 corresponds to 4.711 s TWT, a fortuitous exact match with that predicted from correlations with the synthetic seismogram, and results in an average velocity of 3.617 km/s for this portion of CB5. Assuming this velocity for the entire CB5 unit results in a volcanic basement depth of 1473 mbsf.

CONCLUSIONS

Correlations with synthetic seismograms indicate that the top of the sonic log begins at 4.335 s TWT, exactly between the TWTs predicted by corrected and uncorrected laboratory data, and show that total depth of 1066.4 mbsf reached at Site 999 corresponds to 4.711 s TWT on MCS Line CT1-12a, exactly matching the TWT predicted by analyses of uncorrected laboratory velocity-depth data and well within the range calculated using MCS velocity analysis. The top of volcanic basement lies at a depth of 1420–1473 mbsf, which is derived from extrapolation of average velocities determined by synthetic seismogram correlations and physical properties measurements, respectively. These values are comparable to those using the median to up-

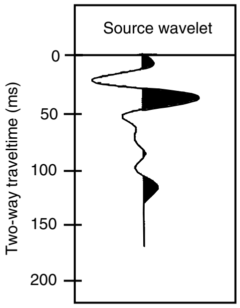

Figure 5. Far-field source wavelet as represented by a 10-trace average of the seafloor reflection from MCS Line CT1-12a at the Site 999 location.

per limits of MCS-derived interval velocities, which result in an estimated depth to volcanic basement between 1330 and 1467 mbsf.

ACKNOWLEDGMENTS

We are grateful to the Ocean Drilling Program for inviting us to participate on Leg 165, to all members of the Shipboard Scientific Party of Leg 165 for their cooperation on board the ship, and to the ODP personnel and the Sedco crew, who made Leg 165 a success. JOI/USSAC provided support for the first author. We thank Patty Ganey at UTIG for supplying MCS data. We also thank Cristina Broglia for insights into log processing and Dr. Sun, at the Borehole Research Group, LDEO, for supplying software for synthetic seismogram calculations.

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Date of initial receipt: 24 June 1998
Date of acceptance: 29 April 1999
Ms 165SR-028