13. *DATA REPORT:* GEOCHEMICAL LOGGING RESULTS FROM THE OCEAN SEISMOGRAPHIC NETWORK OSN-1: LEG 136, SITE 843[1]

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ABSTRACT

Geochemical well logs were obtained through sediment and basaltic basement at Site 843 of Leg 136. Corrections have been applied to the logs to account for variations in borehole size, drilling-fluid composition, and drill-pipe attenuation. Concentrations of Th, U, and Gd, as well as oxide weight percentages have been calculated from the logs and a comparison was made with available X-ray fluorescence (XRF) core measurements. Log-core agreement, except for Al_2O_3, is good throughout the igneous section. The Al_2O_3 log-core comparison is a measurable difference possibly due both to a weak ^{252}Cf source and to the freshest sample selection for the major element analyses by XRF.

INTRODUCTION

Leg 136 of the Ocean Drilling Program (ODP) drilled two sites on the Hawaiian Arch, approximately 225 km south-southwest of the island of Oahu. The geochemical tool (GLT) was not run at Site 842. Site 843, 1 km northwest of Site 842, was drilled as an offset to Site 842 because poor hole conditions made the first site unsuitable for installation of a reentry cone and logging. Site 843 is located on top of a northwest-southeast-trending abyssal hill identified by the site survey performed prior to drilling Site 842.

The preparation of the seafloor site for the development of the Ocean Seismographic Network (OSN) was a primary objective of Leg 136. OSN-1 (Hole 843B) provided a site for borehole seismometer experiments, which include comparing high-quality Oahu station data with site recording teleseismic events, measuring noise, testing a new broad-based sensor, and adding instrumentation for long-term experiments (Fig. 1; Dziewonski et al., 1992).

Site 843B was logged with the GLT, which measures the major elements of a formation at intervals of 0.1524 m. The GLT measurements provide continuous, in-situ chemical measurements of the rock that are not affected by incomplete core recovery or core expansion, problems that core-based studies often encounter.

This report describes the basic principles of the GLT and outlines the post-cruise processing techniques. It then briefly compares the geochemical log values with lithologic core descriptions and available core measurements. The report focuses on presenting the data and explaining how they were derived.

GEOCHEMICAL TOOL STRING

The geochemical logging tool string (GLT) consists of four tool components: the natural gamma-ray tool (NGT), the compensated neutron tool (CNT), the aluminum activation clay tool (AACT), and the gamma-ray spectrometry tool (GST). (GLT, NGT, CNT, AACT, and GST are trademarks of Schlumberger; Fig. 2.) The combination of the tool components uses three separate modes of gamma-ray spectroscopy for a comprehensive elemental analysis of the formation. The NGT, located at the top of the tool string, measures the naturally occurring radionuclides, thorium (Th), uranium (U), and potassium
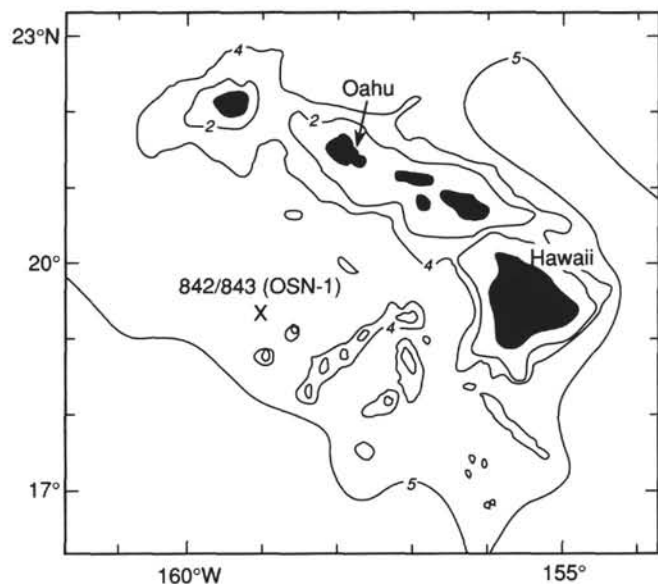

Figure 1. Location of Leg 136 Sites 842 and 843 along with the major geologic features of the Hawaiian Arch and the islands of Hawaii. OSN-1 = Ocean Seismographic Network (after Dziewonski et al., 1992; Fig. 1).

(K) before the formation is irradiated by the nuclear sources contained in the tools below. The CNT, located below the NGT, carries a low-energy californium-252 (^{252}Cf) neutron source to activate the Al atoms in the formation. The AACT, a modified NGT, is located below the ^{252}Cf source, measuring the activated gamma rays in the formation. By combining the AACT measurement with the previous NGT measurement, the background radiation is eliminated, and, as a result, a reading of formation Al is obtained (Scott and Smith, 1973). The GST, at the base of the string, carries a pulsed neutron generator to induce prompt-capture gamma-ray reactions in the borehole and formation and an NaI(Tl) scintillation detector to measure the energy spectrum of gamma rays generated by the neutron capture reactions. Because each of the elements in the formation is characterized by a unique spectral signature, it is possible to derive the contribution (or yield) of each of the major elements silicon (Si), iron (Fe), calcium (Ca), titanium (Ti), sulfur (S), gadolinium (Gd), and potassium (K) from the measured spectrum; then, in turn, to estimate the relative abundance in the formation of each element above by combining with the elemental
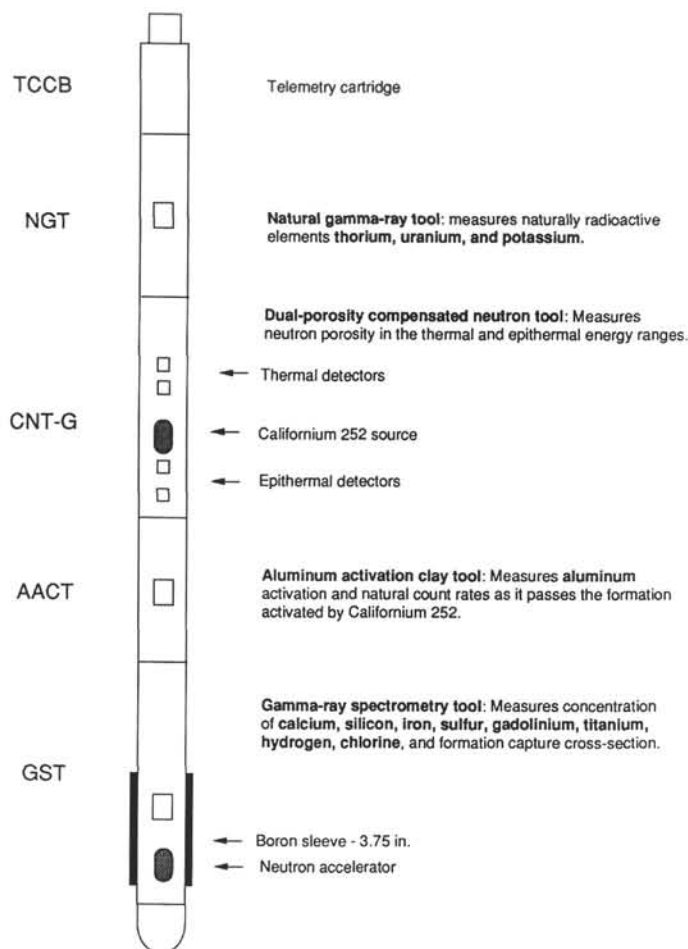
Figure 2. Schematic drawing of the Schlumberger geochemical logging tool string used in the Ocean Drilling Program.

concentrations from the NGT and AACT. The GST also measures the hydrogen (H) and chlorine (Cl) in the borehole and formation, but these elements are not used for determining rock geochemistry.

The only major rock-forming elements not measured by the GST are magnesium (Mg) and sodium (Na); the neutron-capture cross sections of these elements are too small relative to their typical abundances for the tool string to detect. A rough estimate of Mg + Na can be made by using the photoelectric factor (PEF), measured by the lithodensity tool. This measured PEF is compared with a calculated PEF (a summation of the PEF from all of the measured elements). The separation between the measured and calculated PEF is, in theory, attributable to any element left over in the formation (i.e., Mg and Na). Further explanation of this technique is found in Hertzog et al. (1989). The Mg calculation was not attempted for this leg because including it in the normalization with the other elements induces noise into all other elements, which proves to be erroneous in ODP wells (Pratson et al., in press). Generally, MgO + Na$_2$O values from core data are included in the normalization step of the processing. This is explained further in Step 5 of the data reduction section below.

DATA REDUCTION

The well-log data from the Schlumberger tools are transmitted digitally up a wireline, recorded and processed on the *JOIDES Resolution* in the Schlumberger Cyber Service Unit (CSU). The results from the CSU are made available as "field logs" for initial, shipboard interpretation. Subsequent reprocessing is necessary to correct the data for the effects of fluids added to the well, logging speed, and drill-pipe interference. Processing of the spectrometry data is required to transform the relative elemental yields into oxide weight fractions.

The processing is performed with a set of log-interpretation programs written by Schlumberger. The steps are summarized below:

1. Reconstruction of Relative Elemental Yields from Recorded Spectral Data

This first processing step compares the measured spectra from the gamma-ray spectrometry tool with a series of "standard" spectra to determine the relative contribution (or yield) of each element. Each "standard" approximates the spectrum of each element and is combined at each depth with the recorded spectrum in a weighted, least-squares inversion to determine the relative elemental yields.

Six elemental standards (Si, Fe, Ca, S, Cl, and H) are used to produce the shipboard yields, but three additional standards (Ti, Gd, and K) can be included in the post-cruise processing to improve the fit of the spectral standards to the measured spectra (Grau and Schweitzer, 1989). Although Ti, Gd, and K often appear in the formation in very low concentrations, they can make a large contribution to the measured spectra because they have large neutron-capture cross sections. For example, the capture cross section of Gd is 49,000 barns, whereas that of Si is 0.16 barns (Hertzog et al., 1989). Therefore, including Gd is necessary when calculating the best fit of the standard spectra to the measured spectra.

The spectral analysis was performed using the spectral standards for Si, Ca, Fe, Ti, Gd, H, K, and Cl only in Hole 843B. The spectral standard for S was not used, because this element existed in concentrations below the resolution of the tool, and the inclusion of S was found to significantly increase the noise level of all the other yields. A straight, seven-point (3.5 ft, 1.066 m) smoothing filter was applied to all the yields to reduce the noise in the data during this reconstruction step.

2. Depth Shifting

Geochemical processing involves the integration of data from the different tool strings; consequently, it is important that all the data are depth correlated to one reference logging run. The NGT, run on each of the logging tool strings, provides a spectral gamma-ray curve with which to correlate each of the logging runs. A reference run is chosen on the basis of low cable tension (the logging run with the least amount of cable sticking) and high cable speed (tools run at faster speeds are less likely to stick and are less susceptible to data degradation caused by ship heave). The depth-shifting procedure involves selecting several reference points where log characters are similar and then invoking a program that stretches or squeezes sections of the matching logging run to fit the reference logging run.

The quad combo main pass was chosen as the reference run in Hole 843B. The quad combo is a combination logging string that includes a resistivity tool (DITE), a sonic tool (LSS), a density tool (HLDT), a natural gamma-ray tool (NGT), and a temperature tool (TLT).

3. Calculation of Total Radioactivity and Th, U, and K Concentrations

The third processing routine calculates the total natural gamma radiation in the formation as well as concentrations of Th, U, and K, using the counts in five spectral windows from the natural gamma-ray tool (Lock and Hoyer, 1971). This routine resembles shipboard processing; however, the results are improved during post-cruise processing by including corrections for hole-size changes and temperature variations. A Kalman filtering (Ruckebusch, 1983) is used in the CSU processing at sea to minimize the statistical uncertainties in the logs, which can otherwise create erroneous negative values and anti-correlations (especially between Th and U). An alpha filter has been

introduced more recently and is now recommended by Schlumberger for shore-based processing. This filter strongly smooths the raw spectral counts but keeps the total gamma-ray curve unsmoothed before calculating out the Th, U, and K (Charles Flaum, pers. comm., 1988). The outputs of this program are K (wet wt%), U (ppm), and Th (ppm), as well as total gamma-ray and computed gamma-ray (total gamma ray minus U contribution) curves.

4. Calculation of Al Concentration

The fourth processing routine calculates the concentration of Al in the formation using four energy windows recorded with the AACT. During this step, corrections are made for natural radioactivity, borehole-fluid neutron-capture cross section, formation neutron-capture cross section, formation slowing-down length, and borehole size. Porosity and density logs are needed to convert the wet-weight percentages of K and Al curves to dry-weight percentages. A porosity log is recorded on the geochemical tool string; however, it can only be used as a qualitative measurement, because it carries a ^{252}Cf source, which is not calibrated, rather than the americium-beryllium source needed to make a quantitative measurement. Because the density log compared well with shipboard density core measurements, a porosity curve was derived from the density log using the equation

$$\phi_t = (\rho_m - \rho_b) / (\rho_m - \rho_f), \tag{1}$$

where

ϕ_t = percentage of porosity,
ρ_m = matrix density (a constant value of 2.90 g/cm^3 was used),
ρ_b = bulk density from the log in g/cm^3, and
ρ_f = density of fluid = 1.05 g/cm^3.

Because the only formation type in the open-hole portion of the hole was basalt and the measured core data were limited, a constant matrix density of 2.90 was used.

A correction is also made for Si interference with Al; the ^{252}Cf source activates the Si, producing the aluminum isotope ^{28}Al (Hertzog et al., 1989). The program uses the Si yield from the gamma-ray spectrometry tool to determine the Si background correction. The program calculates dry-weight percentages of Al and K, which are used in the calculation and normalization of the remaining elements.

5. Normalization of Elemental Yields from the GST to Calculate the Elemental Weight Fractions

Relative concentrations of the GST-derived elemental yields can be determined by dividing each elemental yield by a relative spectral sensitivity factor, S_i. These factors are constants, which can be measured in the laboratory and are principally related to the thermal neutron-capture cross sections and the gamma-ray production and detection probabilities of the element (Hertzog et al., 1989). The relative elemental concentrations are related to the desired absolute concentrations by a depth-dependent normalization factor, F, as defined by the relationship

$$Wt_i = FY_i / S_i, \tag{2}$$

where

Wt_i = absolute elemental concentration,
Y_i = relative elemental yield,
S_i = relative spectral sensitivity factor, and
F = depth-dependent normalization factor.

The normalization factor is calculated based on the assumption that the sum of all the elemental weight fractions is 100%. The closure model accounts for carbon and oxygen, which are not measured by this tool string, by approximating their amounts in combination with each of the measurable elements as a single carbonate, or oxide factor. The dry weight percentages of Al and K are normalized with the reconstructed elemental yields to the determine F at each depth interval with the following equation:

$$F(\textstyle\sum_i X_i Y_i / S_i) + X_K Wt_K + X_{Al} Wt_{Al} = 100, \tag{3}$$

where

X_i = oxide factor: atomic wt of oxide or carbonate ÷ atomic wt of element i,
X_K = oxide factor of K: atomic wt of oxide of element K ÷ atomic wt of K,
Wt_K = dry wt% of K, measured from NGT,
X_{Al} = oxide factor of Al: atomic wt of oxide of element Al ÷ atomic wt of Al, and
Wt_{Al} = dry wt% of Al, measured from the AACT.

The value X_i accounts for the C and O associated with each element. Table 1 lists the oxide factors used in this calculation. All of the measured elements associate with C and O in a constant ratio in these lithologies, except for Ca, which associates with C and O in one of two ways: $CaCO_3$ or CaO (Table 1). To convert the measured yields to elements, a dominant oxide factor must be assumed at every depth level. A routine that combines both these oxide factors is implemented here, as suggested by James Grau at Schlumberger-Doll (pers. comm., 1992). When the elemental form of Ca is less than 6%, CaO is assumed and an oxide factor of 1.399 is used. When the elemental form of Ca is greater than 12%, $CaCO_3$ is assumed and an oxide factor of 2.497 is used. If the elemental form of Ca falls between 6% and 12%, both forms are assumed to be present and the oxide factor is linearly interpolated between 1.399 and 2.497.

The parameters of 6% and 12% were chosen according to observations of the natural occurrence of Ca. CaO is not likely to occur in quantities greater than 12%. When Ca is less than 6%, even if it is $CaCO_3$, the error will be small using 1.399 as the oxide factor instead of 2.497. The linear interpolation is done to provide a smooth transition from CaO to $CaCO_3$ and to prevent any erroneous chemical changes on the final processed logs. This procedure for calculating Ca is accurate in most cases and minimizes the error when the model is not exactly correct.

As it is not possible to calculate either the Mg or Na content from the logs, because the neutron-capture cross sections of these elements are too small relative to their typical abundances for detection by the tool string, available core information is included. In Hole 843B, Mg + Na represent up to 10.23% of the rock in these holes (Shipboard Scientific Party, 1992). A constant value of 9.3% $MgO + Na_2O$ was used in the normalization, which was derived from the average measured core values.

6. Calculation of Oxide Percentages

The final routine converts the elemental weight percentages into oxide/carbonate percentages by multiplying each by its associated oxide factor, as shown in Table 1.

Table 1. Oxide factors used in normalizing elements to 100% and converting elements to oxides.

Element	Oxide/carbonate	Conversion factor
Si	SiO$_2$	2.139
Ca<6%	CaO	1.399
6%<Ca<12%	CaO and CaCO$_3$	1.399–2.497 (linearly interpolated)
Ca>12%	CaCO$_3$	2.497
Fe	FeO	1.358
K	K$_2$O	1.205
Ti	TiO$_2$	1.668
Al	Al$_2$O$_3$	1.889

COMPARISON OF GEOCHEMICAL LOGS TO CORE

The processed natural gamma-ray curves from Hole 843B are shown in Figure 3 (Shipboard Scientific Party, 1992). The processed NGT curves are from the geochemical logging tool string. Figure 4 displays the oxide weight fractions estimated from the logs at Hole 843B, along with calculated statistical uncertainties of each element (Grau et al., 1990; Schweitzer et al., 1988). This error is strongly related to the normalization factor, which is calculated at each depth (Equation 3). The normalization factor is displayed to the right of the logs. A lower normalization factor represents better counting statistics and higher quality data. A log of the Ca oxide factor used is displayed to the right of the normalization factor. XRF major elemental analyses are displayed as solid circles for comparison with the oxide weight fractions derived from the log data.

The sediment/basement contact was identified at 242 m. Mildly altered pillow basalts, recognized at the sediment/basement interface, overlie massive aphyric lavas that are locally brecciated with veins filled with calcite, pyrite, limonite, and clay (Shipboard Scientific Party, 1992). The portion of the log data recorded through pipe, the interval above 257.2 m, was not processed because the percentage of readings from the formation, averaging 17%, was too low to yield valuable data. In contrast, the average percentage of data from the formation recorded in the open-hole portion of the log is on the order of 48%.

Four similar units of igneous basalts are defined in the igneous section from Hole 843B (Shipboard Scientific Party, 1992). Unit 1 has a consistently holocrystalline texture. Unit 2 is a fine-grained, glassy basalt. Unit 3 resembles Unit 2, except that it contains rare gabbroic xenoliths. Units 3 and 4 are similar and can be distinguished only by a glassy margin.

Log-core agreement, except for Al_2O_3, is good throughout the igneous section in Units 1, 2, and 3. Unit 4 was cored lower than log data were recorded. The Al_2O_3 log-core comparison shows a measurable difference possibly due to an out-of-date source calibration, a weak ^{252}Cf source, the freshest sample selection for the major element analyses by XRF, or a combination of any of these possibilities. The discrepancy may also be attributed to a combination of low-quality hole conditions, a partially washed-out hole, and poor core recovery, which makes exact depth placement of core values questionable and inconsistent with log depths.

SUMMARY

The GLT measurements provide continuous, in-situ chemical measurements of the rock. Improvement in natural gamma-ray log measurements can be obtained by data reprocessing, which incorporates better calibrations of Th, U, and K and hole-size corrections. The information from the GLT, through reprocessing, is converted into elemental and oxide measurements that can be compared with core measurements. Unlike missing or sparse core data, the reprocessed log data provide an invaluable continuous data set from which lithologic interpretation is performed. Four similar units of igneous basalts are defined in the igneous section from Hole 843B. Log-core agreement, except for Al_2O_3, is quite good throughout the igneous section. The Al_2O_3 log-core comparison is a measurable difference possibly due both to any combination of the following possibilities, an out-of-date source calibration, a weak ^{252}Cf source, and/or the freshest sample selection for the major element analyses by XRF. Site 843B of Leg 136 is a seafloor site for the development of the Ocean Seismographic Network (OSN), which was prepared for borehole seismometer experiments.
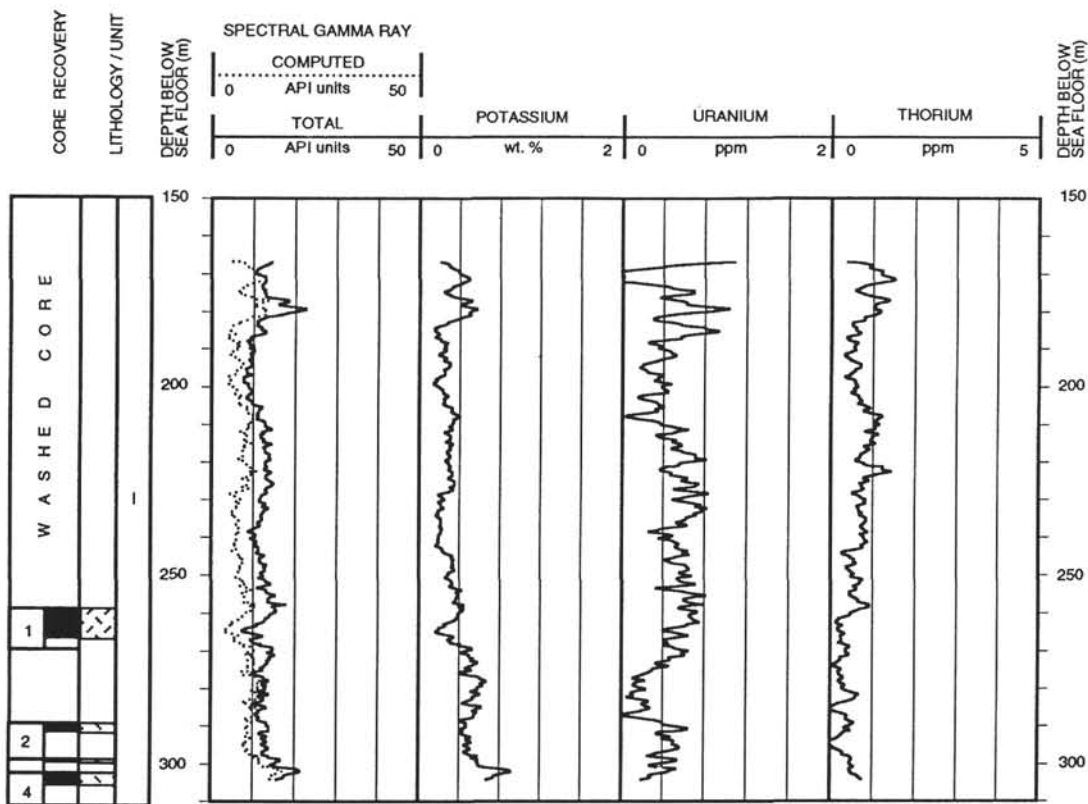
ACKNOWLEDGMENTS

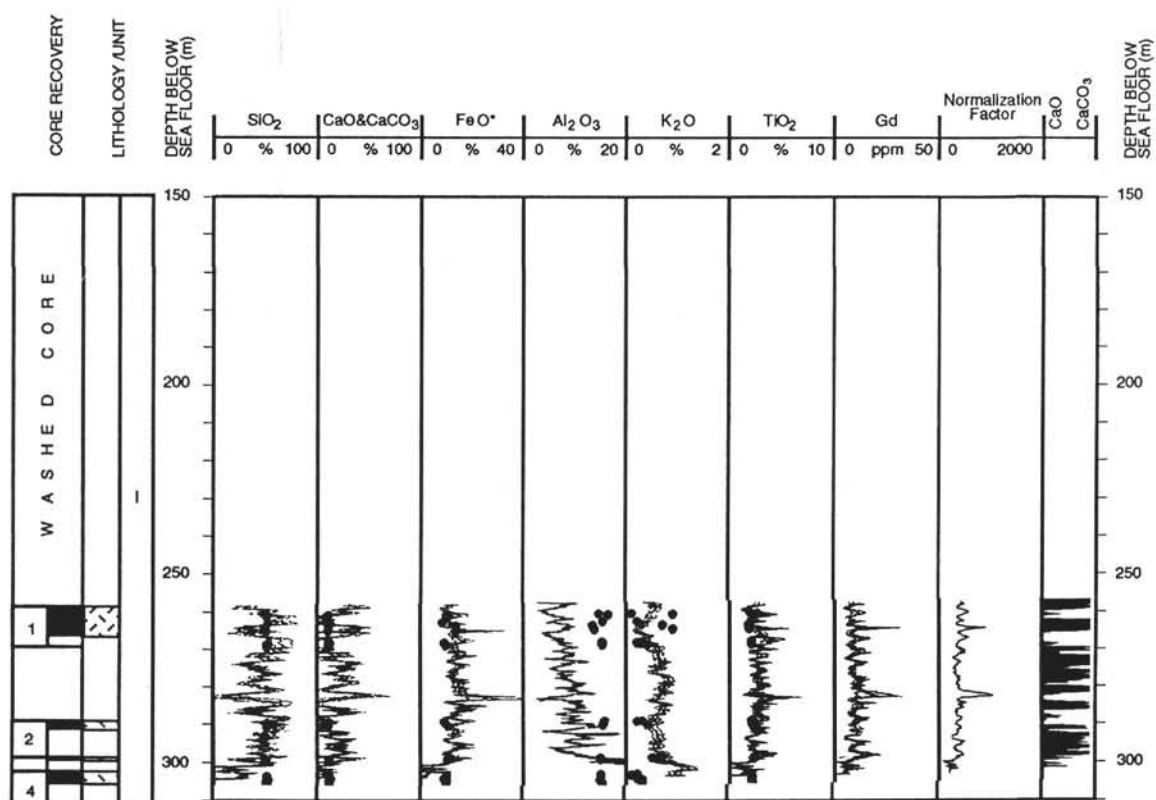Figure 3. Processed natural gamma-ray data, Hole 843B.

Figure 4. Estimates of calcium carbonate and major oxide-weight fractions from geochemical logs, Hole 843B. Solid circles represent XRF measurements (Shipboard Scientific Party, 1992).

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* Abbreviations for names of organizations and publication titles in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).