Borehole Geophysical Logs
in
Meguma Gold Occurences , Nova Scotia
(Beaver Dam, Moose River and Lake Charlotte Areas)

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1. INTRODUCTION AND BACKGROUND

The application of geophysical techniques for mineral exploration requires knowledge of the physical properties of ore deposits, their host rocks and associated alteration. The best way to obtain such data is to measure the physical properties in situ using borehole geophysics. These physical property data are needed for the planning and interpretation of geophysical surveys, and the development of new geophysical survey equipment and techniques.

In 1986, three holes were logged at the Beaver Dam gold deposit and one hole was logged at the Lake Charlotte gold occurrence. In 1989, four holes were logged in the Moose River gold deposit. The holes at Beaver Dam and Moose River were logged to understand the geophysical characteristics of gold deposits. The hole at Lake Charlotte was originally logged to investigate maganese deposits and associated metals by obtaining a stratigraphic section through the contact between the Goldenville Formation and the Halifax Formation of the Meguma Group.

Beaver Dam, Moose River and Lake Charlotte occur in the Goldenville Formation along the eastern shore of Nova Scotia in the Meguma Group, which is considered a typical example of metaturbidite-hosted gold mineralization. See Figure 1 for locations of the three areas. (After Williams and Hy, 1990)

All eight holes were logged using the Geological Survey of Canada (GSC) Research and Development (R&D) borehole logging system. The following multiparameter borehole geophysical measurements were made:

1. Natural gamma-ray spectrometry (total count, K, U, Th)
2. Spectral gamma-gamma/density (SGG ratio, density)
3. Resistivity
4. Induced Polarization (IP)
5. Magnetic Susceptibility (MS)
6. Temperature and temperature gradient

The following abbreviations were used in Table 1, and in some of the following observations for each borehole:

ABBREVIATION	PROBE
GAM	Spectral Gamma
GAM-GAM	Spectral Gamma-Gamma
IP	Induced Polarization
MS	Magnetic Susceptibility
TMP	Temperature

ABBREVIATION	PARAMETER
TC	Total Count
K	Potassium
U	Uranium
Th	Thorium
DEN	Density
SGGR	Spectral Gamma-Gamma Ratio
RES	Resistivity
IP	Induced Polarization
MS	Magnetic Susceptibility
TMP	Temperature
TMG	Temperature Gradient

ABBREVIATION	
cps	Counts per Second

5. RESULTS OF GEOPHYSICAL LOGGING

The geophysical logging results are presented as a series of 14 plots in Appendix 2. Some interpretive notes for these plots are included in this section as an aid to understanding the significance of some of the logs, however this does not represent a detailed or comprehensive interpretation. Detailed lithological logs were provided by Seabright Resources Inc. for their boreholes at Beaver Dam and Moose River, and by Milton C. Graves for the Lake Charlotte borehole, which was drilled by the Nova Scotia Department of Mines and Energy. The lithological logs displayed in Appendix 2 have been simplified for plotting purposes.

5.1 Beaver Dam BD85-25

The density log is in relative units since the probe was not calibrated to provide g/cm^3 for the hole size logged. The IP and resistivity are highly variable in BD85-25 due to large amounts of disseminated sulphides like pyrite, arsenopyrite, chalcopyrite and galena, throughout the argillites and greywackes. The greywackes and argillites have higher gamma-ray values than the quartzite. The quartz zone from 33.11 to 33.6 metres has low gamma-ray, density and SGG ratio values. The detailed geology log notes a broken quartz vein from 38.7 to 40.7 metres, quartz veins at 72.6 to 73.6 metres and at 85.7 metres, a fragmented quartz vein at 120.6 metres and a broken quartz vein at 127.0 to 127.1 metres. These can be clearly seen on the gamma-ray log, and to a lesser extent on the density and SGG ratio logs. There are numerous other quartz veins also noted in the detailed geological log. A low in the density log coincides with lost core from 133.2 to 136.3 metres. The greywacke above 84.4 metres is noted as siliceous. This boundary marker can be seen in the gamma-ray, density, SGG ratio and MS logs as a distinct change in values. This marker on the geophysical logs would have been useful to the geologist logging the core. For more information on the use of geophysical logs as an aid to geological logging see Killeen et al., 1995b.

5.2 Beaver Dam BD85-28

Density was not logged for this hole (due to poor hole conditions). The resistivity and IP logs in the argillites and greywackes are both variable, reflecting a wide distribution of the conductive minerals disseminated pyrite, pyrrhotite and arsenopyrite. Areas of low IP response often coincide with areas of higher silicate concentration. As in BD85-25, the detailed geology notes numerous quartz veins, for example at 22.8 metres which coincide with lower gamma-ray count rate. The temperature gradient log indicates there is water flow between 20 and 30 metres depth.

5.3 Beaver Dam BD85-32

Density was not logged for this hole (due to poor hole conditions). Numerous quartz veins are indicated in the detailed geological log. There is a quartz vein from 40.07 to 40.9 metres, and a broken quartz vein from 88.9 to 90.1 metres. These quartz veins correspond to decreases in the gamma-ray count rate. The impure quartzite at the bottom of the hole can be subdivided into three zones (70 to 93 metres, 93 to 125 metres and 125 to 145 metres), on the basis of both the gamma-ray and magnetic susceptibility logs.

5.7 Moose River MR89-253

The density log shows two low density zones near the top of the hole in zones where the detailed geology indicates carbonate alteration. The detailed geology also indicates a fault at 39 metres and lost core at 38 metres, both of which are reflected by lows on the density log. The low radioactivity anomaly in the rip-up unit indicates that the rip-up unit has a silty matrix.

5.8 Lake Charlotte LC86-1

The following comments are from Mwenifumbo et al. (1990).

The calcareous banded argillites can be distinquished from the carbonaceous slates. The argillites have comparatively low radioactivity, higher resistivity, lower IP, lower MS, higher density and higher SGG ratio. Small fluctuations in the resistivity log probably result from thinly bedded carbonaceous materials and/or pyrite which may occur as layers of grains in the bedding planes. The slates, containing disseminated pyrrhotite and pyrite, have lower resistivity, higher IP, higher MS and lower density and SGG ratio than the argillites. This lower density and SGG ratio may reflect the amount of organic carbon in these slates. The low resistivity between 145 and 165 metres, indicates a wide fracture zone. A corresponding wide low density zone is not present, however two narrow low density zones appearing at 155 and 164 metres, probably indicate open fractures. The hole was known to be a flowing artesian, and water flow at 155 metres is apparent on the temperature and temperature gradient logs.

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1. THE GSC BOREHOLE GEOPHYSICAL LOGGING SYSTEM

Applications of geophysical logging encompass both mining exploration and geotechnical problems. These include: delineating ore zones, identifying and mapping alteration associated with ore, mapping lithology and hole-to-hole stratigraphic correlation. Also possible is in-situ assaying of ore, and in-situ determination of physical rock properties for calculating geotechnical (rock strength) parameters. Groundwater flow patterns in joints and fractures intersected by the holes can be detected as well.

The primary components of the GSC R&D logging system, as used when the data presented in this report were acquired, are as follows:

1. the borehole probe containing the geophysical sensor;
2. the logging cable and winch for sending the signal to the surface instruments, and for sending power down to the probe;
3. a depth counter attached to a wellhead pulley for keeping track of the location of the probe in the hole;
4. an analog-to-digital converter (ADC) to convert the signal to digital form for recording;
5. a computer, keyboard and CRT monitor to acquire data and display information;
6. a 9-track magnetic tape recorder;
7. a multi-pen chart recorder to provide a hard copy in the field.

The GSC now operates both truck mounted and portable logging systems with basic components as above, except data are recorded on the hard disk of the computer and displayed on the monitor.

Most modern 'slim-hole' probes (tools), 38 to 50 mm in diameter, are designed to run in BQ or larger holes. The probes can be run in air- and/or water-filled holes depending on the sensor.

The two GSC logging systems have seven logging probes with different sensors that in total can measure over twenty parameters. The characteristics of the logging probes used at Beaver Dam, Moose River and Lake Charlotte and their measuring principles are briefly described below.

2. GAMMA-RAY SPECTRAL LOGGING

2.1 Geological Interpretation of Gamma-Ray Spectral Logs

Gamma-ray measurements detect variations in the natural radioactivity originating from changes in concentrations of the trace elements uranium (U) and thorium (Th) as well as changes in concentration of the major rock forming element potassium (K). Since the

While the probe is moving along the hole, the gamma rays are sorted into an energy spectrum and the number of gamma rays in three pre-selected energy windows centred over ^{40}K, ^{214}Bi and ^{208}Tl peaks in the spectrum are computed each second, as is the total gamma-ray count. These four numbers represent gamma rays originating from potassium, uranium, thorium and Total Count (TC) detected during that one second of counting time.

These data are recorded along with the depth and are displayed on the chart recorder to produce gamma-ray spectral logs. The raw gamma-ray spectral logs (Total Count log, K-log, U-log and Th-log) provide more information than a non-spectral (gross count) log, and it is possible to convert them to quantitative logs of K, U and Th concentrations. This requires that the probe be calibrated in model boreholes with known concentrations of K, U and Th such as the models constructed by the GSC at Bells Corners near Ottawa (Killeen, 1986).

Because gamma rays can be detected through steel, logging can be done inside drill rod or casing with a slight decrease in sensitivity.

2.3 The Gamma-Ray Spectral Logging Equipment

The GSC R&D logging system utilizes gamma-ray spectral data acquisition equipment similar to that found in modern airborne gamma-ray spectrometers. Full 256-channel gamma-ray spectra over an energy range of approximately 0.07 to 3.0 MeV are recorded from a scintillation detector in the probe. The storage medium is 9-track magnetic tape. Scintillation detectors of different materials, and of different sizes are used by the GSC (see table below).

Name	Composition	Density (g/cm^3)
Cesium Iodide	CsI (Na)	4
Sodium Iodide	NaI (Tl)	3.67
Bismuth Germanate (BGO)	$Bi_4 Ge_3 O_{12}$	7.0

Probe housings of outside diameter 1.25" (32 mm), 1.5" (38 mm) or 2" (50 mm), contain detectors of sizes ¾" x 3", 1" x 3", and 1.25" x 5", respectively, for use in AQ, BQ, and NQ holes, respectively. The probe (and detector) selection is determined by the hole diameter. The largest diameter probe that will safely fit in the borehole will maximize the count rate and provide better counting statistics. For smaller probes, the higher density (higher efficiency) materials are chosen. (These are also higher cost). If the count rate is too low due to the extremely low concentrations of K, U and Th, as is often the case in limestones for example, it is not possible to produce K, U and Th logs. In that case only the Total Count log, which is the count rate of all gamma rays above a preselected threshold energy (usually 100 keV), is produced. A number of factors determine the logging speeds and sample times during the acquisition of gamma-ray data. The critical factors are the anticipated levels of

rate in an energy window above 200 keV while information about the elemental composition or heavy element content is derived from the ratio of the count rates in two energy windows (spectral gamma-gamma ratio, SGG): one at high energy (above 200 keV) and one at low energy (below 200 keV). When the density of the rock increases, the count rate in both windows will decrease due to the change in compton-scattered gamma rays reaching the detector. However, if there is an increase in the content of high-Z (atomic number) elements in the rock, the associated increase in photoelectric absorption (which is roughly proportional to Z^5) will cause a significant decrease in count rate in the low energy window with a small change in the high energy window. Since the low energy window is affected by both density and Z while the high energy window is mainly affected by density, the ratio of counts in the high energy window to the counts in the low energy window can be used to obtain information on changes in Z. This ratio increases when the probe passes through zones containing high-Z materials. Thus the log can be considered as a heavy element indicator, and can be calibrated in some conditions to produce an assay tool for quantitative determination of the heavy element concentration in situ along the borehole, without resorting to chemical assaying of the core (Killeen and Mwenifumbo, 1988).

The SGG sample volume is smaller than for natural gamma-ray logging since the gamma rays must travel out from the probe, into the rock and back to the detector. A 10 to 15 cm radius around the probe is "seen". Data are usually acquired at a logging speed of 6.0 m/minute, with a sample time of 1 second giving a measurement every 10 cm.

4. INDUCED POLARIZATION/RESISTIVITY LOGGING

The Induced Polarization (IP) tool consists of an assembly of electrodes, usually including a current electrode and two potential (measurement) electrodes. A square wave current with an 'off' time between positive and negative parts of the waveform is transmitted (waveforms may be from 1 second to 8 seconds duration). Potential measurements made at selected times in the waveform can be related to the IP effect (chargeability of the rocks), the resistivity (R) of the rocks, and to self-potentials (SP) generated in the rocks. The transmitter is a constant current source located at the surface. A detailed explanation of the IP probe will be given below.

4.1 Geological interpretation of IP/R Logs

4.1.1 Induced Polarization

In time domain IP measurements, the ratio of the secondary voltage (measured during the current off-time) to the primary voltage (measured during the current on-time) is related to the electrical polarizability of the rock and is called chargeability. A high chargeability response is an indication of the presence of metallic sulphides and oxides or cation-rich clays such as illite and montmorillonite (Mwenifumbo, 1990). One of the major alteration

Resistivity measurements are made with the same arrays as are used in the IP measurements. Single point resistance measurements can also be made using a single downhole current/potential electrode and a return/reference electrode on the surface.

5. MAGNETIC SUSCEPTIBILITY LOGGING

5.1 Geological Interpretation of Magnetic Susceptibility Logs

The magnetic susceptibility (MS) of a volume of rock is a function of the amount of magnetic minerals, (mainly magnetite and pyrrhotite), contained within the rock. MS measurements can provide a rapid estimate of the ferromagnetism of the rock. These measurements can be interpreted to reflect lithological changes, degree of homogeneity and the presence of alteration zones in the rock mass. During the process of hydrothermal alteration, primary magnetic minerals (e.g. magnetite) may be altered (or oxidized) to weakly- or non-magnetic minerals (e.g. hematite). Anomalously low susceptibilities within an otherwise homogeneous high susceptibility rock unit may be an indication of altered zones.

Basic flows and diabase dikes containing higher concentrations of magnetic minerals can be easily outlined with magnetic susceptibility measurements when they occur within a sedimentary sequence that normally contains little or no magnetic minerals.

5.2 The Magnetic Susceptibility (MS) Logging Probe Description

The magnetic susceptibility tool is a Geoinstruments model TH-3C probe which uses a signal processing unit developed at the GSC (Bristow and Bernius, 1984; Bristow, 1985). The probe contains a coil, 42 mm in diameter by 0.5 m in length, in an electrical bridge circuit energized at a frequency of 1400 Hz. When the probe passes through magnetically susceptible material, the coil inductance changes causing the bridge to become unbalanced. The bridge is balanced automatically by changing the energizing frequency. This change in frequency is proportional to magnetic susceptibility. Since the measurements are made inductively (i.e., with EM coils not contact electrodes), the tool can be used inside plastic casing and in dry holes. Susceptibilities in the range of 0 to 2.0 SI can be measured with this tool. The volume of investigation or `sample volume' is roughly a sphere of 30 cm radius, surrounding the sensing coil in the probe. Logging is normally carried out at 6 m/minute and a measurement is taken every second or each 10 cm along the hole.

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APPENDIX 2 - Plots of Geophysical and Lithological Logs

The following 14 plots are included in this appendix, in the form of 11" x 17" coloured logs. The depths are hole lengths and not true vertical depths of the hole.

Beaver Dam

BD85-25	- Plot 1 - Multiparameter Logs 0. - 100. metres
	- Plot 2 - Multiparameter Logs 100. - 152.4 metres
BD85-28	- Plot 1 - Multiparameter Logs 0. - 100. metres
	- Plot 2 - Multiparameter Logs 100. - 122. metres
BD85-32	- Plot 1 - Multiparameter Logs 0. - 100. metres
	- Plot 2 - Multiparameter Logs 100. - 145. metres

Moose River

MR88-178	- Plot 1 - Multiparameter Logs 0. - 100. metres
	- Plot 2 - Multiparameter Logs 100. - 149.2 metres
MR88-185	- Plot 1 - Multiparameter Logs 0. - 108.4 metres
MR89-251	- Plot 1 - Multiparameter Logs 0. - 61.0 metres
MR89-253	- Plot 1 - Multiparameter Logs 0. - 45.8 metres

Lake Charlotte

LC86-1	- Plot 1 - Multiparameter Logs 0. - 100. metres
	- Plot 2 - Multiparameter Logs 100. - 200. metres
	- Plot 3 - Multiparameter Logs 200. - 270.1 metres

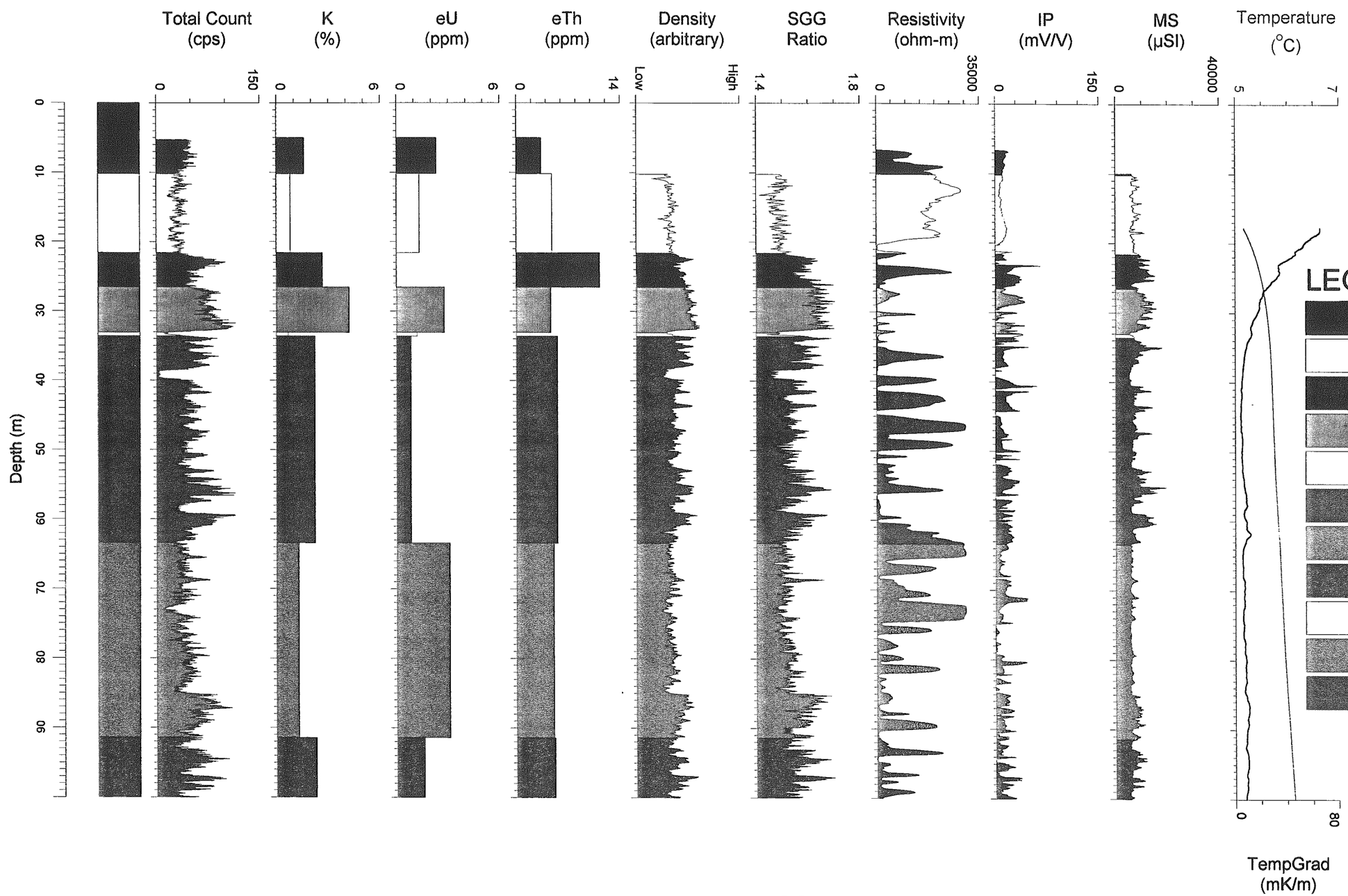
The following abbreviations are used in the plots in Appendix 2.

cps	counts/second
K	Potassium
U	Uranium
Th	Thorium
SGG	Spectral Gamma-gamma
IP	Induced Polarization
MS	Magnetic Susceptibility
TempGrad	Temperature Gradient

(See Section **5. Results of Geophysical Logging** for information on some abbreviations used in the logs.)

Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-25
Plot 1 of 2



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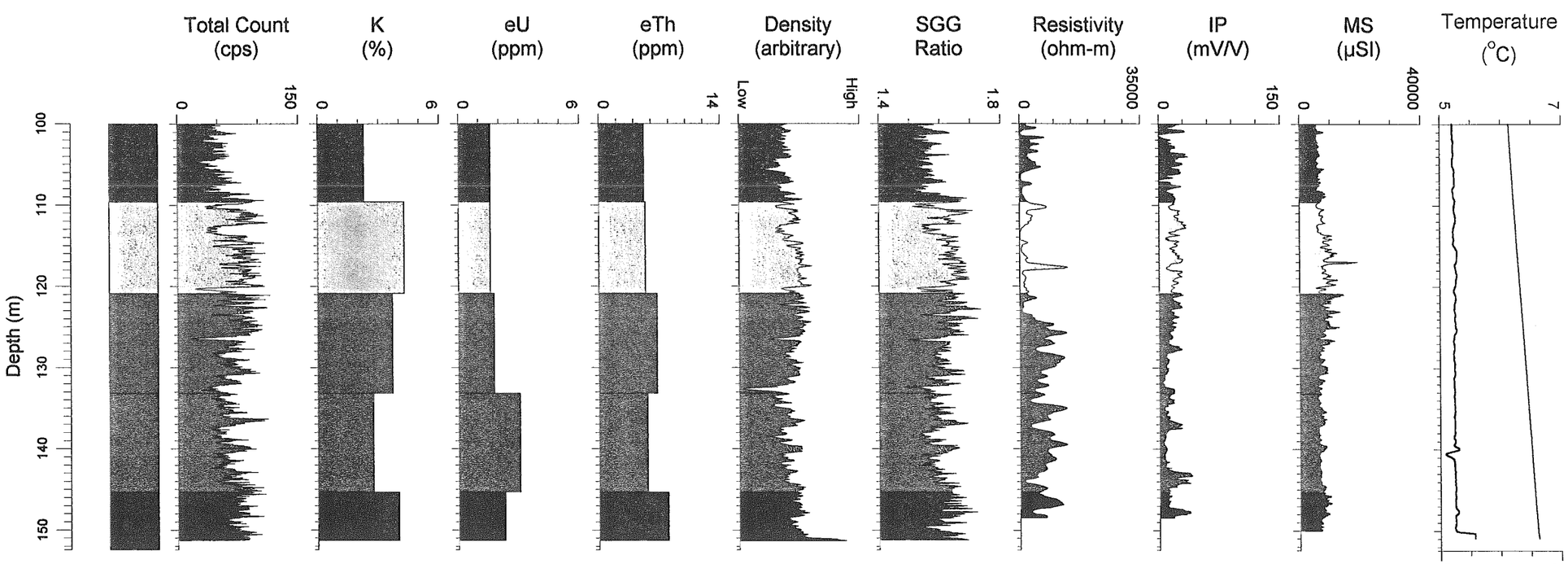
Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-25
Plot 2 of 2



LEGEND

- Overburden
- Quartzite
- Greywacke (minor argillite)
- Phyllitic Argillite
- Quartz
- Greywacke/Argillite
- Greywacke/Quartz
- Greywacke/Quartz/Argillite
- Black Argillite/Quartz
- Greywacke (broken)
- Greywacke/Quartz (some serpentine)

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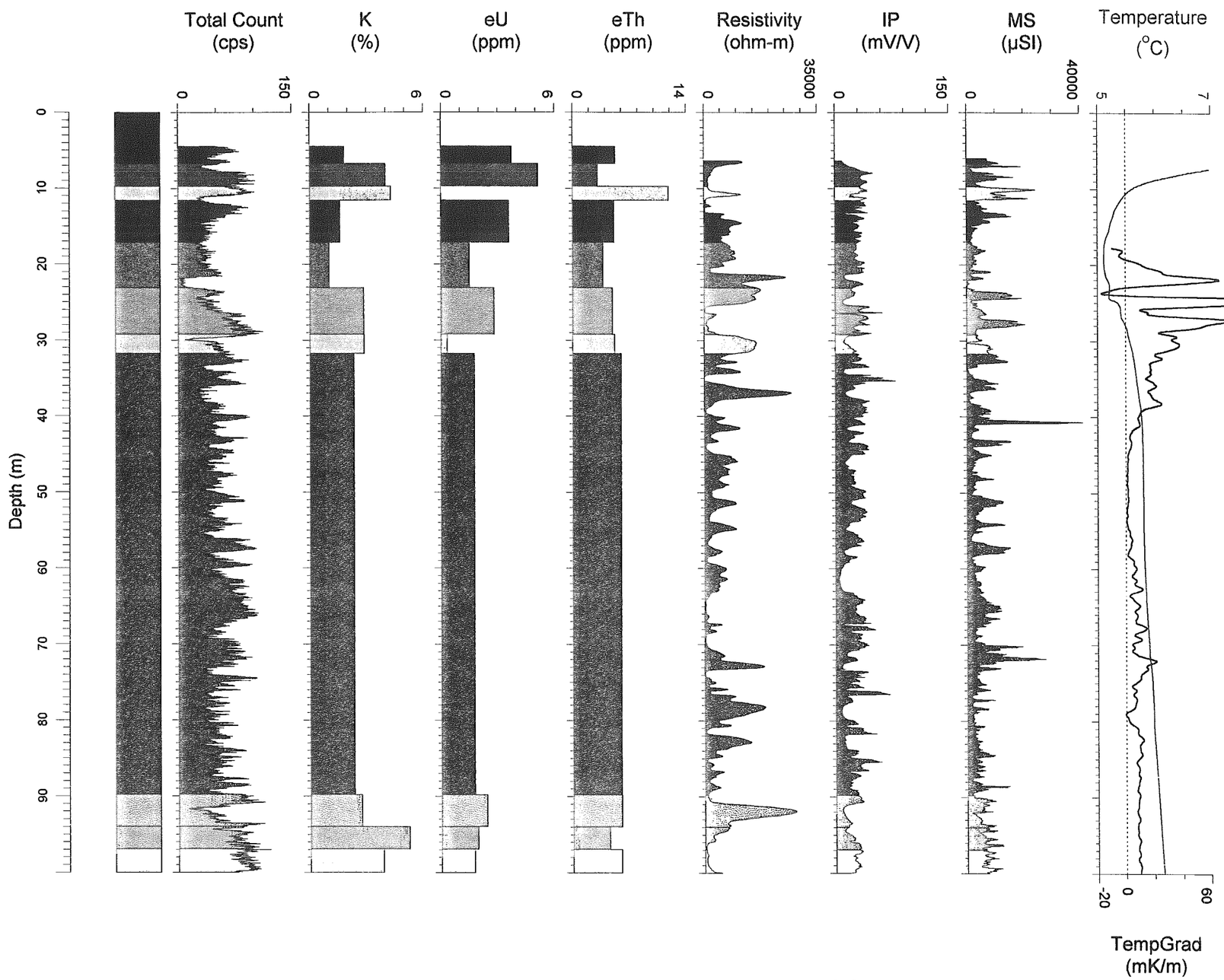
Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-28
Plot 1 of 2



LEGEND

- Overburden
- Greywacke/Argillite
- Argillite
- Greywacke (minor argillite)
- Greywacke/Quartz/Chlorite
- Greywacke/Argillite (minor chlorite)
- Greywacke/Argillite/Quartz/Chlorite
- Argillite/Greywacke/Quartz
- Greywacke/Quartz (minor argillite)
- Argillite/Greywacke/Quartz (minor chlorite and pyrite)

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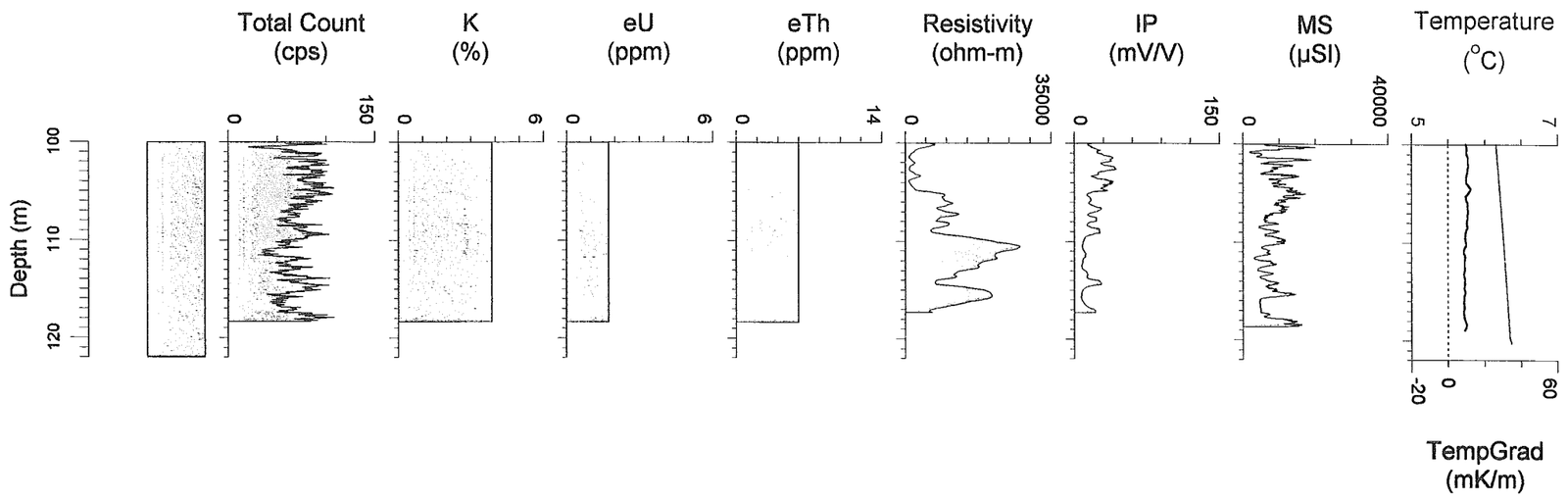
Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-28
Plot 2 of 2



LEGEND

- Overburden
- Greywacke/Argillite
- Argillite
- Greywacke (minor argillite)
- Greywacke/Quartz/Chlorite
- Greywacke/Argillite (minor chlorite)
- Greywacke/Argillite/Quartz/Chlorite
- Argillite/Greywacke/Quartz
- Greywacke/Quartz (minor argillite)
- Argillite/Greywacke/Quartz (minor chlorite and pyrite)

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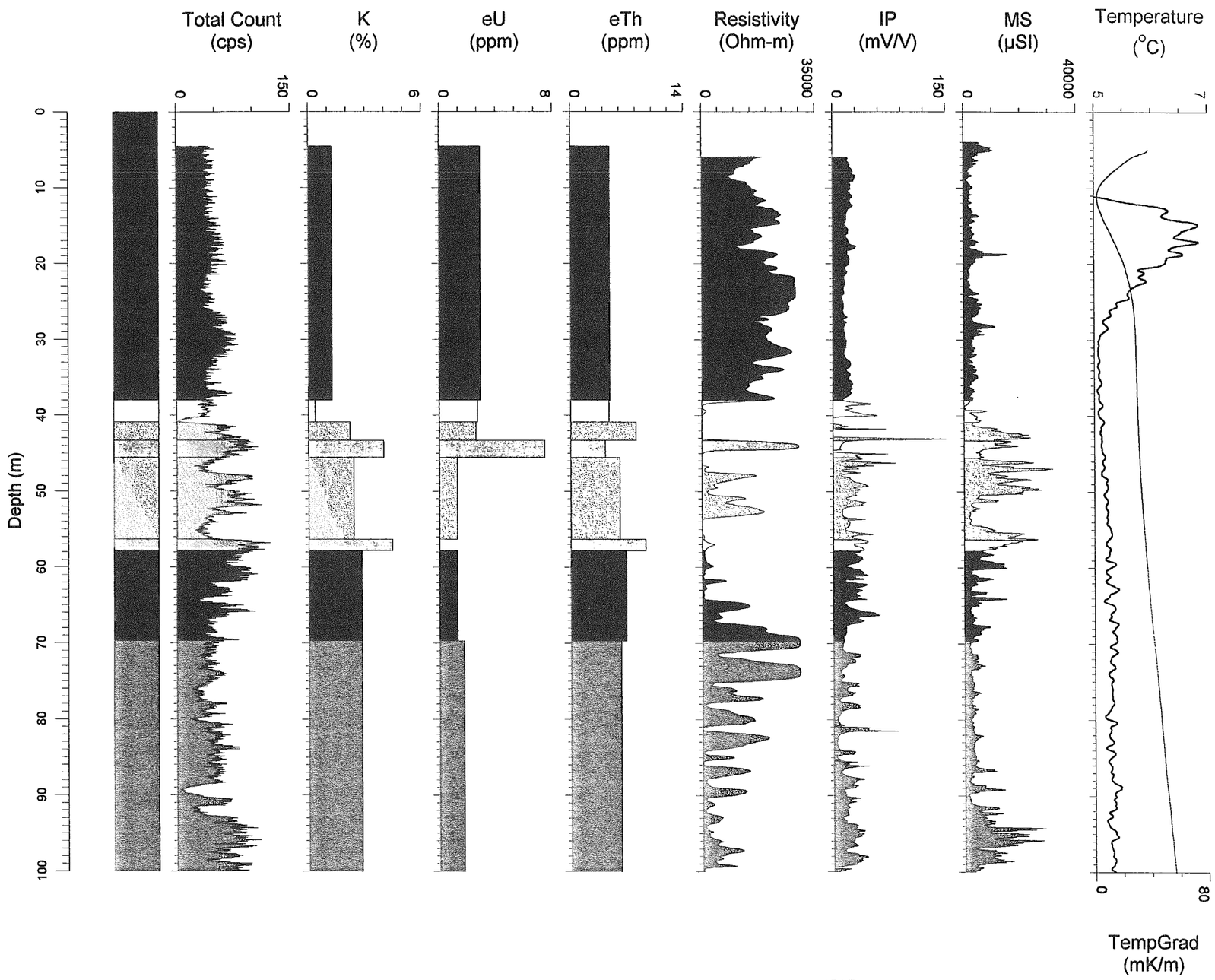
Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-32
Plot 1 of 2



LEGEND

- Overburden
- Greywacke+Quartz
- Quartzite
- Greywacke
- Argillite
- Impure Quartzite (w/argillite,po,py,etc.)

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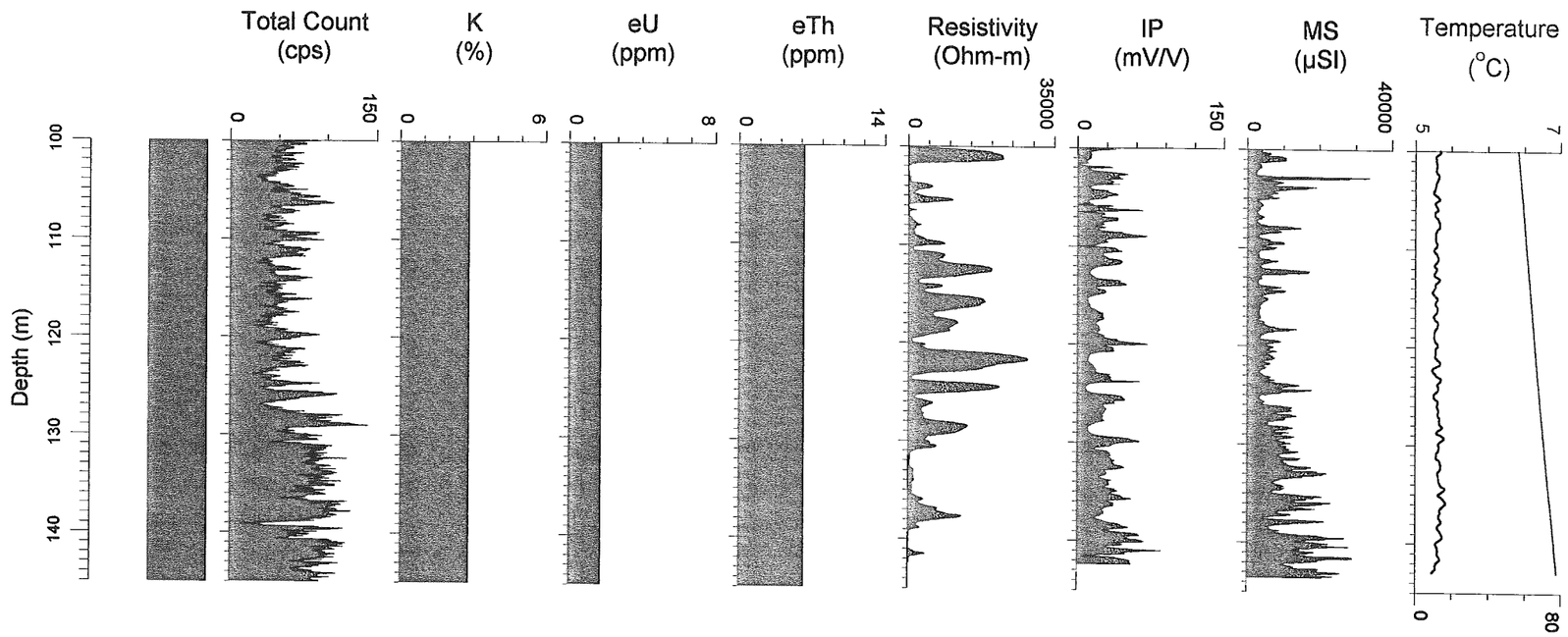
Beaver Dam Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
BD85-32
Plot 2 of 2



LEGEND

- Overburden
- Greywacke+Quartz
- Quartzite
- Greywacke
- Argillite
- Impure Quartzite (w/argillite,po,py,etc.)

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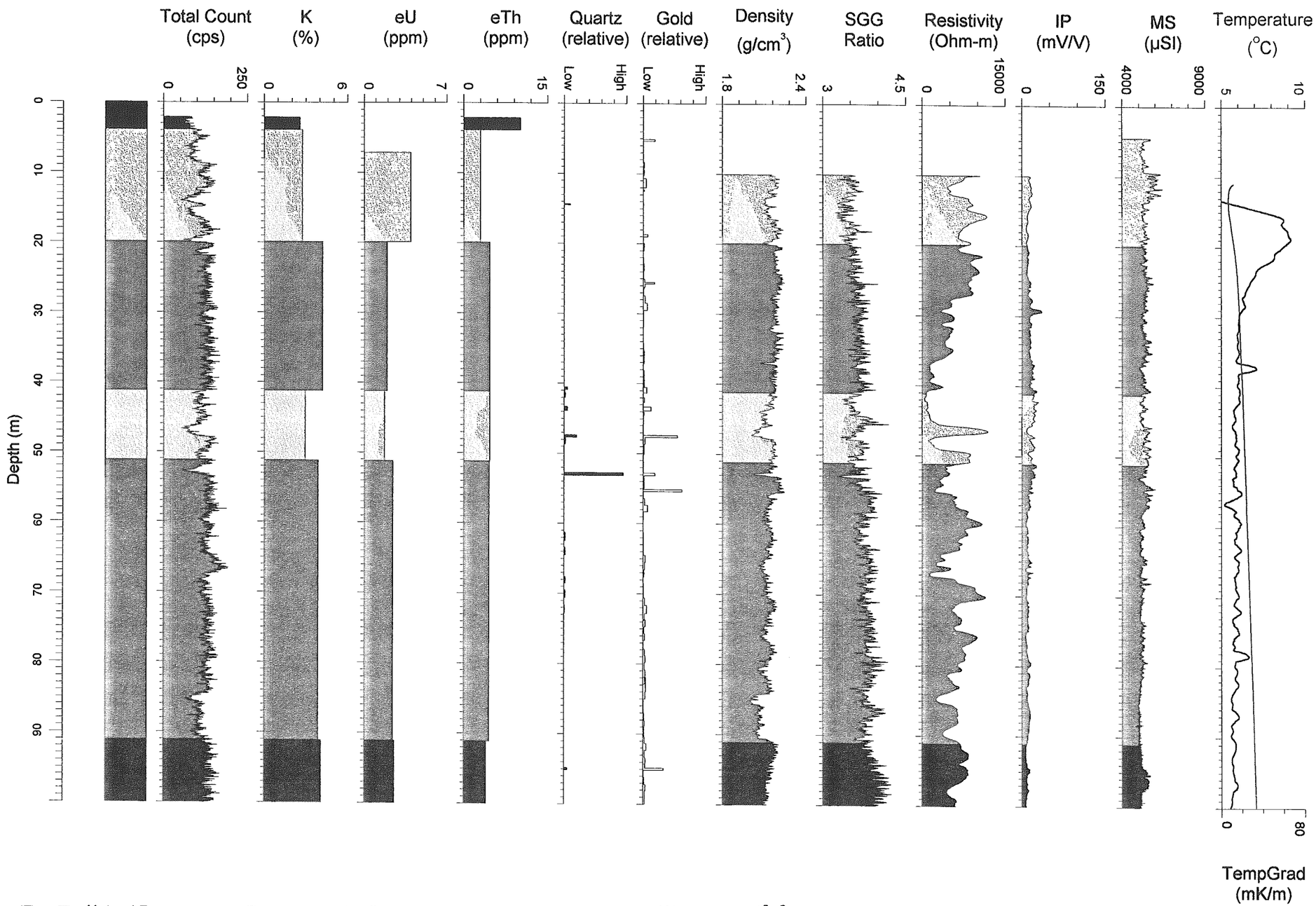
Moose River Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
MR88-178
Plot 1 of 2



LEGEND

- Overburden
- Greywacke
- Interbedded Grey Silty Argillite/Weakly Muddy Argillite
- Grey Silty Argillite
- Grey Silty Argillite with interbedded Weakly Muddy Argillite
- Interbedded Grey Silty Argillite/Mud-poor Argillite

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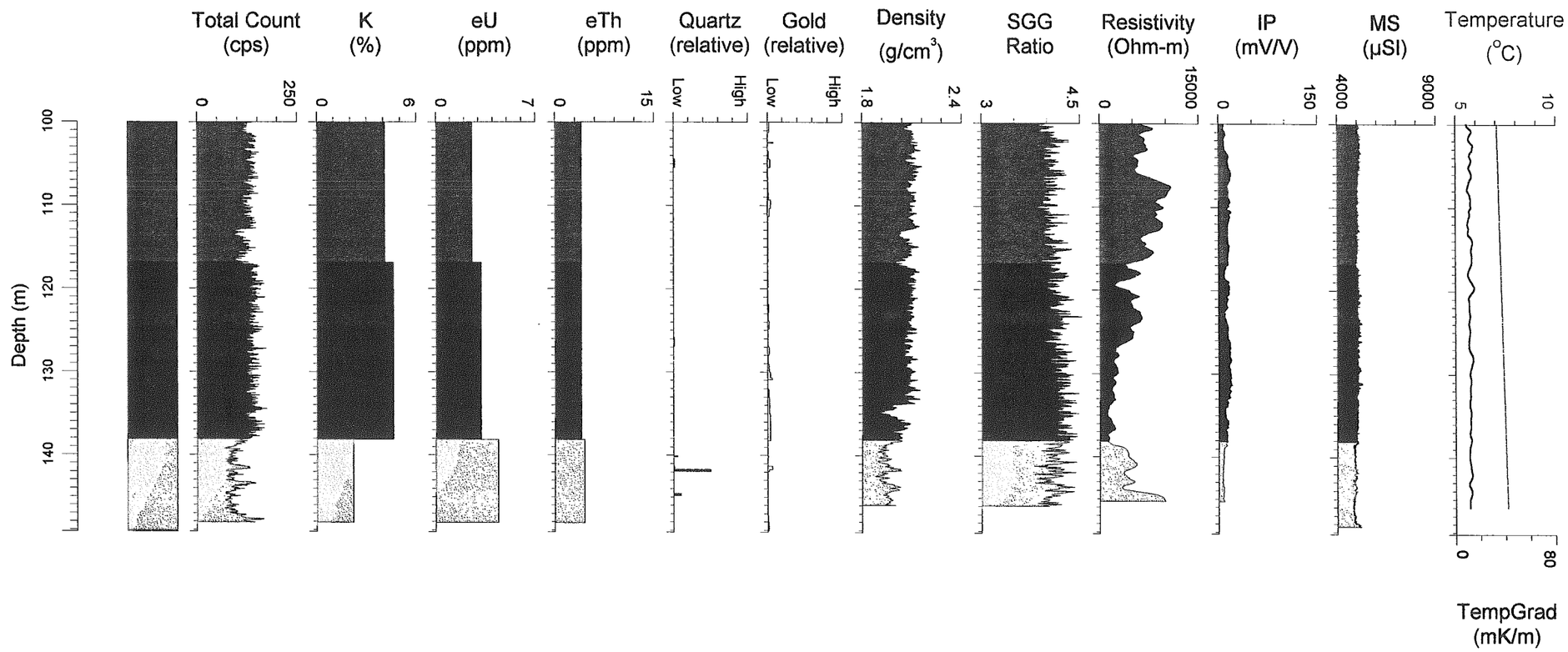
Moose River Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole MR88-178
Plot 2 of 2



LEGEND

- Overburden
- Greywacke
- Interbedded Grey Silty Argillite/Weakly Muddy Argillite
- Grey Silty Argillite
- Grey Silty Argillite with interbedded Weakly Muddy Argillite
- Interbedded Grey Silty Argillite/Mud-poor Argillite

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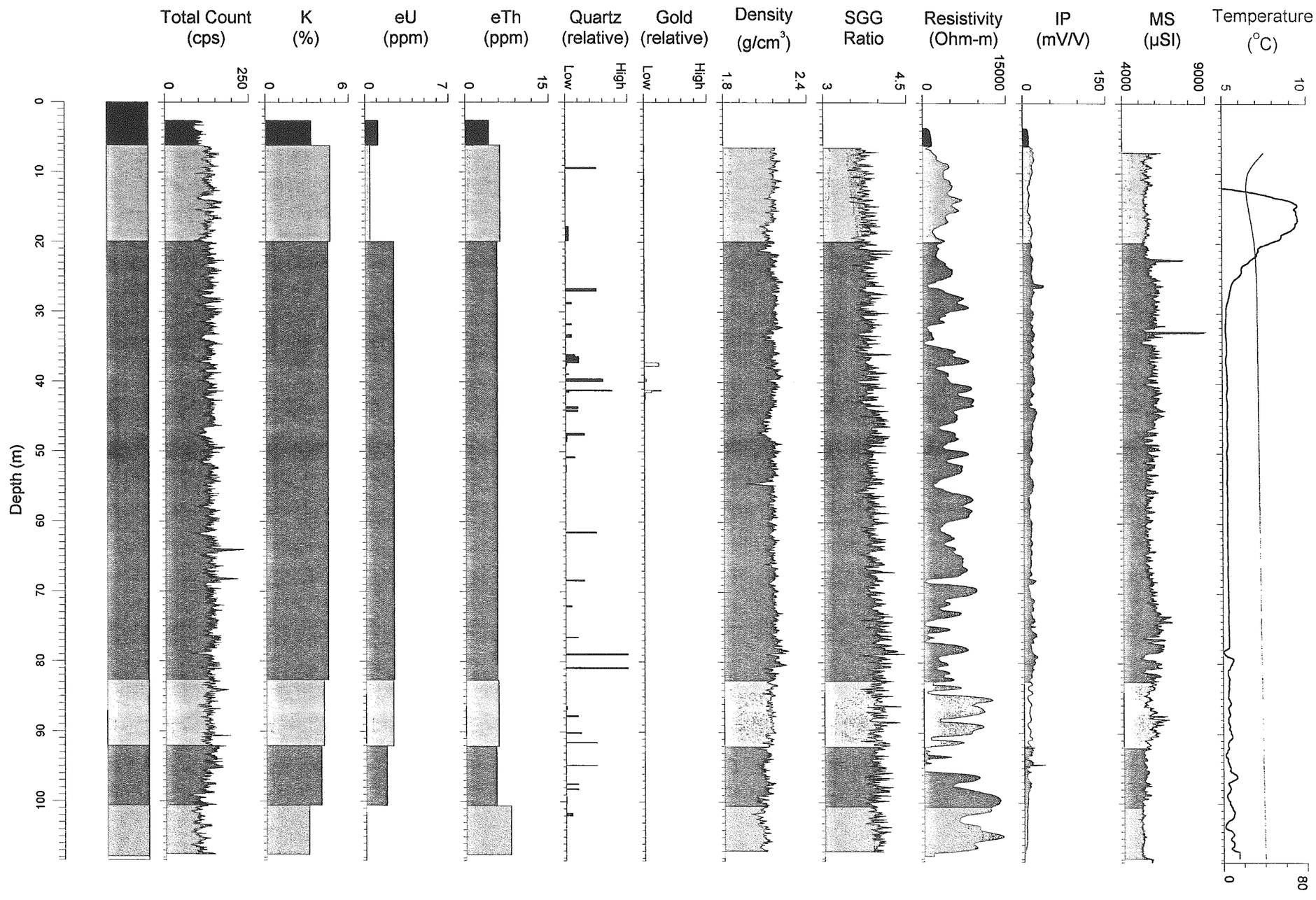
Moose River Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
MR88-185
Plot 1 of 1



LEGEND

- Overburden
- Grey Silty Argillite with interbedded Mud-poor Argillite
- Grey Silty Argillite with interbedded Mud-rich Argillite
- Greywacke with Grey Silty Argillite Mud-poor Argillite

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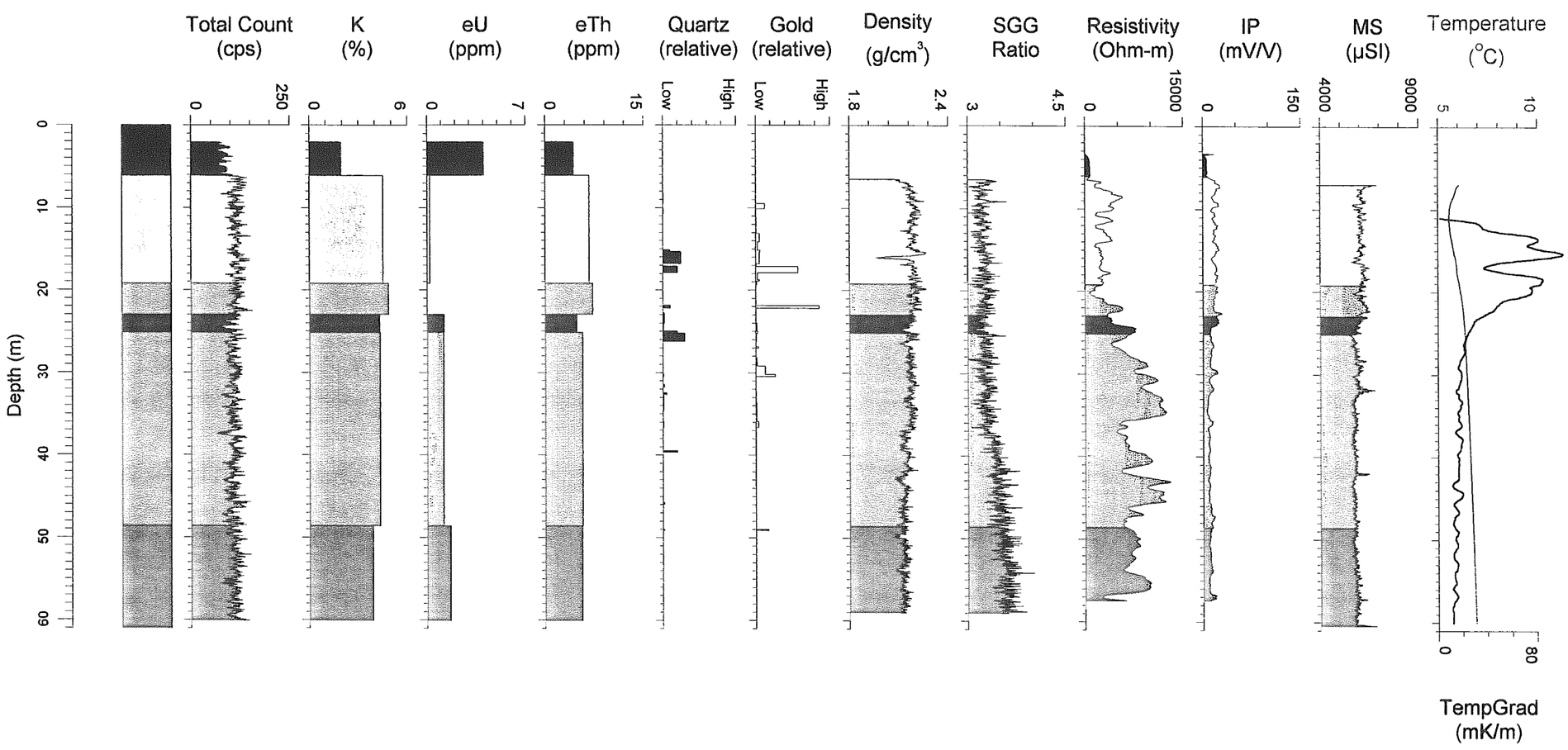
Moose River Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
MR89-251
Plot 1 of 1



LEGEND

- Overburden
- Weakly Muddy Argillite/Grey Silty Argillite
- Grey Silty Argillite/Weakly Muddy Argillite
- Rip-up unit, coarse Grey Silty Argillite with Weakly Muddy Argillite
- Interbedded Grey Silty Argillite/Weakly Muddy Argillite

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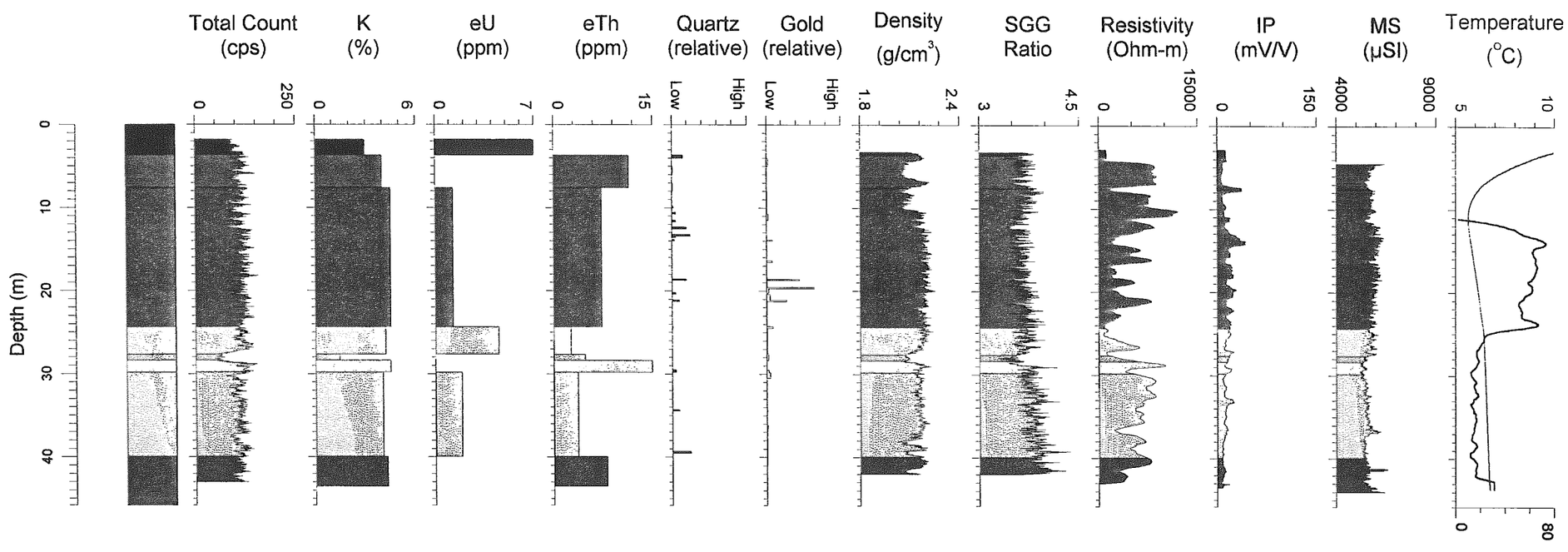
Moose River Gold Deposit, Nova Scotia
Borehole Geophysical Logs

Borehole
MR89-253
Plot 1 of 1



LEGEND

- Overburden
- Grey Silty Argillite with interbedded Weakly Muddy Argillite
- Interbedded Weakly Muddy Argillite/Grey Silty Argillite
- Grey Silty Argillite/Weakly Muddy Argillite
- Rip-up unit
- Grey Silty Argillite (Siltstone?)

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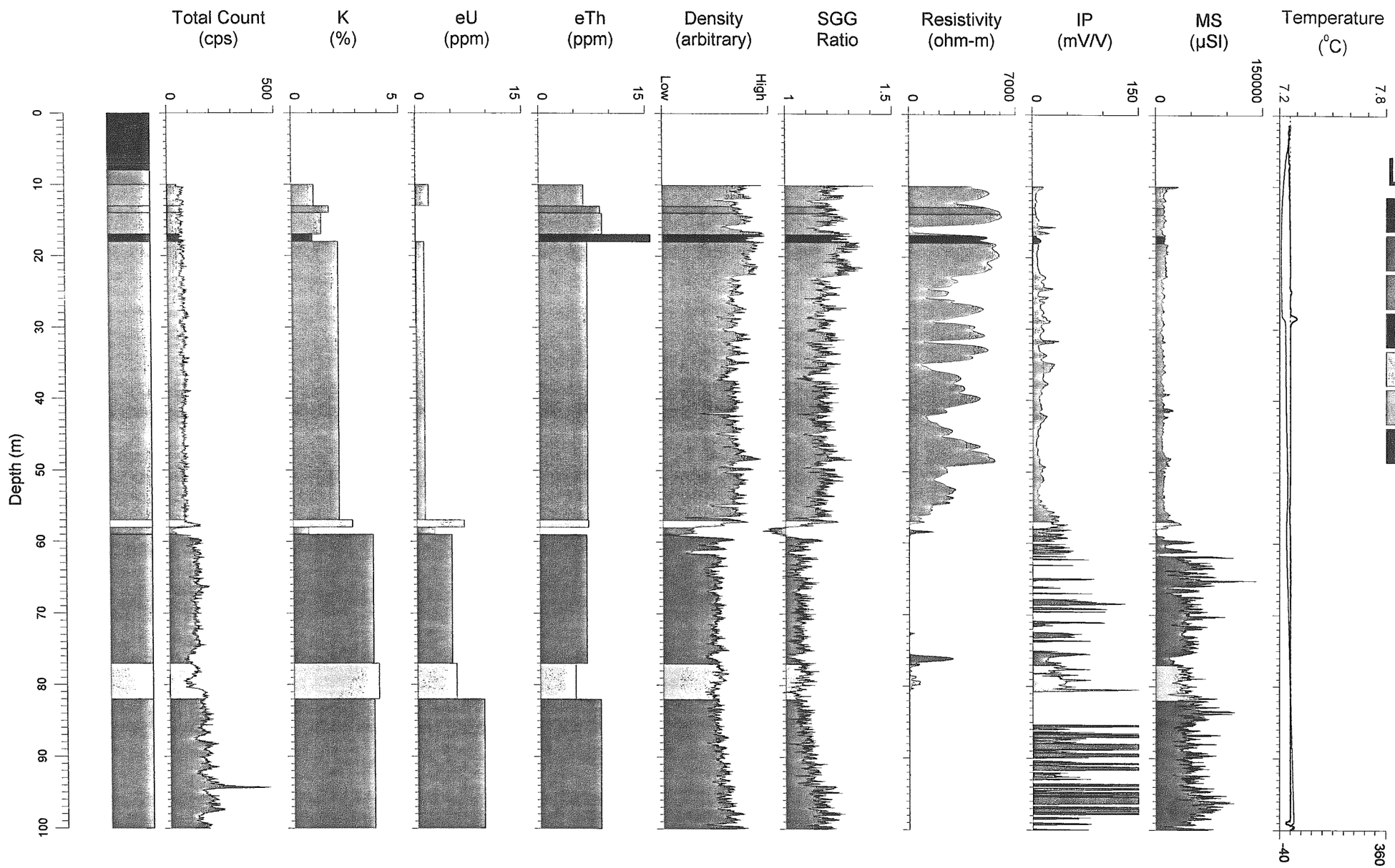
Lake Charlotte, Nova Scotia
Multiparameter Geophysical Logs

Borehole
LC86-1
Plot 1 of 3



LEGEND

- Overburden
- Carbonaceous Slate
- Calcareous Banded Argillite
- Oxidized Calc Banded Argillite
- Chloritic Argillite
- Slate
- Limestone

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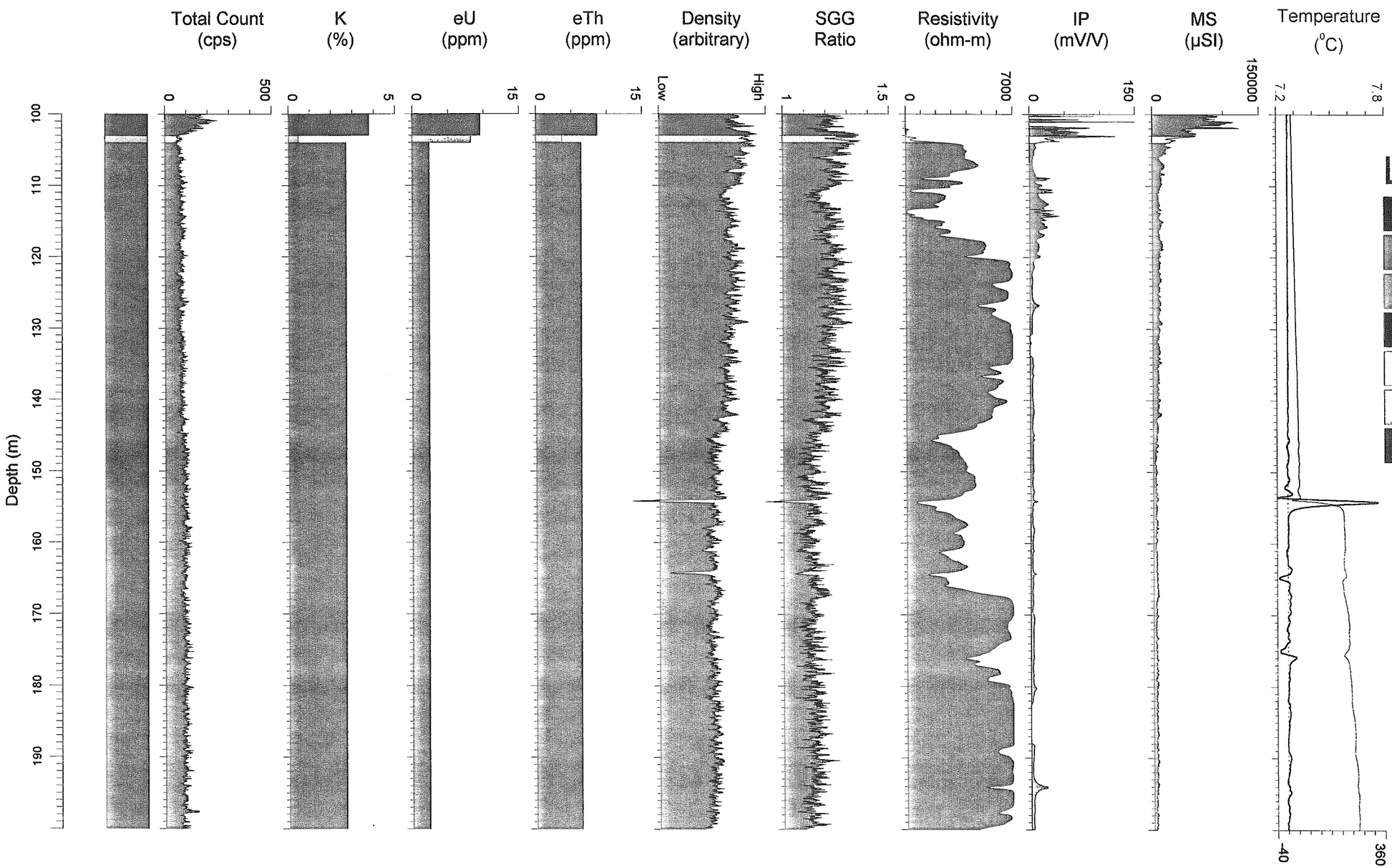
Lake Charlotte, Nova Scotia
Multiparameter Geophysical Logs

Borehole
LC86-1
Plot 2 of 3



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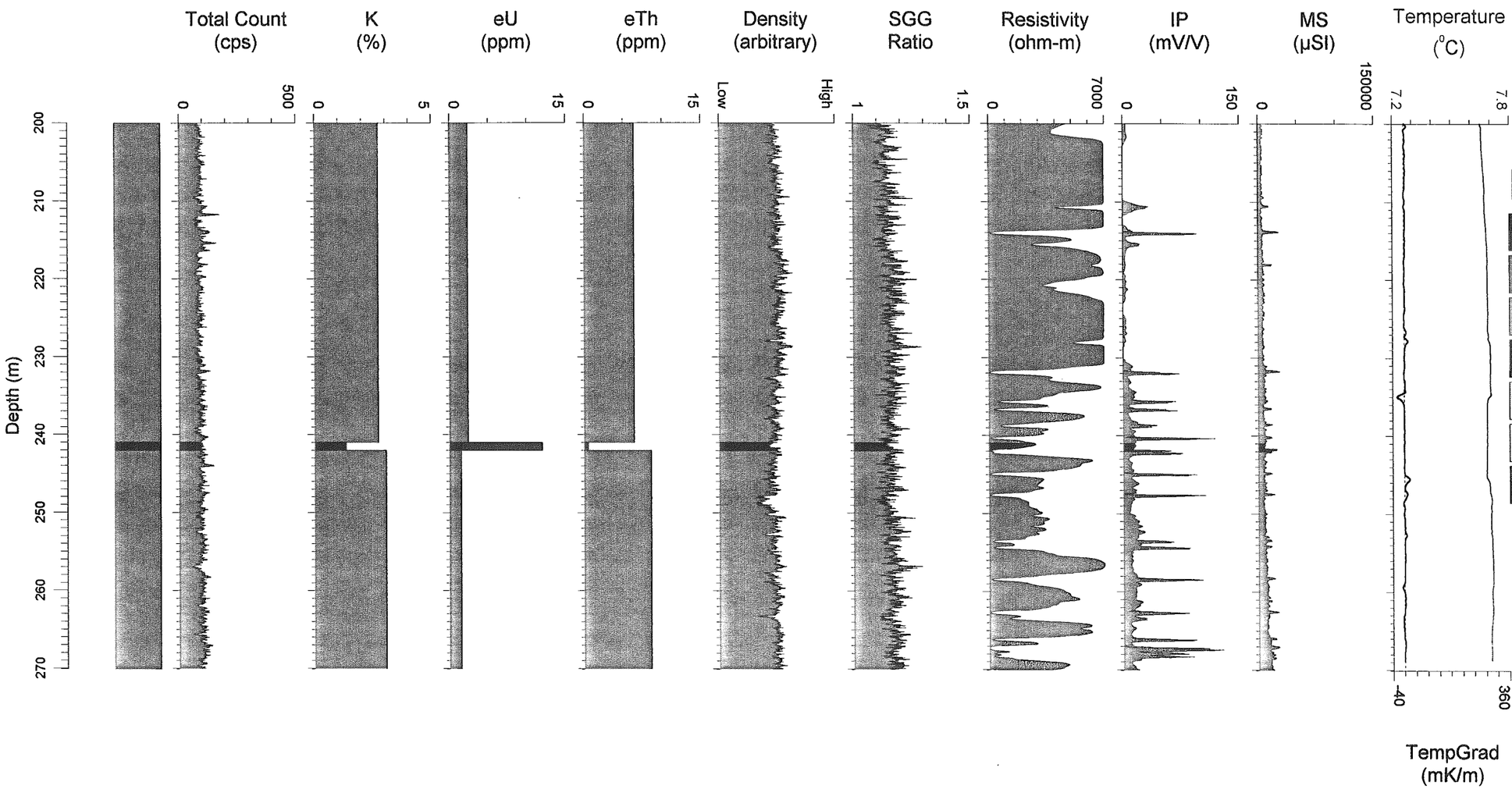
Lake Charlotte, Nova Scotia
Multiparameter Geophysical Logs

Borehole
LC86-1
Plot 3 of 3



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