

Conductivity Logs

INTRODUCTION:

Conductivity logs measure the electrical conductivity of the soils or rock surrounding the borehole. They provide a detailed measure of changes in conductivity with depth. These logs can be very useful in identifying zones of increased groundwater conductivity, often indicative of contaminant concentrations. Conductivity logs are also termed electromagnetic *induction* (EM) logs.

The electrical conductivity of soil or rock (and its reciprocal, electrical resistivity) depends on the porosity, groundwater conductivity, degree of saturation, clay content, and other bulk

soil properties. Hence it is a useful tool in determining the changes with depth of any of these properties.

EM logs are particularly useful in shallow environmental applications as they can be run in 2-inch monitoring wells cased with PVC. Resistivity logs measure the same physical properties, but require an uncased, fluid-filled borehole.

Units of conductivity in the SI system are siemens/meter (S/m) or millisiemens/meter (mS/m). The siemen is equivalent to the mho (1/ohm). A common unit for measuring groundwater conductivity is the micromho/cm or equivalently $\mu\text{S/cm}$. The conversion to logged units is:

$$10 \mu\text{S/cm} = 1 \text{ mS/m}$$

SOIL CONDUCTIVITIES:

The electrical conductivity of soil or rock depends on several factors. In *coarse-grained soils*, with little or no clay content, electrical conduction occurs primarily in the interstitial water. In *saturated soils* the conductivity depends on the pore water conductivity and the porosity. Archie's Law describes this relationship:

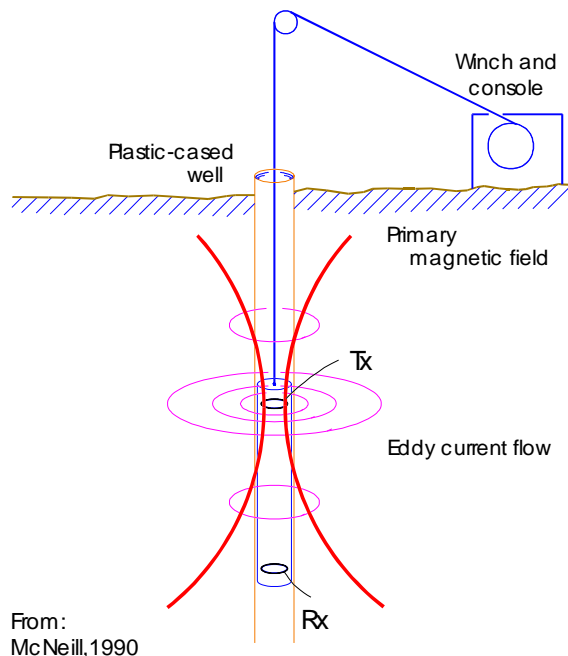
$$\sigma_b = \sigma_w \phi^m \quad [1]$$

where

σ_b = bulk conductivity of the soil (S/m)

σ_w = pore water conductivity (S/m)

ϕ = soil porosity (volume of actual soil moisture divided by total sample volume)



From:
McNeill, 1990

Figure 1
Principles of Operation
Borehole Induction Logger

m = empirical factor which varies with particle shape from 1.2 for spheres to 1.9 for platy fragments (Jackson et al., 1978)

In *coarse-grained, unsaturated soils* most of the electrical conduction still occurs in the interstitial water, and Archie's Law must be modified to account for partial saturation.

In *clayey soils* a significant portion of the electrical conduction occurs within the ionic structure of the clay minerals, and hence is less dependent on the soil moisture, or pore water conductivity.

To summarize, conductivity logs will respond to several factors:

1. variations in ground water conductivity
2. variations in clay content
3. variations in porosity and/or saturation.

Whereas other factors may influence conductivity to a lesser extent, these are most frequently the controlling factors.

When integrated with other information, such as natural gamma logs, lithologic logs, or other geophysical logs, the geologic (or hydrogeologic) cause of the conductivity log response can often be deduced.

PRINCIPLE OF OPERATION:

The principles of operation of borehole induction logging are illustrated in Figure 1.

Faraday's law of electromagnetic induction states that an oscillating magnetic field has an associated electric field. A small transmitter coil in the borehole probe creates a primary magnetic field. That magnetic field creates a toroidal electric field in the material surrounding the borehole (soil or rock), which in turn creates electrical "eddy current" flow within the soils. The strength of those eddy currents depends on the conductivity of the material.

The eddy currents, in turn, create a magnetic field, which is detected and measured with a receiver coil within the probe. Within the normal range of operation of the borehole equipment, the quadrature signal (i.e., the signal 90° out of phase with the primary field) is

proportional to the conductivity of the material surrounding the borehole (soil or rock).

Most induction loggers, including the Geonics EM-39, have additional "focusing" coils to sharpen the vertical resolution of the probe. The EM-39 probe is most sensitive to materials in an annulus 20 cm to 100 cm from the borehole. Hence the effects of drilling mud and grouting surrounding the casing are minimized.

The EM-39 has an intercoil spacing of 0.5 m. This provides a vertical resolution of somewhat less than 0.5 m. Layers as thin as 0.1 m can be detected, if they have sufficient conductivity contrast with the adjacent layers. Increased definition of vertical layering can be attained by modeling of the geologic section to obtain a "best-fit" to the data.

FIELD PROCEDURES:

NGA utilizes the Geonics EM-39 induction probe for conductivity logging. That probe can be used with either the Colog MGX logging system and the LOGSHELL software, or with the Geonics EM-39 logging system and the DAT39 software. Both systems are similar, although the Colog system is adaptable to several different probes.

Both systems obtain their depth information from an "odometer" attached to a pulley suspended over the borehole. Accuracy of the depth measurement is specified as 0.1 meter at 100 meters. For depths up to 100 meters (300 feet) a hand winch is usually employed. EM logs are generally run at a speeds of 5 to 8 meters/minute (15 to 25 feet/ minute).

Data is acquired on a laptop computer, with a real-time screen display, and recorded to a disk file. Data from several runs can be averaged, although one run is all that is generally required. Data is later plotted at a convenient scale.

FURTHER READING:

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GEOPHYSICAL BOREHOLE LOGGING

Conductivity Logs

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