1. Overview - water (and rainy days)

Apart from underground mining operations, most of the logger’s work is performed in the open air. He might have a cosy truck or dog-box to retreat to but, at some stage, he has to get out there and deploy his equipment. Trying to calibrate and produce a meaningful measurement in the pouring rain is not an uncommon scenario, particularly in tropical climes. Oilfield loggers have an advantage here. Most often, just about always in fact, they operate with a large drilling rig on site. The environment is orderly, there may be a concrete base or at least gravel. One can say categorically that the oilfield logger rarely logs from a makeshift tent.

The classic situation in mineral logging is where the drilling rig has left site and there is, hopefully, a length of casing marking the borehole collar. The logger will normally operate from a 4x4 vehicle and, if he is well organised, he can work pretty effectively in adverse weather conditions.

Being organised is the key. Never put tools on the wet ground, minimise clutter, keep your hands clean and don't fall into the mud pit. It is quite easy to miss the outline of the driller’s mud pits in rainy conditions...he fills them in, of course, but they become a bit like an elephant trap when it rains. Digging out the logging truck is a laborious business.

The most difficult situation is the long range job where the logging truck has not been mobilised. In this case, the logger finds himself working from a variety of boxes, tents and from within vehicles that are not perfectly waterproof. The ground may be a bog due to previous drilling activity. An ephemeral stream might bisect the site. It's all in a day's work but adverse site conditions can impact on log quality. The logger is advised to check on local climatic conditions before mobilising to an unfamiliar part of the globe. Tropical rain can be very heavy!
While the logger dislikes water falling on his head, he is generally pleased if the borehole to be logged is full of it. The perfect mineral exploration borehole is of HQ diameter, slightly angled from vertical and full of clean fresh water.

Many log measurements require a water-filled environment. Sonic and electrical logs, including full wave sonic, acoustic televiewer, formation resistivity and dipmeter will not work in dry holes.

Fresh clean water allows best use of tools relying on variations in electrical resistance and, of course, an optical televiewer sonde does not like dirty water.

In coalfield logging, the presence of water damps the effect of minor caving on the density log. This is because of the lower contrast between the density of the voids and the density of coal.

Having a water level within the target zone is always problematic. Quite often, when the logger is running a density combination tool, the natural gamma log will describe a step to higher values as the radioactive source leaves the shielding effect of the water and adds to the environmental count rate at the gamma detector. There will be some impact on the density logs as well which should be compensated for. Both these effects are greater in a large diameter borehole. It is far better if the logged environment is constant in terms of both fluid presence and volume.

The type of fluid can influence the resistivity and density measurements. Very conductive fluid damages a standard resistivity log as it becomes impossible to inject electric current into the formation, particularly where the formation is resistive. The current preferentially passes up the borehole column. In permeable zones, the borehole fluid will normally invade the formation, changing its electrical properties. If a heavy bentonite mud or light oil-based mud is used, some correction to the density log will be needed as it usually defaults to a correction based on water density.

The geologist should be aware of all these environmental factors that might constrain the quality of log measurement.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Wet or Dry</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nat gamma ray</td>
<td>Both</td>
<td>Compensate for hole diameter in wet hole. Affected by source in dry hole.</td>
</tr>
<tr>
<td>Density</td>
<td>Both</td>
<td>Dry hole compensation is significant. Caving more problematic in dry hole.</td>
</tr>
<tr>
<td>Neutron</td>
<td>Wet</td>
<td>Porosity in wet hole. Can describe formation in dry hole.</td>
</tr>
<tr>
<td>Sonic and FWS</td>
<td>Wet</td>
<td>Unusable in dry hole. Affected by gas bubbles in wet hole.</td>
</tr>
<tr>
<td>Resistivity</td>
<td>Wet</td>
<td>Unusable in dry hole. Loses focussing in very conductive fluid.</td>
</tr>
<tr>
<td>Optical TV</td>
<td>Both</td>
<td>Poor images result from dirty water and deposits on borehole wall.</td>
</tr>
<tr>
<td>Acoustic TV</td>
<td>Wet</td>
<td>Unusable in dry hole. Suffers from signal dispersal in heavy drilling mud.</td>
</tr>
<tr>
<td>Mag susceptibility</td>
<td>Both</td>
<td>Produces similar logs regardless of fluid. Requires diameter compensation.</td>
</tr>
<tr>
<td>Dipmeter</td>
<td>Wet</td>
<td>Unusable in dry hole. Suffers from cond fluid / resistive rock contrast.</td>
</tr>
<tr>
<td>Induction</td>
<td>Both</td>
<td>Used in non-conductive mud. Dry hole logs affected by residual moisture.</td>
</tr>
</tbody>
</table>

WIRELINE LOGGING

Manufacturers of slim-hole wireline logging equipment for various applications including:
- Mining & mineral surveys
- Geotechnical studies
- Groundwater management
- Unconventional resources

To find out more, please contact us
email: sales@geologging.com

Robertson Geologging www.geologging.com
2. Measurement Focus

A review of one wireline log measurement

The Temperature sonde

The borehole column may be described in terms of its orientation, its cross section and the properties of the fluid within it. In mineral logging the fluid is usually water and much of this is formation water (groundwater) released when an aquifer is intersected.

Generally speaking, greater depth results in warmer water and any ingress is normally warmer than recently circulated drilling fluid.

A temperature log is a useful measurement because, given sufficient time, the borehole fluid is warmed to a similar temperature to the surrounding rock mass. Rock temperature information is important to mine design. Beyond that primary function, the temperature log may be used to flag groundwater ingress points and to locate anomalous mineral ore bodies whose temperature conductivity is often markedly different from that of the barren host rocks.

Deeper means hotter. The main sources of the Earth's heat are generally agreed to be residual heat from the formation of the planet and ongoing heat generation from the decay of radioactive elements, mainly K, U and Th, in the mantle and crust.

Heat is trapped below the Earth's crust because silicate rocks do not conduct heat particularly well. The average temperature gradient of the crust is about 30°C per kilometre. Relying on conduction rather than convection, it behaves like an insulating blanket and, within the crust, some rocks have more insulating qualities than others. Metallic ores, massive sulphides and rock salt conduct heat rather well but coal and shale do not.

![Temperature Log Image](image)

The effect of coal seams on temperature gradient (from left; density, differential temp and temp)

The log above shows a sequence of coal seams with temperature logs. The depth scale is 4000:1. Temperature logs are descriptors of the big picture and are best plotted at big scales. Notice the gradual downward increase in baseline density that is clear at this depth scale.
Sandstone offers mid-range conductivity and the various igneous rocks, such as granite, have a higher thermal conductivity, partly due to their greater compaction. A temperature gradient in degrees per kilometre can be assigned to different rock types within a lithological column. So the temperature measurement offers various benefits:

- Ambient rock mass temperature
- Description of lithology
- Flagging conductive ore targets
- Flagging fluid ingress points

This might be valuable information in some situations so it is worth getting the log right.

**Case study**

The author once logged a very deep gold exploration borehole with a temperature sonde. On receiving the data, the client was surprised at the high temperatures recorded...over 80 degrees Celsius. This represented a serious threat to his aspirations of mining the ground one day and was much higher than the projected temperature that was based on other mines in the area. The client wanted proof of the tool's accuracy. The best way to do this is to run a bottom hole temperature (BHT) thermometer to various depths and plot the results as point measurements on the previously recorded temperature curve.

A BHT thermometer is a simple maximum thermometer housed in a waterproof pressure tube (with O ring seals) that is attached to a sonde. It is a good idea to include some oil in the tube to improve contact between thermometer and housing. Most digital thermometers switch themselves off before the measurement is completed so an old fashioned mercury in glass type, where you have to shake down the bar, is probably best.

The BHT thermometer measurements confirmed that the logging tool had recorded the correct fluid temperature. A local geological anomaly had caused the higher temperature.

**Temperature measurement and correction**

The fluid temperature detector is normally part of a combination sonde. It might be considered as an addition to any sonde, where practical, because it is important that temperature be measured several times during the overall logging operation.

The temperature tool is based on a slim thermistor normally located at the bottom of a sonde as on page 3, either shrouded within a tube or protected by a cage. Thermistors are temperature sensitive resistors. All resistors vary with temperature, but thermistors (thermal-resistors) are constructed of semiconductor material with a resistivity that is very sensitive to temperature.

The sonde is normally run downwards at about 10 metres per minute. Centralisation is valid in bigger diameter holes or where grease and mud cake might clog up the detector (and reduce its resolution) if it were run down the sidewall. There is some time delay in the measurement so the average of an up-log and a down-log run at the same speed would yield the most accurate result. Calibration is performed in a heated bath of water where a reference probe or thermo-couple device is attached to the sonde next to the thermistor housing.

**Borehole calibration, using the maximum thermometer method, takes longer but is a very reliable way of calibrating a sonde in the field.**

The ambient log is actually a measure of borehole fluid temperature which, over time and if undisturbed, will approach equilibrium with the local geothermal gradient. That does not mean that it will exactly represent the local gradient. Because convection is more efficient than conduction in transferring heat, the fluid-filled
boreshole column does not behave in exactly the same way as the rock mass. The measurement at TD will be the most reliable...and that is usually all that matters.

Even in small diameter boreholes, a meaningful ambient temperature log will rely on the boreshole column being undisturbed for at least 48 hours, so that the borehole fluid and surrounding rocks will stabilise to a temperature close to that of the far field value. This period is practical in mineral boreholes although studies in large diameter oil wells drilled through permeable rocks indicate that it can take months for temperature to approach equilibrium. If multiple runs are made at time intervals then a Horner plot may be used to project final stabilised temperature at a given depth. The Horner plot, suggested by Dowdle and Cobb in 1975, is not perfect but it is the most popular method of projecting temperature at equilibrium.

<table>
<thead>
<tr>
<th>Date and time at depth 1</th>
<th>Logging run</th>
<th>Temperature recorded in deg C</th>
<th>t = time since last circulation in hours</th>
<th>t = time from depth reached to last circulation in hours</th>
<th>T/(t + T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Jan, 17h00</td>
<td>GT1</td>
<td>39.2</td>
<td>12</td>
<td>18</td>
<td>0.400</td>
</tr>
<tr>
<td>8 Jan, 12h00</td>
<td>GC2</td>
<td>46.1</td>
<td>31</td>
<td>18</td>
<td>0.633</td>
</tr>
<tr>
<td>8 Jan, 18h00</td>
<td>GC2</td>
<td>48.1</td>
<td>37</td>
<td>18</td>
<td>0.673</td>
</tr>
<tr>
<td>9 Jan, 05h00</td>
<td>GT1 (relog)</td>
<td>48.1</td>
<td>48</td>
<td>18</td>
<td>0.727</td>
</tr>
<tr>
<td>Projected temperature at equilibrium</td>
<td>54.2 (refer to plot)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Horner plot calculations

The method is described in the table above where the proportion of time required to reach equilibrium is:

\[ E = \frac{T}{t + T} \]

T is the time since the last circulation of drilling fluid (the warming time).

t is the time between the bit reaching the chosen depth and the last circulation (the cooling time).

If the data are plotted on a logarithmic scale, the result will look like the Horner plot below. Where the straight trend line intersects the boundary \( T/(t+T)=1 \), the projected equilibrium temperature is read off the Y axis.

This universally accepted technique at least offers precision and simple rationale. In many cases, mineral holes may be relogged many days and even weeks after drilling is completed. If the temperature has not changed in that time, it can be considered as being in equilibrium.

A Horner plot - the proportion of warming time over warming plus cooling time which reaches 1 when warming time is infinity

If BHT is required, the temperature sonde should be allowed to stand for about one minute at that depth and the exact time and temperature noted on the field report.

It is always prudent to add a BHT thermometer to the sonde as a quality assurance measure.
Differential temperature

A differential temperature log, based on rate of change over time or (more often) depth, is derived from the continuous fluid temperature log.

A temperature log

In the log on the right, the major anomaly on the differential temperature log, at about 800 metres, lines up with an event on the caliper log and seems to indicate an inflow associated with an open fracture. A televiewer log later confirmed that the caliper deflection represented a steeply dipping open fracture.

The temperature sonde was logged downwards immediately after drill rods had been withdrawn from the borehole. No time was wasted in the process and logging speed was 10 metres/minute. The tool carried stand-offs. An up-log was recorded afterwards.

For ambient rock temperature, delay the log as much as possible. For water inflow indications, log downwards immediately after rods are withdrawn.

The principle is that the action of withdrawing the rods, and the replacement of their volume by groundwater aquifers, will result in the depth of those aquifers, or interconnecting fractures, being indicated by the temperature log because the inrushing water should be warmer than the borehole column.

It is important for the driller to circulate the borehole water for at least one hour before withdrawing rods, in order to homogenise and cool the borehole column, and for the logger to lower his temperature sonde as soon as possible. The latter can capture a down-log and an up-log for comparison (especially important if the water level is low at first, but rising).

The problem with the differential log is that the borehole temperature stabilises quickly and any log run several days after drill rods are withdrawn is unlikely to see much of the original induced and detailed information. Note that fluid conductivity signatures of this type do not decay quickly and this measurement is a better option in some circumstances. Since most conductivity sondes carry a temperature detector (for log correction), that combination tool is ideal if available.

Conversely, a very useful "first-run" tool is the Three-Arm Caliper - Gamma Ray - Temperature combination sonde. You get a basic lithology log, a check on hole conditions and a temperature gradient before doing anything clever. This is a great success on deep operations.

It should be noted that the vast majority of mineral logging sondes have an operational temperature limit of 70 degrees Celsius. It is important to run a temperature log first if one expects to test that limit.
An alternative to differential temperature (often called DIFT) or rate of change, is departure from trend (TDIF perhaps). If a much filtered (1000 point MA) temperature curve is deducted from the temperature log (TEMP) the result is useful flag of anomalous events.

A temperature log comparing DIFT and TDIF (centre)

Once the borehole has settled down (after 48 hours at least), inflows will no longer be evident on the log and borehole temperature should be close to equilibrium. This is the time to relog temperature, determine the temperature gradient and differential anomalies not associated with fluid flows from fractured zones.

Differential temperature down-log (red curve on far right) scaled to fit over a shear wave sonic front

Most geologists are not aware of how sensitive a temperature sonde can be in "quiet" conditions. Some remarkable correlations prove the point. The log of chromite layering, above, was recorded several days after the driller had left site. The red log on the left is differential temperature; three runs stacked and filtered and getting warmer to the left. The overlaid red and black logs on the right of “DIFT” are temperature minus averaged temperature (10-metre MA). Again, warm is on the left. Each grid line represents 0.04 degrees Celsius.
This shows that the temperature log is sensitive to lithological changes and that the differential temperature regime, once allowed to settle, clearly moves positive and negative depending on rock type with a sensitivity of 0.01 degrees or better. If DIFT is copied and laid over a shear wave sonic front, imaged on the right of the log, a remarkable correlation is evident.

**If the log analyst is searching for minor inflows, he has to take account of lithological effects, which can perturb the differential temperature log.**

Once again, reference to a fluid conductivity log will be helpful. Where there are no flows, it is likely that a sensitive temperature log would detect orebodies close to, but not actually intersected by, a borehole.

![Example of thermal conductivity changes with elbows aligning with lithological boundaries](image1)

The log above illustrates the value of a temperature log as a lithological tool. This was recorded quite close to an active volcano so “hot” tooling was required...proving that mineral loggers do sometimes go beyond 70 deg C.

It is worth noting that vertical flows between open fractures within the borehole column will perturb the thermal conductivity profile. There is a significant fracture apparent on the caliper log at 545 metres depth which could be influencing the temperature gradient above it. It aligns with an elbow on the log.

![Difference between down-log and up-log at 10m/minute](image2)
3. The logger on site

Accessing formations without the aid of gravity

Logging short horizontal boreholes

Most exploration boreholes are drilled vertically or, at least, within 45 degrees of vertical. If we include in-mine boreholes drilled ahead of workings, then the proportion is reduced somewhat and there are many specialised drilling applications such as coalbed methane production where boreholes are turned to follow a near horizontal target. Normally, the logger relies on gravity to deliver his sonde to the end of a borehole but for horizontal jobs, the sonde must be delivered by means of some rigid mechanical device, such as the drill string.

There are many techniques for delivering a sonde to the end of a horizontal borehole but one simple method for short holes is to employ drain or sewer rods.

A portable push-rod system for underground applications

The rods are attached to a cable head using a special adapter. They are usually assembled in advance and laid out on the floor so that two or three men can push the sonde into the bore while the winch releases cable. Once the sonde is at the end of a borehole, the logger winches out the whole assembly while capturing a log. The rod handlers do not pull. They just guide the rods away from the borehole collar. This manually operated system will log horizontal boreholes of up to about 50 metres in length and vertical (upward) holes to about 30 metres.

Of course, the problem with horizontal boreholes is that they are dry, so the logger is prohibited from using some of the available log measurements. Nevertheless, a very useful set of data can be captured and, in practical terms, one or two are usually enough to satisfy our ambitions in a particular situation. Perfect depth control is important because depth of intersection of a geological boundary is often the main goal.

The author conducting a recent trial at Finsch Diamond mine in South Africa. Note the push rods and cable.

Fairly short, lightweight, dry-hole tools include:
- Natural gamma
- Formation density (single spacing)
- Optical televiewer
- Magnetic susceptibility

The sought-after knowledge is often related to some geotechnical challenge, so the optical televiewer is a particularly useful tool. In the diamond mine example illustrated above, the aim was to determine depth of intersection of a kimberlite pipe without having to employ expensive core drilling. A simple natural gamma sonde did the job perfectly in this particular geological setting ... contrasting kimberlite with the dolomite host rock is fairly straightforward.

The wireline log offers an accurate depth reference as well as a precise, objective in-situ measurement. The result is easily interrogated, stored and transmitted. Drill core requires costly rig time, transport, storage and
geological and/or laboratory analysis. In some circumstances the wireline log is clearly the better option but many mine geologists are unaware of the options available to them. The logging system may be purchased and operated by mining personnel, thus reducing costs further.

An intersection depth achieved with a natural gamma ray sonde (courtesy Petra Diamonds)

### 4. Wireline data processing and analysis

**How to get the best from the logs**

**Presentation matters - or does it?**

Now to the thorny topic of wireline log presentation. It’s thorny because it is so subjective. Beauty is in the eye of the beholder. The options in terms of scale, shading, colour palettes, line weights and juxtaposition are infinite. One thing is certain though:

**Well presented data yield more knowledge than poorly presented data do.**

Generally speaking, while most of us cannot claim to be technical artists, using the computer screen like a canvass and the mouse like a paintbrush, we can usually recognise the difference between incomprehensible scrawl and something pleasing and informative to the eye. Here are a few guidelines that might be useful (responses will be appreciated as always).

1. **Choose a system.** It is helpful if a logging contractor always uses a similar layout and fixed shading colours for particular log types.

2. **Shading should be used with restraint.** Light pastel shades are best, with no large shaded areas dominating the centre of the plot. Frame the presentation with, common shaded logs like gamma and caliper.

3. **Shaded curves do not require heavy line weights.**

4. **Curve filters should be used with restraint and are important to get right...always experiment.**

5. **Offer both detailed and general depth scales.** Big scales, like 2000:1, provide a holistic picture that adds value, particularly in terms of trend recognition.

6. **Separate images and shaded logs with a space.**

7. **Where log variation is subtle, add some interest-level shading to highlight changes.**
One cannot say categorically that one presentation is better than another in terms of appearance but one can say that one was more helpful in terms of what we are trying to achieve.

Two ways of presenting the same rather uninteresting data

Perhaps the important thing to remember is that the logger has done his best to capture high quality data so we should present the fruits of his labour as well as we possibly can.

**Next Issue:**
- Potash and natural gamma ray

---

**Wireline Workshop**

*Marcus Chatfield – November 2015*

*Copyrights apply (www.wirelineworkshop.com)*

*Acting editor/contact: wilno@wirelineworkshop.com*

*For back copies, go to: www.wirelineworkshop.com/bulletin and click on "Previous Issues".*

**Wireline Logging Services**

- Specialised borehole logging technology
- Log processing and analysis
- Training and advice on logging projects
- Supply and commissioning of equipment

Long range technical support and log data analysis is available to everyone.

Contact: marcus@wirelineworkshop.com