Leg 123: Geochemical Processing Report

(based on: Pratson, E. L. et al. (1992). Geochemical well logs from the Argo abyssal plain and Exmouth Plateau, Northeast Indian Ocean, Sites 765 and 766 of Leg 123. In Gradstein, F. M., Ludden, J. N. et al., Proc. ODP, Sci. Results, 123: College Station, TX (Ocean Drilling Program), 637-656.) Whereas the report refers to both Holes 765D and 766A, only the geochemical data from Hole 765D could be included in the online database.
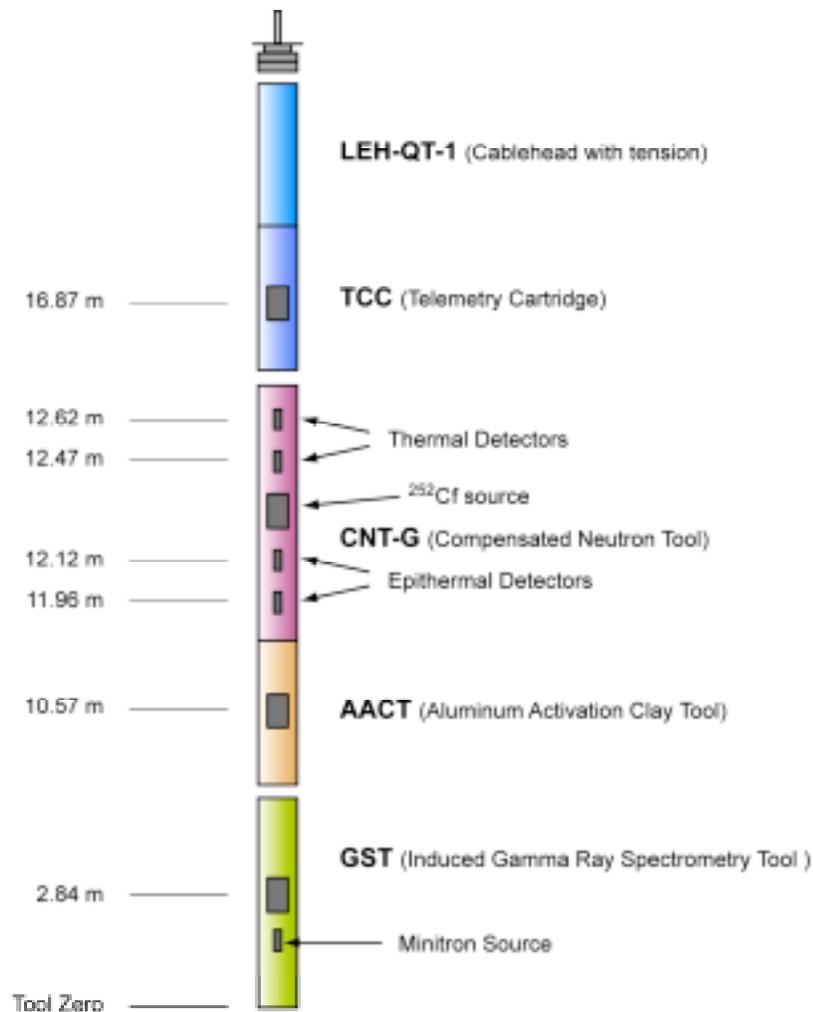
Note: A complete revision of all of the processed data from this leg was performed before putting the data online. This may have resulted in minor depth discrepancies between the published geochemical data and the online database version, particularly before Leg 128.

Geochemical Tool String

The Schlumberger geochemical tool string consists of four logging tools: the natural gamma-ray tool (NGT) the compensated neutron tool (CNT), the aluminum activation clay tool (AACT), and the gamma-ray spectrometry tool (see figure below). The natural gamma-ray tool is located at the top of the tool string, so that it can measure the naturally occurring radio nuclides, Th, U, and K, before the formation is irradiated by the nuclear sources contained in the other tools below. The compensated neutron tool, located below the natural gamma-ray tool, carries a low-energy californium source (^{252}Cf) to activate the Al atoms in the formation. The aluminum activation clay background radiation is subtracted out by the aluminum activation clay tool below and a reading of formation Al is obtained (Scott and Smith, 1973). The gamma-ray spectrometry tool, at the base of the string, carries a pulsed neutron generator to bombard the borehole and formation and an NaI(Tl) scintillation detector, which measures the spectrum of gamma-rays generated by neutron-capture reactions. Because each of the elements measured (silicon, iron, calcium, titanium, sulfur, gadolinium, and potassium) is characterized by a unique spectral signature, it is possible to derive the contribution (or yield) of each of them to the measured spectrum and, in turn, to estimate their abundance in the formation. The GST also measures the hydrogen and chlorine in the borehole and formation, but the signal for these elements is almost entirely due to seawater in the borehole, and they are hence of little value.

The only major rock-forming elements not measured by the geochemical tool string are magnesium and sodium; the neutron-capture cross-sections of these elements are too small relative to their typical abundance for the tool string to detect them. 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 of 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). This calculation was not performed for either Hole 765D or 766A, because the PEF measurement was affected in both holes (1) by the presence of barite in the mud, (2) by previous activation from the GLT, and (3) by attenuation caused by drill pipe and/or casing.

Because of the unstable hole conditions and time constraints, most of the logging data was acquired through pipe or casing. Electrical and acoustic logs do not work through pipe or casing, as neither electrical currents nor sound waves propagate through steel. On the other hand, neutrons and gamma rays can pass and be detected through pipe or casing, though the signal coming from the formations is greatly attenuated and decreases the signal-to-noise ratio. The basement section of Hole 765D was logged open-hole and provided the highest quality geochemical data of Leg 123.

Tool diagram (top to bottom): LEH-QT-1 (Cablehead with tension); TCC (Telemetry Cartridge) — 16.87 m; Thermal Detectors — 12.62 m, 12.47 m; ^{252}Cf source; CNT-G (Compensated Neutron Tool); Epithermal Detectors — 12.12 m, 11.96 m; AACT (Aluminum Activation Clay Tool) — 10.57 m; GST (Induced Gamma Ray Spectrometry Tool) — 2.84 m; Minitron Source; Tool Zero

Data Reduction

The well log data from the Schlumberger tools have been transmitted digitally up a wireline and recorded on the JOIDES Resolution in the Schlumberger Cyber Service Unit (CSU). The results from the CSU have been processed to correct for the effects of drilling fluids, logging speed, and 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 that have been modified to account for the lithologies and hole conditions encountered in ODP holes. The processing steps are summarized below:

Step 1: Reconstruction of relative elemental yields from recorded spectral data

The first processing step uses a weighted least-squares method to compare the measured spectra from the geochemical spectrometry tool with a series of standard spectra in order to determine the relative contribution (or yield) of each element. Whereas six elemental standards (Si, Fe, Ca, S, Cl, and H) are used to produce the shipboard yields, three additional standards (Ti, Gd, and K) can be included in the shore-based processing to improve the fit of the spectral standards to the measured spectra (Grau and Schweitzer, 1989). Although these additional elements 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, that of Si 0.16 barns (Hertzog et al., 1989). Gd is, therefore, included in the calculation of a best fit between the measured and the standard spectra.

Before the yields could be manipulated further, the Fe yield has to be corrected for the iron contained in (1) the steel drill pipe, (2) the bottom hole assembly, (3) the casing, and (4) the tool itself. Although Schlumberger routinely uses a boron sleeve, it has been removed from the GST tool used in ODP because the internal diameter of the drill pipe is too small. The boron sleeve would prevent the detector from picking up the iron contribution from the tool itself. After these corrections, a10-point smoothing filter was applied to all the yields to reduce noise.
The recomputed yields are loaded in the file 765D-yields.dat.

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. A total gamma-ray curve (from the gamma-ray tool, which is run on each tool string) is usually chosen as a reference curve, based on cable tension (the logging run with the least amount of cable sticking) and cable speed (tools run at faster speeds are less likely to stick).

The geochemical data were chosen as the reference for all of the other logs.

Step 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 resembles shipboard processing, except that corrections for hole-size changes are made in the shore-based processing of these curves. A Kalman filter (Ruckebusch, 1983) is applied to minimize the statistical uncertainties in the logs, which would otherwise create erroneous negative readings and anti-correlation (especially between Th and U). At each depth level calculations and corrections also were performed for K contained in the mud. This K correction is particularly useful where KCl is routinely added to the borehole fluid to inhibit clay swelling.
The outputs of this program are: K (wet wt %), U (ppm), and Th (ppm), along with a total gamma-ray curve and a computed gamma-ray curve (total gamma-ray minus U contribution).

The processed gamma-ray data are loaded in the files 765D-ngt-bas.dat and 765D-ngt-sed.dat (basement and sediments, respectively).

Step 4: Calculation of Al concentration

The fourth processing routine calculates an Al curve using four energy windows, while concurrently correct for natural activity, borehole fluid neutron-capture cross-section, formation neutron-capture cross- section, formation slowing-down length, and borehole size. Porosity and density logs are needed in this routine to convert the wet weight percent K and Al curves to dry weight percent.

The density log was used to calculate the porosity from the following equation:

$$\phi_t = (\rho_m - \rho_b)/(\rho_m - \rho_f)$$

where:

ϕ_t = percentage of porosity,
ρ_m = matrix density
(a constant value or log matrix density can be used in g/cm^3),

ρ_b = bulk density from the log in g/cm^3, and

ρ_f = density of fluid = 1.05 g/cm^3.

An offset was applied to log data to match core measurements at Hole 765D; at Hole 766A, interpolated density and porosity measurements from core were used instead.

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 outputs dry weight percentages of Al and K, which are used in the calculation and normalization of the remaining elements.

Step 5: Normalization of elemental yields from the GST to calculate the elemental weight fractions

This routine combines the dry weight percentages of Al and K with the reconstructed yields to obtain dry weight percentages of the GST elements using the relationship:

$$Wi = F\ Yi/Si$$

where
Wi = dry weight percentage of the i-th element
F = normalization factor determined at each depth interval
Yi = relative elemental yield for the i-th element
Si = relative weight percentage (spectral) sensitivity of the i-th element

The normalization factor, F, is a calibration factor determined at each depth from a closure argument to account for the number of neutrons captured by a specific concentration of rock elements. Because the sum of oxides in a rock is 100%, F is given by

$$F\ (\Sigma\ Xi\ Yi\ /\ Si) + XK\ WK + XAl\ WAl = 100$$

where
Xi = factor for the element to oxide (or carbonate) conversion
XK = factor for the conversion of K to K$_2$O (1.205)
XAl = factor for the conversion of Al to Al$_2$O$_3$ (1.889)
WK = dry weight percentage of K determined from natural activity
WAl = dry weight percentage of Al determined from the activation measurement

The sensitivity factor, Si, is a tool constant measured in the laboratory, which depends on the capture cross-section, gamma-ray production, and detection probabilities of each element measured by the GST (Hertzog et al., 1989).

The factors Xi are simply element to oxide (or carbonate, sulfate) conversion coefficients and effectively include the O, C or S bound with each element. In processing the GLT data the correct choice of Xi is important in the closure algorithm described above and requires geological input. All of the measured elements associate with C and O in a constant ratio, except for Ca, which associates with C and O to make either calcium carbonate or calcium oxide. To convert the measured elemental yields to elements and then oxides, the dominant form of Ca must be assumed. The assumption is made based on the lithologic description from cores. In both Holes 765D and 766A, the factor for CaCO$_3$ was used throughout the sedimentary section, and that for CaO in the basement.

Step 6: Calculation of oxide percentages

This routine converts the elemental weight percentages into oxide percentages by multiplying each by its associated oxide factor (Table 1).

The oxide weight percentages are loaded in the files 765D-oxides-bas.dat and 765D-oxides-sed.dat (basement and sediments, respectively).
Core measurements are loaded in the files 765D-core.dat.

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

Element	Oxide/carbonate	Conversion factor
Si	SiO_2	2.139
Ca	CaO	1.339 (basement)
Ca	$CaCO_3$	1.497 (sediments)
Fe	FeO*	1.358
K	K_2O	1.205
Ti	TiO_2	1.668
Al	Al_2O_3	1.889
Mg	MgO	1.658

References

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