Borehole Geophysical Logs

Overburden Holes, Southeastern Manitoba

C.J. Mwenifumbo, P.G. Killeen and L.H. Thorleifson
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
K1A 0E8

Natural Resources Canada
Ressources naturelles Canada

Canada

OPEN FILE
DOSSIER PUBLIC
2775
Geological Survey of Canada
Commission Géologique Du Canada
OTTAWA

GSC OPEN FILE 2775

BOREHOLE GEOPHYSICAL LOGS OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

C.J. Mwenifumbo, P.G. Killeen and L.H. Thorleifson

INTRODUCTION

A total of seventeen overburden holes were geophysically logged in Southeastern Manitoba as part of a 'Prairie NATMAP' study in 1992. The project was a mineral resource reconnaissance and determination of overburden stratigraphy in support of till geochemistry and indicator mineral tracing as well as regional groundwater studies. Logs of seven parameters were recorded with the GSC R&D logging system in five holes, while the remaining twelve were logged with a portable system made by Geonics of Toronto, which recorded three parameters. Geophysical logs are presented along with their associated geological log, in a series of colour plots. Locations of the holes are shown in the map in figure 1. Table 1 serves as an index to the parameters measured in each hole. An interpretive description of the logs and their relationship to the geology is given for four of the holes logged with the GSC system (Holes B,I,Q and R). Detailed logging tool descriptions are given at the end of this text, along with information about the geologic significance of each type of geophysical measurement. This serves as an aid to interpretation of the seventeen sets of geophysical logs.

Borehole Locations

The holes were approximately 15 cm diameter, lined with 10 cm PVC drainline, which proved adequate to keep most holes open for logging, but was of insufficient strength and collapsed at depth in the deeper holes. Holes were water-filled, and the plastic casing was capped at the bottom. Table 2 is a detailed listing of hole locations both as lats and longs, and as UTM grid coördinate northings and eastings.

INTERPRETATION OF THE GEOPHYSICAL LOGS:

For all four holes discussed (Holes B,I,Q and R), the EM39 conductivity log and GSC multiparameter geophysical logs were recorded. The GSC logs included gamma ray, density (in arbitrary units), spectral gamma gamma (SGG), magnetic susceptibility (MS), temperature and temperature gradient.

HOLE B.

The different tills and sand units are clearly defined on the gamma-ray log. Good correlation between gamma ray and conductivity reflects increases in percentage of conductive clays. Sand and sandy till exhibit higher susceptibilities and densities. The spike in the susceptibility log at 24 m is due to a granitic boulder.

HOLE I.

The stratigraphy is clearly defined by all logs. Weathered bedrock is fairly conductive with low susceptibilities. Susceptibility of sand is higher than the tills suggesting higher percentages of magnetite in the sand.

HOLE Q.

Stratigraphic units are clearly defined on the gamma-ray log. The good correlation between gamma-ray and conductivity within clay and clayey silt reflects increases in conductive clay content. Sand and sandy till are characterized by low conductivity and low gamma-ray activity but also higher susceptibilities and densities. Anomalous temperatures within the clay between 52 and 63 m are probably due to fluid flow.

HOLE R.

Stratigraphic units are clearly defined on the gamma-ray log. The clay unit between 25 and 61 m shows high but variable conductivity that correlates with gamma-ray activity and probably reflects variations of the conductive clay content.

LOGGING TOOL DESCRIPTIONS

GSC R&D Logging System:

The GSC multiparameter borehole geophysical measurements included: 1) total count natural gamma-ray logs, 2) density and SGG ratio logs, 3) magnetic susceptibility, 4) temperature gradient and temperature logs. Electrical logs were not recorded because the holes were cased with plastic pipe. A general description of the GSC logging tools and their geologic responses is given in Appendix I.

Geonics EM-39 System:

The Geonics Limited (Mississauga, Ontario) EM39 system consists of three separate borehole probes which are described briefly below.

EM39 Borehole Conductivity Probe

The EM39 Borehole Conductivity Probe measures the electrical conductivity of the soil and rock surrounding a borehole using the inductive electromagnetic technique. The unit employs a coaxial coil geometry with an intercoil spacing of 50 cm which is roughly the radius of exploration into the formation. Measurement is unaffected by a conductive borehole fluid.

The EM39 was designed for detection of groundwater contamination in the earth and rock surrounding a borehole by virtue of the associated increase in the electrical conductivity. However, an increase in conductivity can also be caused by conductive clays .

GAMMA 39 Gamma-ray Probe

The Gamma 39 natural gamma ray probe was designed by Geonics to resolve the ambiguity often caused by detecting conductive clays. This is accomplished by detecting the increased gamma ray activity associated with the potassium in the clay. The probe has a 25 x 65 mm NaI(Tl) detector.

EM39S Magnetic Susceptibility Probe

The EM39S probe also measures the magnetic susceptibility of the formation inductively using an intercoil spacing of 50 cm.

The conductivity probe, the gamma ray probe and the magnetic susceptibility probe responses are unaffected by plastic casing in the well.

Specifics of Logging Procedures and Tools:

Holes B, I, Q, R and S:
GSC multiparameter geophysical logs:

Temperature log:	3 m/min
M.S. Log:	3 m/min
Gamma-ray log:	1 m/min detector = 38 x 127 mm NaI(Tl)
Density/SSG log:	3 m/min detector = 22 x 76 mm CsI(Na); source = 10 mCi Co-60; (note: hole Q was logged at 6 m/min).

Acknowledgements

The authors wish to thank Bill Hyatt, Barbara Elliott, Angela Tchen and Susan Davis for their contribution to this report in all aspects from field data acquisition, to data processing and graphics presentation.

The EM39 logging was completed by Gilles Gobert and Gerald Olsen, and the equipment was set up by Jim Hunter and Robbie Burns. Drilling was done in cooperation with Gaywood Matile of Manitoba Energy and Mines.

Bibliography

Mwenifumbo, C.J., Thorleifson, L.H., Killeen, P.G. and Elliott, B.E.
1989: Preliminary results on the use of borehole geophysics in overburden stratigraphic mapping near Geraldton, northern Ontario; in Current Research, Part C, Geol. Surv. Can., Paper 89-1C, p. 305-311.

Mwenifumbo, C.J., Killeen, P.G. and Elliott, B.E.
1994: Downhole logging measurements in the Fraser Delta, British Columbia; in Geological Survey of Canada Current Research no. 1994-E pages 77-84.

Thorleifson, L.H. and Matile, G.
1993: Till geochemical and indicator mineral reconnaissance of Southeastern Manitoba; GSC Open File 2750.

TABLE 1.
Overburden Holes, Southeastern Manitoba

Parameters Logged:

Hole	Gamma	Cond.	MS	Density	SGG Ratio	TMP and TMG
A	x	x	x			
B	x	x	x	x	x	x
D	x	x	x			
E	x	x	x			
G	x	x	x			
H	x	x	x			
I	x	x	x	x	x	x
J	x	x	x			
L	x	x	x			
M	x	x	x			
P	x	x	x			
Q	x	x	x	x	x	x
R	x	x	x	x	x	x
S	x	x	x	x	x	x
U	x	x	x			
V	x	x	x			
W	x	x	x			

TABLE 2.

Overburden Holes, Southeastern Manitoba

Location	Hole	Latitude	Longitude	Sheet	Z	Easting	Northing
East Braintree	A	(49,33,23)	(95,45,08)	52E/12	15	300950	5492750
Harrison Creek	B	(49,21,18)	(95,20,32)	52E/6	15	329900	5469350
Harrison Creek	C	(49,22,36)	(95,12,02)	52E/6	15	340250	5471450
Poplar Creek	D	(49,18,28)	(95,20,04)	52E/6	15	330300	5464100
Moose L	E	(49,15,09)	(95,27,54)	52E/6	15	320600	5458250
Moose L	F	(49,16,50)	(95,31,00)	52E/5	15	316950	5461500
Whitemouth L	G	(49,13,53)	(95,47,13)	52E/4	15	297100	5456700
Vassar	H	(49,04,48)	(95,46,40)	52E/4	15	297150	5439850
Buffalo Point	I	(49,01,07)	(95,18,26)	52E/3	15	331300	5431900
Middlebro	J	(49,00,58)	(95,26,08)	52E/3	15	321900	5431900
Sprague	K	(49,01,41)	(95,33,58)	52E/4	15	312400	5433550
Sprague	L	(49,00,57)	(95,43,42)	52E/4	15	300500	5432600
S Junction	M	(49,03,01)	(95,47,18)	52E/4	15	296250	5436600
Whitemouth L	N	(49,10,39)	(95,47,56)	52E/4	15	296000	5450750
Carrick	O	(49,14,13)	(96,03,26)	62H/1	14	714200	5457750
Zhoda	P	(49,15,58)	(96,28,56)	62H/8	14	683150	5459900
Pansy	Q	(49,18,53)	(96,42,30)	62H/7	14	666550	5464750
St Malo	R	(49,18,06)	(96,53,53)	62H/7	14	652800	5462900
Landmark	S	(49,39,58)	(96,52,02)	62H/10	14	653900	5503500
Oakbank	T	(49,56,01)	(96,50,19)	62H/15	14	655100	5533300
Lewis	U	(49,52,36)	(96,06,47)	62H/16	14	707400	5528700
Giroux	V	(49,34,30)	(96,30,51)	62H/10	14	679700	5494150
Ross	W	(49,46,17)	(96,19,20)	62H/16	14	692800	5516450

APPENDIX I

THE LOGGING SYSTEM

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, lithologic interpretation and hole-to-hole stratigraphic correlation for unravelling complex structures. Also possible is in situ assaying of ore, and determining in situ physical rock properties for use in 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 display monitor to sort out and record the signals and display information; 6. A 9-track magnetic tape recorder; 7. A multi-pen chart recorder to provide a hard copy in the field.

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

The 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

Theory

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). Gamma-ray logs are important for detecting alteration zones, and for providing information on rock types.

In sedimentary rocks, ^{40}K is in general the principal source of natural gamma radiation, primarily originating from clay minerals such as illite and montimorillonite. 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. 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 unconsolidated sediments, sand can be distinguished from clay for the same reason.

In igneous and metamorphic geologic environment 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 exploration areas, the principal source of the natural gamma radiation is potassium-40 because alteration, characterized by the development of sericite (sericitization) is prevalent in some of the lithologic units. Sericitization results in an increase in the element potassium 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 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. The gamma-ray spectral logs can delineate zones of increased radioactivity, and in addition, identify which radioelements are present.

Principle of Gamma-Ray Spectral Logging

A gamma-ray probe's sensor is usually a sodium iodide or cesium iodide scintillation detector and logging occurs while lowering or raising the probe in the hole at about 3 m/minute. Unlike an ordinary gamma-ray tool which only counts the 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. 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 radioisotopes. As each isotope 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 radioisotope. 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 of time while the probe is moving down the hole, the gamma-ray energies are sorted into an energy spectrum in a computer memory. The number of gamma rays in three pre-selected energy windows centred over peaks in the spectrum is computed, as is the total gamma-ray count. These four numbers represent potassium, uranium, thorium and Total Count (TC) detected during that one second counting time.

These data (including depth) are recorded and also displayed on the chart recorder to produce gamma-ray spectral logs. Although 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, 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, it is even possible (at a slight decrease in sensitivity) to log inside drill rod or casing.

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 are recorded from a scintillation detector in the probe. The recording 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 a K log, U log and Th log. In that case only the Total Count log is produced which is the count rate of all gamma rays above a preselected threshold energy (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/min or as slow as 0.5 m/min 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

The Density/SGG Ratio log or heavy element indicator log is derived from the spectral gamma-gamma probe that also provides the density (Killeen and Mwenifumbo, 1988). The SGG/density 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 effect 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 with a logging speed of 6.0 m/minute with a sample time of 1 second, giving a measurement every 10 cm.

The density of the 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, Al 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. Open fractures intersected by the borehole often appear as low density zones on the density log (Wilson et al, 1989).

3: MAGNETIC SUSCEPTIBILITY LOGGING

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.

The volume of investigation or 'sample volume' is roughly a sphere of 30 cm radius, surrounding the sensing coil in the probe. The sensing coil forms part of a balanced electrical circuit. When the coil passes near ferromagnetic material, the inductance changes causing a phase shift in the current in the coil. The probe is calibrated so that this shift is converted into a measurement of the magnetic susceptibility. Logging is carried out at 6m/minute and a measurement is taken every second or each 10 cm along the hole.

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. Susceptibilities within the range from 0 to 20000 microSI can be measured with this tool. Since the measurements are made inductively (ie with e.m. fields not electrodes), the tool can be used inside plastic casing.

4: TEMPERATURE/T-GRADIENT LOGGING

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.

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 6m/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.

Selected Bibliography on Borehole Geophysical Logging

Bogoslovsky, V.A. and Ogil'vy, A.A.
1970: Natural potential anomalies as a quantitative index of the rate of seepage from water reservoirs. Geophysical Prospecting, 18:261-268.

Bogoslovsky, V.A. and Ogil'vy, A.A.
1972: The study of streaming potentials on fissured media models (faults). Geophysical Prospecting, 20:109-117.

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.

Corwin, R.F. and Hoover, D.B.,
1979: The self-potential method in geothermal exploration. Geophysics, 44:226-245.

Hovdan, H. and Bolviken, B.,
1984: Sulphide self potentials in relation to oxygen content in drill-hole water. Geoexploration, 23:387-394.

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, Geol. Surv. Can., Paper 85-27, 1986, p. 29-46.

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, p. 231-260.

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, p.23-29

Mwenifumbo, C.J.
1989: Optimization of logging parameters in continuous, time-domain induced polarization measurements. Proceeding of the 2nd International Symposium on Borehole Geophysics for Mineral, Geotechnical, and Groundwater Applications, MGLS, Las Vegas, Nevada,1,201-232.

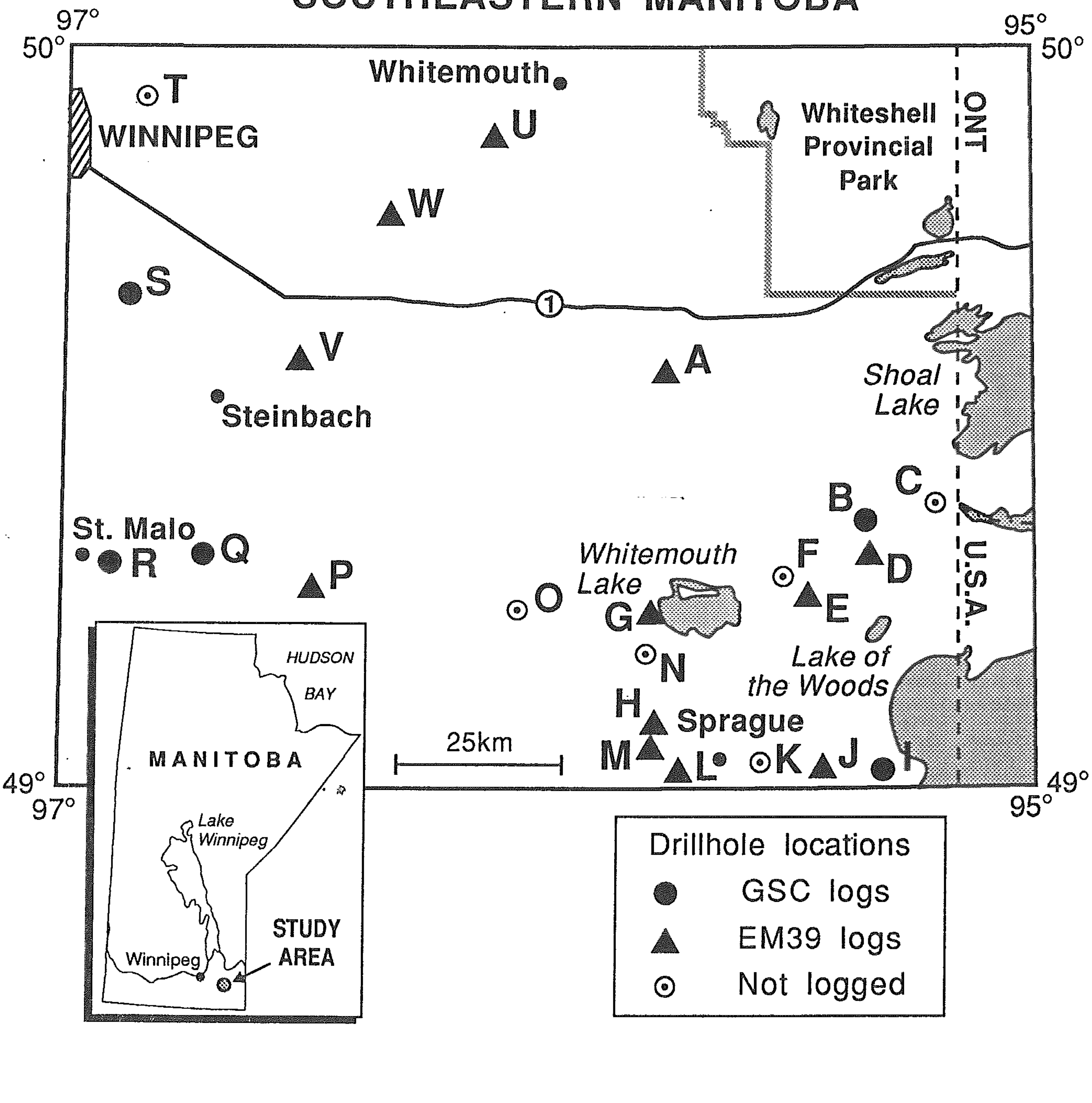
Mwenifumbo, C.J.
1993: Temperature logging in mineral exploration. Journal of Applied Geophysics, 30:297-313.

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.

Sato, M. and Mooney, H.M.
1960: The electrochemical mechanism of sulphide self potentials. Geophysics, 25:226-249.

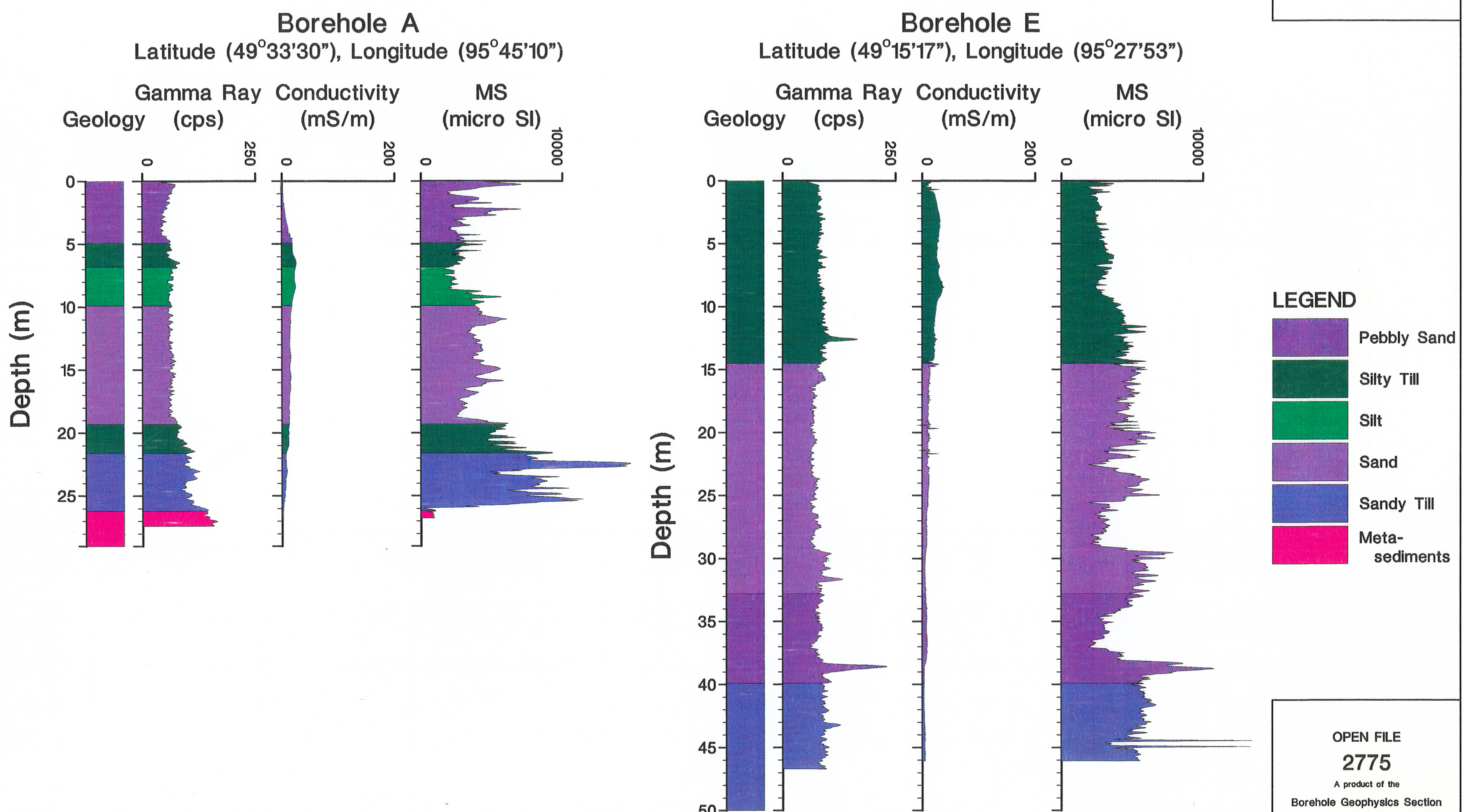
Wilson, H.C., Michel, F.A., Mwenifumbo, C.J. and Killeen, P.G.
1989: Application of borehole geophysics to groundwater energy resources; in Proceedings of the 3rd International Symposium on Borehole Geophysics for Minerals and Geotechnical Logging, 2-5 Oct., 1989, Las Vegas, Nevada, p. 317-336.

DRILLHOLE LOCATIONS SOUTHEASTERN MANITOBA



OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Boreholes A and E



OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

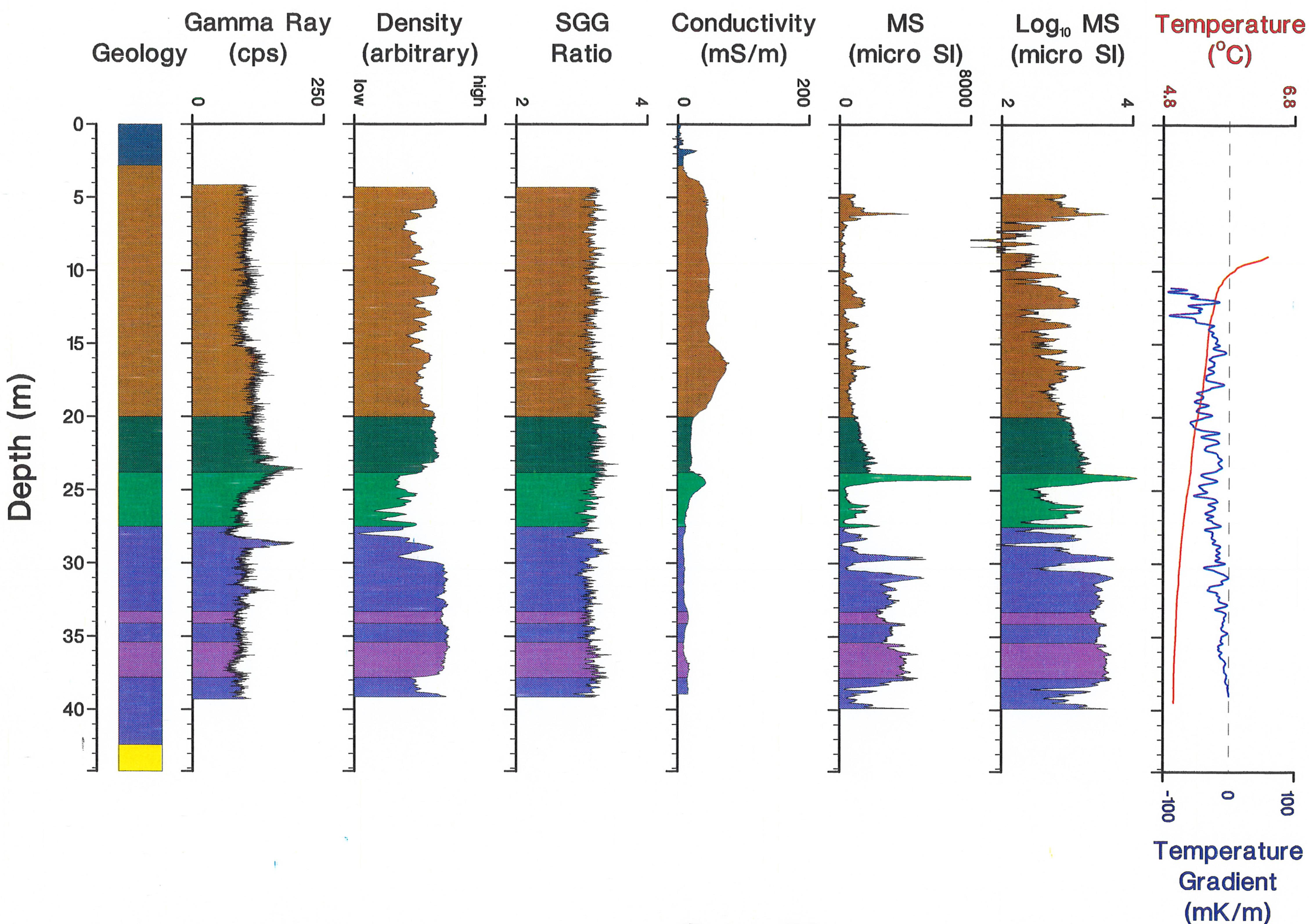
Natural Resources Canada / Ressources naturelles Canada

Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°21'20"), Longitude (95°20'30")

Borehole B



LEGEND

- Gravel
- Clayey Till
- Silty Till
- Silt
- Sandy Till
- Sand
- Meta-volcanics

Natural Resources Canada   Ressources naturelles Canada

Canada

OPEN FILE

2775

A product of the

Borehole Geophysics Section

Mineral Resources Division

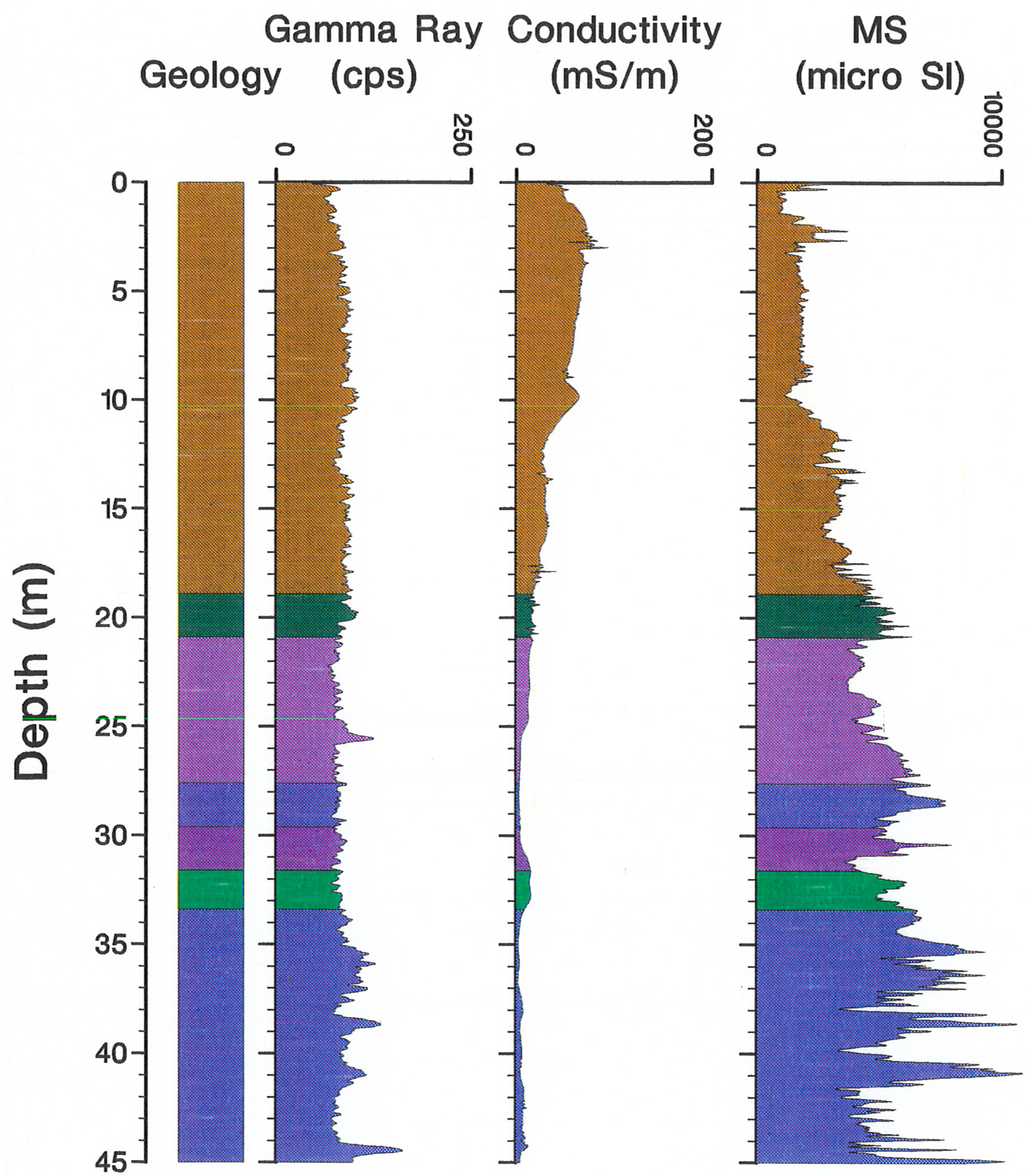
Geological Survey of Canada

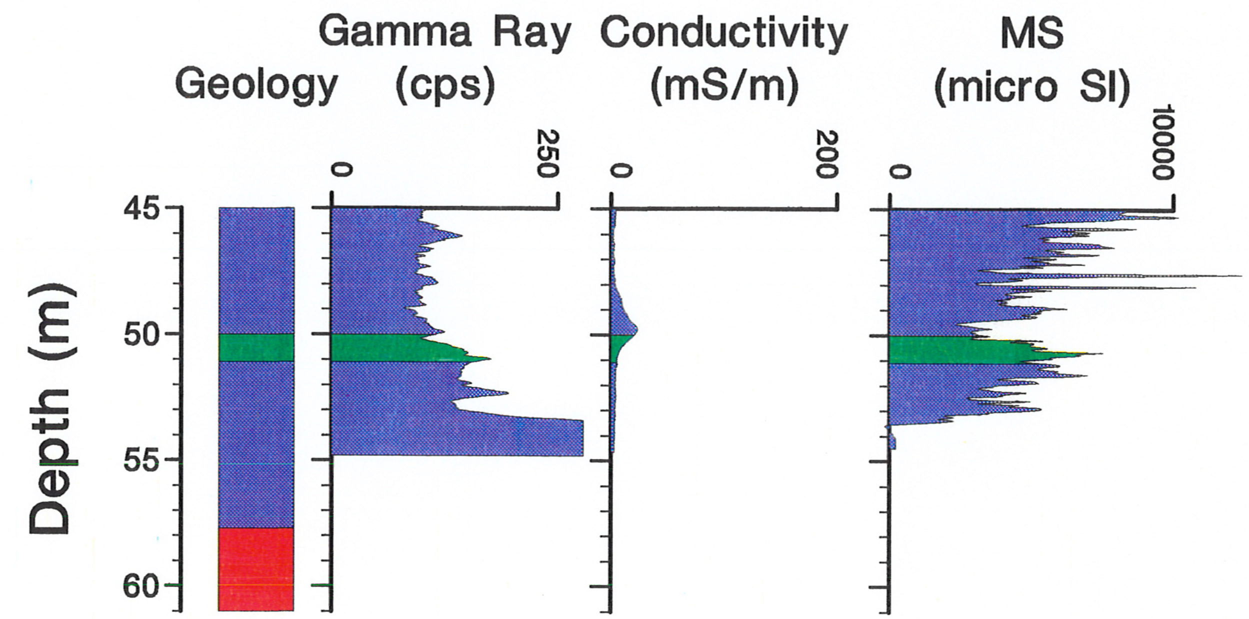
OTTAWA

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°18'30"), Longitude (95°20'06")

Borehole D





LEGEND

- Clayey Till
- Silty Till
- Sand
- Sandy Till
- Pebbly Sand
- Silt
- Weathered Bedrock

OPEN FILE

2775

A product of the

Borehole Geophysics Section

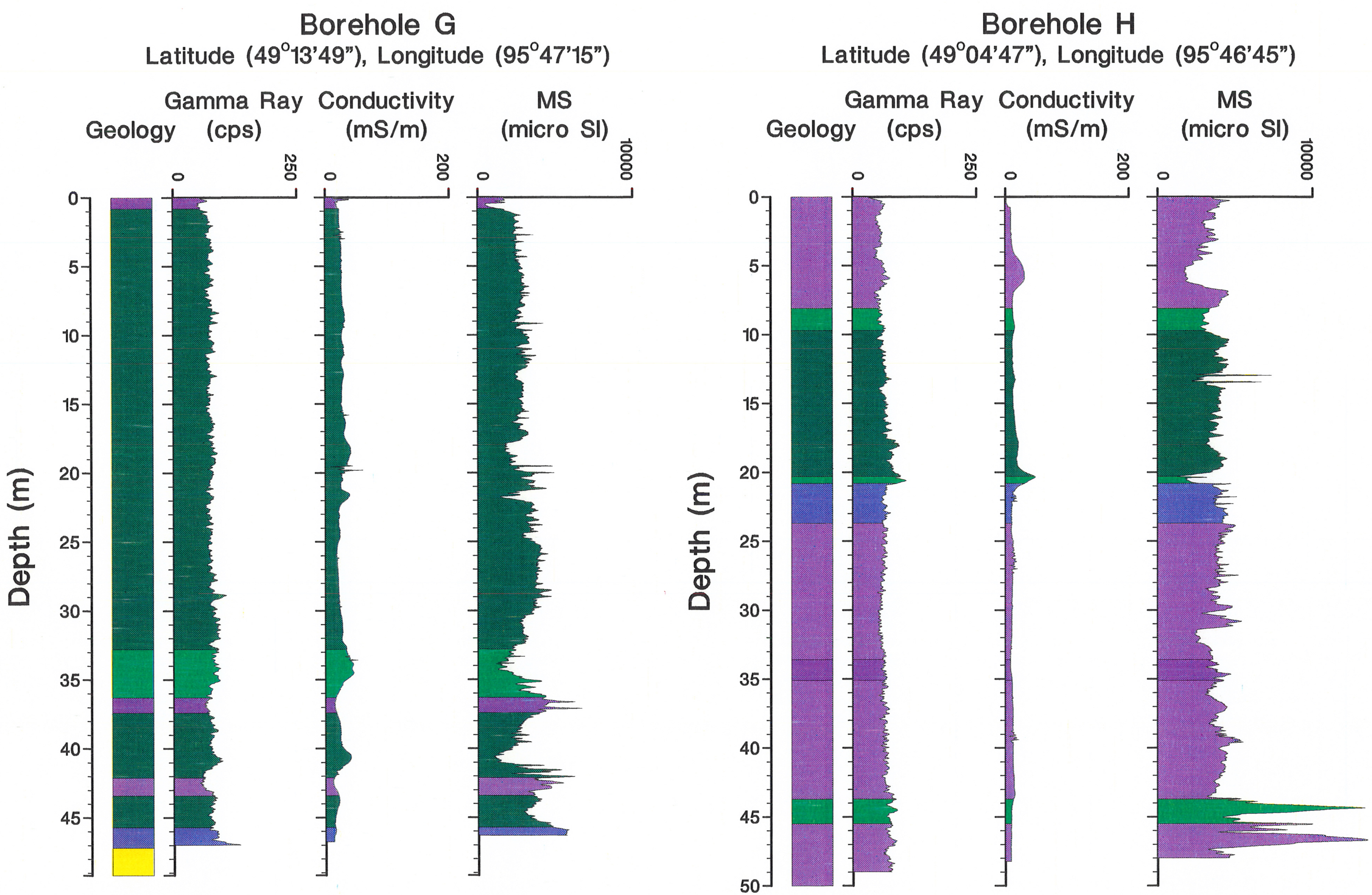
Mineral Resources Division

Geological Survey of Canada

OTTAWA

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Boreholes G and H



LEGEND

- Pebbly Sand
- Silty Till
- Silt
- Sand
- Sandy Till
- Meta-volcanics

OPEN FILE

2775

A product of the

Borehole Geophysics Section

Mineral Resources Division

Geological Survey of Canada

OTTAWA

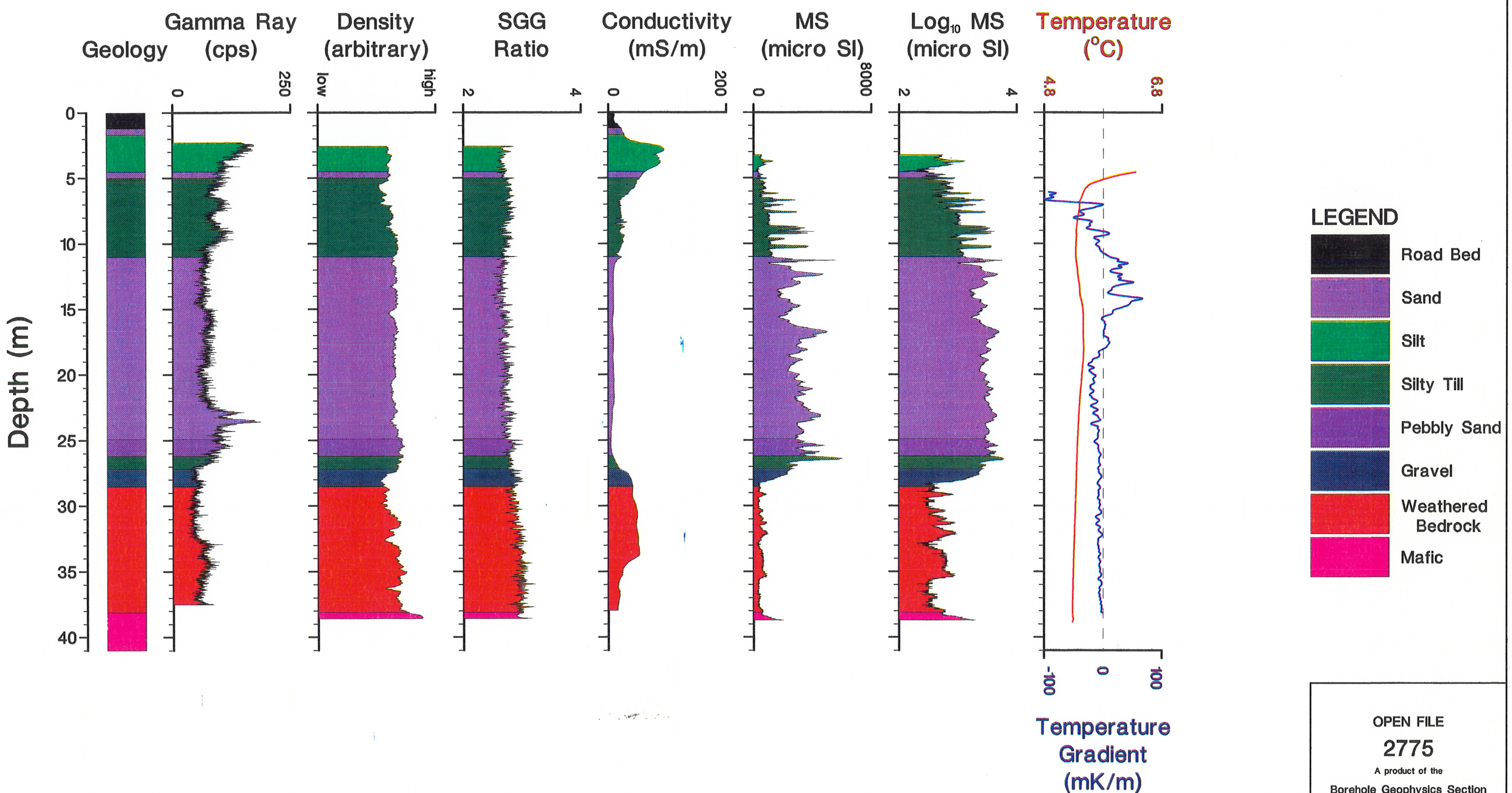
Natural Resources Canada Ressources naturelles Canada

Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°01'05"), Longitude (95°18'30")

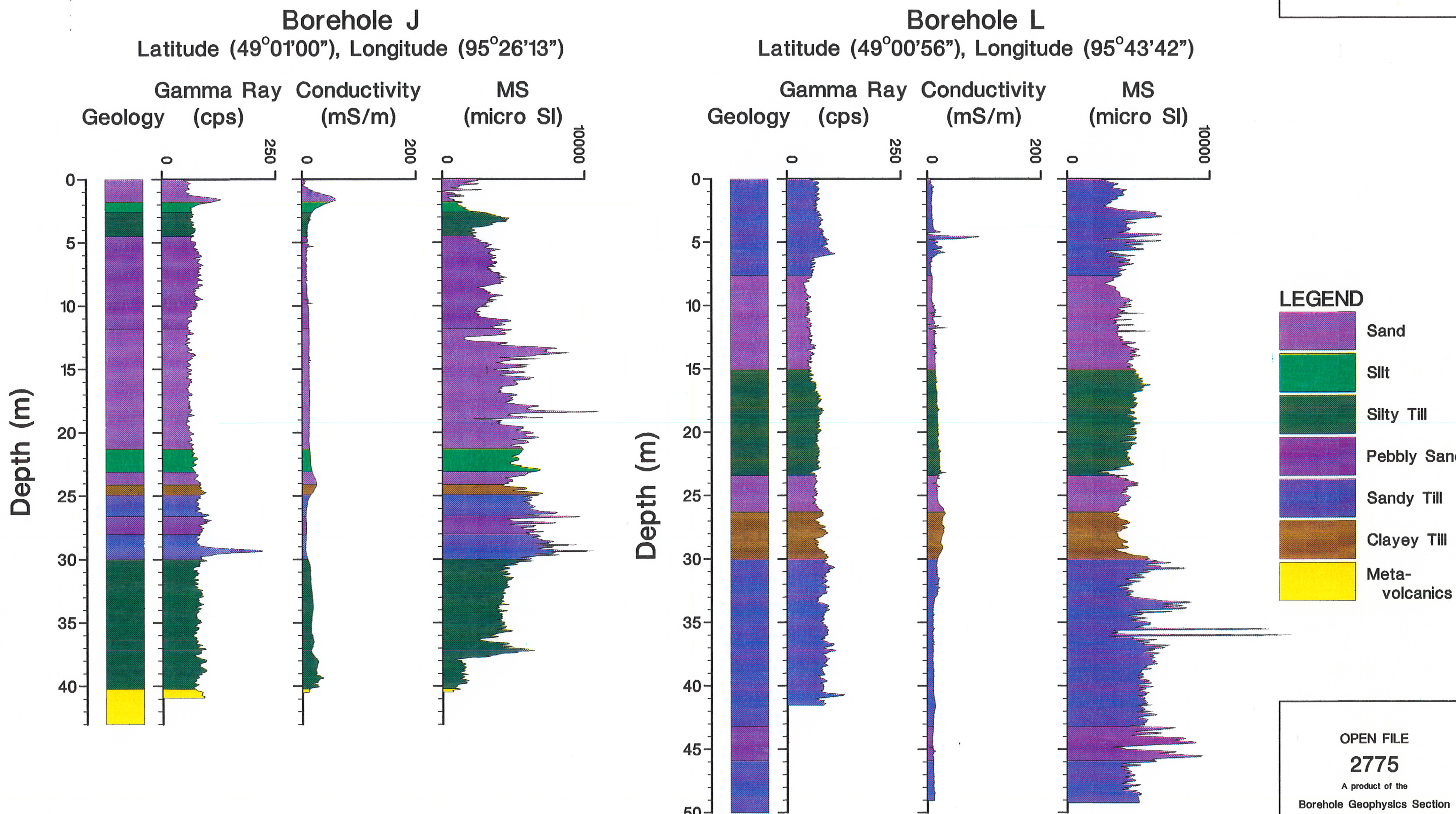
Borehole I



OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Boreholes J and L

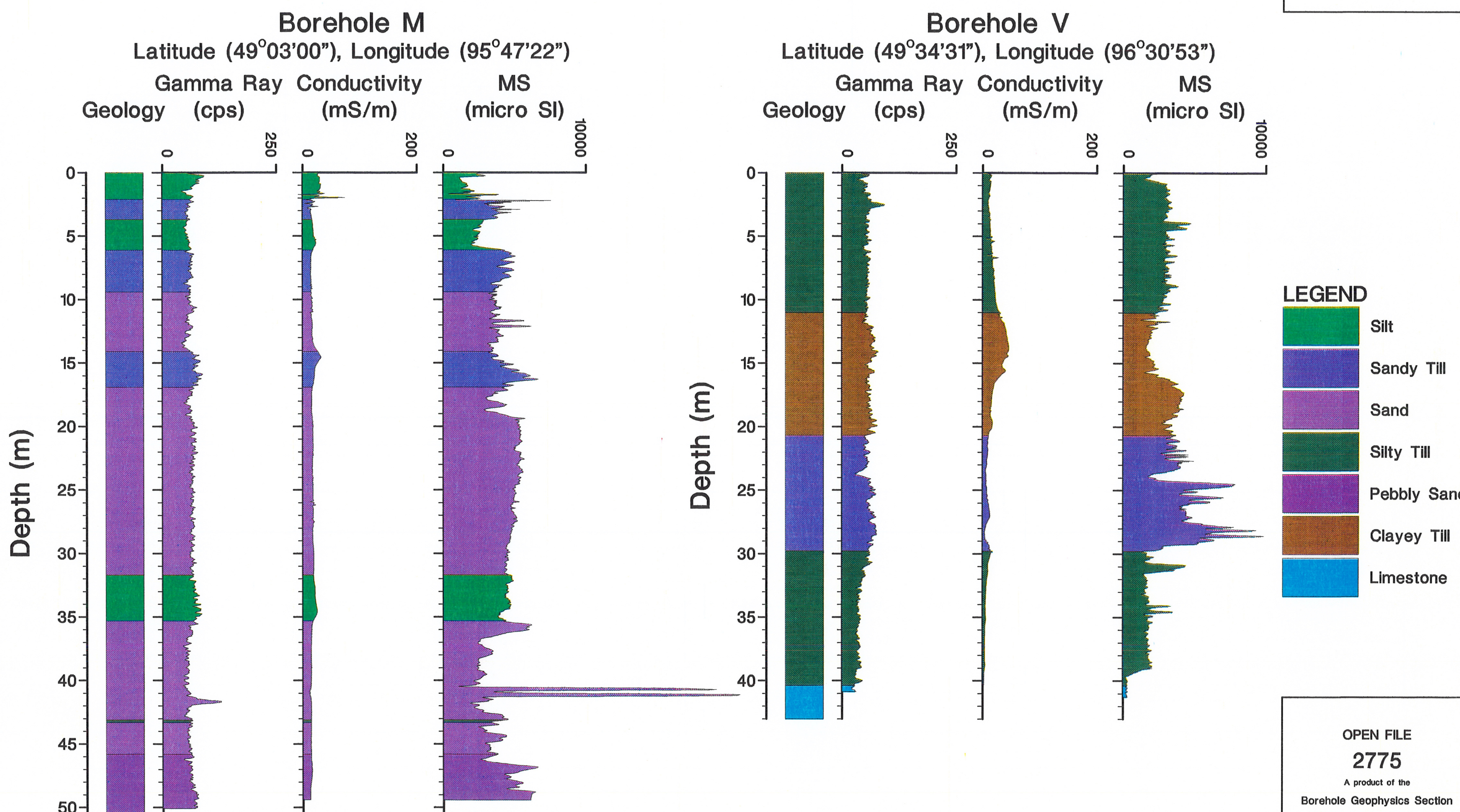


OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

Natural Resources Canada
Ressources naturelles Canada
Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Boreholes M and V

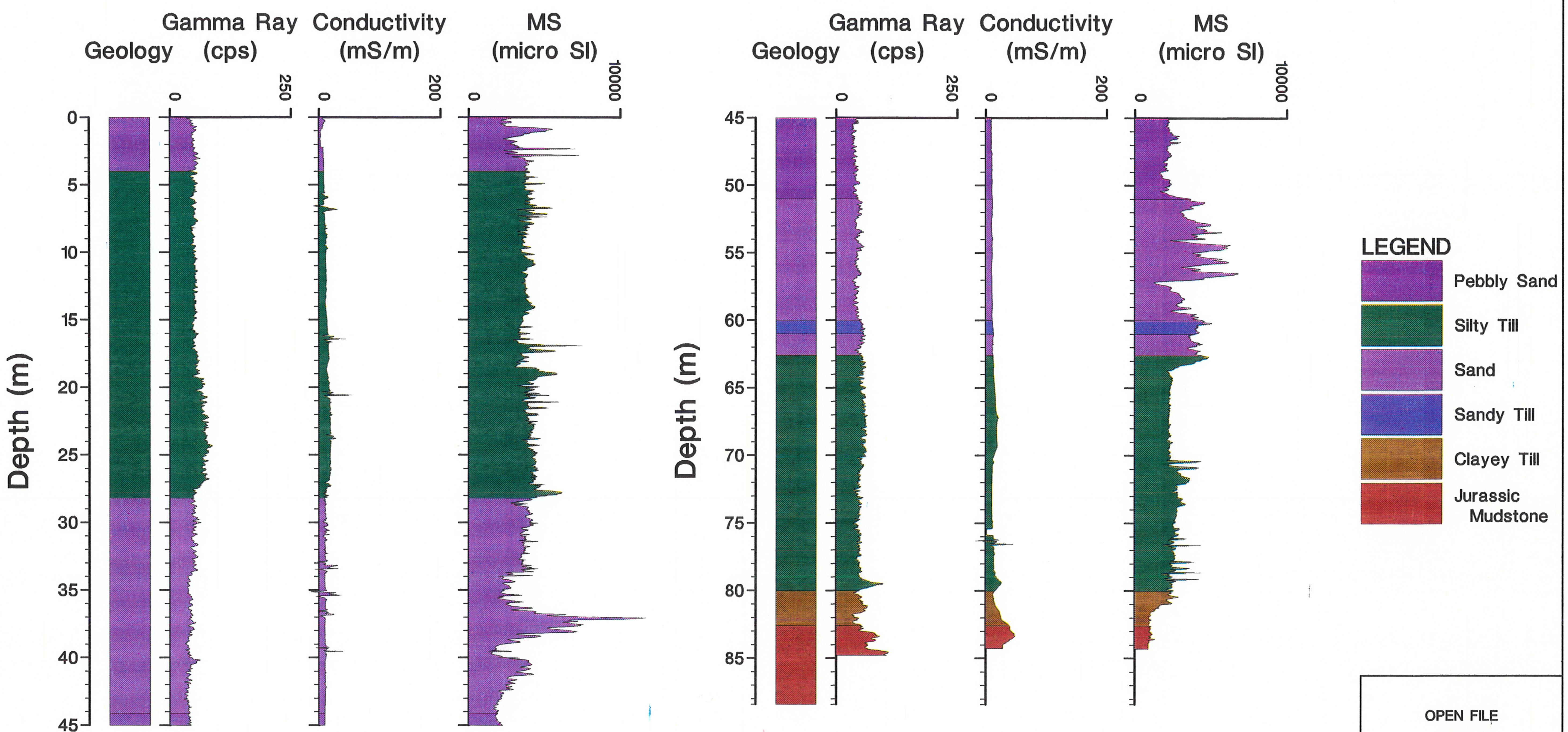


OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°16'00"), Longitude (96°29'58")

Borehole P



OPEN FILE

2775

A product of the

Borehole Geophysics Section

Mineral Resources Division

Geological Survey of Canada

OTTAWA

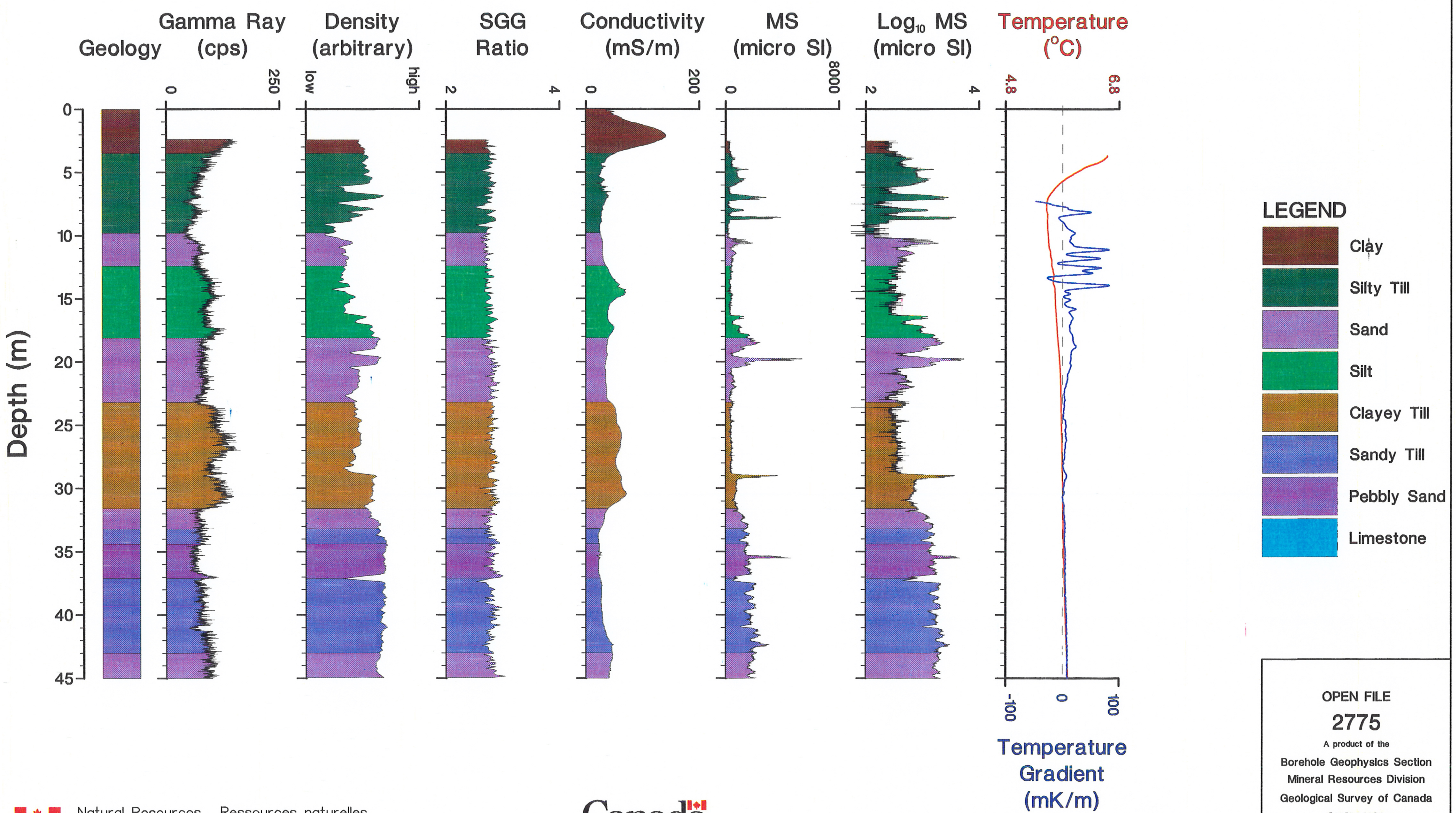
Natural Resources Canada   Ressources naturelles Canada

Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°18'52"), Longitude (96°42'30")

Borehole Q
Plot 1 of 2



OPEN FILE

2775

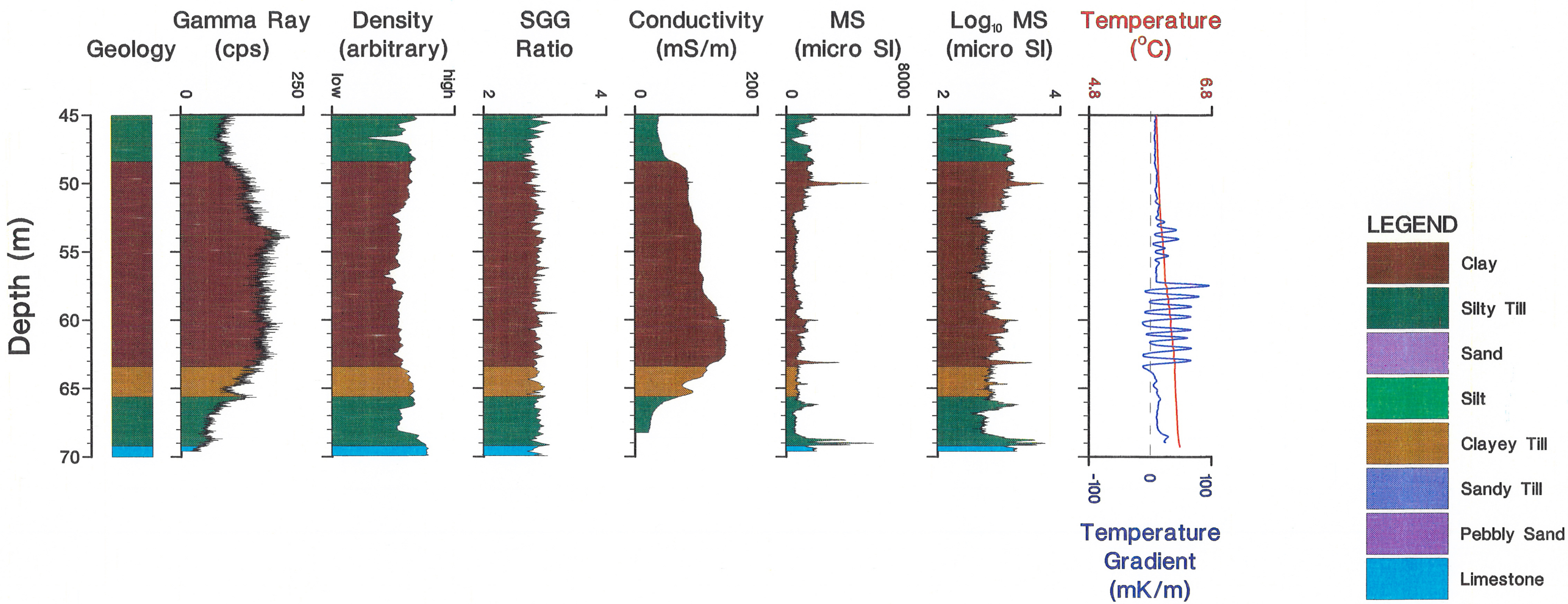
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

Natural Resources Canada Ressources naturelles Canada

Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°18'52"), Longitude (96°42'30")

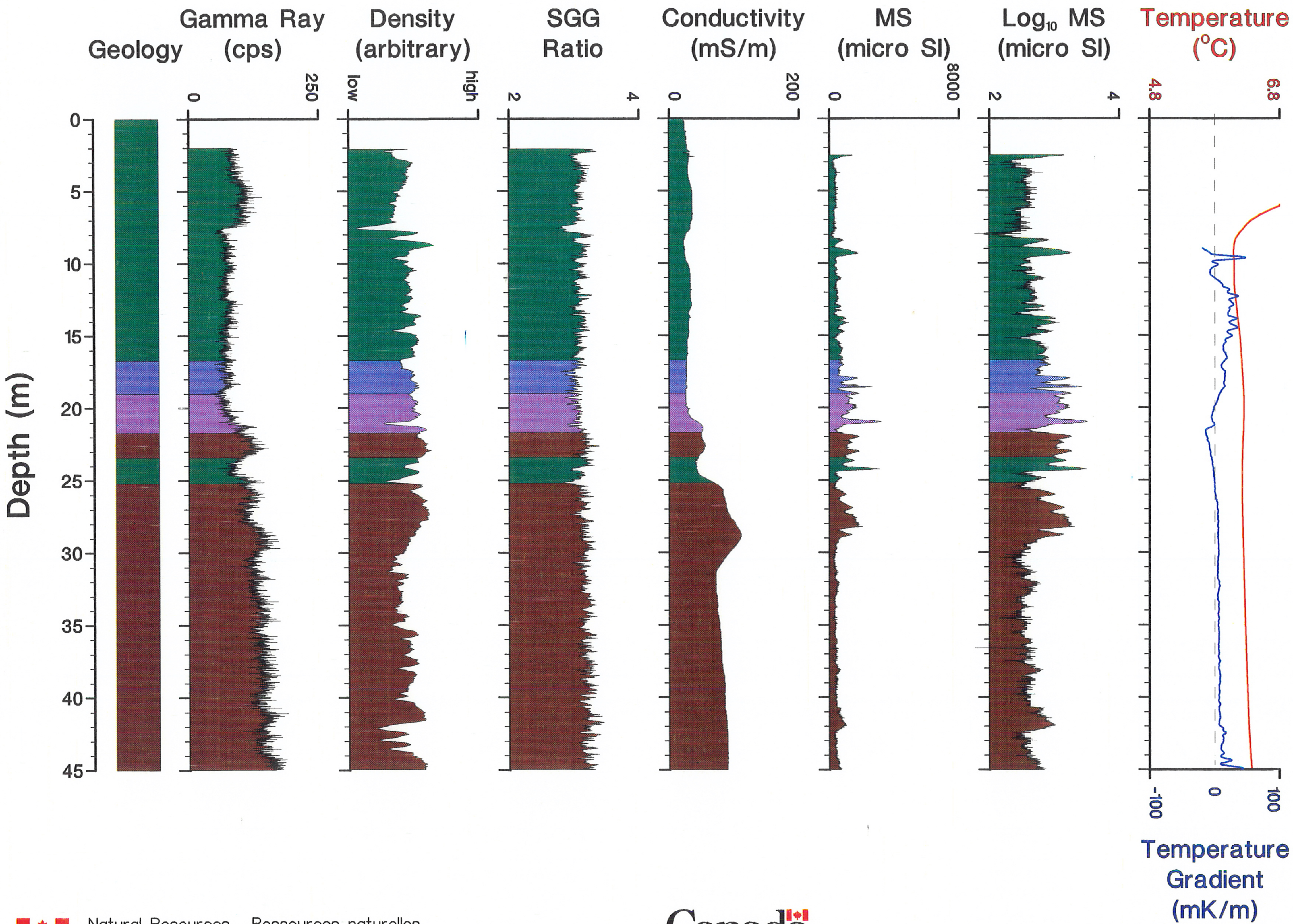


OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

Natural Resources Canada   Ressources naturelles Canada
Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°18'08"), Longitude (96°56'10")



LEGEND

- Silty Till
- Sandy Till
- Sand
- Clay
- Clayey Till
- Gypsum

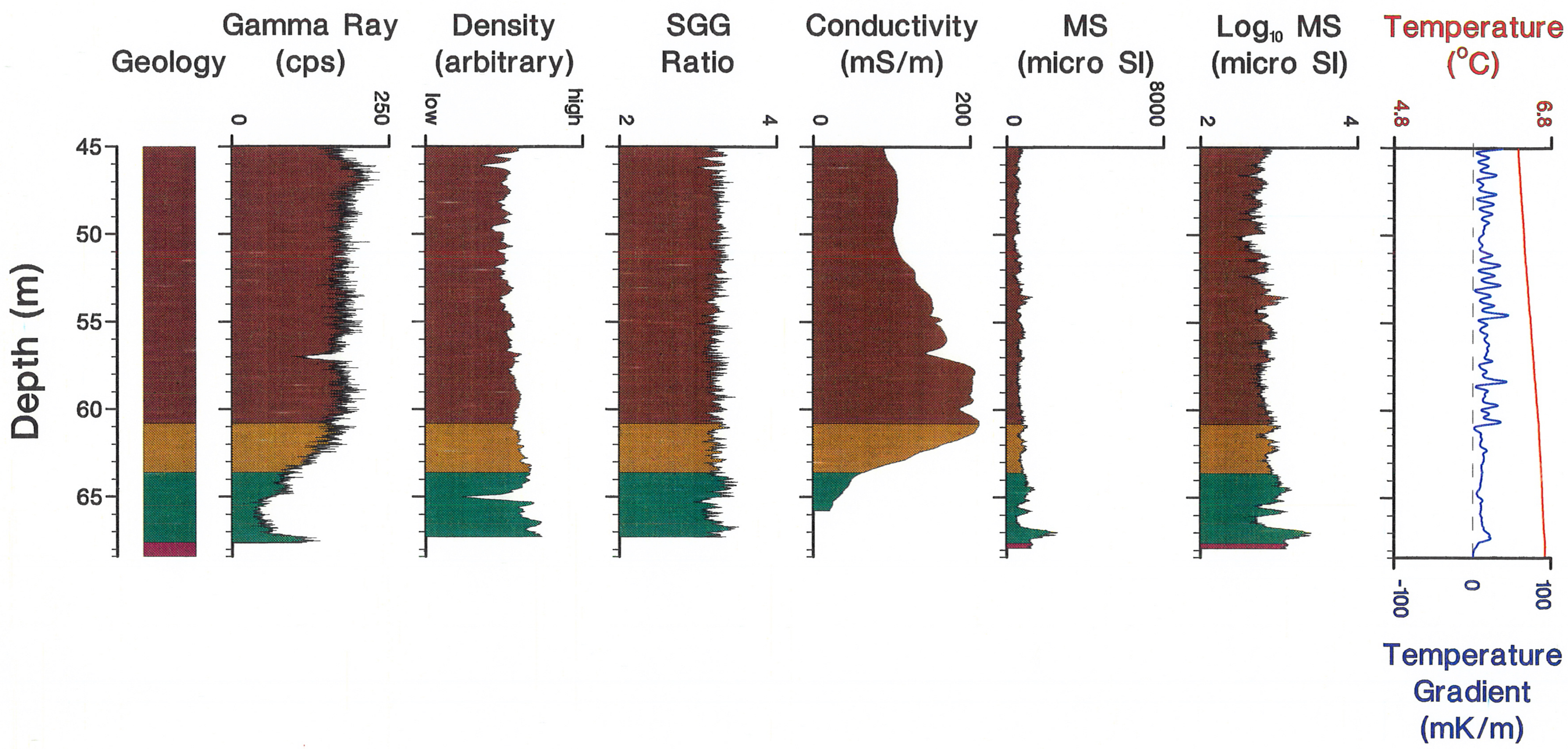
OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

Natural Resources Canada
Ressources naturelles Canada
Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°18'08"), Longitude (96°56'10")

Borehole
R
Plot 2 of 2



LEGEND

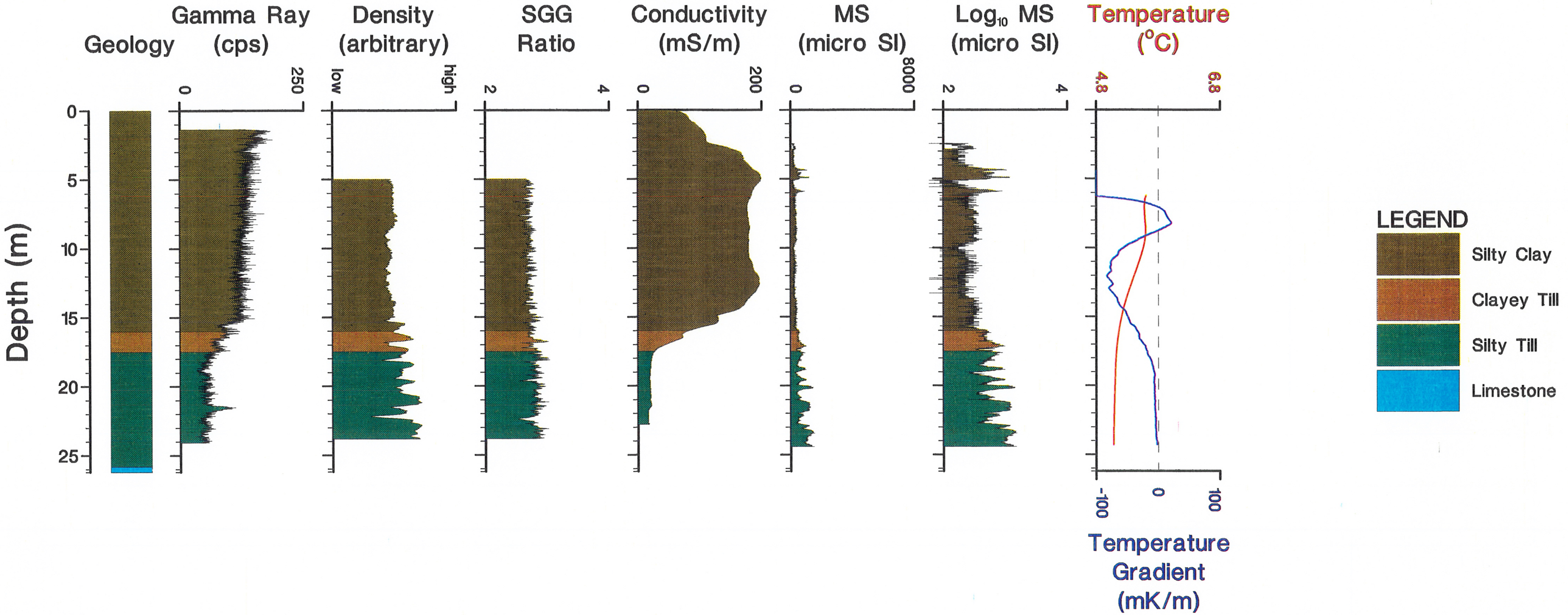
- Silty Till
- Sandy Till
- Sand
- Clay
- Clayey Till
- Gypsum

OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°40'00"), Longitude (96°52'59")

Borehole S



OPEN FILE 2775

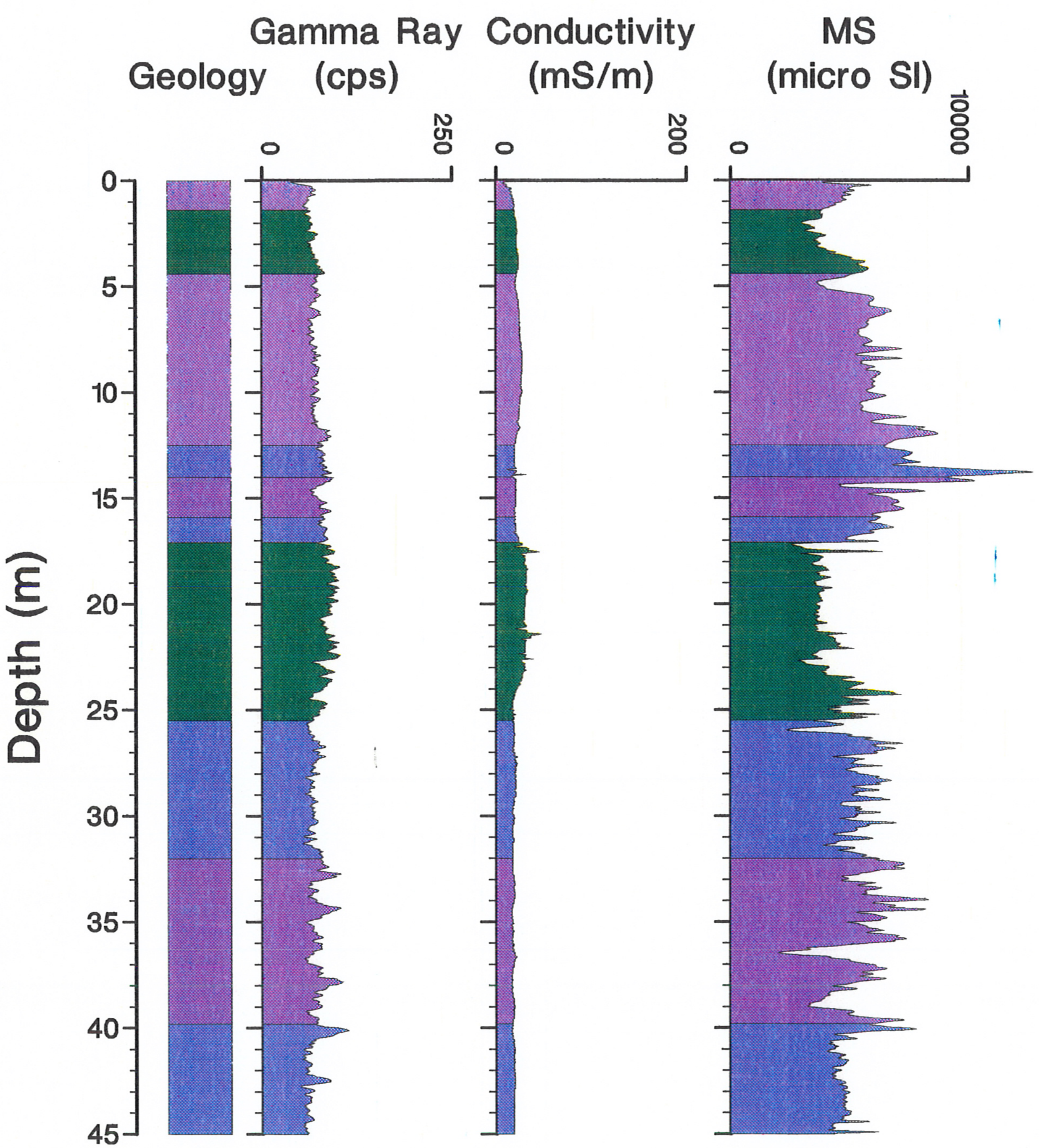
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

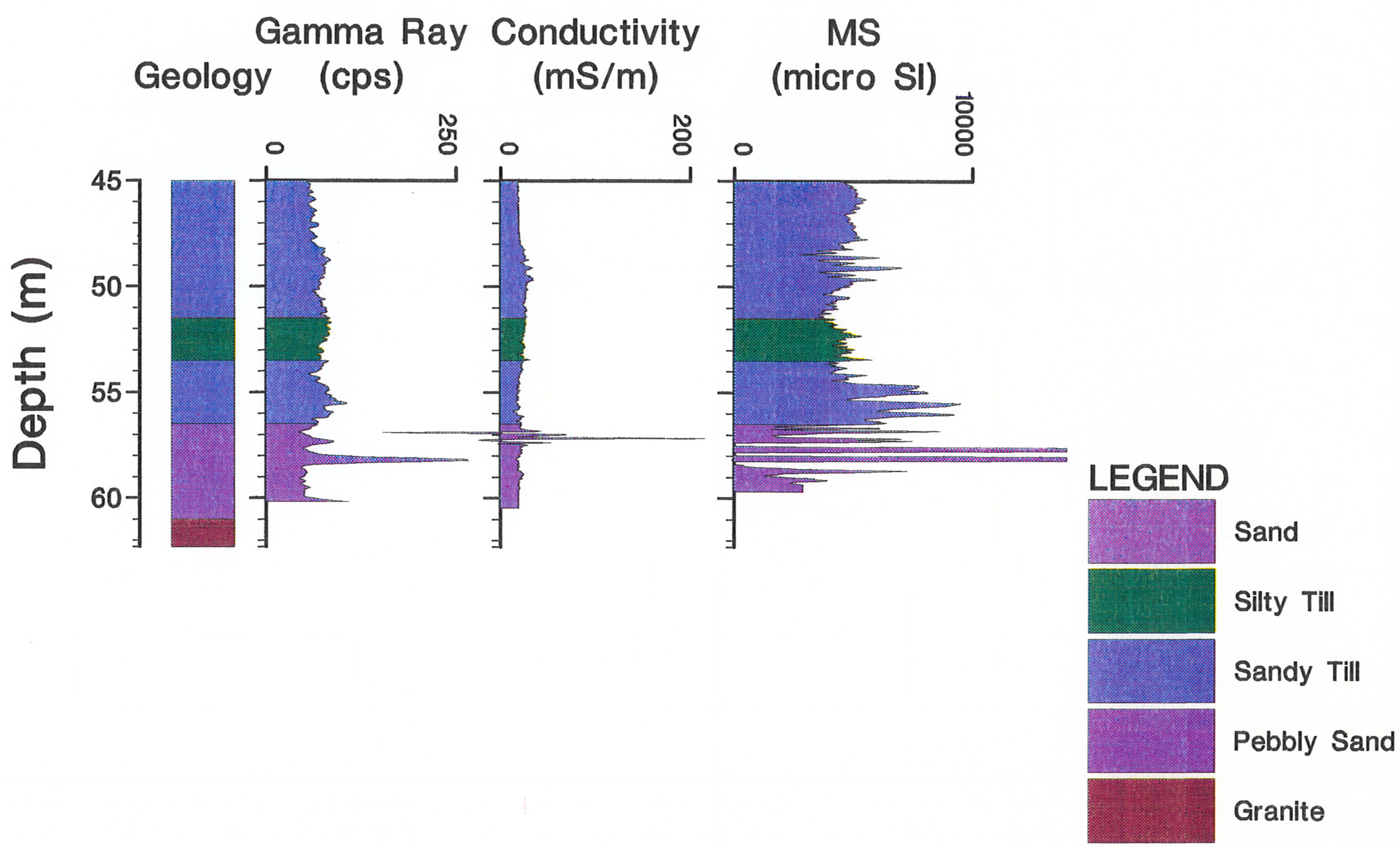
Natural Resources Canada | Ressources naturelles Canada
Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°52'37"), Longitude (96°05'50")

Borehole U





OPEN FILE

2775

A product of the

Borehole Geophysics Section

Mineral Resources Division

Geological Survey of Canada

OTTAWA

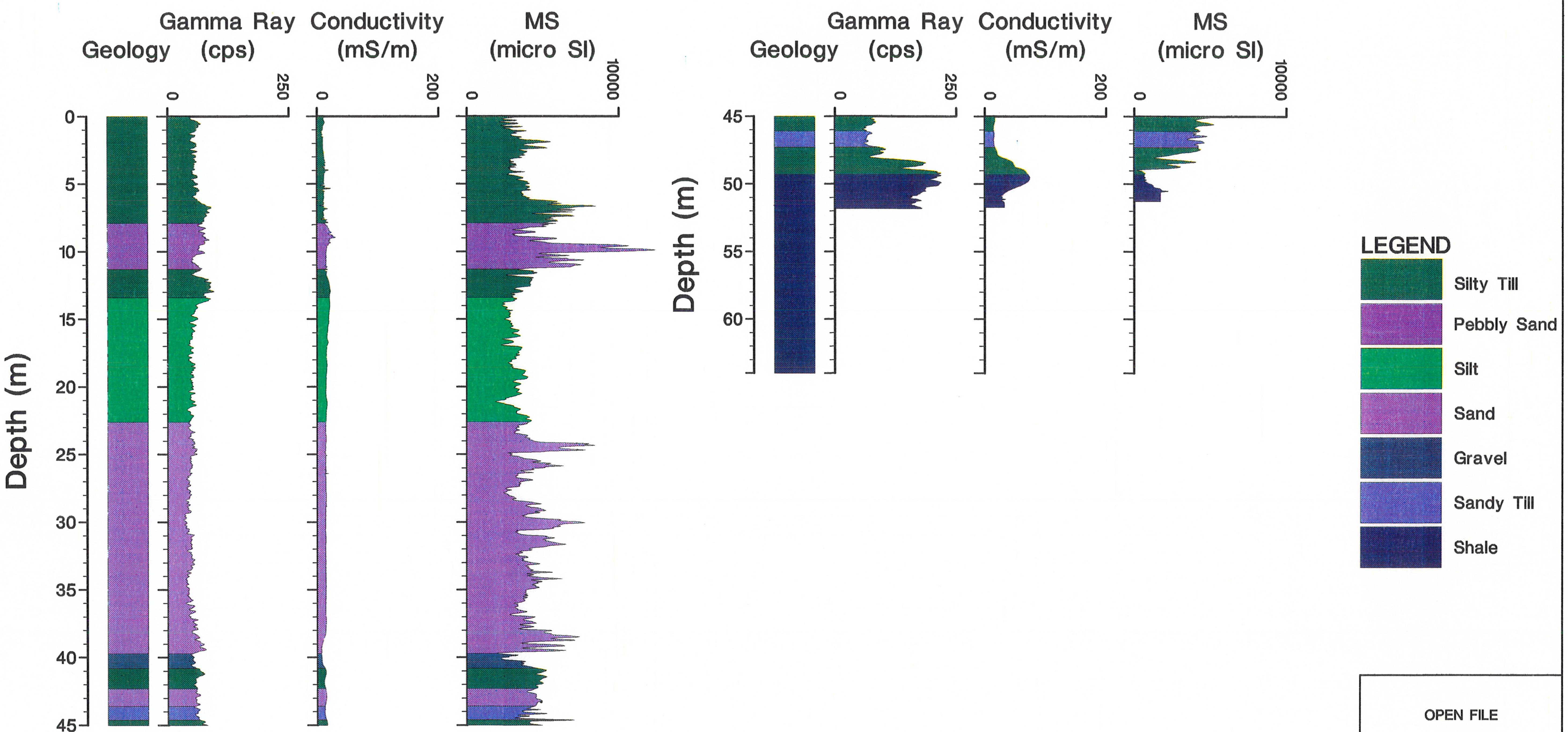
Natural Resources Canada　Ressources naturelles Canada

Canada

OVERBURDEN HOLES, SOUTHEASTERN MANITOBA

Latitude (49°46'15"), Longitude (96°19'23")

Borehole W



OPEN FILE
2775
A product of the
Borehole Geophysics Section
Mineral Resources Division
Geological Survey of Canada
OTTAWA

Natural Resources Canada
Ressources naturelles Canada
Canada