Geological Applications of Borehole Geophysical Logs in Nova Scotia

(Brazil Lake, Cape Sable Island, Chaswood, New Canaan)

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TABLE OF CONTENTS

1. INTRODUCTION AND BACKGROUND 3

2. GEOLOGY 5
   2.1 Brazil Lake 5
   2.2 Cape Sable Island 5
   2.3 Chaswood 6
   2.4 New Canaan 6

3. LOGGING SYSTEM AND GEOPHYSICAL LOGS 7

4. DATA PROCESSING 9

5. RESULTS OF GEOPHYSICAL LOGGING 10
   5.1 Interpretative Notes 11
      5.1.1 Brazil Lake 11
      5.1.2 Cape Sable Island 11
      5.1.3 Chaswood 12
      5.1.4 New Canaan 13

6. ACKNOWLEDGEMENTS 13

7. REFERENCES 14

APPENDIX 1 - The Logging System

APPENDIX 2 - Plots of Geophysical and Lithological Logs

1. INTRODUCTION AND BACKGROUND

The application of geophysical techniques for mineral and aggregate exploration requires knowledge of the physical properties of the 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. The physical properties are needed for the planning and interpretation of geophysical surveys, and the development of new geophysical survey equipment and techniques.

For several years, the Geological Survey of Canada (GSC) has acquired borehole geophysical logs in numerous holes in mineral deposits and occurrences in Nova Scotia to document their geophysical signatures. Much of this work was jointly funded by the federal and provincial governments under the Canada-Nova Scotia Agreement on Mineral Development, a subsidiary agreement under the Canada-Nova Scotia Economic and Regional Development Agreement.

In a drilling program, the Nova Scotia Department of Natural Resources has investigated the characteristics and economic potential of Be and Li pegmatites of southwestern Nova Scotia. The Brazil Lake and Cape Sable Island geophysical logs of the GSC provide physical property data related to layering or zonation in pegmatites and distribution of Be and Li mineralization. Geophysical investigation of Li and Be concentrations in the pegmatites will add to an evaluation of the economic potential of the Brazil Lake and Cape Sable Island mineralization.

Borehole geophysical measurements were made by the GSC in the Meguma Terrane of Nova Scotia in order to provide geophysical downhole signatures related to lithological changes in the stratigraphic sections near New Canaan, which was previously devoid of information due to sparsity of outcrops. Geophysical measurements were also taken at the Chaswood test site to help determine the economic viability of kaolin clays in the area.

This report presents the results of downhole geophysical measurements which were made using the GSC R&D logging system at four holes in Nova Scotia. The approximate locations of the holes are shown in figure 1. The hole at Chaswood was logged in December of 1995 and the Brazil Lake hole was logged in August of 1994 . The holes at Cape Sable Island and New Canaan were logged in late August and early September of 1993. The geophysical measurements included spectral gamma-ray (total count, potassium, uranium, thorium), density, spectral gamma-gamma ratio (heavy element indicator), resistivity, induced polarization, magnetic susceptibility, temperature and temperature gradient. Some of the data were presented as posters at the annual Open House of the Nova Scotia Department of Natural Resources and some of the Brazil Lake data were published in Nova Scotia Mines and Energy Branch report 95-001 (Killeen and Mwenifumbo, 1995).

2. GEOLOGY

The Brazil Lake, Cape Sable Island, Chaswood and New Canaan boreholes are all located in southern Nova Scotia in the Meguma Terrane. A brief description of the geological setting of each borehole site is presented below.

2.1 Brazil Lake

Brazil Lake, located 25 km northeast of Yarmouth, is an example of the rare-element-bearing pegmatites that occur in the Meguma Terrane of southern Nova Scotia. Recent research (Corey, 1995) has been performed to determine if the Brazil Lake site could sustain economically viable mining operations.

The following description of the Brazil Lake mineralization is taken from Corey (1995):

"The occurrence consists of several northeast-trending, folded sequences of mixed, metavolcanics and metasediments of Ordovician to Silurian age, informally termed the Yarmouth syncline. Recent study (O'Reilly et al., 1992) indicates that the portion of the syncline which hosts the pegmatite also encompasses the extrapolated extension of a regional northeast trending shear zone. The Brazil Lake pegmatite is characterized by the presence of very large (≤60 cm) spodumene crystals, and an accessory mineral assemblage which includes; tourmaline, apatite, cassiterite, wolframite, zircon, columbite/tantalite and epidote."

"Drilling has established the presence of a single, sub-vertical, zoned pegmatite dyke traceable along strike for 100 m and to 75 m depth. The dyke shows considerable variation in thickness ranging from <10 m to approximately 25 m. The drilling suggests that the dyke has a lenticular shape which may thicken to the south."

"The wall rock comprises interbedded, pelite, psammite and amphibolite and minor mafic tuff; and a massive milky to glassy quartz rich unit which occurs above the uphole pegmatite contact. These units show local intense sub-vertical foliation and tourmalinization. Below the downhole contact the host rock is a massive to locally intensely foliated, fine- to medium-grained amphibolite."

"These units have been placed by Hutchinson (1982) within members of the Silurian-Devonian, White Rock Formation as described by Sarkar (1978). The massive, milky to glassy quartz-rich rock has been interpreted by Taylor (1967) and Hutchinson (1982) to be orthoquartzite typical of that occurring within the White Rock Formation."

2.2 Cape Sable Island

A pegmatite outcrop on Cape Sable Island situated adjacent to the contact between the Barrington Passage pluton and the Shelburne pluton was drilled, revealing it to be a zoned, subhorizontal, 25 m thick dyke.

thick layers (≥30 m) of sulphide-rich black shales which show zinc mineralization. The sulphides occur as discrete bedding, parallel laminations, disseminations and veinlets. Lithologies suggest that the black shales occurred in restricted brine pools adjacent to an active volcano.

3. LOGGING SYSTEM AND GEOPHYSICAL LOGS

Table 1 lists the holes logged with their depths and hole sizes for each area. Table 2 lists the geophysical measurements recorded or computed for each hole.

Table 1:Boreholes, depths, depths logged, hole sizes and areas

Hole Number	Total Depth (m)	Depth Logged (m)	Size	Area
BZL-93-4	120.6	119.14	NQ	Brazil Lake
CSI-93-1	191.7	190.75	NQ	Cape Sable Island
MUSC-95-4	122.6	108.6	HQ	Chaswood
NC-91-1	411.48+	376.2	NQ*	New Canaan

* NC-91-1 has hole size NQ to 411.48 m (1350 ft.) and BQ below 411.48 m.

Table 2:Parameters Measured

Hole Number	Gamma Probe	Density/SGG Probe	IP/R Probe	MS Probe	Temperature Probe
BZL-93-4	TC, K, U, Th	DEN, SGGR	IP, RES	MS	TMP, TMG
CSI-93-1	TC, K, U, Th	DEN, SGGR	IP, RES	MS	TMP, TMG
MUSC-95-4	TC, K, U, Th	DEN, SGGR	_	MS	TMP, TMG
NC-91-1	TC, K, U, Th	DEN, SGGR	IP, RES	MS	TMP, TMG

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 are 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 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 located at 136 cm depth when the 'zero' is set on the well head pulley at the beginning of logging. Therefore, all depth values have to be corrected for this 136 cm offset. 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 (spectral gamma and spectral gamma-gamma) and hole size (diameter) corrections for magnetic susceptibility logs. Spectral stripping and conversion to concentrations (%K, ppm U, and ppm Th) may be done for spectral gamma logs if counting statistics warrant. The spectral gamma-gamma density log is a count rate which is inversely proportional to density. Thus raw logs labeled in cps (counts per second) show high values for low density zones. The density logs presented in this open file have been converted from cps to grams per cubic centimetre using the appropriate calibration factors (except for Chaswood).

The third step is to compute any '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 and correct any additional small depth discrepancies that may 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. The corrected geophysical logs are then correlated to the geology if the geological logs are available.

The logs are now ready for interpretation.

5.1 Interpretative Notes

The following interpretative notes are based on observations of the plots presented in Appendix 2 and comparison with the geological log information.

5.1.1 Brazil Lake

1. Several geologic units are distinguishable by the density log, for example the pelites and amphibolites (high density), and the pegmatites (low but variable density).
2. The Temperature and Temperature-gradient logs indicate a significant water flow at about 26 m depth and lesser flows at about 44 m and 60 m.
3. The high resistivity values, decreased density values, and decreased MS values between 110 and 111 m suggest a possible silicified zone such as indicated by the geological log one metre below.
4. There are a few thin zones (at 57, 78, 102 m) with low SGG Ratio values which could be indicative of the presence of low atomic number material such as beryllium and lithium minerals.
5. Pegmatites are clearly outlined by low magnetic susceptibility and high count rates in the natural gamma-ray log. The gamma-ray logs also indicate the relative inhomogeneity of the pegmatite which contains numerous thin zones of higher activity. The variability in the U-log implies that much of this is due to uranium variations. It is interesting to note that the Th-log shows a lower concentration in the pegmatites than the adjacent rocks, including the amphibolites which usually have low radioactivity. A thin zone of relatively high magnetic susceptibility occurs in the middle of the pegmatite (60 to 89 m) at a depth of about 67 m suggesting increased magnetite content. (The very slight increase in MS values with depth, across the pegmatites, is likely a small drift in the electronics.
6. The amphibolite between 97 and 100 m has been silicified, which explains its low density compared to the other amphibolites. The amphibolite between 30 and 33 m is more magnetic than the other amphibolites intersected by the borehole.
7. The 'mineralized zone' is anomalously low in radioactivity compared to the enclosing pegmatite, except for a thin zone between 55 and 56 m. It is also characterized by very low magnetic susceptibility.

5.1.2 Cape Sable Island

1. The reduction in density, resistivity and induced polarization at approximately 14 m may be caused by a 15 cm garnet-bearing aplite zone mentioned in the geological log at that depth. Similar zones at 9 m and 22 m, may also be aplite. The small decrease in density and induced polarization in the pegmatite at 22 m could also be caused by the 20 cm wide biotite chlorite-rich foliated metasediment xenolith described in the geological log.

5.1.4 New Canaan

1. The geological log was not available for borehole NC-91-1.

2. Very low gamma-ray counts such as observed from 234 to 236 m may be indicative of limestone units.

3. In general the New Canaan borehole can be separated into two different geophysical zones. The upper zone, above 266 m, has high resistivities and low gamma-ray counts, magnetic susceptibilities and IP values. The lower zone has low resistivities and high magnetic susceptibilities, IP values, gamma-ray counts, potassium, uranium, and thorium concentrations. High gamma-ray values in the lower zone suggest shales, while the low resistivities, high IP values, and high magnetic susceptibility are possibly indicative of sulphides in these shales.

4. The temperature gradient log displays considerable fluctuations from about 280 m to the bottom of the borehole indicating small water flows in fractures or bedding planes. Fluctuations in temperature gradient can also be caused by changes in thermal conductivity due to the presence of sulphides (Mwenifumbo, 1993).

6. ACKNOWLEDGEMENTS

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Stea, R.R., Finck, P.W., Pullan, S.E. and Corey, M.C., 1996a, Cretaceous Deposits of Kaolin and Silica Sand in the Shubenacadie and Musquodoboit Valleys, Nova Scotia, Canada, Nova Scotia Department of Mines and Energy, Open File Report 96-003.

Stea, R.R., Finck, P.W., Pullan, S.E. and Corey, M.C., 1996b: Shubenacadie and Musquodoboit Basins showing the extent of early Cretaceous sediments. (Part of map Sheet 11E/03), Colchester and Halifax Counties, Nova Scotia.

Taylor, F.C., 1967, Reconnaissance Geology of the Shelburne map area; Geological Survey of Canada, Memoir 349, Natural Resources Assessment Report 20P/13C 29-R-02(02), p. 83.

APPENDIX 1 - The Logging System

TABLE OF CONTENTS

1. THE GSC BOREHOLE GEOPHYSICAL LOGGING SYSTEM 1

2. GAMMA-RAY SPECTRAL LOGGING 2
   2.1 Geological Interpretation of Gamma-Ray Spectral Logs 2
   2.2 Principle of Gamma-Ray Spectral Logging 2
   2.3 The Gamma-Ray Spectral Logging Equipment 3

3. DENSITY/SPECTRAL GAMMA-GAMMA (SGG) LOGGING 4
   3.1 Geological Interpretation of Density and SGG Logs 4
   3.2 The Density/SGG Logging Equipment 4

4. INDUCED POLARIZATION (IP)/RESISTIVITY LOGGING 5
   4.1 Geological interpretation of IP/Resistivity Logs 5
      4.1.1 IP 5
      4.1.2 Resistivity 6
   4.2 The IP/Resistivity Logging Probe Description 6
      4.2.1 IP 6
      4.2.2 Resistivity 6

5. MAGNETIC SUSCEPTIBILITY (MS) LOGGING 7
   5.1 Geological Interpretation of MS Logs 7
   5.2 The MS Logging Probe Description 7

6. TEMPERATURE/TEMPERATURE GRADIENT LOGGING 7
   6.1 Geological Interpretation of Temperature Logs 7
   6.2 The Temperature Logging Probe Description 8

7. REFERENCES 9

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 to convert the signal to digital form for recording;
5. a computer, keyboard and 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 and portable 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 characteristics of the logging probes used at Brazil Lake, New Canaan, Cape Sable Island and Chaswood and their measuring principles are briefly described below.

^{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 the daughter products ^{214}Bi and ^{208}Tl, respectively, if the probe has been properly calibrated (Killeen, 1982).

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 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 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 almost no 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 (IP)/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/Resistivity Logs

4.1.1 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

5. MAGNETIC SUSCEPTIBILITY (MS) LOGGING

5.1 Geological Interpretation of MS 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 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.

6. TEMPERATURE/TEMPERATURE GRADIENT LOGGING

6.1 Geological 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.

7. REFERENCES

Bristow, Q. and Bernius, G., 1984: Field evaluation of a magnetic susceptibility logging tool; in Current Research, Part A, Geological Survey of Canada, Paper 84-1A, pp. 453-462.

Bristow, Q. and Conaway, J.G, 1984: Temperature gradient measurements in boreholes using low noise high resolution digital techniques; in Current Research, Part B, Geological Survey of Canada, Paper 84-1B, pp. 101-108.

Bristow, Q., 1985: A digital processing unit for the GeoInstruments magnetic susceptibility sensors, with analogue and RS-232C outputs; in Current Research, Part B, Geological Survey of Canada, Paper 85-1B, pp. 463-466.

Killeen, P.G., 1982: Borehole logging for uranium by measurement of natural gamma radiation - a review; International Journal of Applied Radiation and Isotopes, Vol. 34, No. 1, pp. 231-260.

Killeen, P.G., 1986: A system of deep test holes and calibration facilities for developing and testing new borehole geophysical techniques; in Borehole Geophysics for Mining and Geotechnical Applications, ed. P.G. Killeen, Geological Survey of Canada, Paper-85-27, 1986, pp. 29-46.

Killeen, P.G. and Mwenifumbo, C.J., 1988: Downhole assaying in Canadian mineral deposits with the spectral gamma-gamma method; in Current trends in nuclear borehole logging techniques for elemental analysis, IAEA-TECDOC-464, pp. 23-29.

Mwenifumbo, C.J., 1989: Optimization of logging parameters in continuous, time-domain induced polarization measurements; in Proceedings of the Third International Symposium on Borehole Geophysics for Minerals, Geotechnical, and Groundwater Applications, Oct. 2-5, Las Vegas, Nevada, pp. 201-232.

Mwenifumbo, C.J., 1993: Temperature logging in mineral exploration. Journal of Applied Geophysics, Volume 30: pp. 297-313.

Mwenifumbo, C.J. and Killeen, P.G., 1987: Natural gamma-ray logging in volcanic rocks: the Mudhole and Clementine base metal prospects; in Buchans Geology, Newfoundland, ed. R.V. Kirkham; Geological Survey of Canada, Paper 86-24, pp. 263-272, Report 16, 1987.

Wilson, H.C., Michel, F.A., Mwenifumbo, C.J. and Killeen, P.G., 1989: Application of borehole geophysics to groundwater energy resources; in Proceedings of the Third International Symposium on Borehole Geophysics for Minerals, Geotechnical, and Groundwater Applications, 2-5 Oct., 1989, Las Vegas, Nevada, pp. 317-336.

APPENDIX 2 - Plots of Geophysical and Lithological Logs

The following 7 plots are included in this appendix.
The depths are hole lengths and not true vertical depths of the hole.

Brazil Lake	Borehole BZL-93-4	Multiparameter logs, depths 0 to 120 m
Cape Sable Island	Borehole CSI-93-1	Multiparameter logs, depths 0 to 120 m
Cape Sable Island	Borehole CSI-93-1	Multiparameter logs, depths 120 to 190 m
Chaswood	Borehole MUSC-95-4	Multiparameter logs, depths 0 to 110 m
New Canaan	Borehole NC-91-1	Multiparameter logs, depths 0 to 120 m
New Canaan	Borehole NC-91-1	Multiparameter logs, depths 120 to 240 m
New Canaan	Borehole NC-91-1	Multiparameter logs, depths 240 to 370 m

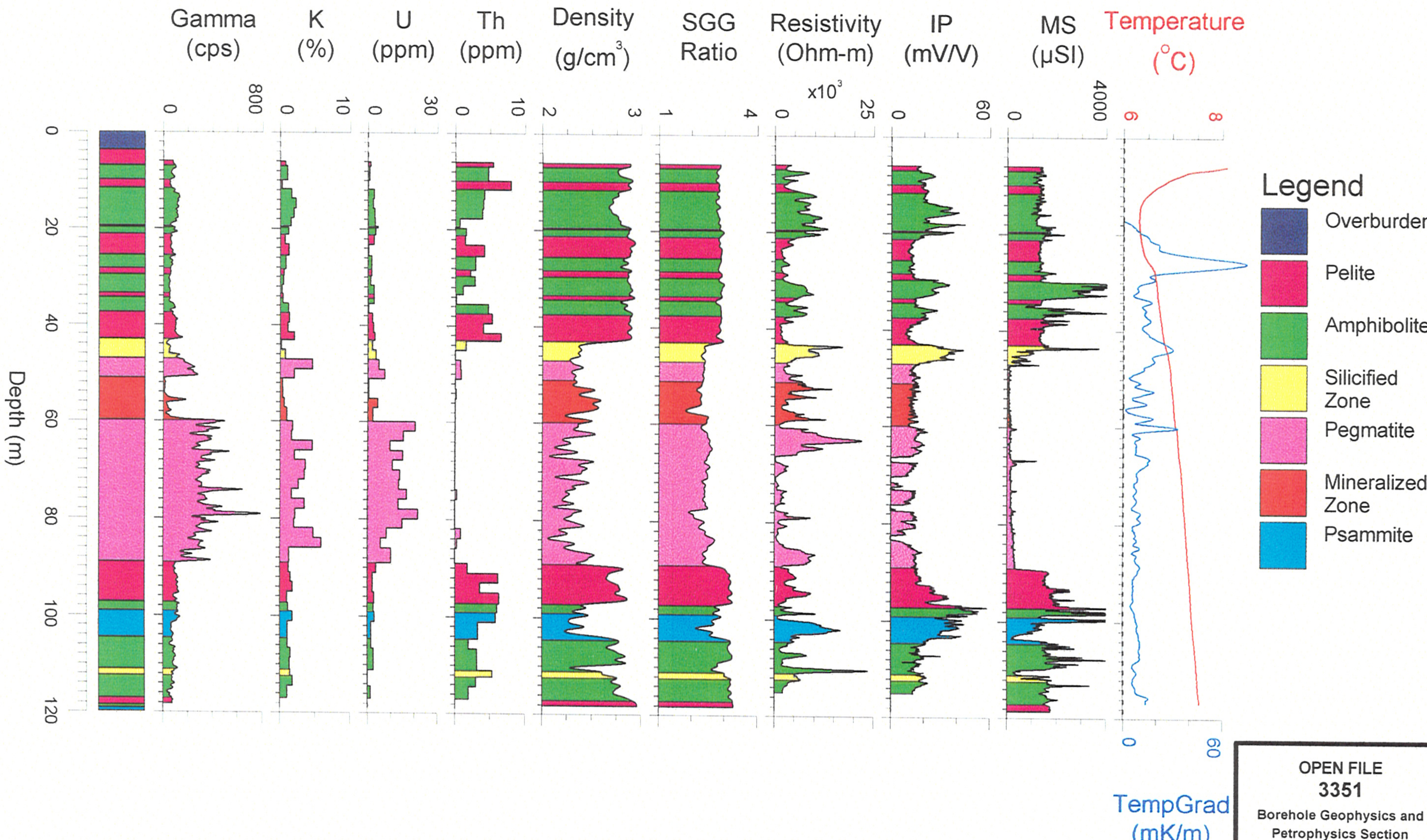
Abbreviations:
Gamma - Total count gamma ray
K - Potassium
U - Uranium
Th - Thorium
SGG - Spectral gamma-gamma
IP - Induced Polarization
MS - Magnetic Susceptibility
TempGrad - Temperature Gradient

Reference:
The granularity log for Chaswood, borehole MUSC-95-4 was reproduced from the following publication:

Stea, R.R., Finck, P.W., Pullan, S.E. and Corey, M.C., 1996: Shubenacadie and Musquodoboit Basins showing the extent of early Cretaceous sediments. (Part of map Sheet 11E/03), Colchester and Halifax Counties, Nova Scotia.

Borehole Geophysical Logs
Brazil Lake, Nova Scotia

BOREHOLE
BZL-93-4



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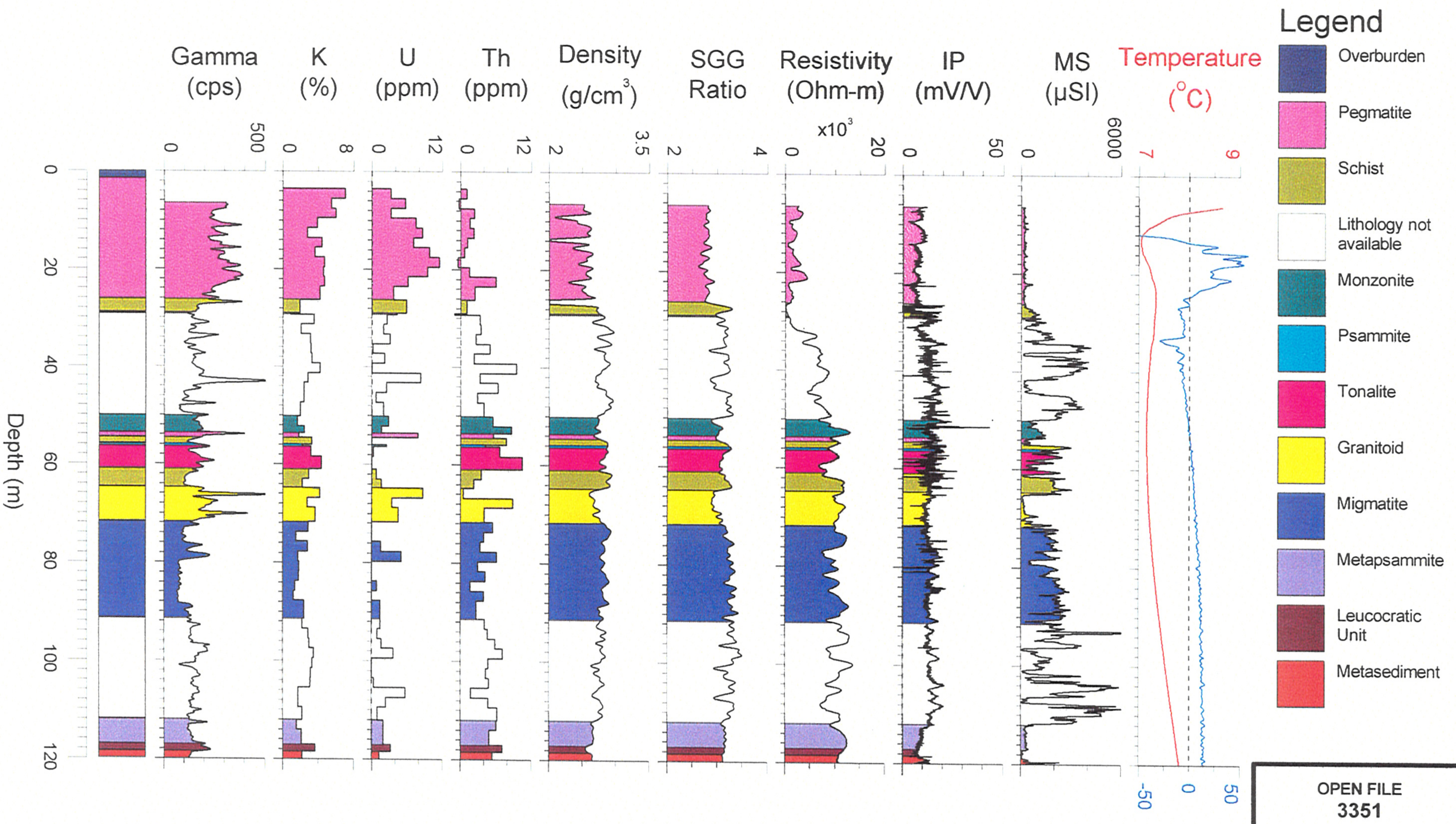
Borehole Geophysical Logs
Cape Sable Island, Nova Scotia

BOREHOLE
CSI-93-1
Plot 1 of 2



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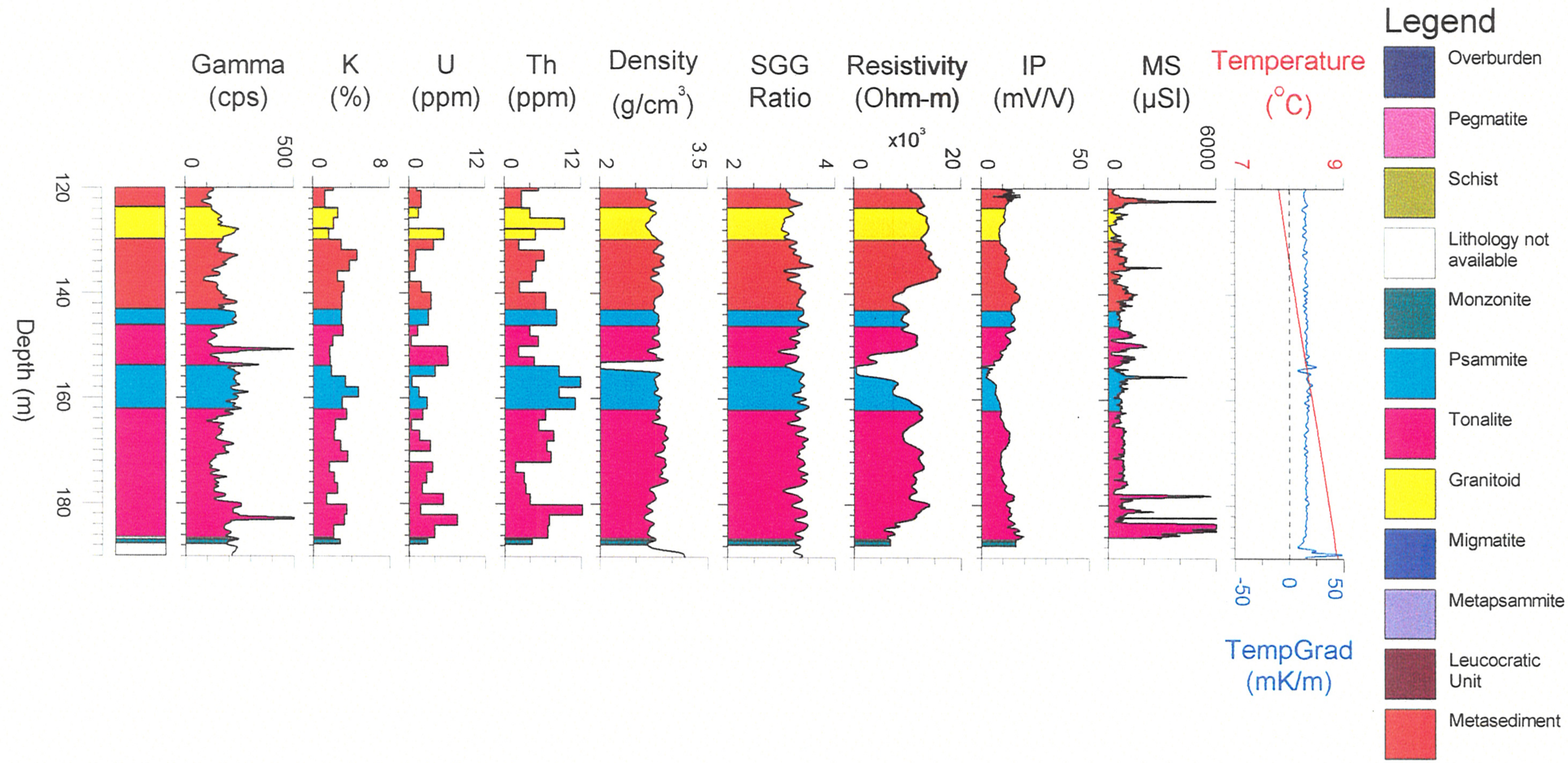
Borehole Geophysical Logs
Cape Sable Island, Nova Scotia

BOREHOLE
CSI-93-1
Plot 2 of 2



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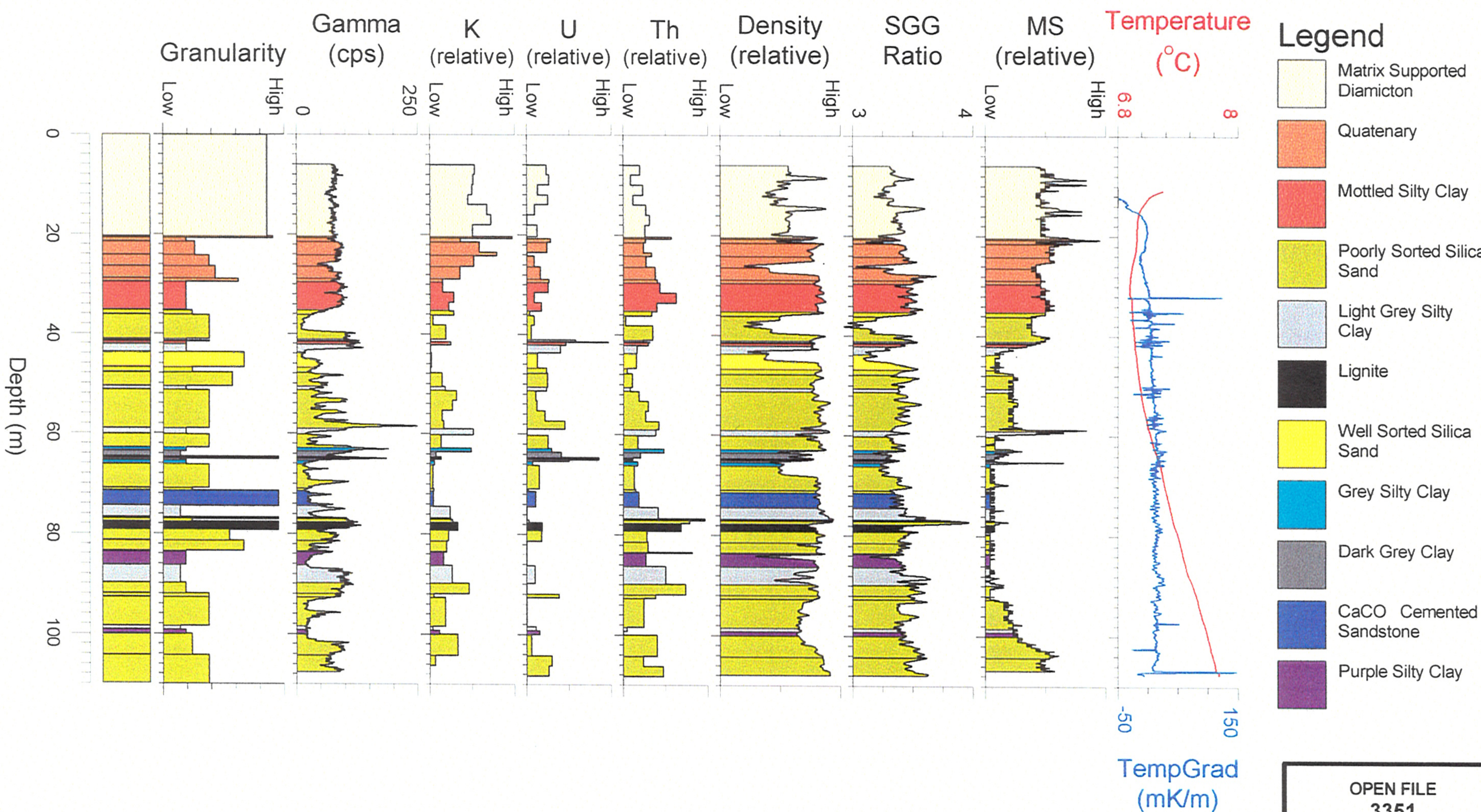
Borehole Geophysical Logs
Chaswood, Nova Scotia

BOREHOLE
MUSC-95-4



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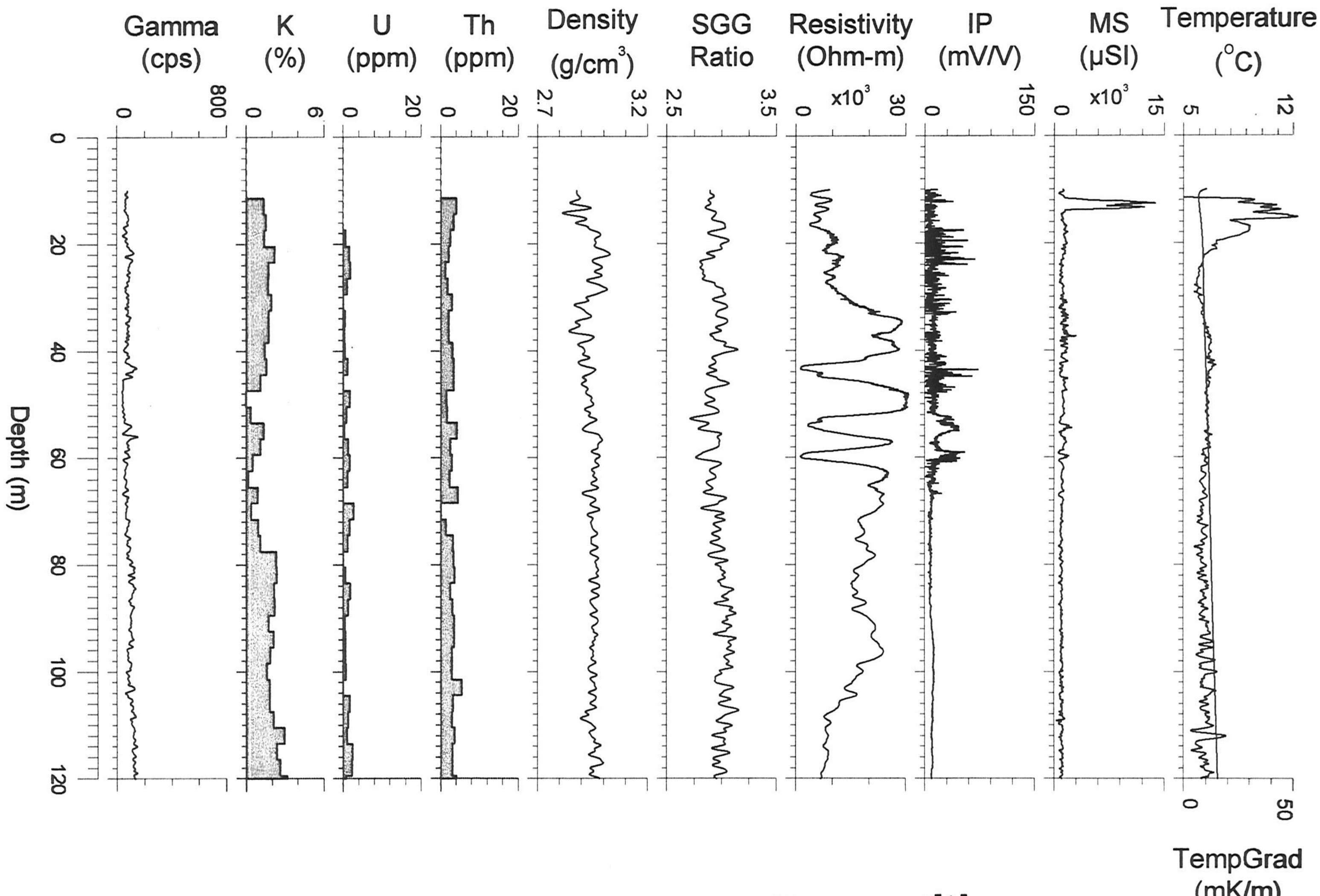
Geological Survey of Canada
OTTAWA
2001

Borehole Geophysical Logs
New Canaan, Nova Scotia

BOREHOLE
NC-91-1
Plot 1 of 3



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Borehole Geophysical Logs
New Canaan, Nova Scotia

BOREHOLE
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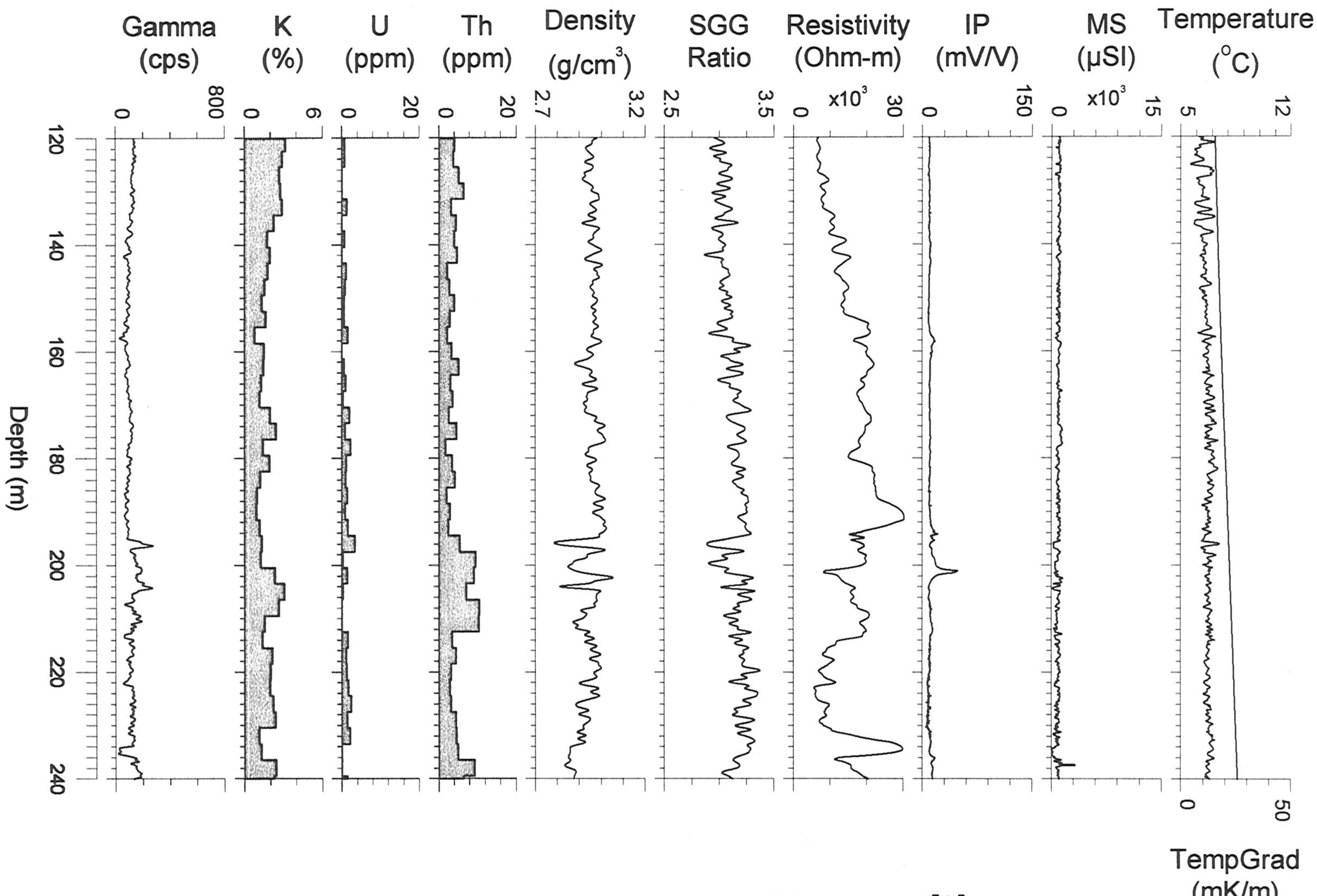
Plot 2 of 3



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New Canaan, Nova Scotia

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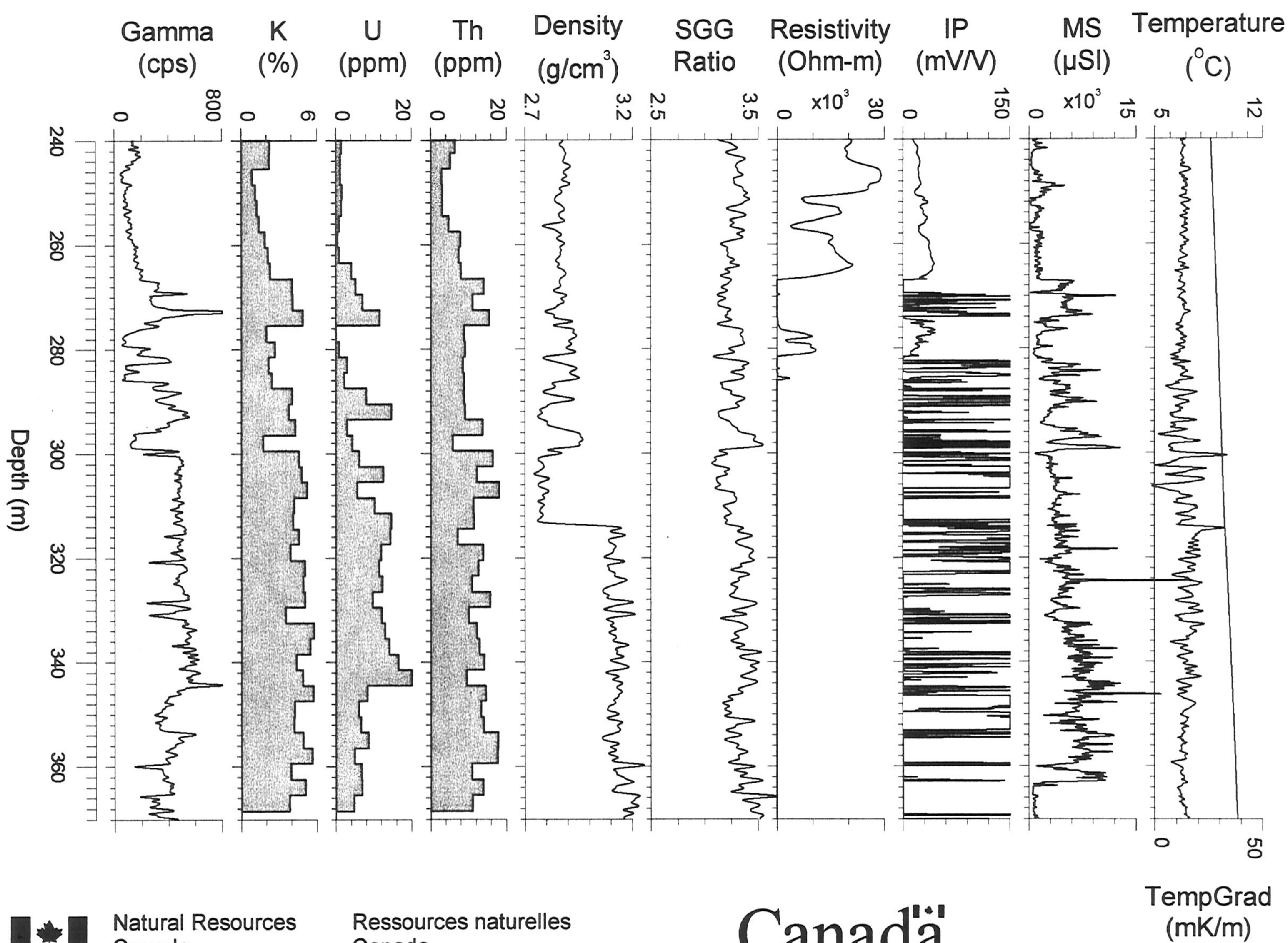
Plot 3 of 3



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