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 tool below subtracts out the aluminum activation background radiation and a reading of formation Al is obtained (Scott and Smith, 1973).
The DIT/SDT/HLDT/CNTG/NGT main run was chosen as the reference run in Hole 869B. As a reference curve, based on cable tension (the logging run with the least amount of cable), the total gamma-ray curve (from the gammaraytool, which is run on each tool string) is used. Consequently, it is important that all the data are depth-correlated to one reference.

Geochemical Step 2: Depth-shifting

The recomputed yields are loaded in the file 869B-yields.dat. The calculation of a best fit between the measured and the standard spectra requires that the yields, fractions. 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.

The recomputed yields are loaded in the file 869B-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 gammaraytool, 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 DIT/SDT/HLDT/CNTG/NGT main run was chosen as the reference run in Hole 869B.
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). 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 the Th, U, and K. The outputs of this program are K (wt %), U (ppm), and Th (ppm), as well as total gamma-ray and computed gamma-ray (total gamma-ray minus U contribution) curves.

The processed gamma-ray data are loaded in the file 869B-ngt.dat.

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.

A correction is also made for Si interference with Al; the $^{252}\text{Cf}$ source activates the Si, producing the aluminum isotope, $^{28}\text{Al}$ (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:

$$W_i = \frac{F Y_i}{S_i}$$

where

- $W_i$ = dry weight percentage of the i-th element
- $F$ = normalization factor determined at each depth interval
- $Y_i$ = relative elemental yield for the i-th element
- $S_i$ = 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

$$F \left( \sum X_i Y_i / S_i \right) + X_K W_K + X_{Al} W_{Al} = 100$$

where

- $X_i$ = factor for the element to oxide (or carbonate) conversion
- $X_K$ = factor for the conversion of K to $K_2O$ (1.205)
- $X_{Al}$ = factor for the conversion of Al to $Al_2O_3$ (1.889)
- $W_K$ = dry weight percentage of K determined from natural activity
- $W_{Al}$ = 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. In most lithologies the elements measured by the tool occur in silicates where the compositions can be expressed completely as oxides.

With carbonate or carbonate-rich lithologies the measured calcium is more likely to be present as CaCO₃ (XCa: 2.497) than as the oxide (CaO; XCa: 1.399). A good indication of the choice of calcium conversion factors can often be gained from shipboard X-ray diffraction (XRD) and CaCO₃ measurements, which estimate acid-liberated CaCO₃. In the absence of suitable shipboard data a rough rule of thumb is generally used such that if elemental Ca is below 6% then all Ca is assumed to be in silicate, above 12%, in carbonate. Ca concentrations between these figures are converted using linear interpolation.

The parameters, 6% and 12% were chosen according to observations of how Ca occurs in nature. CaO is not likely to occur in quantities greater than 12%, therefore, CaCO₃ is a logical assumption in these instances. When Ca is less than 6%, even if CaCO₃ was incorrectly assumed, the error would be very small when 1.39 is used as the oxide factor instead of 2.49. The linear interpolation is done in order to provide a smooth transition and avoid invoking any erroneous chemical changes on the final processed logs. This procedure for Ca gives the best model in most cases and minimizes the error when the model is not exactly correct.

Steps 6-7: Calculation of oxide percentages and statistical uncertainty

These routines convert the elemental weight percentages into oxide percentages by multiplying each by its associated oxide factor (Table 1); finally the statistical uncertainty of each element is calculated, using methods described by Grau et al. (1990) and Schweitzer et al. (1988). This error is strongly related to the normalization factor, F, which is calculated at each depth level. A lower normalization factor represents better counting statistics and therefore higher quality data.

The oxide weight percentages are loaded in the file 869B-oxides.dat.
The statistical uncertainties are loaded in the files 869B-oxierr.dat 869B-elerr.dat.
Core data are in the file 869B-core.dat.

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

<table>
<thead>
<tr>
<th>Element</th>
<th>Oxide/carbonate</th>
<th>Conversion factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>SiO₂</td>
<td>2.139</td>
</tr>
<tr>
<td>Ca&lt;6%</td>
<td>CaO</td>
<td>1.399</td>
</tr>
<tr>
<td>6%&gt;Ca&lt;12%</td>
<td>CaO-CaCO₃</td>
<td>1.399-2.49 linearly interpolated</td>
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<tr>
<td>Ca&gt;12%</td>
<td>CaCO₃</td>
<td>2.49</td>
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<tr>
<td>Fe</td>
<td>Fe₂O₃</td>
<td>1.43</td>
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<tr>
<td>K</td>
<td>K₂O</td>
<td>1.205</td>
</tr>
<tr>
<td>Ti</td>
<td>TiO₂</td>
<td>1.668</td>
</tr>
<tr>
<td>Al</td>
<td>Al₂O₃</td>
<td>1.889</td>
</tr>
</tbody>
</table>
References


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