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Borehole Geophysical Logs from the Hemlo Gold Deposit, Ontario

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1. INTRODUCTION AND BACKGROUND

Borehole geophysical measurements with the GSC R&D logging system were conducted in five holes in the Hemlo Gold Mining Area of Ontario. The logs were recorded in 1984 as part of the research and development activities of the Borehole Geophysics Section of the GSC. Some of the data have been used in publications and oral presentations as examples (Mwenifumbo et. al., 1993) of the application of geophysical logging to mineral exploration (Killeen, 1986; Mwenifumbo, 1985). The present compilation makes all of the data available for use in on-going studies in the Hemlo area.

Most recent applications of borehole geophysics to gold exploration have shown that significant geophysical anomalies are observed in gold bearing zones. Gold mineralization in the Abitibi Greenstone belt is associated with four major types of alteration processes: sericitization, pyritization, carbonatization and silicification. These types of alterations, under favorable conditions, can be detected by geophysical techniques (Mwenifumbo, 1985; Pflug et. al., 1995).

Sericitization is one of the most common types of wall-rock alteration in gold deposits developed in acidic, intermediate and basic igneous and metamorphic rocks. It consists of the development of potash, mica generally sericite or hydromuscovite, as a result of the hydration or from rearrangement of K, A1 and SiO_2 within intensely altered wall rocks. Chemically, sericitization generally involves the introduction of K and H_2O into the rocks affected. An increase in K results in a corresponding increase in the radioactive isotope K-40. Zones enriched in potassium can thus be detected by gamma ray spectrometry.

Pyritization is the most common type of alteration in gold deposits. The presence of pyritized zones can be detected by induced polarization and resistivity methods (Urbancic and Mwenifumbo, 1986).

Carbonatization consists of the development of secondary carbonates (dolomite, ankerite etc.) in the host rock, whereas silicification consists of the development of secondary quartz and other varieties of silica in the wall rock. The introduction of these secondary minerals generally results in a reduction of the pore space within the wall rock and hence increases the formation resistivity. Resistivity logging can therefore be used to delineate carbonatized and silicified wall rocks.

Highly sensitive temperature gradient measurements may be used to identify different lithologic units with contrasting thermal conductivities and to locate structural features such as fractures and faults.

Borehole geophysical logging was conducted at the TECK-Corona and Noranda gold properties in the Hemlo gold mining camp. This included three boreholes (TE-173, TE-179, TE-192) on the east zone of the Corona Gold deposit, one borehole (NGG-18) on the Golden Goliath deposit and one borehole (NGE-02) on the Goliath East deposit. These holes ranged in depth from 250 to 800 metres and measurements of eleven geophysical parameters were made in all of them. The geophysical parameters included: natural gamma ray spectrometry (Total Count), potassium (K), uranium (U), thorium (Th), density, spectral gamma-gamma ratio (SGG ratio, a heavy element indicator), induced polarization (IP), resistivity, magnetic susceptibility (MS), temperature and temperature gradient.

2. GEOLOGY AND GEOPHYSICAL LOG SIGNATURES

2.1 GEOLOGY

There is considerable literature published on the geology of the Hemlo Gold Camp since its discovery in 1981. For example, Harris (1989) provided a good description of the mineralogy and geochemistry of the Hemlo Gold Deposit. A selection of eighteen other papers related to Hemlo geology are included in the reference section below (part 8).

The Hemlo Gold camp is located near the north shore of Lake Superior, about 300 km north-northwest of Sault Ste Marie (figure 1.). It lies within a belt of Archean metavolcanics and metasedimentary rocks. The metavolcanic rocks include hornblende schists and volcaniclastics, while the main metasedimentary rocks include metagreywacke, etc. Within the Hemlo Gold camp, pyritization, sericitization and silicification are the major types of alteration processes associated with the gold mineralization.

Geophysical logging was carried out mainly to determine the characteristic geophysical signatures of the lithology and the mineralized zones in the camp and also to evaluate the optimum geophysical parameters for delineating lithologic units favourable for gold mineralization.

The deposit names, hole numbers and the property owners/operators at the time of logging are given below.

Deposit Name	Hole No.	Diameter	Owner/Operator
GOLDEN GOLIATH	NGG-18	76 mm	Noranda
GOLIATH EAST	NGE-02	76 mm	Noranda
CORONA	TE-173	60 mm	Teck
	TE-179	60 mm	
	TE-192	60 mm	

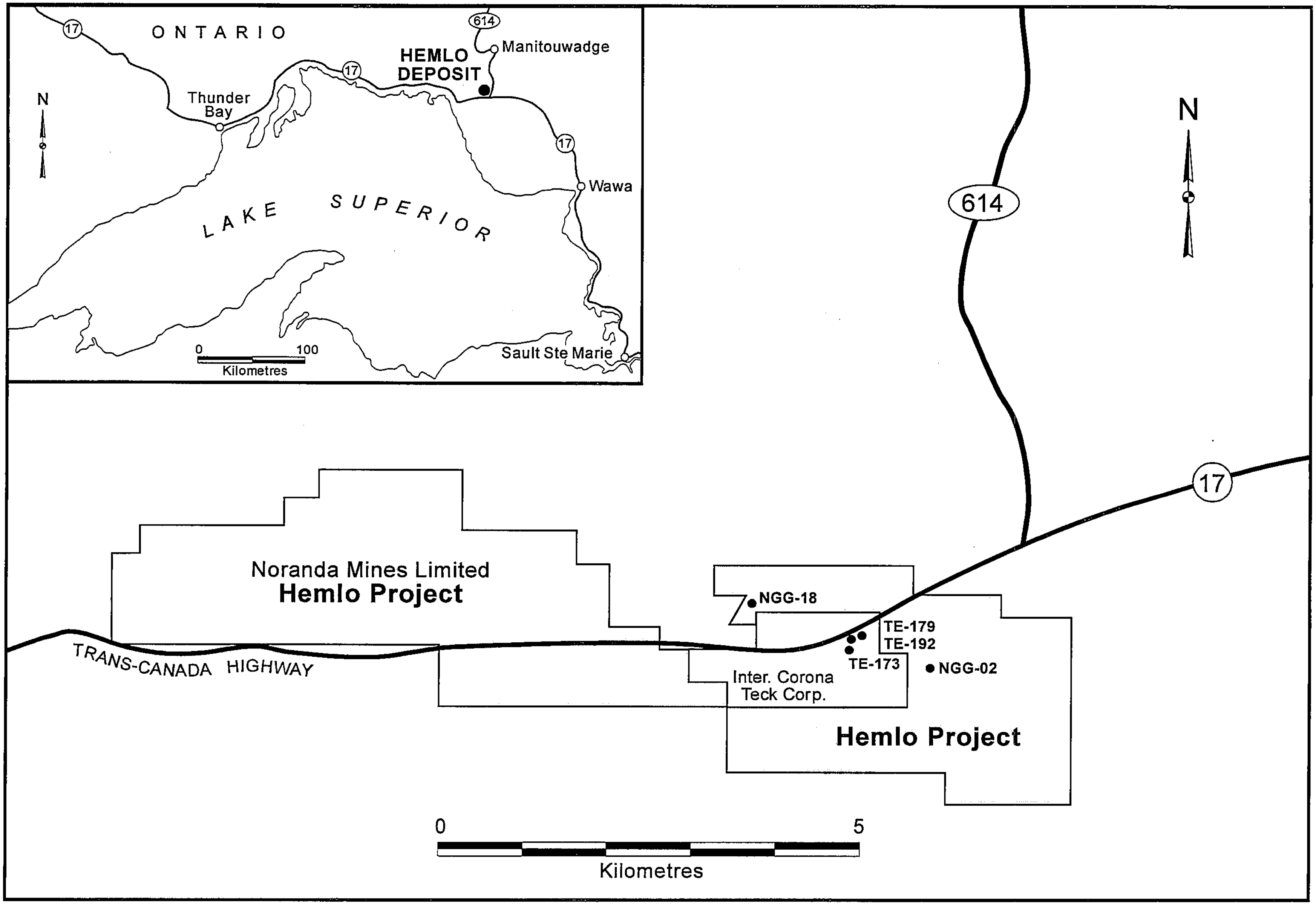

FIGURE 1 - Location of Boreholes Geophysically Logged

2.2 GEOPHYSICAL LOG SIGNATURES (RESPONSE CHARACTERISTICS)

Before proceeding with discussion of the geophysical logs obtained in the Hemlo Gold camp it is important to understand the physical properties of the rocks to which each of the geophysical logs respond, particularily with respect to the geological environment present in the area. A single geophysical log can yield similar results in different lithologies. Also a number of geophysical logs recorded in a single hole may provide different lithologic interpretations. Some of the geophysical logs respond to specific physical properties of the rocks and others respond to a combination of physical property changes. The following is a brief discussion of the response characteristics of each of the geophysical logs carried out in the Hemlo Gold camp.

2.2.1 INDUCED POLARIZATION (IP)

In the time domain induced polarization measurements, the ratio of secondary voltage measured during the current off-time to the primary voltage measured during 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 disseminated metallic sulphides and oxides or cation-rich clays such as illite and montmorillonite. In the Hemlo Gold deposits, gold occurs as finely disseminated native gold in pyritiferous schists and these zones were the targets of IP logging. The ore bearing rocks also contain an appreciable amount of molybdenite which is polarizable and is a good electrical conductor.

2.2.2 ELECTRICAL RESISTIVITY

The electrical resistivity of rocks depends on several factors. The amount of conductive minerals such as iron and base metal sulphides, oxides and graphite in the rock has a strong influence on the resistivity. Most rocks are usually poor conductors and their resistivities are governed primarily by their porosity and salinity of the pore water and to a lesser extent by the intrinsic minerals that constitute the rock. Some alteration processes such as silicification and carbonatization tend to reduce the porosity of the rock and hence increase the resistivities. Thus in rocks where no significant amounts of conductive minerals occur, the most important factors affecting the resistivities are fracturing, porosity, the degree of saturation of pore spaces and the nature of the electrolytes in the pore fluids. Since resistivities depend on a number of factors, interpreting a geologic section from resistivity measurements is fairly difficult without complimentary information from other geophysical parameters or geological logs. The Hemlo Gold deposits contain appreciable amounts of pyrite (5-20 percent) and therefore delineation of the ore horizons by electrical resistivity logging is fairly straight-forward.

2.2.3 NATURAL GAMMA RAY

The gamma ray probe measures the natural gamma radiation emitted by potassium-40, uranium and thorium series isotopes in the rocks surrounding the borehole. In igneous and metamorphic geologic environments, these sources of natural radiation may contribute equally to the total gamma rays detected by the gamma probe. In the Hemlo Gold camp, the principal source of the natural gamma radiation would be potassium-40 because alteration, characterized by the development of sericite (sericitization), is prevalent in some of the lithologic units within the area. Sericitization results in an increase in the potassium element and hence a corresponding increase in the potassium-40 isotope. This renders sericitized zones excellent targets for gamma ray logging. The presence of feldspar porphyry sills in the area with abnormal concentrations of K-feldspar minerals would also be indicated by higher than normal radioactivity on the gamma ray logs. During metamorphism and hydrothermal alteration processes, uranium and thorium may be preferentially concentrated in certain lithologic units. The gamma ray spectral logs would be able to identify such areas.

2.2.4 MAGNETIC SUSCEPTIBILITY

The magnetic susceptibility of a volume of rock is a function of the amount of ferrimagnetic minerals - magnetite, ilmenite and pyrrhotite - contained within the rock. Magnetic susceptibility measurements can provide a rapid estimate of the magnetic minerals in the rock. These measurements can be interpreted to reflect lithological changes, degree of homogeneity and the presence of alteration zones in the rock mass. Basic flows and diabase dikes containing higher concentrations of magnetic minerals can be easily outlined from magnetic susceptibility measurements when they occur within a sedimentary sequence which normally contains little or no magnetic minerals. During the process of hydrothermal alteration responsible for ore mineralization, magnetic minerals in the host rock (magnetite and ilmenite) may be altered to weakly magnetic minerals - (hematite and limonite) or to non-magnetic minerals. Within a homogeneous high magnetic susceptibility rock unit, anomalously low magnetic susceptibilities are an indication of altered zones.

2.2.5 TEMPERATURE

Temperature gradient data can provide complimentary information to resistivity data. An inverse relationship is known to exist between temperature gradients (equivalent to thermal resistivities) and electrical resistivities in coal and sedimentary environments. Low electrical resistivities correlate with high temperature gradients. It was thought that the different lithologies encountered within the Hemlo Gold camp may possess contrasting thermal resistivities that could be delineated by temperature logging (Mwenifumbo, 1993).

Fracture or shear zones may provide pathways for ground water flow if hydrologic pressure gradients exist within the rock mass. Ground water flow produces some characteristic thermal anomalies and their detection could provide some information on the location of the fractured rock mass and hence aid in the structural interpretation of the area under study.

Large concentrations of metallic sulphides and oxides may perturb the isothermal regime locally since metallic minerals have very high thermal conductivities. This perturbation may be delineated with the high sensitivity temperature logging system. This, however, would be observed only in a thermally quiet environment. In areas where there are numerous fracture zones with ground water movements, thermal anomalies due to ground water flow are much larger than those that would be observed due to perturbation caused by the presence of metallic minerals. Also, if climatic changes affect the heat flow pattern to the depths of investigation, then the detection of temperature anomalies due to the presence of thermally conductive minerals would be difficult. Temperature logging was carried out in the Hemlo Gold area to investigate whether the technique could be used to delineate fracture zones and map lithologies and mineralized zones.

2.2.6 DENSITY

The density-probe response is primarily a function of the rock bulk density. The probe consists of a gamma ray source and a gamma ray detector. Gamma rays emitted by the source are scattered by the enclosing rock wall and absorbed as a direct function of the electron density of the rock unit. The compton-scattered gamma radiation that is measured at the gamma ray detector in the probe is inversely related to the density of the rock. This information may be used to compute the Spectral Gamma Gamma Ratio (SGG Ratio) which is an indicator of the presence of heavy elements (Killeen and Mwenifumbo, 1988b; Killeen et. al., 1990) (see Appendix 1) The electron density of the rocks is affected by the chemical composition of the rock and by secondary physical properties such as porosity and water content. A barite-pyrite-gold association is a feature which appears to be unique in the Hemlo Gold camp. The volume content of barite in ore zones ranges from 5 to 40 percent. Ore reserves on the Noranda property are estimated to contain 10 to 13 percent barite. Barite and pyrite are very dense minerals and can be easily and accurately delineated by gamma gamma density logging (Killeen and Mwenifumbo, 1988a;Killeen, 1991). In the ore tonnage and reserve computations, one of the parameters used is the specific gravity and hence a knowledge of in-situ densities of the rocks may provide valuable information for ore reserve estimations.

3. LOGGING SYSTEM AND GEOPHYSICAL LOGS

All the borehole logging carried out in the Hemlo Gold camp was done with the GSC R&D borehole logging system. The data acquisition system for all the parameters logged was based on a 16-bit minicomputer. Full IP waveforms, full gamma ray spectra, magnetic susceptibility and temperature were digitally recorded on 9 track magnetic tapes.

Accessibility to all the boreholes was logistically difficult. None of the boreholes were accessible by the GSC 4-wheel drive logging truck. The logging equipment had to be stripped out of the truck and hand-carried to the borehole sites. The suggestion of skidding the equipment to borehole sites was rejected because of the delicate nature of the equipment and the roughness of skidder trucks. Some of the holes were in swamps and special platforms had to be built for the equipment.

A general description of the GSC logging tools and the general geologic features to which they respond, is given in Appendix 1. However, some notes specific to the use of these logging tools in this project are given below.

3.1 BOREHOLE IP AND RESISTIVITY LOGGING

Borehole induced polarization (IP) and resistivity data were obtained with the lateral (pole-dipole) array. The potential dipole spacing (MN) was 0.4 m and the distance between the current electrode and the potential dipole centre was 2.8 m. The downhole current and potential electrodes consisted of gold-plated brass cylinders, 4 cm in diameter. The surface return current electrode consisted of steel rods about a metre in length and were located approximately 1 to 1.5 kilometre away from the borehole under survey. The measurements were carried out with the GSC time domain IP/resistivity logging system. The transmitter on this system is a constant current source, capable of supplying currents up to 250 mA. There are 4 selectable periods for the current waveform; 1, 2, 4 and 8 seconds. In the present study, IP and resistivity measurements were made using a period of 1 second (ie. a current ON time of 0.25 seconds followed by an equal current OFF time, a current ON time (with polarity reversed) of 0.25 seconds and another equal current OFF time). Complete IP waveforms were recorded on 9 track magnetic tape. The apparent resistivities are computed from the primary voltages, that is, voltages observed during the current ON time, with the appropriate geometric factor. The IP chargeability data are determined from the decay voltages during the current OFF time. It is standard practice to integrate under a portion of the decay curve and normalize it with the primary voltage. In the present IP measurements, the chargeabilities were determined by integrating from 62 milliseconds to 138 milliseconds after the current was switched off. The apparent chargeability parameter is given in mV/V. The logging speed was 3 m/minute with measurements taken every second (equivalent to a sampling interval of 5 cm). The depth capability of the IP/resistivity logging system was limited to about 550 m and therefore the deep hole at Noranda Golden Goliath (NGG-18) was only logged down to about 550 m.

Because of current leakage problems in the cable near the cable head, the IP data are suspect and should be looked upon as being relative and not absolute. The change in the electrode geometry due to a secondary source at the point of current leakage creates complex current flow patterns within the medium around the borehole. The change in the IP response along the hole reflects changes in the electrical properties along the hole, however, the interpretations of these changes may not be simple.

3.2 GAMMA RAY SPECTRAL LOGGING

Full gamma ray spectra were recorded on a 9 track magnetic tape. The spectra were recorded in 256 channels covering a gamma ray energy range from approximately 0.1 MeV to 3.0 MeV. Gamma ray counts in ten preselected windows were also accumulated and recorded on tape. The four standard windows frequently used in data analysis include the potassium window (1.36-1.56 MeV) centred on the K-40 gamma ray peak at 1.46 MeV, the uranium window (1.61-2.3 MeV) centred on the 1.76 MeV gamma ray emissions of bismuth-214 in the uranium decay series, and the thorium window (2.4-3.0 MeV) centred on the 2.62 MeV gamma ray peak from Thallium-208 in the thorium decay series. The fourth window, the total count window, covers a wide energy range between 0.4 MeV to 3.0 MeV and is used to monitor the overall levels of radioactivity. The scintillation detector that was used was a 32 mm x 127 mm (1.25 x 5.0 inch) sodium iodide (thallium activated, NaI(Tl)) detector. The logging speeds for the data acquired at Hemlo varied from 3 m/minute to 1.5 m/minute, and the sample interval varied from 5 cm to 2.5 cm.

3.3 MAGNETIC SUSCEPTIBILITY LOGGING

Magnetic susceptibility measurements were acquired with the Geo Instruments Model TH-3C magnetic susceptibility logging tool, with a 42 mm diameter, 0.5 m length coil. The susceptibility logging tool has been interfaced to the GSC computerized data acquisition system so that data is acquired on a continuous basis along the hole length. Susceptibilities within the range from 0 to 2 SI can be measured with this tool. All the holes were logged at 6.0 m/minute with a 1 second sample time, giving a measurement at every 10 cm along the hole.

3.4 TEMPERATURE LOGGING

Temperature logging was done with a probe consisting of a 10 cm long tip of thermistor beads with an equivalent temperature sensitivity of 0.0001 degrees Celsius. In temperature logging, changes in temperature are recorded as changes in the thermistor resistance. The response of the thermistor to changes in temperature is exponential and the measured thermistor resistances are converted into true temperatures by means of an inverse operator with the appropriate probe time constant. The temperature gradient data are derived from the temperatures by means of a combined gradient and smoothing operator. All temperature data were acquired at a logging speed of 6.0 m/minute and data were sampled every 1/3 of a second giving a measurement every 3 cm. This high spatial resolution of data is necessary if accurate temperature gradients are to be derived from the temperature data with the use of derivative operators.

3.5 GAMMA GAMMA DENSITY SPECTRAL LOGGING

The gamma gamma density probe consists of a gamma ray source and a gamma ray detector. The source in the probe that was used in the logging was an Iridium source and the detector was a 25 x 75 mm sodium iodide (thallium activated, NaI(Tl)) detector. Gamma rays emitted by the source are scattered by the enclosing rock mass and absorbed as a direct function of the electron density of the rock unit. The compton-scattered gamma radiation that is measured by the gamma ray detector on the probe is inversely related to the electron density of the rock. The source-detector spacing for the logging carried out at Hemlo was 11 cm for all holes except hole TE-172 which was logged with a source-detector spacing of 17 cm. All data were acquired at a logging speed of 6.0 m/minutes with a sample time of 1 second giving a measurement every 10 cm.

3.6 SUMMARY OF LOGGING PROCEDURES

Logging at Hemlo

Probe	Procedures and Tools Used at Hemlo
Spectral Gamma:	Holes TE-179 and TE-192 were logged at 1.5 m/minute, with a 1 second counting time. All other gamma-ray logging was at 3 m/minute with a 1 second counting time. The gamma-ray, K, U, and Th logs for holes NGG-18 and NGE-02 in appendix 2 were smoothed with a 5 point Savitzky-Golay filter except for the K, U, and Th logs from hole NGE-02 that were smoothed with a 9 point filter. For all logging a 32mm x 127mm (1.25" x 5") Sodium Iodide detector was used.
Spectral Gamma-gamma:	Hole TE-173 was logged at 3 m/minute. All other density logging was at 6 m/minute. Sample intervals were all 1 second. The SGG Ratio logs for holes TE-173, TE-179, and NGE-02 were smoothed with a 5 point Savitzky-Golay filter. For all logging a 25mm x 76mm (1" x 3") Sodium Iodide detector and a 1 millicurie Iridium-192 source were used. In all holes an 11cm spacer was used between the source and the detector except for hole TE-173 in which a 17cm spacer was used.
IP/Resistivity:	Hole NGG-18 was logged at 6 m/minute. All other electrical logging was at 3 m/minute. Sample intervals were all 1 second. The lateral array was used in all the electrical logging.
Magnetic Susceptibility:	All logging was at 6 m/minute with a 1 second sample interval.
Temperature:	All logging was at 6 m/minute with a 1 second sample interval.

4. DATA PROCESSING

A general description of data processing techniques is presented below (see also Elliott, 1991). Details about methods for extracting physical property information from the logs was given in GSC Open File 2610 by Killeen et al., (1995).

General Correction and Compilation Techniques

The first step in data processing is to apply a depth shift related to the position of the sensing element in each of the five logging tools so that the location of "zero depth" is the same for all parameters measured. For example, in gamma ray logging the detector is actually located at 60 cm depth when the 'zero' is set on the well head pulley at the beginning of logging. Therefore, all depth values are in error by 60 cm until this correction is applied. At the same time a casing correction is applied to compensate for the length of casing protruding above ground level, and on which the well head pulley and depth counter are mounted. This brings the geophysical log zero depth into line with ground level for correlation with drill core geological logs.

The second step is to apply corrections to the data as required for each parameter. This may include dead time corrections for nuclear logs (gamma ray and gamma gamma density), hole size (diameter) corrections for magnetic susceptibility logs. Spectral stripping and conversion to concentrations (%K, ppm U, and ppm Th) may be done for gamma ray logs if counting statistics warrant, however because of the low count rates recorded at Hemlo this was not done. Only the raw count for K, U, and Th are presented as logs in Appendix 2. The gamma gamma density log is a count rate which is inversely proportional to density. Thus raw logs labelled in cps (counts per second) show high values for low density zones, and where appropriate calibration factors were available, the density logs presented in this open file have been converted from cps to grams per cubic cm.

The third step is to compute any desired 'derived' logs such as the temperature gradient log.

The fourth step is to plot all of the digitally recorded logs on a single sheet of paper. Additional depth discrepancies become evident. Usually it can be seen from the logs that certain discontinuities associated with the geological contacts or dikes, etc. are not aligned properly from log to log. A cross-correlation program is used to shift all logs to a best fit match with each other. The geophysical logs are then correlated to the geology if the geological logs are available and if it appears necessary.

Sometimes, in addition to a depth shift, a 'stretch' must be applied to the logs for proper depth alignment. Logs from the same tool and same run (e.g. IP/R) don't need shifting since they were recorded simultaneously.

It is also possible to correct the logs for 'drift' if required. In certain cases some smoothing may be applied to the logs, or averaging over greater lengths of hole than the original detailed measurements taken every few centimeters.

5. RESULTS OF GEOPHYSICAL LOGGING

The geophysical logging results are presented as a series of 12 coloured plots in Appendix 2. Table 1 (see page 18) summarizes the parameters presented in the coloured log plots. Some interpretive notes for the geophysical logs recorded in the five Hemlo holes are also given 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 of the data.

The following will concentrate on the description of the geophysical responses of all the logged parameters. An attempt is made to correlate the geophysical log with the available geological information. No attempt is made to carry out hole-to-hole correlation of the geophysical information with geological information because of the inconsistency in the nomenclature of the lithologic units between the TECK-Corona and NORANDA holes. It should be noted, however, that there are problems in attempting to make correlations between the geophysical and the geological data. These problems arise in the accuracy of depth determinations in both data sets. Errors exist in core data depths due to possible missing or lost core during drilling. Also geologic contacts are not always well defined. They are quite often gradational and are determined somewhat subjectively. These interpreted geologic contacts may not coincide with the changes in the bulk physical or bulk chemical properties of the rock mass. Errors also exist in depths from geophysical logs. These errors are mainly due to slippage and cable stretching. These errors have been corrected for all the logging data. All depths on the logs are not true vertical depths but lengths along the boreholes.

The discussion of the data is on a hole by hole basis.

BOREHOLE NGE-02 - Goliath East, NORANDA

The resistivity log indicates a number of low resistivity zones (< 1,000 ohm-m). The most prominent one occurs between 40 and 70 m. This low resistivity zone correlates with unit 7a (The table below gives the relationship between these units and geological terms). Fairly high resistivities (10,000 to 100,000 ohm-m) occur at shallow depths (5-30 m) and near the bottom of the hole (255-270 m). The resistive zone near the top of the hole is a diabase dike.

Unit	Geological Description (Noranda Boreholes)
6a	Upper Volcaniclastic Member
7a	Garnetiferous Metasediments
7b	Pelitic Unit
7c	Pelitic Metasedimentary Series
7d	Calc-Silicate Unit
7e	Siliceous Sulphide Rich Sediment
7f	Chloritic Schist

On the gamma gamma density log, the diabase dyke is indicated by a fairly uniform, high density zone. The rest of the lithologic units seem to have relatively low densities compared to the diabase dyke. The garnetiferous unit between 150 and 255 m, has higher than average densities.

The diabase dyke intersected by hole NGE-02 is indicated by a relatively uniform magnetic susceptibility high. A few thin high susceptibility values in the log may be magnetite or pyrrhotite rich zones (e.g. 257 m).

The total count gamma ray log shows well defined changes in radioactivity which correlate with the geology. The diabase dyke (5-30 m) is characterized by low count rates. Unit 7a (150-255 m) is also characterized by low count rates. High count rates are observed between 70 and 150 m. This region consists of 3 different lithologic units (6a, 7e, and 7b). The contacts between these units cannot be easily defined based on the total count gamma ray log. Unit 7a between 35 to 70 m has a higher count rate than the corresponding unit below (150-255 m) implying that these two units are chemically different. They may have been subjected to different degrees of alteration. Most of the radioactivity seems to originate from potassium (see NGG-18 below). The quartz biotite unit at the bottom of the hole seems to have a higher than average thorium content.

The temperature gradients are fairly constant except for the anomaly at about 20 m which is due to perturbation of the thermal gradients as result of climatic changes. The low resistivity zone between 40 to 70 m has anomalous temperature gradients.

BOREHOLE NGG-18 - GOLDEN GOLIATH, NORANDA

There is a considerable variation in resistivity along this hole. These variations are of smaller wavelength than the lithological changes. The IP log shows an inverse correlation with the resistivity; low resistivities correlating with high IP. As mentioned earlier the IP data are relative not absolute because of the current leakage problems. A few low resistivity zones are notable at the following depth intervals: 90-100 m, 115-125 m, 385-390 m and 470-475 m. These resistivity lows may be associated with fracture zones, e.g. the 90 to 100 m zone. There is no indication of the occurrence of iron sulphides within these low resistivity zones.

The gamma gamma density log seems to have been quite successful in outlining high concentrations of high density minerals: -barite and iron sulphides (from 670 to 715 m and from 740 to 765 m). Higher than average formation densities are observed at the following depth intervals:- 165-180 m, 220-240 m and 435-475 m. These zones may correspond to an increase in the percentage of garnets or an increase in the mafic minerals, e.g. hornblende, within the rock units.

The magnetic susceptibility log shows quite a few prominent anomalies at 220-275 m, at 520-575 m and within the ore zones. The high susceptibility zone between 220 and 275 m seems to correlate with the volcaniclastic unit, 6a. The anomalies at approximately 520 to 575 m do not correspond to any change in lithology, but occur within the pelitic metasediment-carbonate unit which ranges from 480 to 575 m.

The natural gamma ray logs indicate variations in radioactivity which may be correlated to lithologic units. The following depth intervals on the total count log are worth noting with respect to lithologic changes.

-From 10 to 90 m the average count rate is approximately 130 cps and this region correlates with unit 7a.
-From 90 to 220 m the average count rate is approximately 85 cps. This region encompasses three

units (7d, 7a, 7f and 7d (repeated), respectively). Unit 7a at about 10-90 m and unit 7a at about 125-165 m has different levels of radioactivity suggesting that unit 7a at these two locations may be chemically different. There is some variability in radioactivity within unit 7f.

-From 220 to 410 the average count rate is about 130 cps and this region encompasses units 6a, 7c, quartz biotite, 7c and 6a, respectively.

-From 410 to 500 m the average count rate is approximately 85 cps. An anomalously high radioactivity zone is observed between 540 and 575 m. This zone does not correspond to any change in lithology as outlined in the geologic log. This anomaly is associated with a high magnetic susceptibility.

-The ore zone has fairly high levels of radioactivity.

Because of the low radioelement concentrations encountered in this type of environment and hence low count rates, there are very poor counting statistics in the K, U and Th windows. The low count rates create problems in processing and deconvolving data to derive the actual radioelement concentrations and distributions. Counting for 1 second at each sample depth is not enough to accurately determine the amount of radiation emanating from the volume of rock being sampled. The random nature of gamma radiation requires a fairly long counting time in order to get good counting statistics. In general, the variation in radioactivity along hole NGG-18 is mainly due to the variation in the concentrations of potassium as also indicated on the K log. The exception to this is the anomaly at 540 to 575 m which seems to have an associated high concentration of thorium and possibly uranium.

The temperature log does not show any anomalies. There appears to be a linear increase in temperature with depth. However, the temperature gradients indicate that there are anomalous gradients along the hole. The temperature gradient anomaly at about 155 m may be ascribed to ground water flow. In general, the temperature gradient log shows a number of short wavelength variations which may represent genuine variability in the thermal conductivity along the borehole. This is certainly true of gradient anomalies at 675-715 m and at 740-765 m, which occur within the ore horizon that has large concentrations of thermally conductive iron sulphides.

BOREHOLE TE-173 - TECK-Corona

The Teck-Corona geological units are defined in the table below.

Unit	Geological Description
a	Mafic Sediments
b	Siliceous Sediments
c	Siliceous Tuff
g	Mafic Tuff

There are a number of low resistivity zones (< 1,000 ohm-m) along the length of this hole. There is, however, no correlation between changes in resistivity and major changes in the lithology. The resistivity low at approximately 205 m may be correlated with the pyritized ore zone. An anomalously high resistivity zone is observed at about 160 m.

The gamma gamma density log seems to correlate well with the geology. Unit, "a", (e.g. 5-50 m) has the highest density followed by unit, "g", (215-245 m). The ore horizon at about 205 m is characterized by a slightly higher density mainly due to its association with barite and iron sulphides. Unit, "b", (50-150 m) has the lowest density.

The magnetic susceptibility log shows scattered anomalies along the entire hole. There was some drift in the magnetic susceptibility measurements that has been corrected. The high magnetic susceptibility zone between 45 and 55 m correlates with the low resistivity zone suggesting the presence of iron oxides or sulphides. Variations in the gamma ray activity are not that characteristic of the different lithologic units intersected along the hole. Within each unit there is a bit of amplitude variation in the count rate.

There is quite a bit of character in the temperature and temperature gradient logs. Step like changes in temperature occur at about 70 m and 90 m. These changes in temperature relate to ground water flow. The temperature gradients below 90 m are higher than those above.

BOREHOLE TE-179 - TECK-Corona

The resistivity logs show variations in resistivities which in general do not correlate with the geologic log. Low resistivity zones are observed at the following depth intervals: 30-35 m, 90-120 m, 235-245 m and 285-295 m.

The density log shows variations associated with lithology. A number of narrow high density zones are indicated along the hole. This indicates the variability in the concentration of high density minerals within the intersected lithology. In general, the region between 90 to 240 m has higher density than most of the units below, except for the mafic dyke.

The SGG ratio has been truncated at the bottom of the hole (250-360 m) because of drift problems.

A series of magnetic susceptibility highs are observed between 10 and 70 m in the pelitic unit.

The temperature gradients indicate a number of ground water flow points in the upper 100 metres of the borehole. A relatively constant gradient is observed below 100 m.

BOREHOLE TE-192 - TECK-Corona

The resistivity log along this hole indicates two fairly wide resistivity lows (< 1,000 ohm-m) from 40 to 60 m and from 175 to 190 m. The region between 60 and 195 m shows a uniform resistive rock unit (approximately 30,000 ohm-m).

The gamma gamma density log indicates two distinct units along the entire length of the hole. The unit above 190 m is indicated to have a higher density than the unit below. There are also narrow, high density zones within these units.

There are three areas of high magnetic susceptibility along the hole. The one at about 175 to 185 m has a corresponding high density and resistivity low.

The natural gamma ray log indicates a fairly uniform level of radioactivity between 40 and 180 m. Below 180 m the total count rate is variable. One interesting thing to note on the K log is that there is a gradual increase in potassium with depth which is not observed in the total count log. This implies that radioactive sources other than potassium are contributing to the radioactivity observed along the top part of the borehole. Uranium seems to be the main contributing radioelement to the count rate observed in the upper 180 m of the borehole.

The temperature logs show small wavelength variations in gradient which may be ascribed to variations in the thermal conductivity of the lithology intersected by the borehole.

The following abbreviations are used in Table 1 and in some of the logs in Appendix 2.

Abbreviation	Probe
GAM	Spectral Gamma
GAM-GAM	Density / Spectral Gamma-gamma Ratio
IP	Induced Polarization
MS	Magnetic Susceptibility
TMP	Temperature

Abbreviation	Parameter
TC	Total Count Gamma-Ray
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

Table 1: Areas, Boreholes, and Parameters Logged

Borehole	**GAM**	**GAM-GAM**	**IP**	**MS**	**TMP**
Teck TE-173	TC, K, U, Th	DEN SGG	IP RES	MS	TMP TMG
Teck TE-179	TC, K, U, Th	DEN SGG	IP RES	MS	TMP TMG
Teck TE-192	TC, K, U, Th	DEN SGG	IP RES	MS	TMP TMG
Noranda NGE-02	TC, K, U, Th	DEN SGG	IP RES	MS	TMP TMG
Noranda NGG-18	TC, K, U, Th	DEN SGG	IP RES	MS	TMP TMG

Notes on coloured log displays in Appendix 2

1) All depth scales are 12 metres per centimetre on paper.

2) All gamma ray logs are total count logs in counts per second (cps) for an energy window of 0.1 to 3.0 MeV.

3) No logs were recorded in the steel casing in the overburden at the top of the holes.

4) Density and electrical logs were recorded only in the water-filled part of the holes.

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Table of contents

APPENDIX I

THE LOGGING SYSTEM

APPENDIX 1 - The Logging System

The GSC Borehole Geophysical Logging System

Applications of geophysical logging encompass mining exploration, hydrogeological 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 digital logging system are:

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 for data storage;
7. a multi-pen chart recorder to provide a hard copy in the field.

Most modern 'slim-hole' tools are 38 to 50 mm in diameter, designed to run in BQ holes or larger. The logging speed is usually about 6 m/minute and can be run in air- and/or water-filled holes depending on the sensor. Data sampling rate ranges from 1 to 5 samples per second, providing a measurement every 2 to 10 cm along the hole.

The GSC truck-mounted system has five logging tools (probes) with different sensors that in total can measure up to twelve parameters. The characteristics of the logging tools and their measuring principles are briefly described below.

General Description of GSC Logging Tools and Geologic Responses

1. GAMMA-RAY SPECTRAL LOGGING

1.1 Geologic 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 concentrations of these naturally occurring radioelements vary between different rock types, natural gamma-ray logging provides an important tool for lithologic mapping and stratigraphic correlation. Gamma-ray logs are important for detecting alteration zones, and for providing information on rock types. For example, in sedimentary rocks, sandstones can be easily distinguished from shales due to the low potassium content of the sandstones compared to the shales.

In sedimentary rocks, potassium is in general the principal source of natural gamma radiation, primarily originating from clay minerals such as illite and montmorillonite. In igneous and metamorphic geologic environments, the three sources of natural radiation may contribute equally to the total number of gamma rays detected by the gamma probe. Often in base metal and gold exploration areas, the principal source of the natural gamma radiation is potassium because alteration, characterized by the development of sericite (sericitization), is prevalent in some of the lithologic units and results in an increase in the element potassium in these units. This renders sericitized zones excellent targets for gamma-ray logging. The presence of feldspar porphyry sills, which contain increased concentrations of K-feldspar minerals, would also show higher than normal radioactivity on the gamma-ray logs. During metamorphism and hydrothermal alteration processes, uranium and thorium may be preferentially concentrated in certain lithologic units.

1.2 Principle of Gamma-Ray Spectral Logging

A gamma-ray probe's sensor is usually a sodium iodide or cesium iodide scintillation detector. Unlike an ordinary gamma-ray tool which only counts the total gamma rays, the spectral gamma-ray tool also measures the energy of each gamma ray detected. K, U and Th produce gamma rays with characteristic energies so geophysicists can estimate the individual concentrations of the three radioelements.

Potassium decays into two stable isotopes (argon and calcium) which are no longer radioactive, and emits gamma rays with energies of 1.46 MeV. Uranium and thorium, however, decay into daughter-product isotopes which are unstable (i.e. radioactive). The decay of uranium forms a series of about a dozen radioactive elements in nature which finally decay to a stable form of lead. The decay of thorium forms a similar series of radioelements. As each radioelement in the disintegration series decays, it is accompanied by emissions of alpha or beta particles or gamma rays. These gamma rays have specific energies associated with the decaying radioelement. The most prominent of the gamma rays in the uranium series originates from decay of ^{214}Bi (bismuth), and in the thorium series originates from decay of ^{208}Tl (thallium).

Because there should be an equilibrium relationship between the daughter product and parent, it is possible to compute the quantity (concentration) of parent uranium (^{238}U) and thorium (^{232}Th) in the decay series by counting gamma rays from ^{214}Bi and ^{208}Tl respectively, if the probe has been properly calibrated (Killeen, 1982).

During each second while the probe is moving along the hole, the gamma rays are sorted by energy into an energy spectrum. The number of gamma rays in three pre-selected energy windows centred over ^{40}K, ^{214}Bi and ^{208}Tl peaks in the spectrum is computed, 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 (TC 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 percent K, ppm U and ppm Th. 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.

1.3 The GSC 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 media is a 9-track magnetic tape. Scintillation detectors of different materials, and of different sizes are used by the GSC. These include:

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 selection of probe (and detector) for logging is determined by the hole diameter. The largest diameter probe that will safely fit in the borehole is selected to maximize the count rate and provide good 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, such as is often the case in limestones for example, it may not be possible to produce K, U and Th logs. In that case only the Total Count log is produced which is the count rate of all gamma rays above a preselected energy threshold (usually 100 KeV or 400 KeV). 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 radioactivity and the size of detector in the probe. Gamma-ray spectral logging is usually done at 3 m/minute but can be done as fast as 6 m/minute or as slow as 0.5 m/minute for more detailed information. The volume sampled is about 0.5 cubic metres of rock surrounding the detector, at each measurement (i.e. 10 to 30 cm radius depending on the rock density).

2. DENSITY/SPECTRAL GAMMA-GAMMA (SGG) LOGGING

2.1 Geologic Interpretation of Density and SGG Logs

The density/SGG logging tool measures rock density and SGG ratio. The SGG ratio (defined below) is related to the effective atomic number of the rock, which depends on the chemical composition of the rock. The SGG ratio log is particularly useful for detecting base metals since these elements have high atomic numbers compared to most rock forming minerals, and they can occur in high enough concentrations to significantly increase the effective atomic number of the rock. The SGG ratio log may also be useful for lithologic mapping in areas where the iron content differs significantly between different rock types.

The density of rock is affected by porosity, water content and chemical composition. Most of the density variations within igneous and metamorphic rocks are due to variations in mineralogical composition. Rocks with higher percentages of mafic minerals (Fe, Mg silicates) have higher densities than those with higher percentages of felsic minerals (Ca, Na, K, Al silicates). The presence of minerals containing heavy elements such as base metals tend to increase the overall density of the host rock. In sedimentary rocks, density variations may be a result of differing degrees of compaction (induration) rather than changes in elemental composition.

In ore tonnage and reserve computations, one of the parameters used is the specific gravity and hence a knowledge of in-situ densities of the rocks may provide valuable information for ore reserve estimations. The density log is also useful for locating fractures since open fractures intersected by the borehole often appear as low density zones on the density log (Wilson et al, 1989).

2.2 The GSC Density/SGG Logging Equipment

The density and SGG ratio (or heavy element indicator) logs are derived from the spectral gamma-gamma probe (Killeen and Mwenifumbo, 1988). The density/SGG tool is essentially a spectral gamma-ray logging tool with the addition of a weak (10 millicurie = 370 MBq) gamma-ray source (e.g. ^{60}Co) on the nose of the probe. The tool has a 23 mm by 76 mm (0.9" x 3") cesium iodide detector which measures gamma rays from the source that are backscattered by the rock around the borehole.

Complete backscattered gamma-ray spectra are recorded in 1024 channels over an energy range of approximately 0.03 to 1.0 MeV. Density information is determined from the count 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 there is a change in the density of the rock being measured, the count rates recorded in both windows will increase or decrease due to the associated 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 relatively little 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 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 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 acquired at a logging speed of 6.0 m/minute with a sample time of 1 second, giving a measurement every 10 cm.

3. IP/RESISTIVITY LOGGING

The Induced Polarization (IP) tool consists of an assembly of electrodes which are placed in the borehole, 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) and the resistivity (R) of the rocks. The transmitter is a constant current source located at the surface. A detailed explanation of the IP probe will be given below.

3.1 Geological interpretation of IP/Resistivity Logs

3.1.1 Induced Polarization (IP)

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, 1989). One of the major alteration processes within a number of base metal and gold mining camps is pyritization and this is a target for most IP logging.

3.1.2 Resistivity

The electrical resistivity of rocks depends on several factors including the presence of conductive minerals such as base metal sulphides or oxides and graphite in the rock. Most rocks without these minerals are usually poor conductors and their resistivities are governed primarily by their porosity, degree of fracturing, salinity of the pore water, the degree of saturation of the pore spaces, and to a lesser extent by the intrinsic minerals that constitute the rock. Some alteration processes such as silicification and carbonatization tend to reduce the porosity and hence increase the resistivity of the rock. In igneous and metamorphic rocks, the resistivity log is useful mainly in mapping conductive minerals and fracture zones. In sedimentary rocks, the resistivity log is frequently used in lithologic mapping because changes in lithology are often associated with changes in porosity.

3.2 The IP/Resistivity Logging Tool Description

The transmitter on surface is a constant current source capable of supplying up to 250 mA. There are 4 selectable pulse times for the current waveforms: 0.25s, 0.5s, 1s and 2s (i.e. full waveforms of 1 second to 8 seconds duration). The long pulse times would mean logging at very low speeds in order to avoid errors that may be introduced in smearing measurements over large depth intervals. The volume of rock sampled is roughly related to the electrode spacings. The full waveform is recorded (digitized at 4ms intervals) on 9-track magnetic tape. Logging speed varies in the range 1 to 6 m/minute according to the chosen pulse length (waveform duration). The sample interval is dependant on the chosen logging speed and chosen waveform period. Typically, a 1 second period with a logging speed of 6 m/minute results in sampling every 10 cm along the borehole. This tool must be run in uncased, water-filled holes.

3.2.1 Induced Polarization

The standard IP parameter is the chargeability determined during the early middle or center of the 'off' time of the decaying waveform. The apparent chargeabilities can be measured with 3 types of electrode arrays: 40-cm normal array, lateral array (pole-dipole array) and the 10-cm Dakhnov micronormal array. The downhole current and potential electrodes are gold-plated brass cylinders, 40 mm in diameter.

3.2.2 Resistivity

The resistivity measurements are derived from the waveforms received during the constant current 'on' time of the square waveform, after the initial IP charging effects are over. 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 (Pb) and a return/reference electrode on the surface.

4. MAGNETIC SUSCEPTIBILITY LOGGING

4.1 Geologic 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 (ferromagnetic) rock unit may be an indication of altered zones.

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

4.2 The Magnetic Susceptibility Logging Tool Description

4.2.1 MS Measurement with the Geoinstrument TH-3C Probe

The magnetic susceptibility tool consists of a Geoinstruments model TH-3C probe and 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 converted 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 within the range from 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.

5. TEMPERATURE/TEMPERATURE-GRADIENT LOGGING

5.1 Geologic Interpretation of Temperature Logs

Temperature measurements are used to detect changes in thermal conductivity of the rocks along the borehole or to detect water flow through cracks or fractures. Fractures or shear zones may provide pathways for groundwater to flow if hydrologic gradients exist within the rock mass. Groundwater movements produce characteristic anomalies and their detection may provide information on the location of the fractured rock mass and hence aid in the structural interpretation of the area. The temperature gradient log amplifies small changes in the temperature log, making them easier to detect.

Large concentrations of metallic sulphides and oxides may perturb the isothermal regime locally since metallic minerals have very high thermal conductivities. This perturbation may be delineated with the high sensitivity temperature logging system. This, however, would be observed only in a thermally ‘quiet’ environment. In areas where there are numerous fracture zones with ground water movements, thermal anomalies due to ground water movements are much larger than those that would be observed due to perturbation caused by the presence of metallic minerals.

5.2 The Temperature Logging Tool Description

The ultra-high sensitivity temperature probe designed at the GSC has a 10 cm long tip of thermistor beads with sensitivity of 0.0001 degrees Celsius. Changes in temperature of the fluid in the borehole are measured and sent as a digital signal to the surface. The signal is then converted into true temperature after correcting for the effect of the thermistor time constants; the temperature gradients are computed from the temperature data. All temperature logging is carried out during a downhole run so the sensor is measuring the temperature of the undisturbed fluid. The usual logging speed is 6 m/minute with data sampled every 1/5 of a second (approximately every 2 cm). This high spatial resolution of data is necessary if accurate temperature gradients are to be determined from the temperature data.

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Borehole Geophysical Logs
from the
Hemlo Gold Deposit
Ontario

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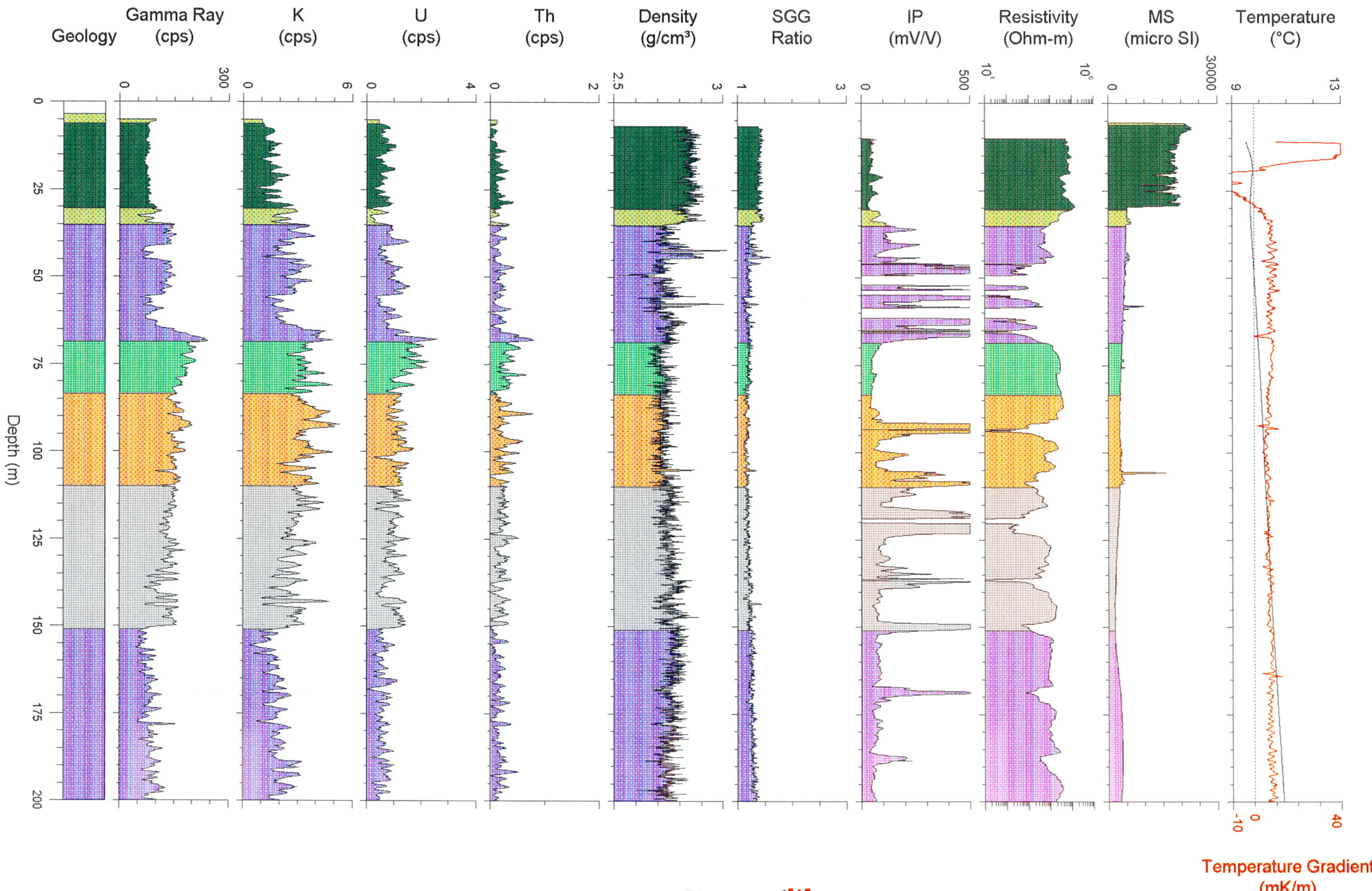
from the
Hemlo Gold Deposit, Ontario

Borehole
NGE-02
Plot 1 of 2



LEGEND

7d	Calc-Silicate Unit
	Diabase
7a	Garnetiferous Unit
6a	Upper Volcaniclastic Member
7e	Siliceous Unit
7b	Pelitic Unit
	Quartz Biotite Unit

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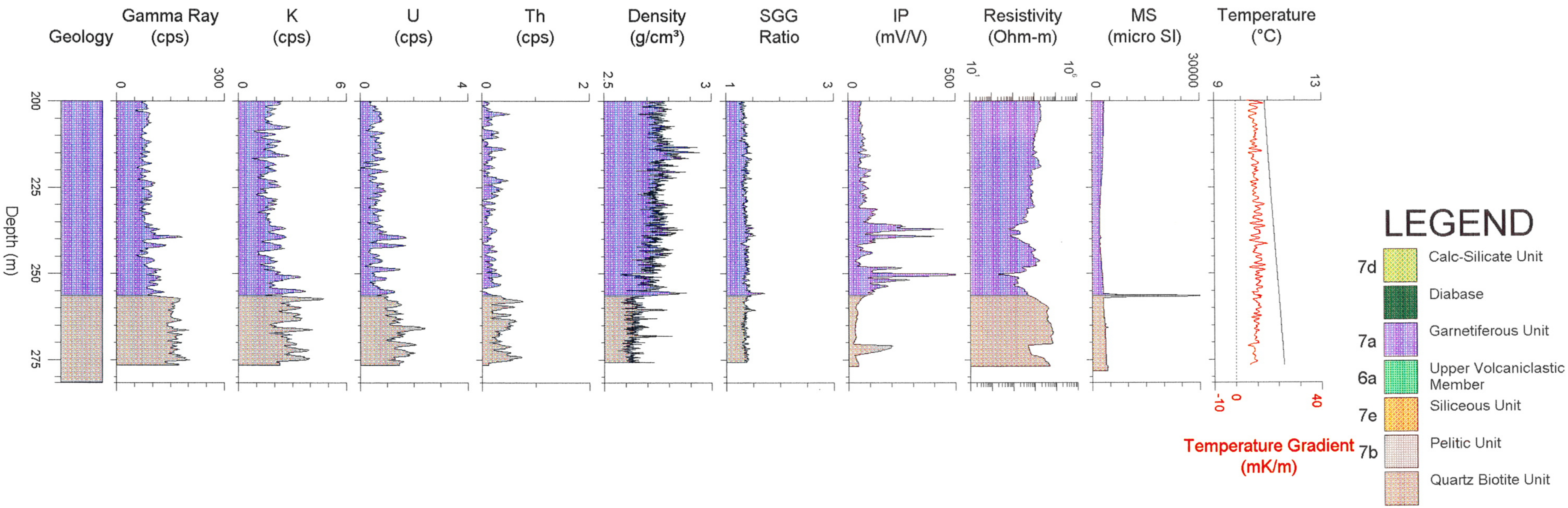
Borehole
NGE-02
Plot 2 of 2



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Borehole Geophysical Logs
from the
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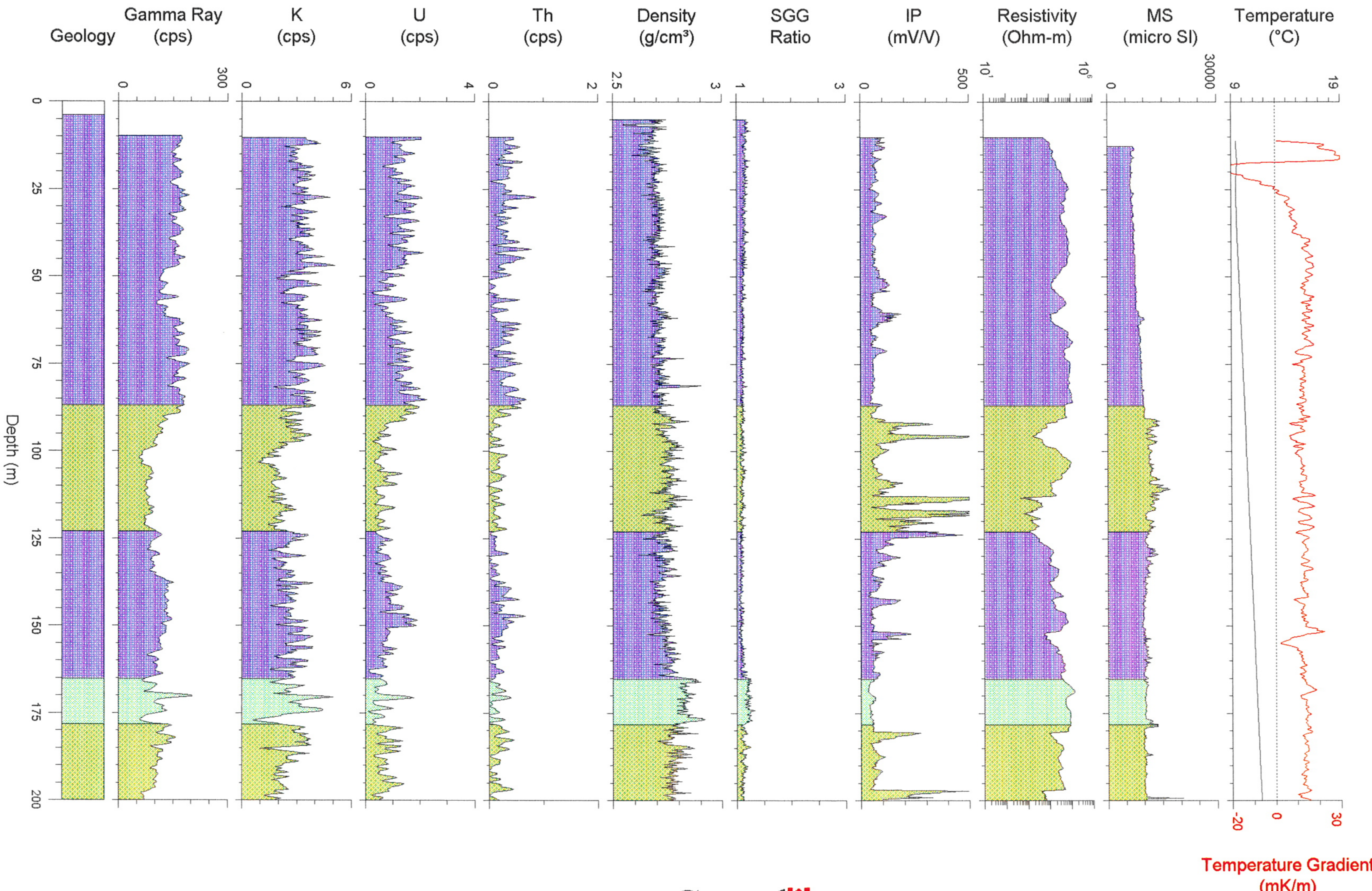
Borehole
NGG-18
Plot 1 of 4



LEGEND

- 7a Garnetiferous Metasediments
- 7d Calc-Silicate Unit
- 7f Chloritic Schist
- 6a Upper Volcaniclastic Member
- 7c Pelitic Metasedimentary
- Quartz Biotite Unit
- Lost Core
- Pelitic Unit
- Pelitic Metasediment-Carbonate Unit
- 7e Siliceous Sulphide Rich Sediment
- Mineralized Series-Contact Horizon
- Lower Schist Formation
- Mineralized Series-Footwall Horizon
- Mafic Dyke
- Quartz Feldspar Porphyry
- Laminated Sediment Formation

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from the
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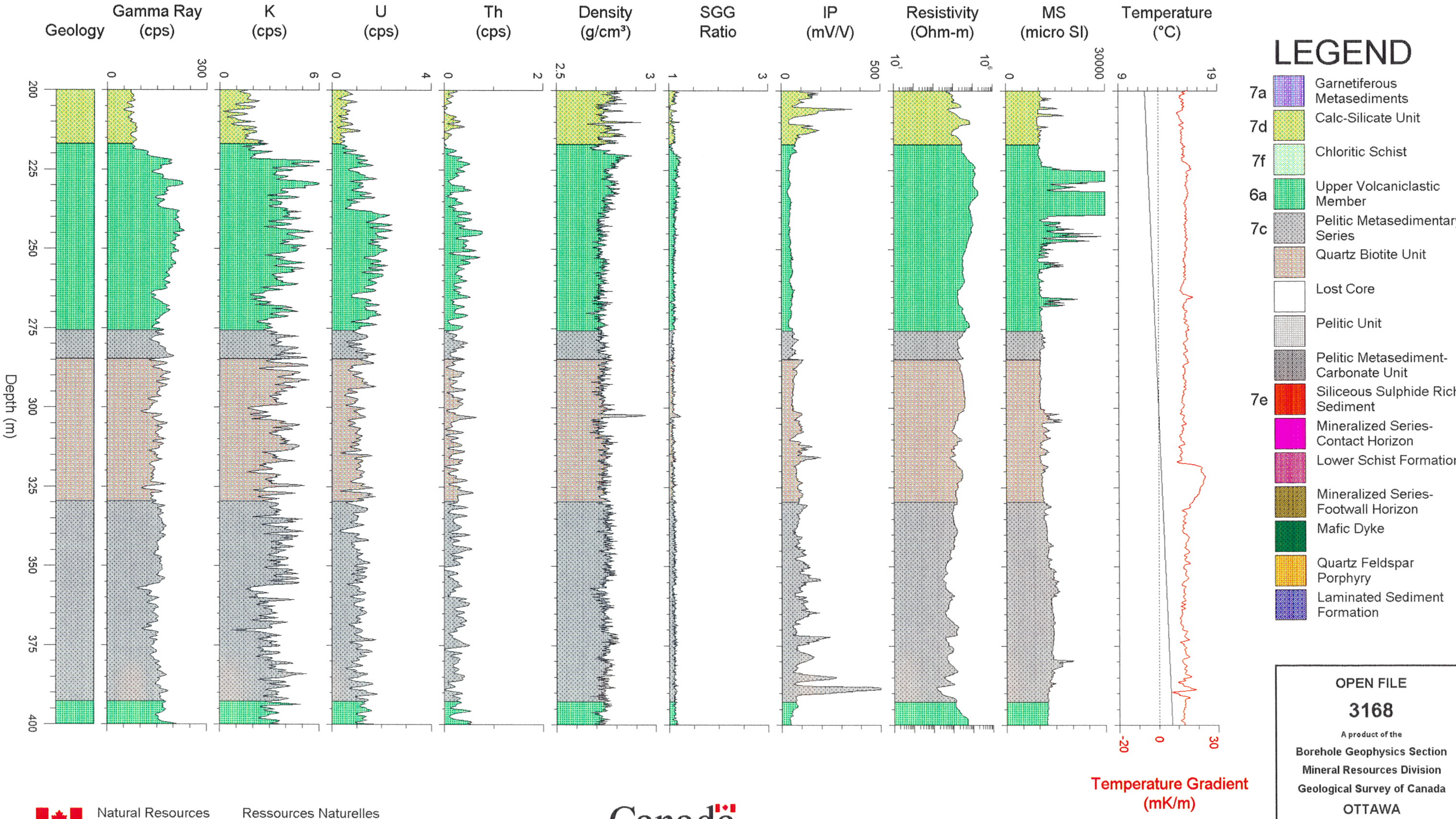
Borehole
NGG-18
Plot 2 of 4



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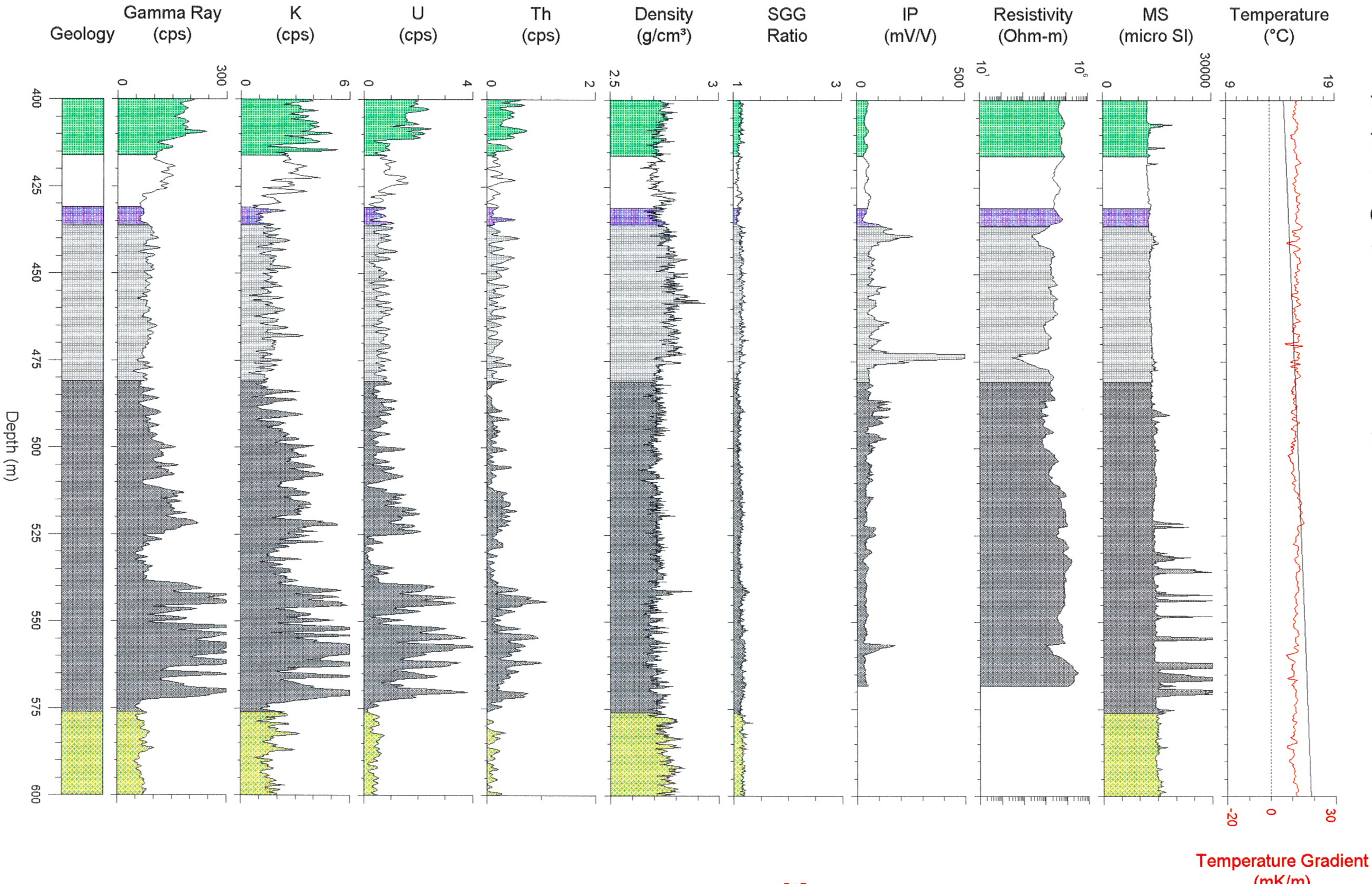
Borehole
NGG-18
Plot 3 of 4



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Borehole Geophysical Logs
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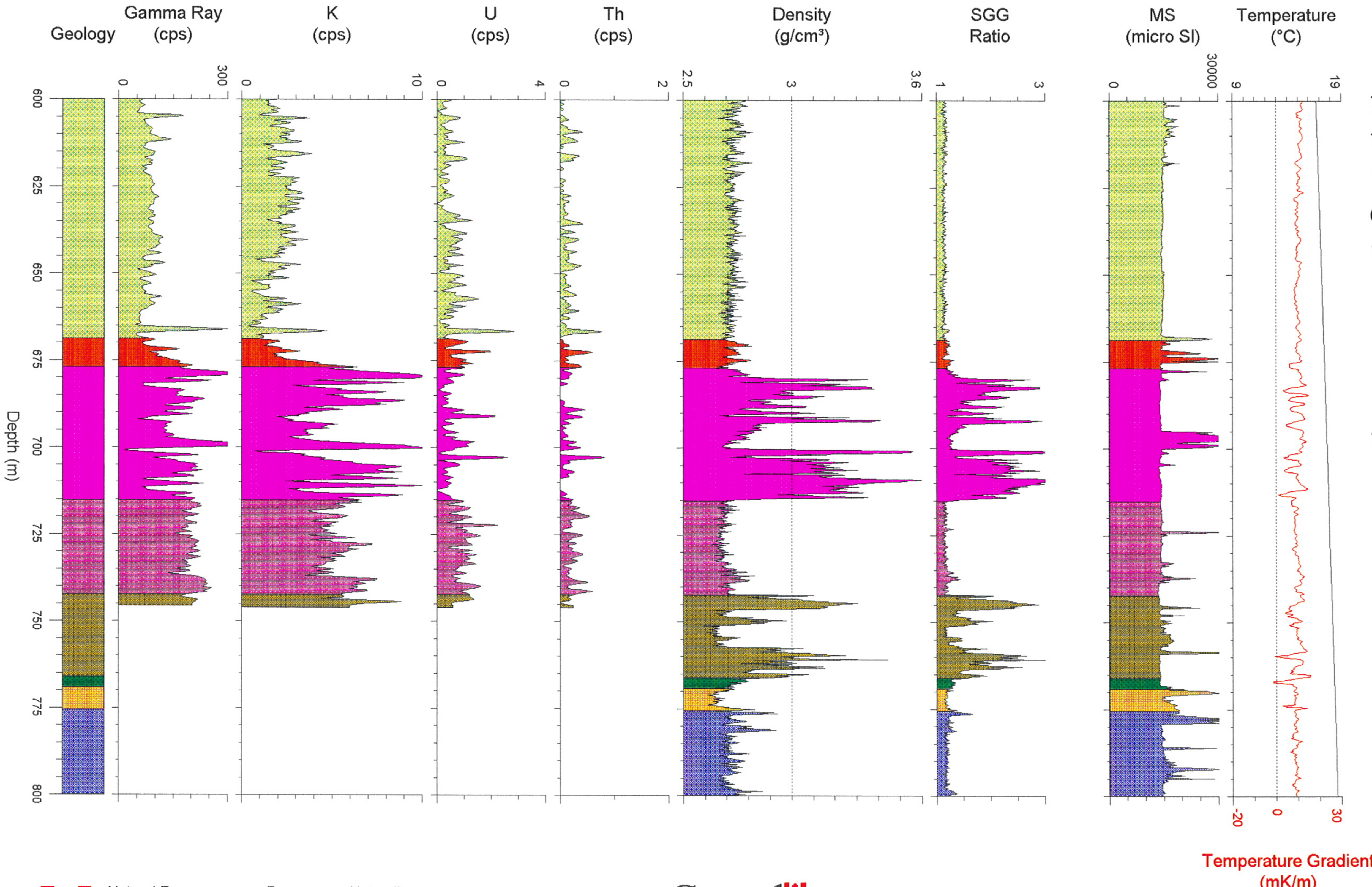
Borehole
NGG-18
Plot 4 of 4



LEGEND

7a	Garnetiferous Metasediments
7d	Calc-Silicate Unit
7f	Chloritic Schist
6a	Upper Volcaniclastic Member
7c	Pelitic Metasedimentary Series
	Quartz Biotite Unit
	Lost Core
	Pelitic Unit
	Pelitic Metasediment-Carbonate Unit
7e	Siliceous Sulphide Rich Sediment
	Mineralized Series-Contact Horizon
	Lower Schist Formation
	Mineralized Series-Footwall Horizon
	Mafic Dyke
	Quartz Feldspar Porphyry
	Laminated Sediment Formation

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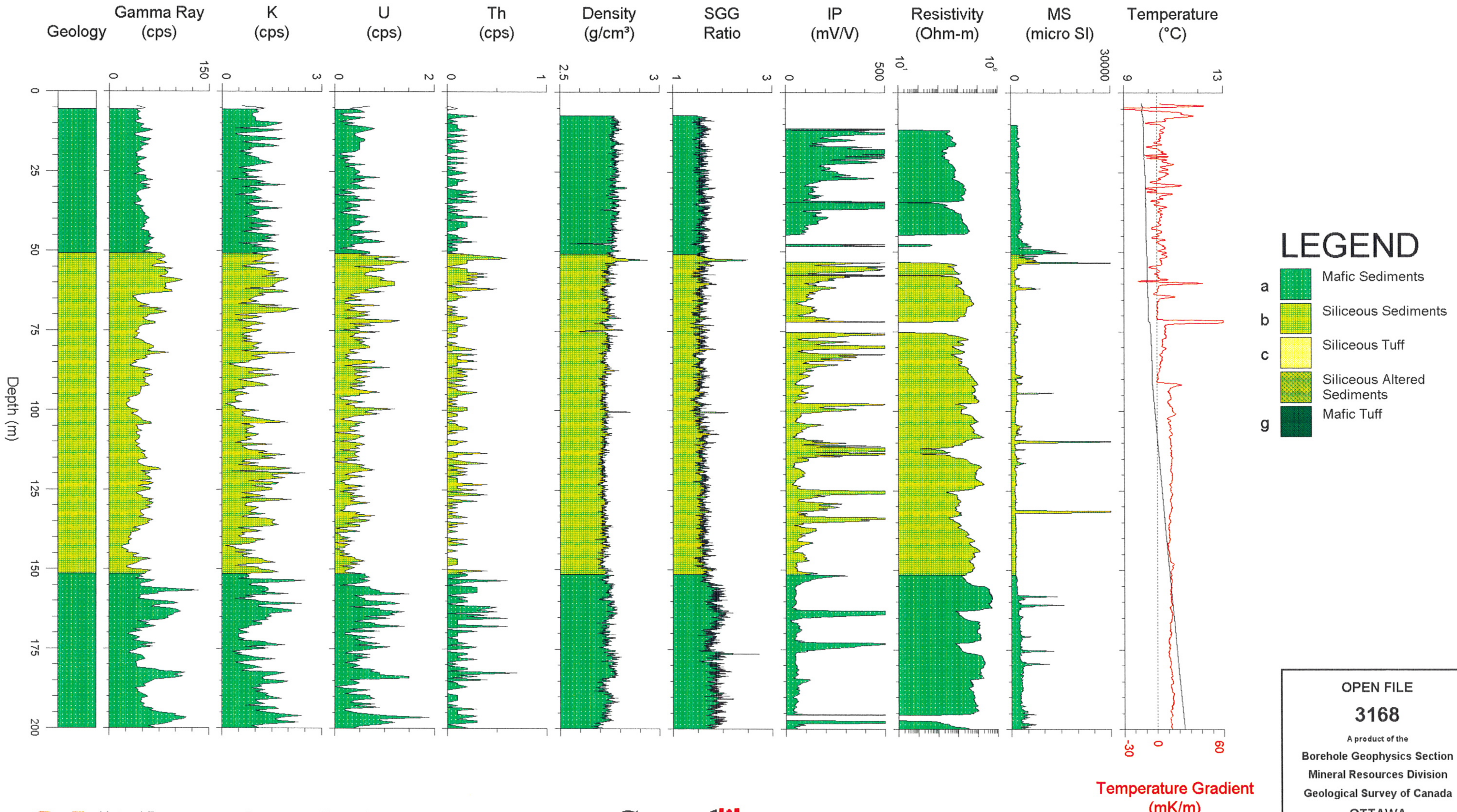
Hemlo Gold Deposit, Ontario

Borehole
TE-173
Plot 1 of 2



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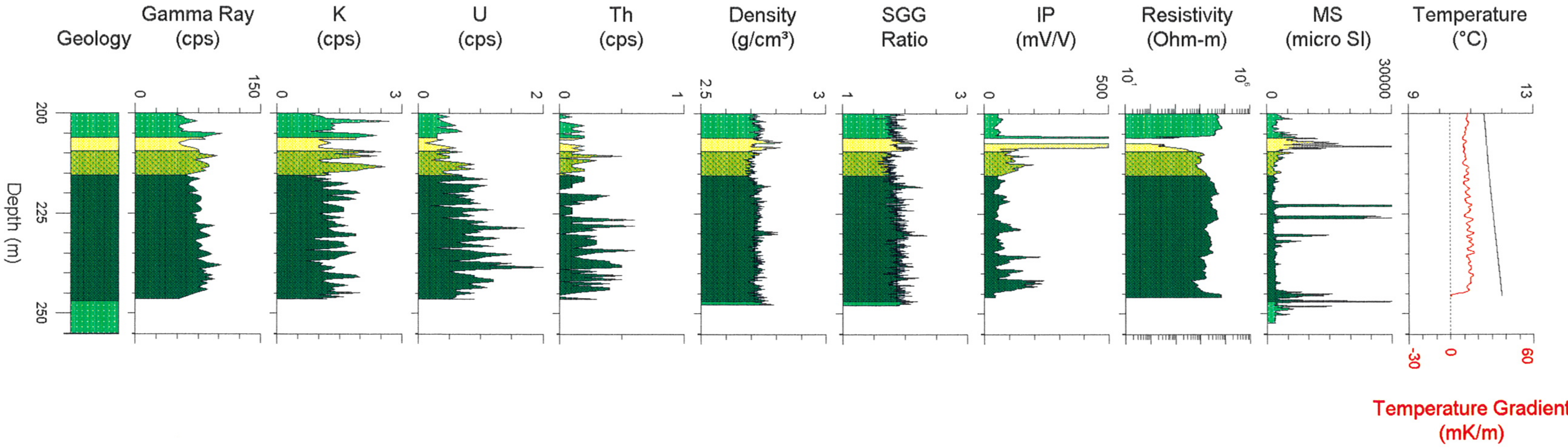

LEGEND

a Mafic Sediments
b Siliceous Sediments
c Siliceous Tuff
Siliceous Altered Sediments
g Mafic Tuff

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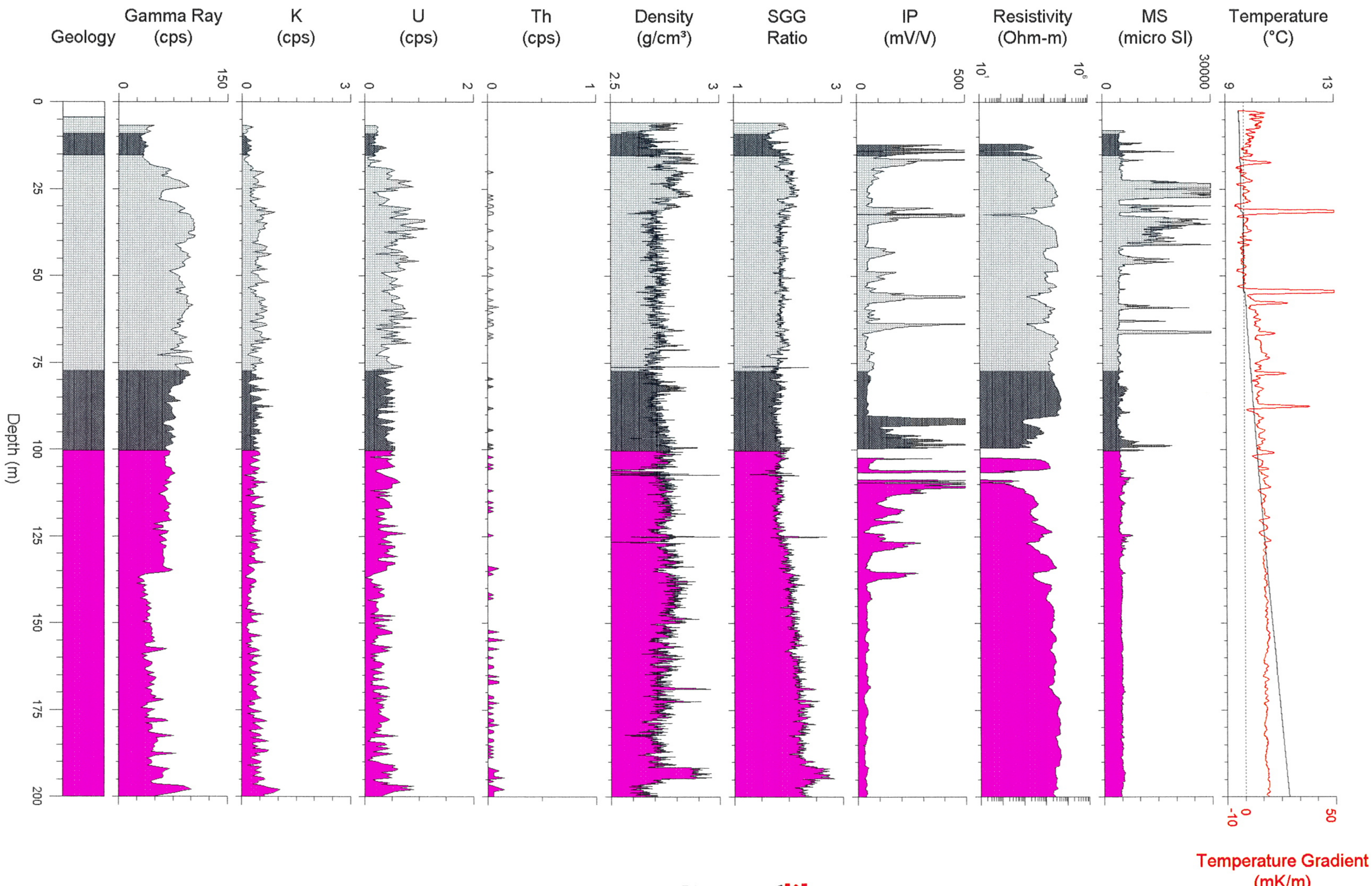
Borehole
TE-179
Plot 1 of 2



LEGEND

- Pelitic Unit
- Shale
- Barren Sulphides
- Felsic Volcanics-Disseminated
- Silicified Felsic Volcanics
- Felsic Volcanics
- Greywacke
- Tuff
- Mafic Dyke
- Sandstone
- Sulphide Rich Tuff

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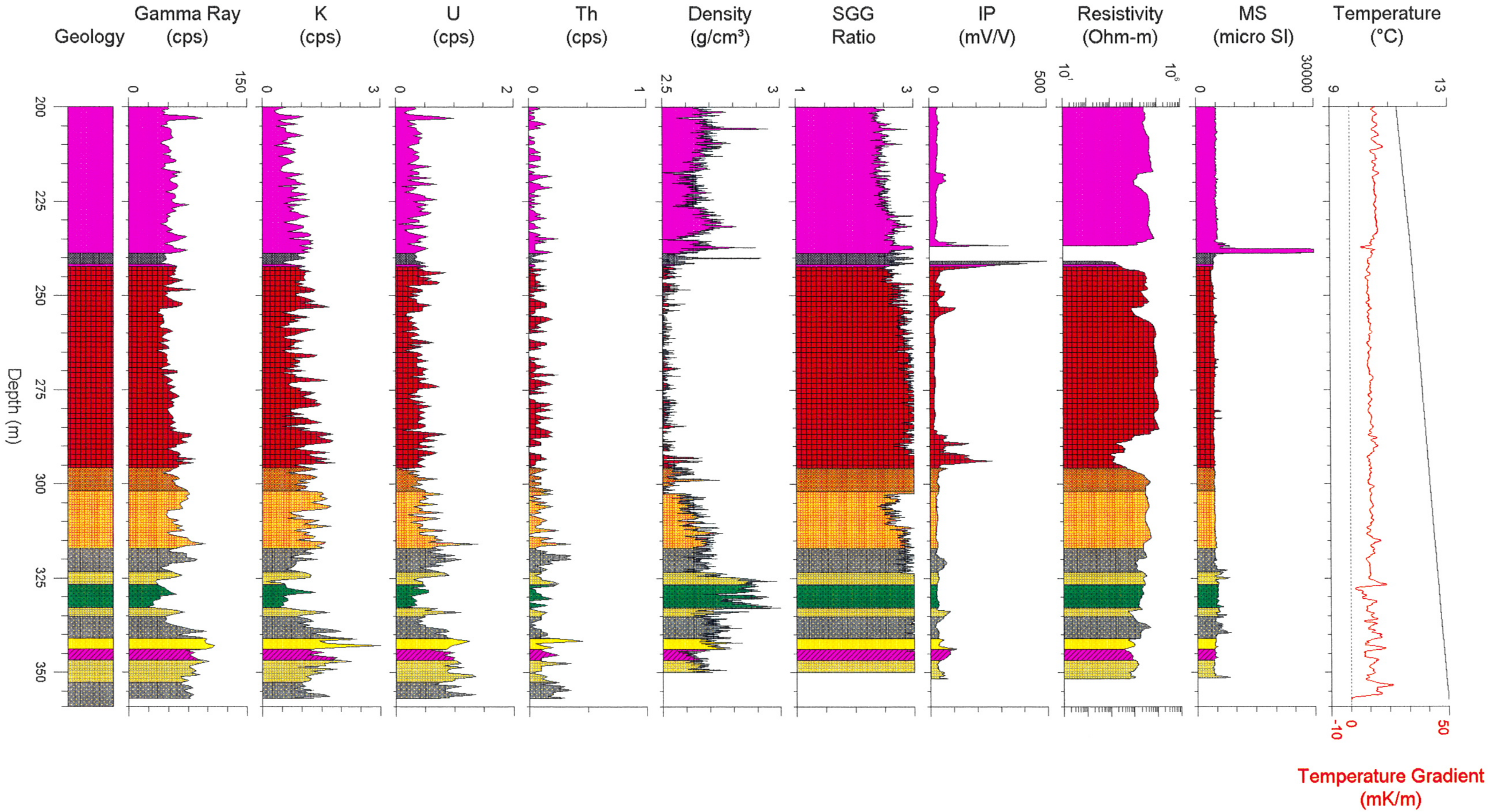
Borehole
TE-179
Plot 2 of 2



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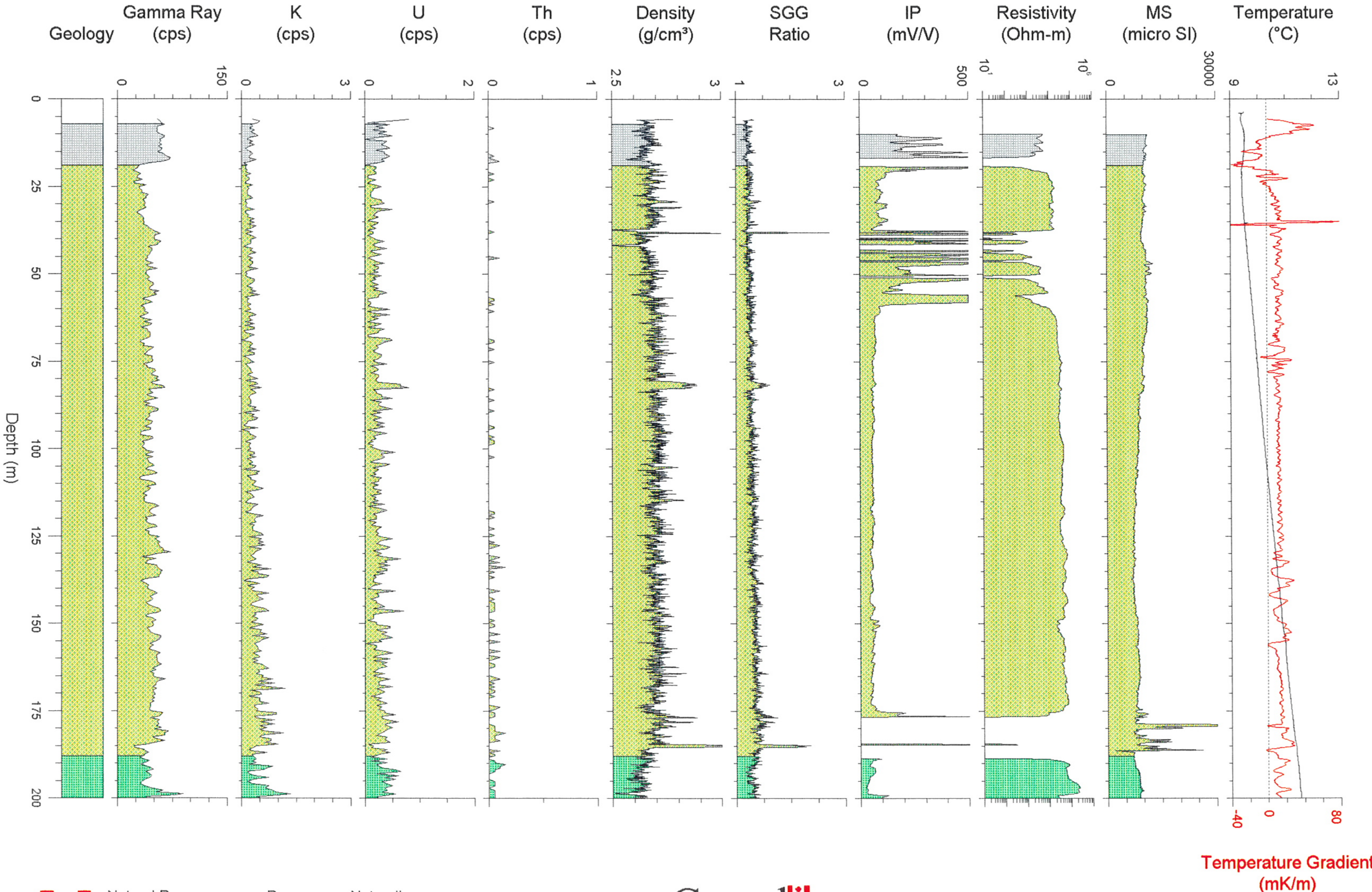
Borehole
TE-192
Plot 1 of 2



LEGEND

- Pelitic Unit
- Calc-Silicate Unit
- Upper Volcaniclastic Member
- Porphyry Series
- Creek Metasedimentary
- Mineralized Zone
- Lower Volcaniclastic Member

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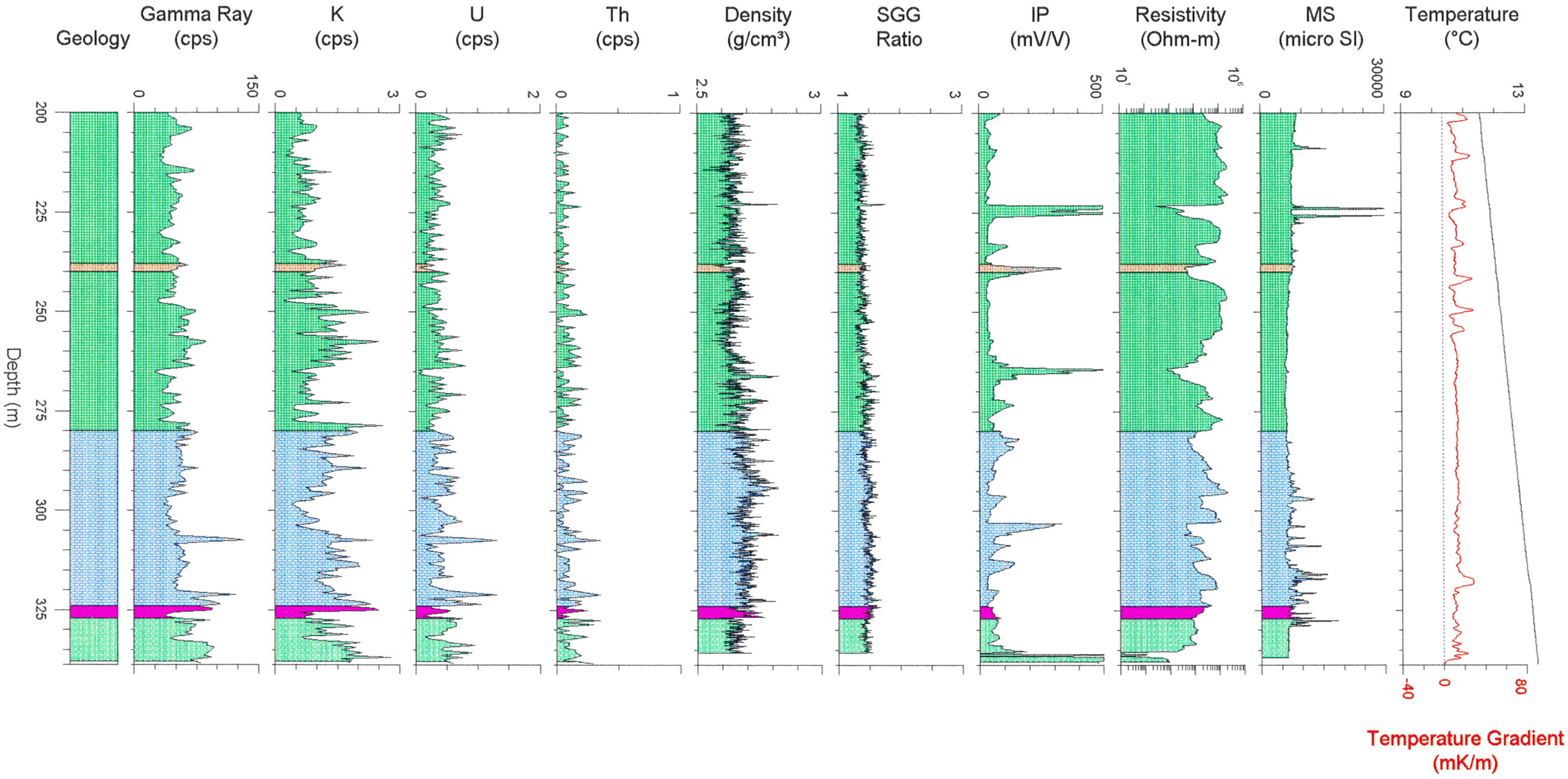
Borehole
TE-192
Plot 2 of 2



LEGEND

- Pelitic Unit
- Calc-Silicate Unit
- Upper Volcaniclastic Member
- Porphyry Series
- Creek Metasedimentary
- Mineralized Zone
- Lower Volcaniclastic Member

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