Not-So-Boring Geology

An Introduction to Borehole Geophysical Logging

Geologists have a choice of methods to use when they want to see what is underground. **Borehole geophysical logging** is the process of viewing, collecting, analyzing, and interpreting the data from boreholes. Borehole geophysics is the study of geologic (rock) and hydrologic (water) information of the shallow earth. Boreholes provide a way to view rock, water, and other materials, as well as physically obtain samples.

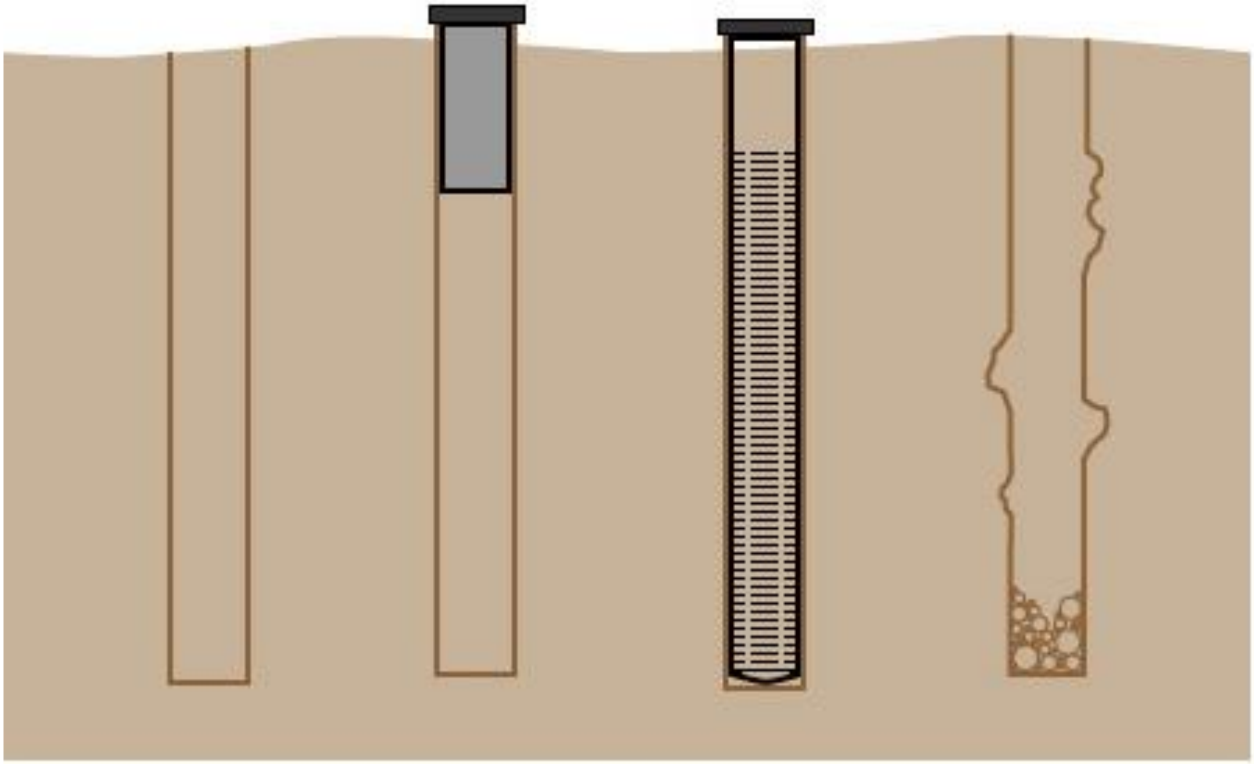
There are numerous tools that scientists can use to obtain information from boreholes. In this exercise, you will learn about different kinds of tools used in borehole geophysical logging, what they do, and what information they provide. Then you will "read" real geophysical logs and put together what you have learned by answering some questions.

What is borehole geophysical logging?

First, what is a borehole? Essentially, a **borehole** is a cylindrical, open space created in the ground by a drilling rig. Boreholes can be as short as a few feet deep or as much as thousands of feet deep. They can be drilled at any angle but those for basic study are usually vertical. Boreholes can simply be open holes (when drilled in solid rock). A metal pipe the same diameter of the borehole – known as *casing* – can be inserted at least a few feet into a rock borehole to support the near-surface area of the hole. When a borehole is drilled in sand or other weak material it may be lined with casing, which prevents the hole from caving in. Wells that have already been drilled into the ground to extract or test water are convenient and often used for borehole studies.

> *Info Bit:* Russia's Kola Superdeep Borehole is the longest true vertical borehole in the world, at 40,230 feet deep. That is over 7.5 miles of borehole!

Below, left to right, are an uncased open borehole, a partially cased borehole or well, a screened well, and an open borehole that has material loss on the walls and buildup at the bottom. Boreholes are often imperfect – pieces of the wall may still break away or collapse in places and sediment will build up in the bottom of the hole, shortening the original depth.



Borehole geophysical logging is a method of observing and determining physical and electrical properties of subsurface geology via a borehole. The work is performed with the help of **geophysical logging tools**, which are specialized instruments used in subsurface studies. These tools are slender, long, waterproof devices that can be lowered down a borehole or well with a cable on a winch. The data they provide may help determine information such as rock characteristics (e.g.: angle, fractures) and contact between different rock units. Geophysical studies may be done simply to get a better picture of the basic geology of an area, to seek natural resources (minerals, oil, etc.), or to gather information in support of environmental projects, for a few examples.

> *Info Bit:* Borehole geophysical logging can be used to help locate new groundwater sources as well as remediate historically polluted areas, helping to maintain water quantity and quality.

A borehole geophysical log is a pictorial representation of the data from a logging tool. Created with specialized computer programs, data from the logging tools is put into graph and image format. Logs from all the tools used in one borehole are laid out side by side in one comprehensive document to easily view and compare the data. Depending on the programs used, logs can look vastly different. You will examine various logs later in this document.

The process

Initially, a borehole must be created. Machinery is used to auger or drill a hole in the ground to a certain depth (this step would be skipped if existing boreholes or wells are used). Boreholes can range from only a few inches wide to a few feet in width. The size and depth of a boring is dependent on the type of project the hole is drilled for (e.g.: oil, gas, geothermal heating and cooling, monitoring).

Logging can begin right away in a brand-new borehole; ideally, the water is settled and clear. One geophysical logging tool is slowly lowered by cable into the borehole. The cable has internal conductors to send power and transmit data. The information is obtained by a field computer or other device. Then, the tool is raised, a different tool is lowered in, and the process repeats. It can take a full workday to do this. Multiple tools can be connected and lowered together to speed up the process, but the increased weight can be risky and hard on the equipment.

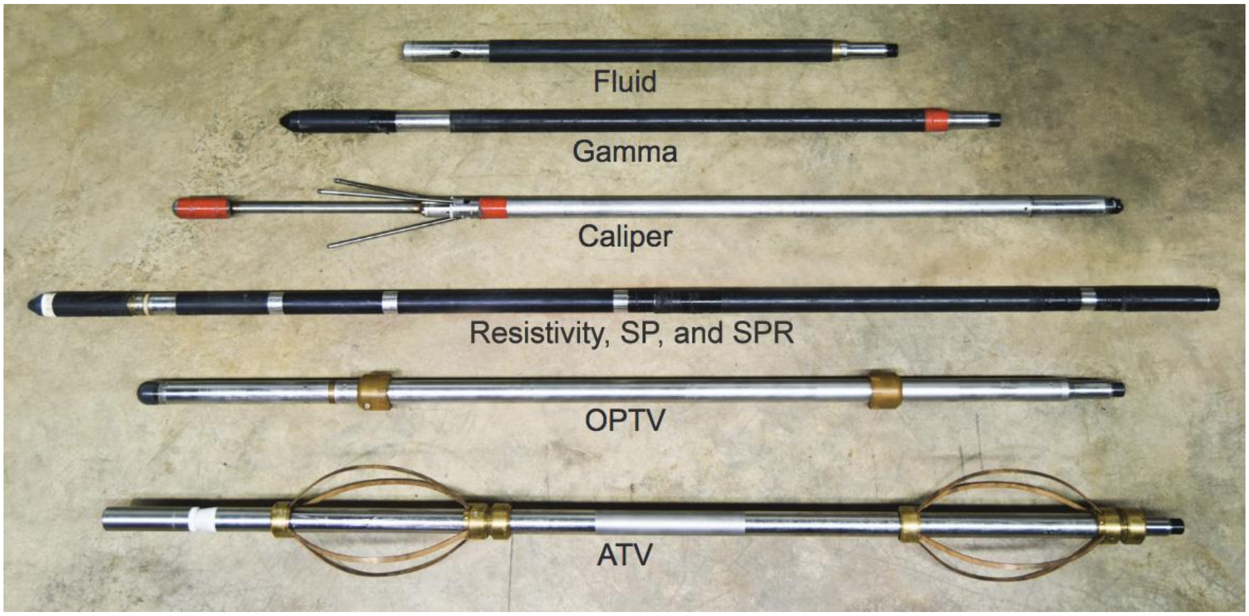
In the picture below, a logging tool with a cable is being placed in the well. A tripod is set up over the well so that the cable can run over the wheel and to a winch in the back of the truck. The winch is programmed to lower the tool at a slow speed.

In the following photograph, one geologist is taking notes in a field notebook while the other is using a laptop to view and analyze real-time data from the logging tool. A motorized winch is visible in the back of the truck. The thin cable suspending the tool is hard to see but it is running between the two geologists and out to a borehole or well that is not in the picture.

Immediately in the field and later at the office, geophysicists use specialized computer programs to interpret, tabulate, and/or process the data gathered from the different tools. They interpret the data by using their knowledge of geology, physics, mathematics, technology, and lots of field experience. Finally, all the data is put together as one comprehensive, pictorial log.

Types of Logging Tools

Below is an image of some of the tools used in geophysical logging. As you can see, the tools look like each other – this is out of necessity of design, to fit down small holes – but most perform tasks and provide information unique from the others.



Fluid Temperature and Conductivity (FTC) Tool

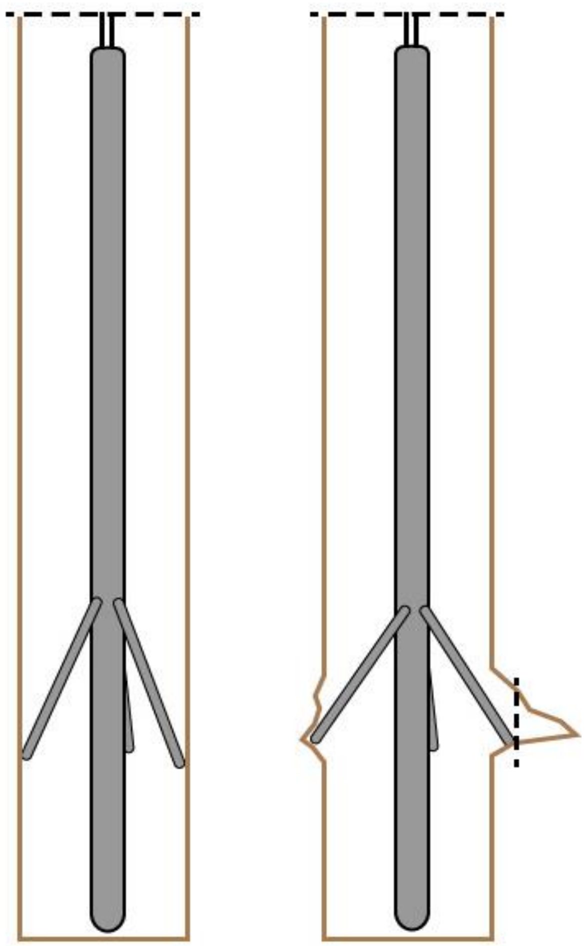
One function of the FTC tool is to determine changes in conductivity of fluid with depth. A DC current (direct current, which flows only one way) passes between two internal electrodes; if there is a drop or spike in conductivity, the readings from the tool will reflect that. For example, if salt water suddenly has a freshwater intrusion halfway down the borehole, the electrodes will pick up that change and lower conductivity will be noted in the data. The other function of the FTC tool is to determine the temperature of the surrounding geology as well as points of sudden temperature changes, which could indicate where water or another fluid enters the borehole, for example. It cannot read conductivity when outside of a fluid, but it can record air temperature. The FTC tool is usually used with others in determining the overall characteristics of a borehole.

Gamma Ray (GR) Tool

There are three types of radiation: alpha, beta, and gamma. The gamma ray tool measures the amount of gamma radiation that occurs naturally. Different materials have different amounts of gamma radiation; thus, different rock and mineral types can be determined from this tool. The gamma tool is most useful in finding clay and shale, which have more radioactive material compared to other geologic material, but it is hard for this tool to detect thin layers.

Caliper Tool

A caliper is an instrument that measures the distance between surfaces. The caliper tool measures the diameter of the borehole with arms (usually three) that move in and out depending on the contour of the borehole surface. Where open spaces occur in the wall (fractures, collapses, breakouts, etc.), the arms move outward and record a greater diameter. Most caliper tools have arms that do not move independently, so that if there are two voids at one depth (one deep, one shallow) the tool will read only the shallower void. This tool can determine not only the locations of fractures and voids in the borehole wall, but also joints, holes, and breakage in the casing, as well as the bottom of casing. The caliper tool only works in one direction: from the bottom of the borehole, upward. The arms are retracted while the tool is lowered and released before pulling the tool up. The arms slip past openings this way; If the tool were pushed down, the arms would become stuck. You can use the caliper where casing exists, but it will generally show nothing of importance.



To left is a diagram showing calipers down two different boreholes. The hole on the left is generally smooth and all caliper arms reach equidistantly around the hole. The borehole on the right exhibit's voids at a certain depth. The right caliper arm is next to a deeper void, but it is prevented from reaching further because it is restricted by the left arm (and possibly the rear arm) that extends into a shallower void. This shows the limitation of the caliper tool and how imaging tools are important to use in conjunction with the caliper tool to evaluate open spaces.

Info Bit: Sometimes geophysical logging tools become stuck in boreholes. Uneven borehole walls, twisted cables, freshly disturbed or broken rock down the hole, and other factors can cause a tool to lodge or wedge in the hole... and give geologists a touchy problem to solve!

Resistivity / Spontaneous Potential (SP) / Single Point Resistance (SPR) Tool

Notice in the image that resistivity and spontaneous potential functions exist in one tool (SPR is often included). Devices may be combined in one tool when their modes of operation and the geological properties that are sought are similar. In this case, resistivity, SP, and SPR use sets of electrodes to determine electrical properties of the geology through water, so it makes sense to combine them in one tool and save the trouble of using three.

Resistivity

Inside the resistivity tool are two electrodes (conductors that emit and collect electrical energy) that are sensitive to moisture. The resistance to a DC electric current is measured. The resistivity of water-holding or water-bearing layers like clay and fractures with flowing water is easily detected. Some resistivity tools have just one set of electrodes; other tools have up to four, set at different distances apart (usually 8, 16, 32, and 64 inches apart). The greater the spacing, the deeper into the rock/sediment the tool reads resistivity. The tool must be immersed in water – but it works in mud-filled holes, as well.

Spontaneous Potential

Spontaneous potential (SP) is the natural electrical potential of geology. It is one of the first types of electrical measurements ever performed in boreholes. The SP function reads electrochemical activity of the geology through the water, measuring the difference in voltage between two electrodes: one inside the tool and another at ground surface. A live electrical current (like DC) is not used. SP is particularly useful in detecting clay layers, water-bearing layers, and rock beds that happen to have conductive material within them (metals, metal-containing minerals). The SP tool cannot be used out of water and it does not perform well in rock with high resistivity.

Single Point Resistance

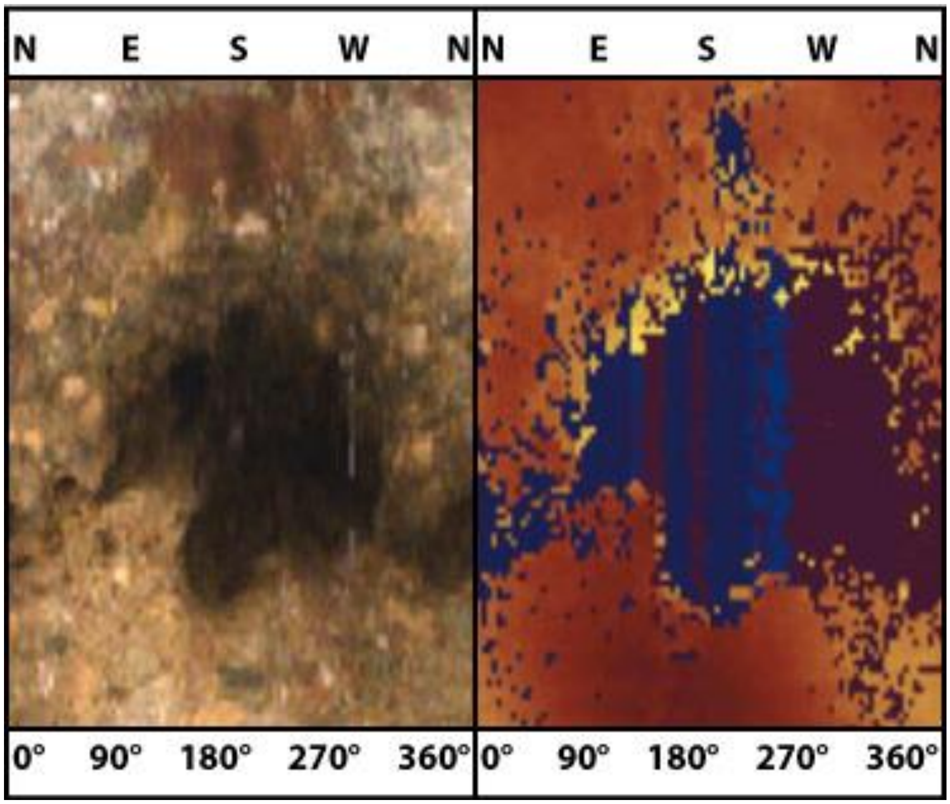
Single Point Resistance (SPR) requires two separate electrodes: one at ground surface and another on a small caliper that touches the wall of the borehole. The unit emits a constant DC electrical current while the caliper detects a loss of voltage between the two electrodes. The drop in voltage is the resistance (opposition of current flow) of the rock/sediment. The tool needs to be used in a borehole with water. Some factors that cause resistance include fractures in rock, salt water (a good conductor of electricity), and the proximity of water-bearing and non-water-bearing layers of rock.

Imaging Tools – Televiewers

Televiewers are tools that provide two-dimensional images of the inside of a borehole (basically, a series of stitched photographs). There are two types of televiewers:

> 1) An **optical televiewer** (abbreviated as either **OPTV** or **OTV**) takes 360° ring photographs in 1-millimeter-wide intervals down the borehole; the rings are stacked together to form one long image of the borehole. The image is used to identify rock types, angles, contacts, fractures, veins, and other properties. OPTVs work best in boreholes without water or with clear water. The cloudier the water, the more difficult it is to see and interpret the imagery.
>
> 2) An **acoustic televiewer** (or **ATV**) uses ultrasonic sound waves in 360° to "see" features. The borehole must contain water for this instrument to work since air is too weak to return a strong signal. The waves first reflect off the *interface* (a shared boundary of two materials) of the water and the borehole wall; then they return to the ATV. Contact between rock types, layers, fractures, and veins of minerals are some types of features that can be detected. The resulting image of the borehole is a digital representation of the amplitude of waves and travel time, not a photographic image such as that produced by an OPTV.

These tools are normally aligned with a geographic direction (typically north). By knowing the direction of the start/end point, the direction and angles of rock beds, fractures, and other features can be determined. OPTVs can start recording from the top of a borehole even where there is casing. However, until the open borehole is reached, all that can be seen is the casing.



An OPTV photographic image, *left*, and an ATV digital image, *right*, show a fracture in a short section of a borehole wall. Each image is a 360° view around the cylindrical borehole wall "unrolled" to be a flat image. The opening of the fracture cuts through most of the borehole. You can see that both tools were aligned with North to start and end imaging. Roughly, the center or largest part of the void is aligned southwest.

Electromagnetic Induction (EM) Tool (not shown)

The EM tool provides results like those of the resistivity tool; therefore, it is not often used. However, the EM tool can be used in a borehole that is lined with PVC casing or filled with air instead of water; in those situations, the resistivity tool cannot be utilized.

> *Info Bit:* Geophysical logging tools can be quite expensive. Today, some range from $5,000 to $40,000 each. Therefore, trained scientists use these tools... and take good care of them.

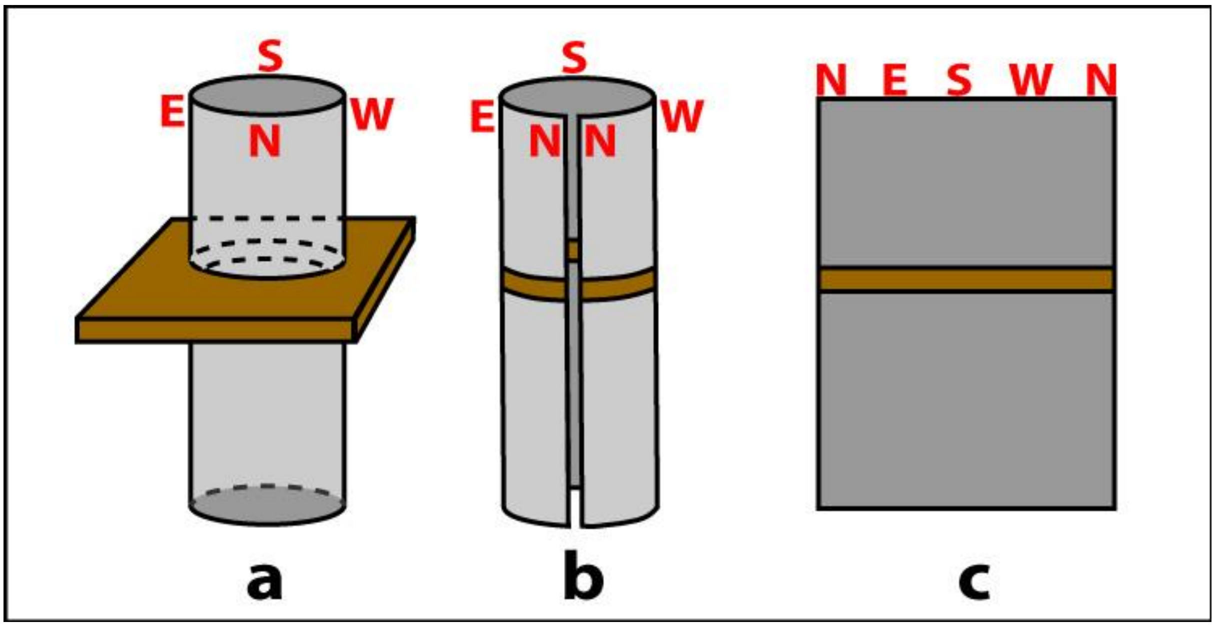
In summary, all the logging tools work together to form a detailed concept and a good understanding of underground geology and water flow in a certain area. On a site where there are multiple boreholes or wells, logging each hole can "connect the dots" across the property and provide a picture of the greater geology of an area. Where resistivity, gamma, SP, and other parameters show a connection at certain depths in each log, geologists can trace rock layers, slopes, water pathways, and more. Even when every tool cannot be used, a good sense of the geology is still possible.

Deciphering Borehole Imagery and Data

As you just learned, an idea of what the walls of boreholes look like and how the surrounding rock or sediment behaves is made possible by using a range of logging tools. But what do images and data tell us about the geology? How do we read logs?

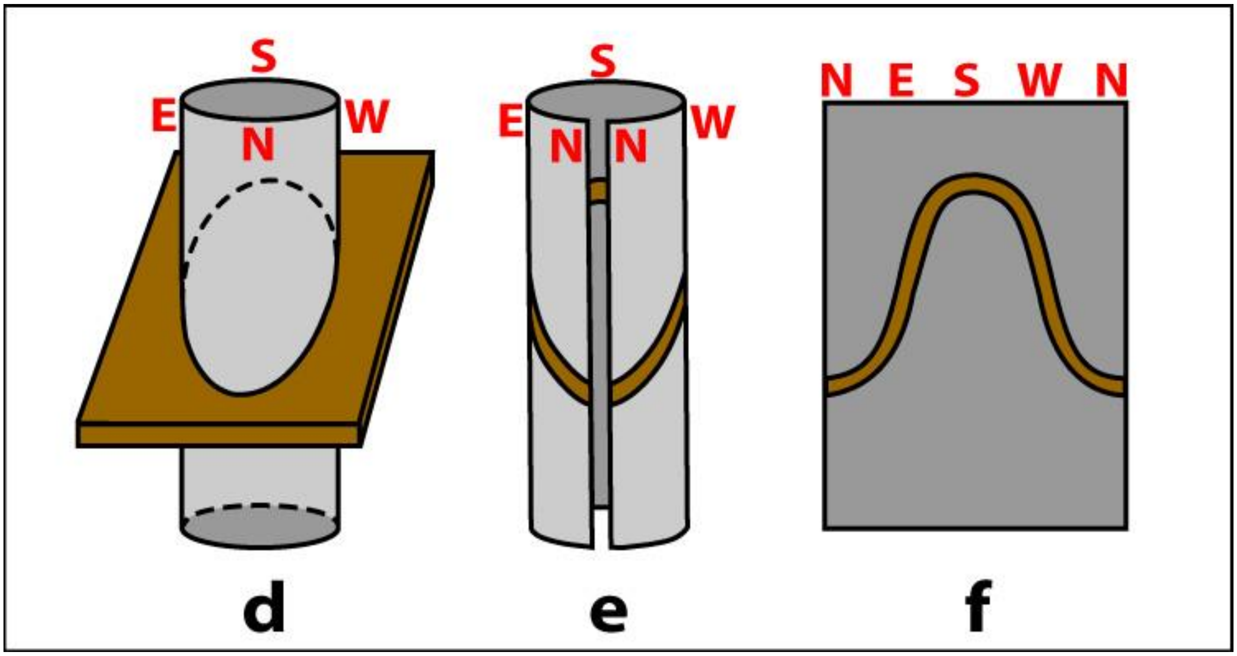
Imagery

First, let us work with imagery. How do you go from a three-dimensional borehole to a two-dimensional image? Following is a cartoon of a short section of an imaginary borehole. Geographic directions were added so that you become familiar with direction when images are "unrolled".



The three-dimensional cylinder (**a**) shows how the borehole exists in the ground with a layer of different geology (brown) intersecting it**.** When an OPTV or ATV is inserted within the borehole, it collects imagery of the inner wall of the cylinder. The televiewer image is virtually "cut" (**b**) and then "unrolled" into a flattened, 2D image (**c**) so that it is more easily observed. It is a representation of the layers of rock in that section. The geographic directions show that the imagery was cut at North. Also, both ends of the flattened image have been labeled North for clarity.

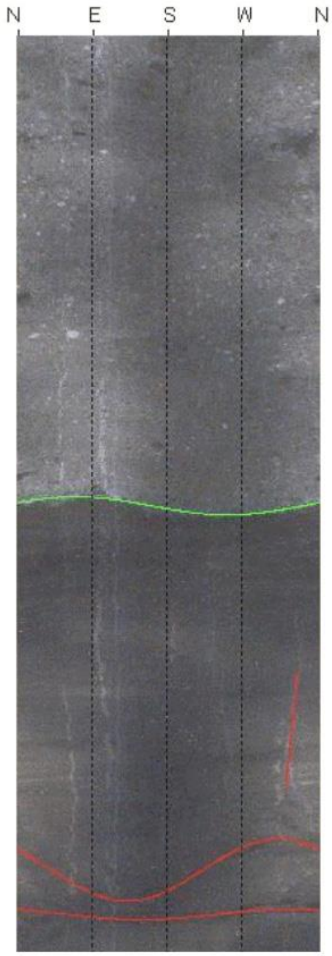
The brown layer appears horizontal. However, geology is rarely perfectly horizontal. Through the movement of land over billions of years, the subsurface has been tilted and folded in all sorts of amazing ways. Most rock and sediment sit at an angle, no matter how small. Here is what happens with imagery when features occur at an angle:

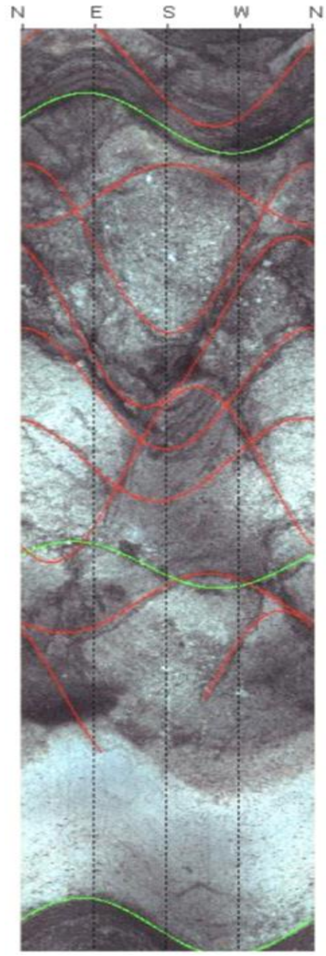


Returning to a 3D cylinder, the brown layer now intersects the gray layer at an angle (**d**). The inner borehole image is "cut" (**e**), but in this example unrolling the section to a 2D image creates a sine-shaped curve (**f**). The curve is only one *wavelength* long – there is only one top peak and one (split) bottom peak. The *amplitude*, or height, of that wave can change depending on how shallow or how steep the angle of the layer is.

> *Thinking Point*: If the brown layer were at a steeper angle than in the above image, what would the resulting "rolled out" curve look like? If the brown layer were at a shallower angle, what would that curve look like? You can use paper and pencil to help you visualize this.
>
> *Answer:* The curve of a steeper brown layer would be taller/have a higher amplitude than the one shown. At a shallower angle, the brown layer would show as a flatter (lower amplitude) curve.

Geology is usually not so simple and straightforward. In complex terrain, there may be multiple layers of rock, veins, fractures, and other features intersecting each other in one borehole. Below and left, you see a simple and straightforward OPTV image of a borehole wall. But on the right... here, an experienced geologist has picked out 12 different features, some of which intersect. The rock on the right might be puzzling to you, but what is important is that you understand the difference in the complexity of the geology in the two boreholes.





Exercise 1: Understanding a borehole image

You will need items that are easily found in your household:

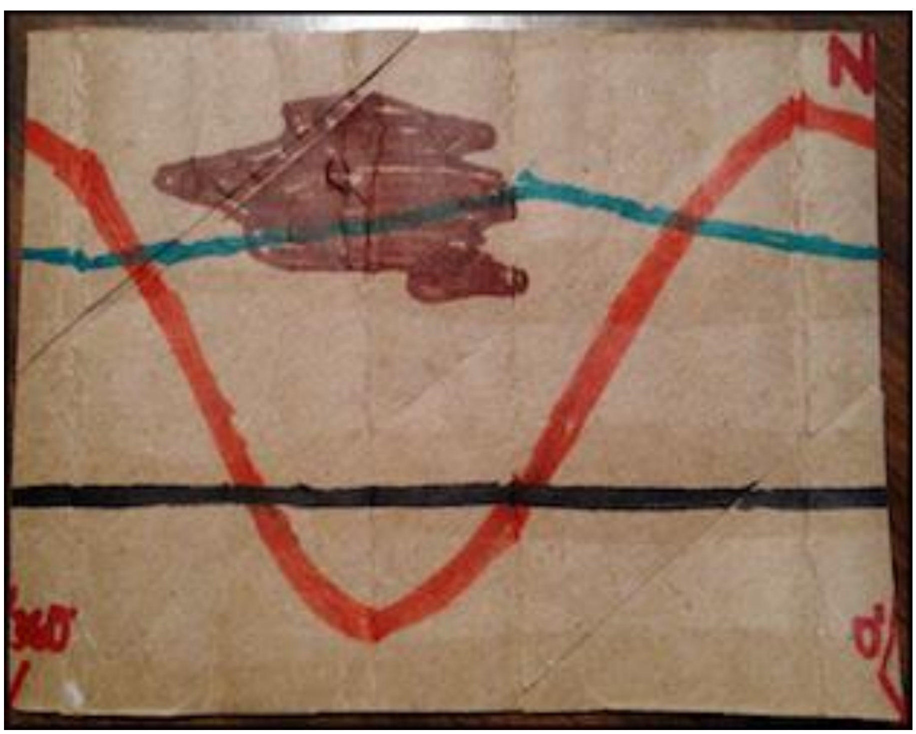
- **A toilet paper tube, or paper towel tube (cut in half; use one half)**
- **Colored markers**
- **Scissors – *always practice caution and safety with scissors!***
- **Tape**

You will create a borehole image with multiple features: Press the tube flat. Using one marker color, draw a thick line at any angle on the tube. Now flip the tube and, using the same marker, draw a mirror image of your line, being sure to join the ends on the other side. Use different marker colors to draw more lines and blobs (but not too many) at different angles and in different places for water, voids, mineral veins, or layers of different rock. Indicate direction by placing N for North on the tube – but *do not* write all four geographic directions on the tube yet. If you want to fancy it up, you can add degrees to mark the OPTV start/end (0°/360°), but it is not necessary. Your tube could look something like this:

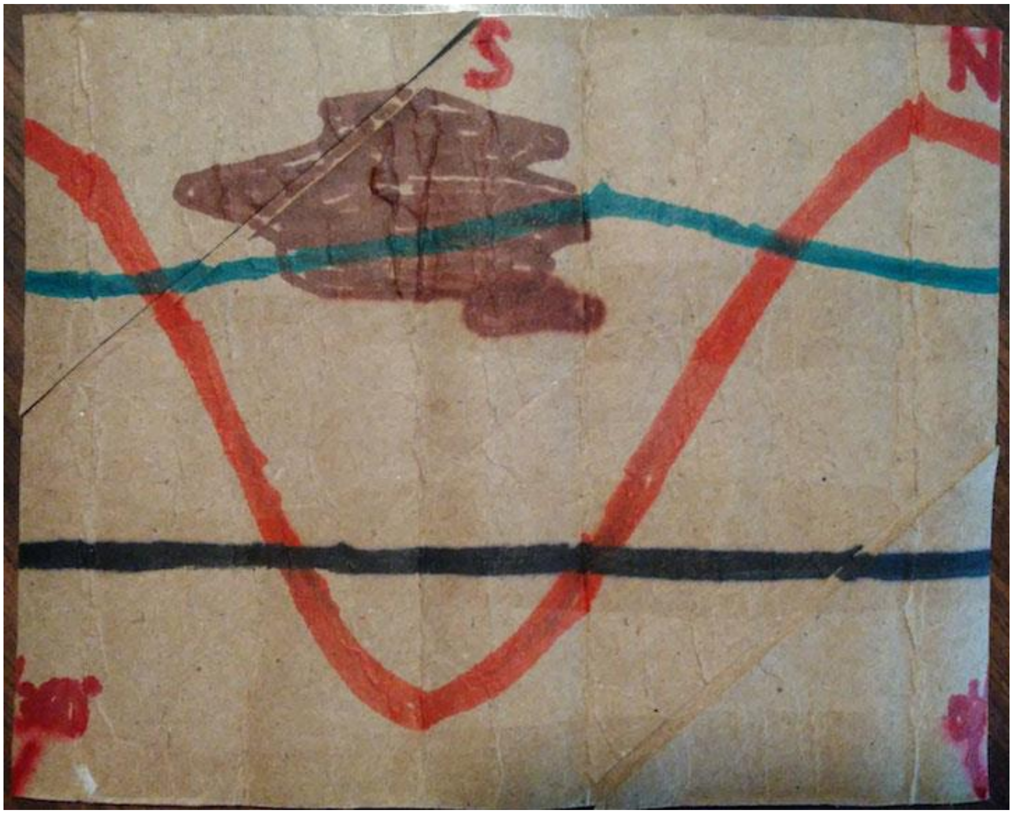
On the left side of this image, one half of the example tube, flattened, is visible. At right, the other flattened half is shown. Note how lines of the same color meet each other. A red N for North and 0°/360° were written on the tube to mark direction and where the OPTV was aligned to start imaging (conveniently, North). The blue line represents a fracture with water, the orange line is a thin clay layer, and the brown area is a void. The tube was folded in different places so that features were started at different directions.

The tube is just like a core. You can pretend that it is a cylinder of hard rock. You are seeing the same features that you would on the borehole wall. If you inserted the core back into the borehole and lined it up, it would match. But the borehole wall is what we need to study all the properties of the rock. Here is how we turn the cylinder into the wall:

At the North mark, cut the tube in a straight line from one open end to the other, and flatten it out:



The result? A nice, unrolled image that shows the clay layer (orange) at a steep angle, the fracture with water (blue) at a shallow angle, a black layer that appears horizontal, and a void (brown) that suddenly appears to be quite a large part of this small section of borehole. The beauty of marking and cutting at North is that South will always be halfway across from it. Take a few seconds to mark S for South, as in the example below, halfway across from North on *your* flattened tube.



On this example tube, we can say that the clay layer rises from South to North. If you cannot quite "see" this, try the following: starting at South, use your finger to trace along the orange line to the right. You will end at North. Start over and trace toward the left instead. You still end at North. Now, if you trace starting at North, you be brought South. Therefore, the clay layer is undeniably slanted at a South-North (or North-South) angle.

Borehole Image Thinking Points:

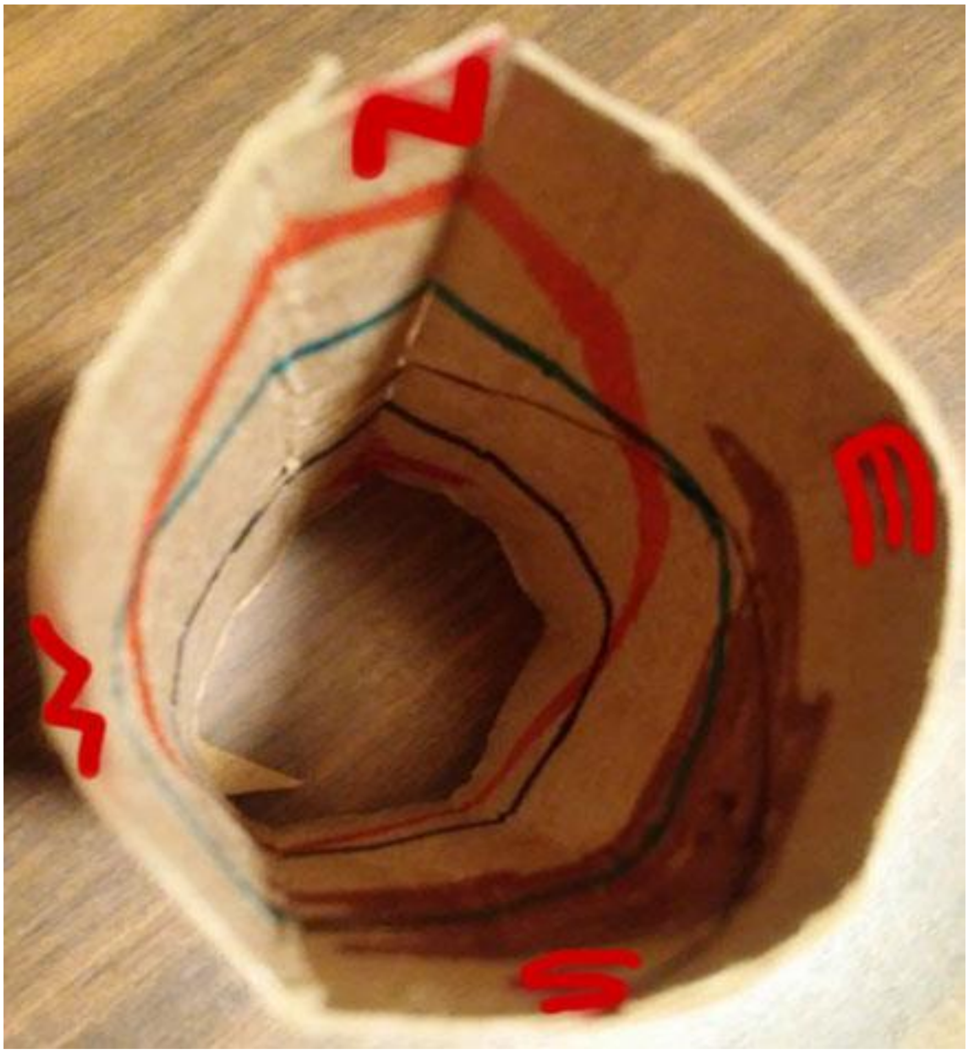
1. If you have drawn a horizontal line on your tube, can you say that it is *perfectly* horizontal? How does this relate to the way layers of rock/sediment are found underground?
2. On the example tube, in what direction is the void situated?
3. On your tube, what cardinal direction (N, S, E, or W) is your void at? Is it in between (NE, NW, SE, or SW)?

Borehole Image Answers:

1. No – realistically, your "straight" lines are probably the tiniest bit crooked. Similarly, nature rarely creates perfectly horizontal rock/sediment layers, and most have been tilted or altered by additional earth processes over millions of years.
2. The void is South. While it does spread left and right, it is centered at South.
3. That is for you to figure out!

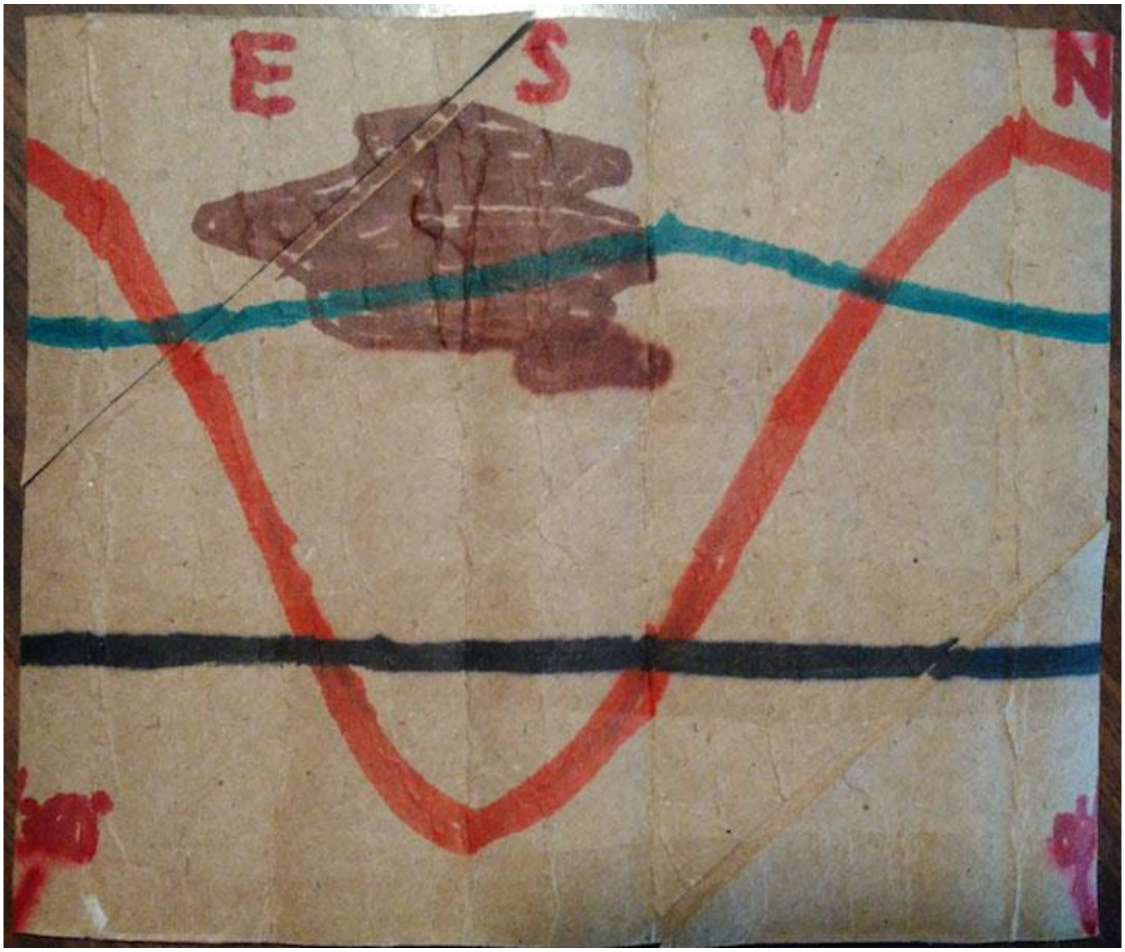
Now you can add East and West. Here is how:

Re-roll your tube so that your markings are on the *inside*, and tape it together. Hold the tube like a telescope so that the N and S directional markings are near you. Rotate the tube so that North is at the top, South at the bottom. Take a marker and mark E for East inside on the right between N and S, and W for West inside on the left between N and S. Finally, you should have a proper borehole image like below (letters have been digitally enhanced for clarity). You now see how a borehole appears in the ground.



If you need proof that East and West would have been backwards, cut the tape and re-roll the tube so that the drawing is on the outside again. Hold North at the top. Suddenly, West is on the right – you know that is incorrect.

As a final step, lay the image flat again, as shown below. The letters are in a line as in the cartoons seen earlier in this section. It may be awkward to grasp at first, but this is how borehole imagery is viewed. Do not think of the image as a hole or cylinder – simply use the directional letters to tell you where features are located. For example, the fracture with water (blue) is highest at Southwest; the void (brown) extends side-to-side from East to Southwest; and if you trace the blue line, it shows that the fracture is angled from the Northeast up toward the Southwest.



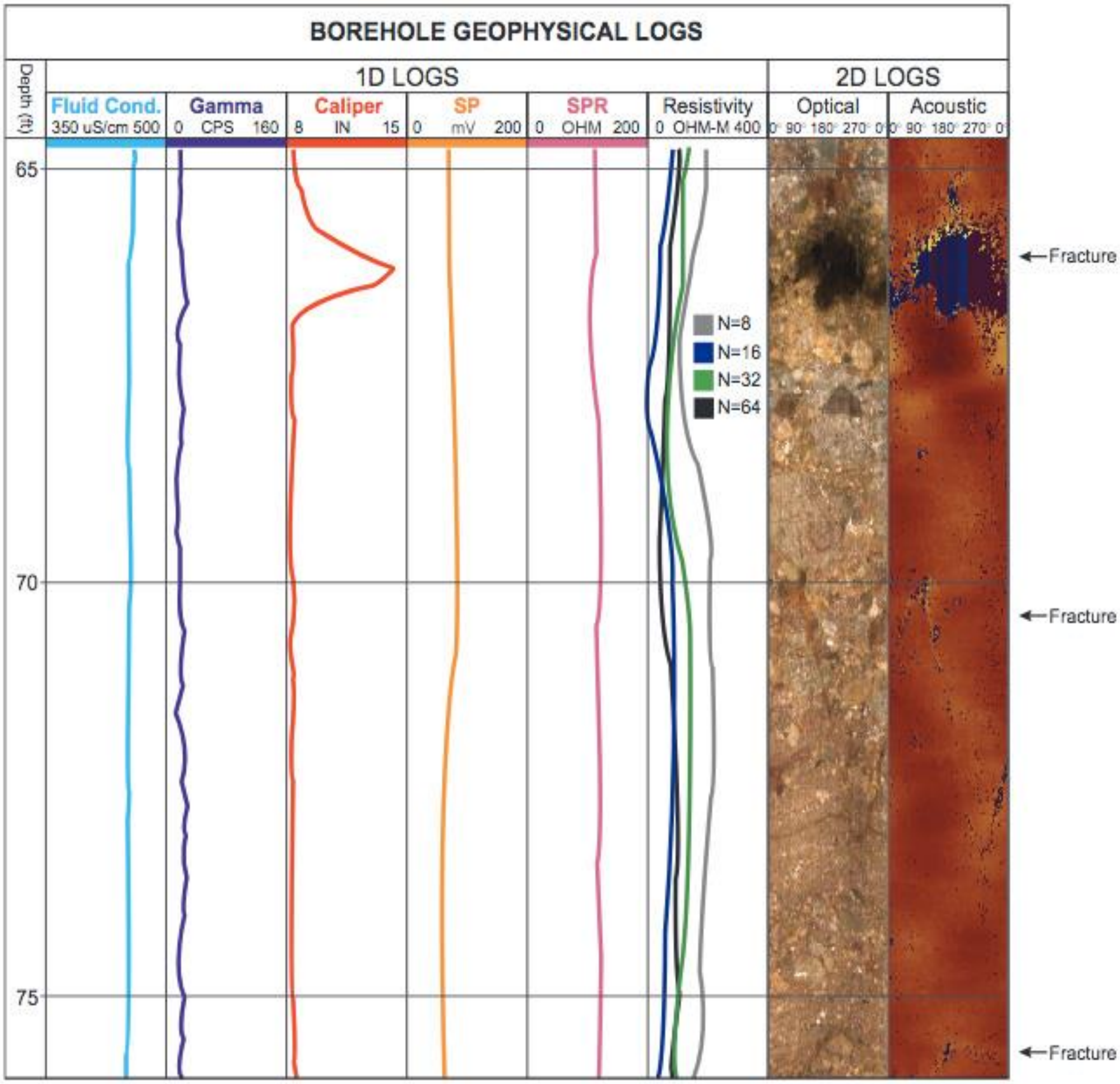
Your tube borehole is narrower and drastically shorter than a real borehole, but it should be clear that it is difficult to observe anything down a long cylindrical hole without geophysical technology.

What about the characteristics of geology that cannot be seen, such as electrical properties? Next, you will learn how to evaluate borehole data.

Data

Logging tools that do not create imagery instead compile numerical data. This data is sent from the tool to a field computer. Hundreds of numbers by themself do not mean much in terms of understanding a borehole, so the data is exported to special logging software that converts numbers into user-friendly visual formats like graphs.

Below is a sample **borehole geophysical log** – a pictorial representation of the various data gathered by different logging instruments, placed side-by-side, and aligned by depth. Imagery is to the right, whereas the greater portion of the log shows some of the many kinds of information that may be gathered. Look carefully – column to column, you should notice activity at certain depths.



Conveniently, fractures have already been picked out for you. Clearly, the strongest data occurs at the topmost fracture at about 66 feet deep. The caliper line correlates with the imagery. Gamma readings peak highest at the bottom of this large fracture and SPR, FC, resistivity, and gamma show little offsets in their data where the top and middle fractures occur. The second and third fractures are harder to determine without a trained eye, but most of the data lines show little peaks, "kicks", or other changes. Together, both types of data provide strong clues that features exist there.

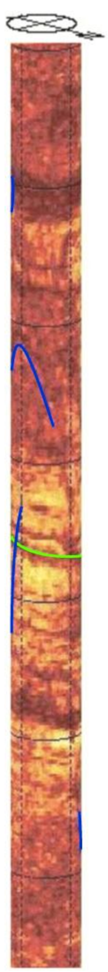
Data Thinking Points:

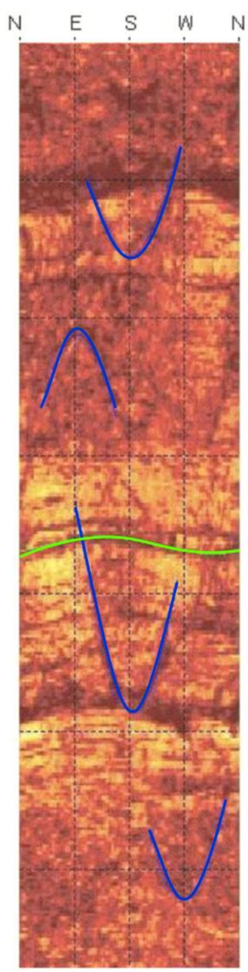
1. Can you determine the drilled diameter of the borehole? What is it?
2. Approximately how wide is the caliper reading at the topmost fracture and is this the true width of the void? Why or why not?

3. This borehole contains freshwater – but if the large fracture were to admit saltwater, which readings would spike on the log?

Data Answers:

1. The drilled diameter of the borehole can be gleaned from the data. The caliper reads approximately eight inches for most of the length of the hole; this was the drilled diameter. Also, geologists would know that eight inches is a common diameter for wells and boreholes.
2. The caliper reading at the topmost fracture is about 14 to 15 inches wide. It may not the true width of the void: because the arms of the caliper cannot move independently of each other, one arm may have only reached to 14 or 15 inches while another arm may have been next to an even deeper void but could not extend into it.
3. If saltwater intruded this borehole at the large fracture, then conductivity, SPR, SP, resistivity, and FC would show stronger readings because saltwater is highly conductive and the electrical currents to the tools would be strongly affected.





To recap what you have learned and seen, here are two images of a short section of a pretty and colorful sandstone borehole from central New Jersey, with features (in green and blue) picked out.

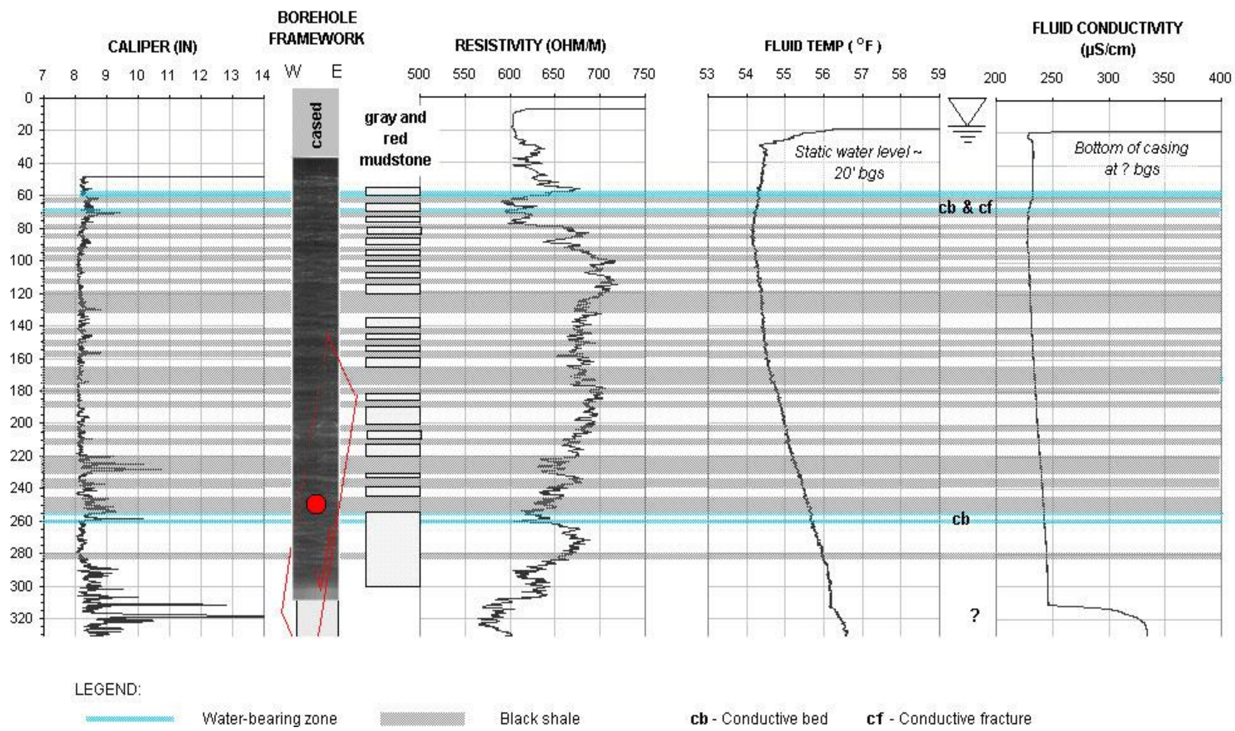
The leftmost image shows a cylindrical view of the borehole. You can see the front half of the cylinder but not the back half. *Unlike* the toilet paper tube, the geographic directions for the cylinder are correct because it was imaged in the ground as it was, not created inside-out like your tube. The compass-like element above the cylinder picks out North -- East is clockwise from there, in proper orientation.

The image to the right shows the cut and unrolled cylinder. Note how North was conveniently used as a starting point. You should now understand how features wrap around the inside of a borehole and appear quite different in the ground versus as a flat image.

Exercise 2: Starting to See Features

Use the geophysical log below for this exercise (disregard the red dot and box). Answer the following questions to understand the features and data the log exhibits.

Note: the geology is shale and mudstone (derived from clay)



1. At what depth (approximately, or give a small range) does the caliper begin reading the borehole? Does the caliper seem to get larger diameter readings at certain depth intervals? What features are associated with the larger readings?

2. One tool that may have been useful in logging this borehole was not used – which tool is that and why would it be useful? (Hint: geology type)

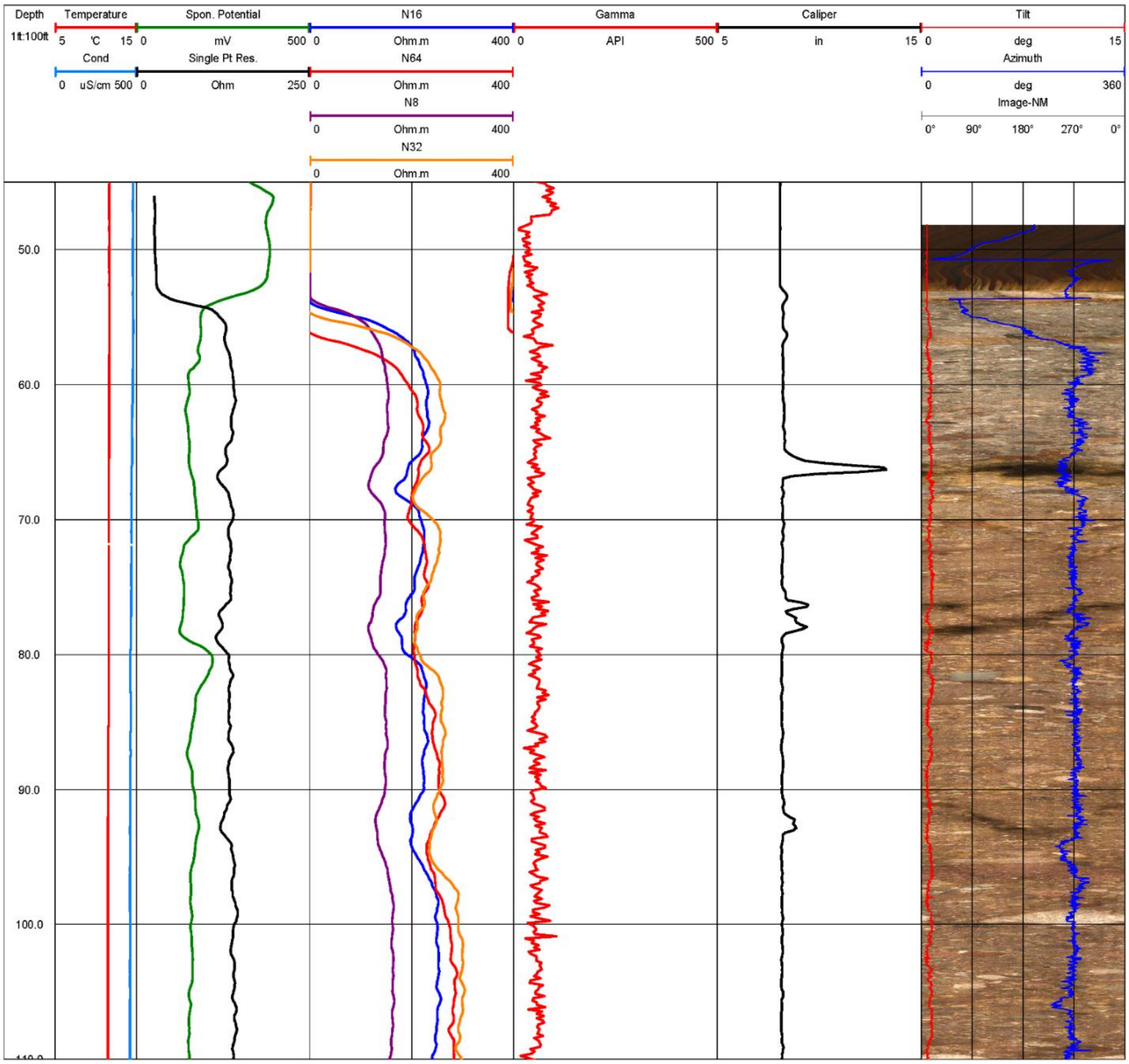
3. What is notable at approximately 60-80 feet? Which tools/logs are showing this change and how have they changed?

4. Pretend that this borehole is lined with PVC screen to 200 feet. You already noticed that something important is happening around 70 feet, but now two of the tools seen in the image below will not be useful in the 0-200 interval. Which are those? Can you use them anyway? What other tool could be used where there is plastic lining?

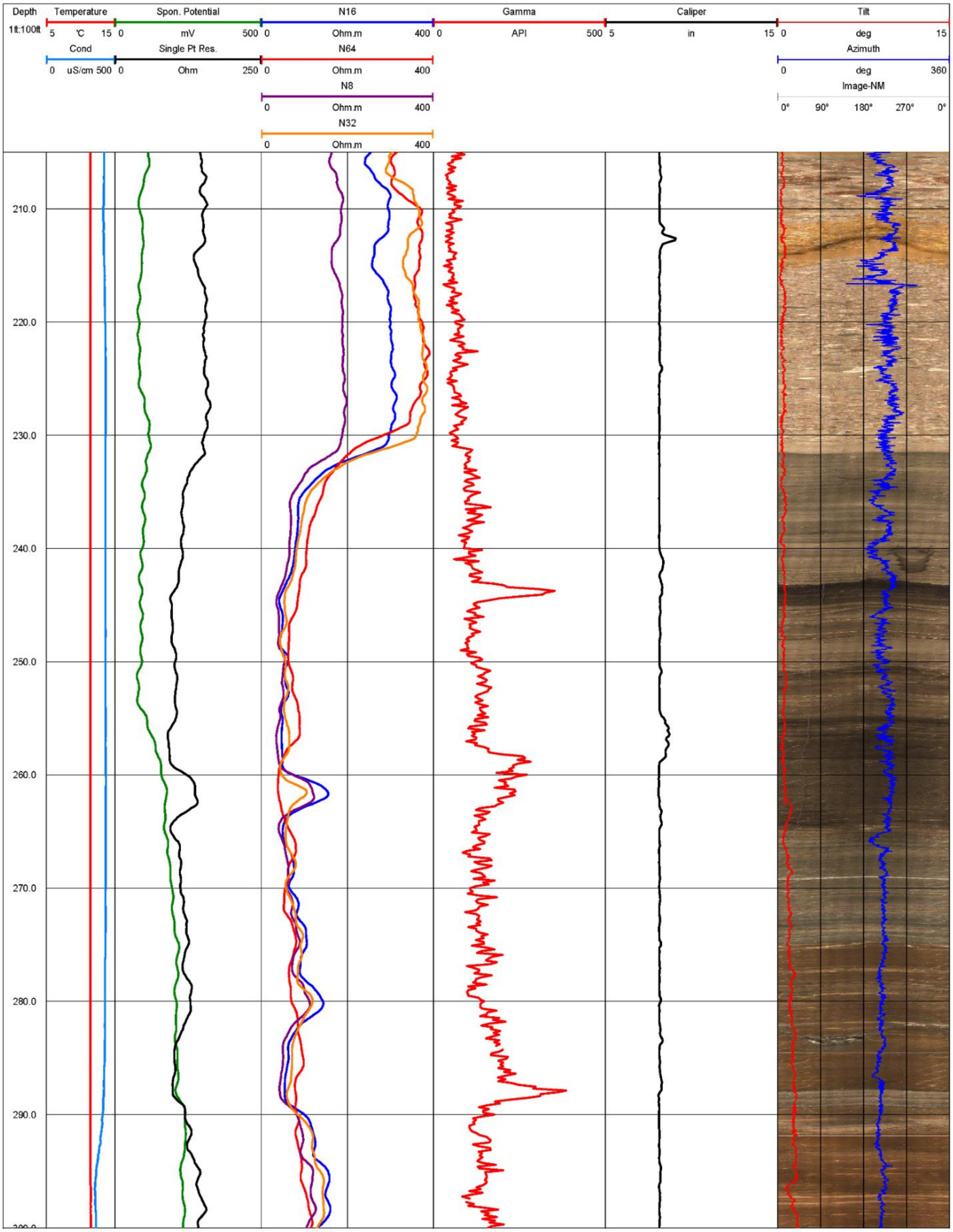
Exercise 3: Expanding Your Knowledge

Below is one more geophysical borehole log. As you can see, logs may be designed in a wide variety of ways and can include or exclude certain data. This log includes some information that was not explored in this lesson, but you should be able to recognize the types of data that you have learned about. Remember the abbreviations used for certain tools.

This log was hundreds of feet longer and has been shortened as well as had its less-interesting portions removed. Each of the two sections you see (a 50 to 105-foot interval and a 205 to 300-foot interval) are continuous, however. Answer the questions following the log to evaluate the features and data it exhibits.



Ignore the Temperature and Tilt columns.


Depth
1ft:100ft
Temperature
5 °C 15
Cond
0 uS/cm 500
Spon. Potential
0 mV 500
Single Pt Res.
0 Ohm 250
N16
0 Ohm.m 400
N64
0 Ohm.m 400
N8
0 Ohm.m 400
N32
0 Ohm.m 400
Gamma
0 API 500
Caliper
5 in 15
Tilt
0 deg 15
Azimuth
0 deg 360
Image-NM
0° 90° 180° 270° 0°
210.0
220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0

Exercise 3 Questions:

1. What are you seeing in the top five feet of the OPTV image? How do you know?
2. The fourth column from the left (headed with "N16") does not tell you which tool was used, yet it can be determined. Which tool is it? How do you know?
3. Using the OPTV image, what outstanding features or changes in the geology can you see? At approximately what depths? What data backs this up?
4. Suppose that this borehole was drilled to locate clay. Do you think clay has been found? Support your answer using the data.

Congratulations! You are now a geophysical borehole logging pro! Well, perhaps not quite yet... reading logs is just a small part of the process of obtaining and evaluating boreholes, and it takes much practice, besides. By now you should know:

- how geologists can "see" underground, geophysical logging being one of many methods
- what boreholes, geophysical borehole logging, and borehole logs are
- some reasons why logging is performed
- that boreholes are not perfect and come in many forms
- that Earth rarely has perfectly horizontal layers, and that layers undergo alteration
- the names and purposes of nine types of logging instruments
- how to observe and evaluate borehole imagery
- how to evaluate and compare borehole data, especially in conjunction with imagery
- how to begin explaining or theorizing what is occurring in the geology

Exercise 2 Answers

1. The caliper begins reading between 45 and 50 feet below ground surface. Yes, the caliper does get higher readings at certain intervals – roughly 70-75, 220-230, 255-260, and after 300 feet below ground surface. At approximately 70 and 260 feet, water is noted – so there may be a connection between fractures/voids and water.

2. The gamma tool was not used, and it might have been useful because it is good at detecting shale layers. Here, it may have differentiated between the mudstone and shale.

3. Around 70 feet, there is a water-bearing layer, resistivity drops, conductive beds and fractures are noted, and conductivity has also decreased at about that level. Resistivity, fluid conductivity, and caliper are showing us that the geology at this level has fractures and is a water-bearing layer.

4. The caliper tool is not necessary where the PVC lining exists because it will not tell you much, but it still may be used to collect data. The resistivity tool will not provide viable data for 200 feet and should not be used. In place of the resistivity tool, the EM tool can be used since it works well in plastic lining.

Exercise 3 Answers:

1. Casing. The caliper is reading a perfectly straight line at a slightly lesser diameter than anywhere else down the log – this indicates a smooth lining or casing. SPR and resistivity are not recording data, which is another clue to the presence of casing.

2. The resistivity tool, because the four lines labeled 8, 16, 32, and 64 are from the 4 sets of electrodes with different spacing.

3. Yes. The most obvious features on the log are described below:

   At roughly 66, 77, 93, and 213 feet deep, there are voids – likely fractures – in the borehole. They are visible and caliper readings increase at those points. The SP tool shows increased readings at some of these depths and may indicate that the fractures bear water.

   Around a depth of 232 feet, the geology visibly changes from a tan, speckly/striated geology to smoother, grayish-brown material. Gamma increases and resistivity decreases – the geology is conductive and could be slate, shale, or clay.

   At 244 feet, there is a dark band where gamma increases and resistivity decreases. Near the 260-foot mark, there are more dark layers. SP, resistivity, and gamma readings increase here. This is a conductive material, again.

   Finally, at 288 feet, there is a thin, dark line between brown and tan geology. SP, SPR, resistivity, and gamma increase. The gamma tool struggles to see thin layers of clay, but this may be a thin layer with a stronger radioactive and/or conductive signal or another material entirely.

4. You have probably found clay or at least some clay layers from around 232 feet downward. The geology visibly changed to smooth, thin layers. The resistivity is good for locating clay and the gamma tool is good at locating clay and shale.

Select material taken from:

"New Jersey Geological and Water Survey borehole geophysics program", a New Jersey Geological Survey Information Circular, 2018. https://www.nj.gov/dep/njgs/enviroed/infocirc/BoreholeGeoTools.pdf

Herman, G. C., and Serfes, M. E., eds., "Contributions to the geology and hydrogeology of the Newark basin". New Jersey Geological Survey Bulletin 77, 2010. http://www.impacttectonics.org/gcherman/publications.htm.

Thanks to Michelle Spencer and Mike Gagliano of the New Jersey Geological and Water Survey for supplying well logs and information on geophysical tools and methods.

Could this be you one day?

New Jersey Student Learning Standards: High School Science

S-ESS2-2. Develop a model based on evidence to illustrate the relationships between systems, or parts of a system. (ESS2-1), (ESS2- 3), (ESS2-6)
Use a model to provide mechanistic accounts of phenomena. (ESS2-4)
Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) to make valid and reliable scientific claims or determine an optimal design solution. (ESS2-2)

- Much of science deals with constructing explanations of how things change and how they remain stable. (ESS2-7)
- Change and rates of change can be quantified and modeled over short or long periods of time. Some system changes are irreversible. (ESS2-1)
- Feedback (negative or positive) can stabilize or destabilize a system. (ESS2- 2)
- Science knowledge is based on empirical evidence. (ESS2-3)
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (ESS2-3)
- Science includes the process of coordinating patterns of evidence with current theory. (ESS2-3)
- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. (HSESS2-3)

New Jersey Student Learning Standards: High School ELA/Literacy

WHST.9-12.7 Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (ESS2-5)
SL.11-12.5 Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (ESS2-1), (ESS2-3), (ESS2-4)

New Jersey Student Learning Standards: High School Mathematics

MP.2 Reason abstractly and quantitatively. (ESS2-1), (ESS2-2), (ESS2-3), (ESS2-4), (ESS2-6)
MP.4 Model with mathematics. (ESS2-1), (ESS2-3), (ESS2-4), (ESS2-6)
HSN-Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (ESS2-1), (ESS2-2), (ESS2-3), (ESS2-4), (ESS2-6)
HSN-Q.A.2 Define appropriate quantities for the purpose of descriptive modeling. (ESS2-1), (ESS2-3), (ESS2-4), (ESS2-6)
HSN-Q.A.3 Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (ESS2-1), (ESS2-2), (ESS2-3), (ESS2-4), (ESS2-5), (ESS2-6)