Geophysical characterization of glacial and postglacial sediments in a continuously cored borehole near Ottawa, Ontario

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Abstract: Borehole conductivity, gamma, and magnetic susceptibility logs have been compared with high resolution seismic reflection data from a site near Ottawa formerly occupied by a number of glacial and postglacial environments. Approximately 58 m of subglacial, proglacial, glaciolacustrine, marine, and fluvial sediments overlie a nearly horizontal bedrock surface. The seismic data show a series of nearly horizontal, parallel reflection events separating units displaying various internal characteristics. The borehole geophysical logs reveal subtle attributes of the strata that will require further investigation.

Résumé : Les auteurs ont comparé des diagraphies d'induction, de rayonnement gamma et de la susceptibilité magnétique mesurées dans des trous de forage aux données de sismique réflexion de haute résolution recueillies à un site près d'Ottawa qui avait été le site de divers milieux glaciaires et postglaciaires. Environ 58 m de sédiments sous-glaciaires, proglaciaires, glaciolacustres, marins et fluviatiles reposent sur un substratum rocheux quasi horizontal. Les données sismiques montrent une série d'événements parallèles quasi horizontaux qui séparent des unités présentant diverses caractéristiques internes. Les diagraphies géophysiques révèlent que les couches possèdent des attributs ténus qu'il faudra approfondir par d'autres analyses.

INTRODUCTION

The Terrain Geophysics and Geothermal Section of the Terrain Sciences Division arranged for the drilling of a continuously sampled borehole at a location 10 km from its Ottawa office for use as a demonstration site when training operators in the operation of the section's EM-39 borehole logging unit (Fig. 1). The site was selected, in part, on the basis of a high resolution seismic reflection line shot over the area which showed a succession of glacial and postglacial strata overlying Paleozoic bedrock. The site is located near the centre of a streamlined 'island' formed in the proto-Ottawa River during the regression of the Champlain Sea and preserved when the river switched channels away from the Mer Bleue area 7650 years ago (Gadd, 1987). This report will present the borehole geophysical data and a portion of the seismic reflection data and provide some preliminary correlations and interpretations.

SEISMIC METHODS

The seismic section presented in this report is a portion of a 1.6 km line of high resolution reflection data collected in July and October of 1992 in the drainage ditch on the side of Anderson Road 2 km south of Blackburn Hamlet. The complete line, from Blackburn Station south to the GSC's Geomagnetic Laboratory, straddles the transition between Mer Bleue bog, lying in an abandoned channel of the Ottawa River, and a low, elongate, east-west oriented hill which was once an island in that same river. Only the southern-most 324 m of seismic data, from the top of the old island, are included here.

The 'optimum offset' seismic reflection method or presentation of data was designed as a technique for delineating overburden stratigraphy and bedrock topography (Pullan and Hunter, 1990). The technique involves the selection of an optimum source-receiver separation which allows the target reflection to be observed with a minimum

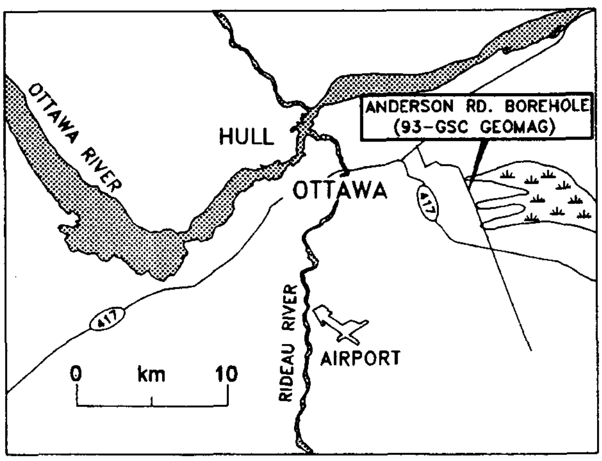

Figure 1. Location of the Anderson Road borehole. The high resolution seismic reflection line extends parallel to the road, north-northeastward about 300 m from the borehole.

of interference from other seismic events. The vertical resolution of the subsurface is dependent on the transmission and recording of high frequency seismic energy, and is generally highest when surface sediments are fine grained and water saturated. This area is an excellent site for high resolution seismic surveys, and reflections with a dominant frequency of 500 Hz were recorded (3 m wavelength).

The source-receiver offset for the seismic section shown in this report is 12 m. The source was a 12 gauge Buffalo gun (Pullan and MacAulay, 1987) and the receivers were single, 100 Hz, vertically oriented geophones planted in the bottom of the roadside ditch at intervals of 3 m. A Bison D9000 engineering seismograph was used to collect and record the data. Low cut and high cut filters of 192 and 2000 Hz, respectively, were applied. A 100 ms record, comprised of 1000 samples, was recorded at each geophone location. Final processing prior to presentation consisted of shifting each trace to align the first arrival (the refraction from the water table) to a single datum, applying a 300 to 800 Hz digital band-pass filter, and modifying the display with automatic gain control and time-varying gain tapers.

An average overburden velocity of 1500 m/s, calculated from the moveout of various reflection events on the multichannel records, is confirmed by the agreement between the depth to bedrock determined from the borehole and that calculated from the time of arrival of the bedrock reflection on the seismic record and the overburden velocity.

BOREHOLE GEOPHYSICAL METHODS

In March 1993, a 62.5 m borehole was drilled at the south end of the seismic line, near the intersection of Anderson Road with the driveway of the GSC Geomagnetic Laboratory. The hole is tentatively identified as GSC-93 GEOMAG. Although the hole was continuously sampled using Shelby tubes, at the time of the preparation of this report, the cores have not been extruded. Figure 2 includes a lithological log based on the on-site inspection of the cored material that was exposed at the ends on the tubes, or was observed on the bit between trips to sample. The hole was cased with 2.5 inch I.D. plastic pipe, the bottom 3.3 m of which was perforated to allow the hole to be used as a ground water monitoring well for the bedrock aquifer. After drilling, the hole was logged using a Geonics EM-39 logging system. Successive passes with the conductivity and magnetic susceptibility probes (which utilize an inductive electromagnetic method) and the natural gamma probe, were recorded digitally on a laptop computer linked to the EM-39 logger.

The effective measurement radius of the conductivity probe is estimated to be 1 to 1.5 m, and as the tool is claimed by the manufacturer to be unaffected by fluids in plastic casing, the conductivity measured is taken to be that of the surrounding formation and associated ground water.

The magnetic susceptibility probe measures how strongly the material adjacent to the borehole is affected by a magnetic field, in this case the Earth's field. It is accepted that the

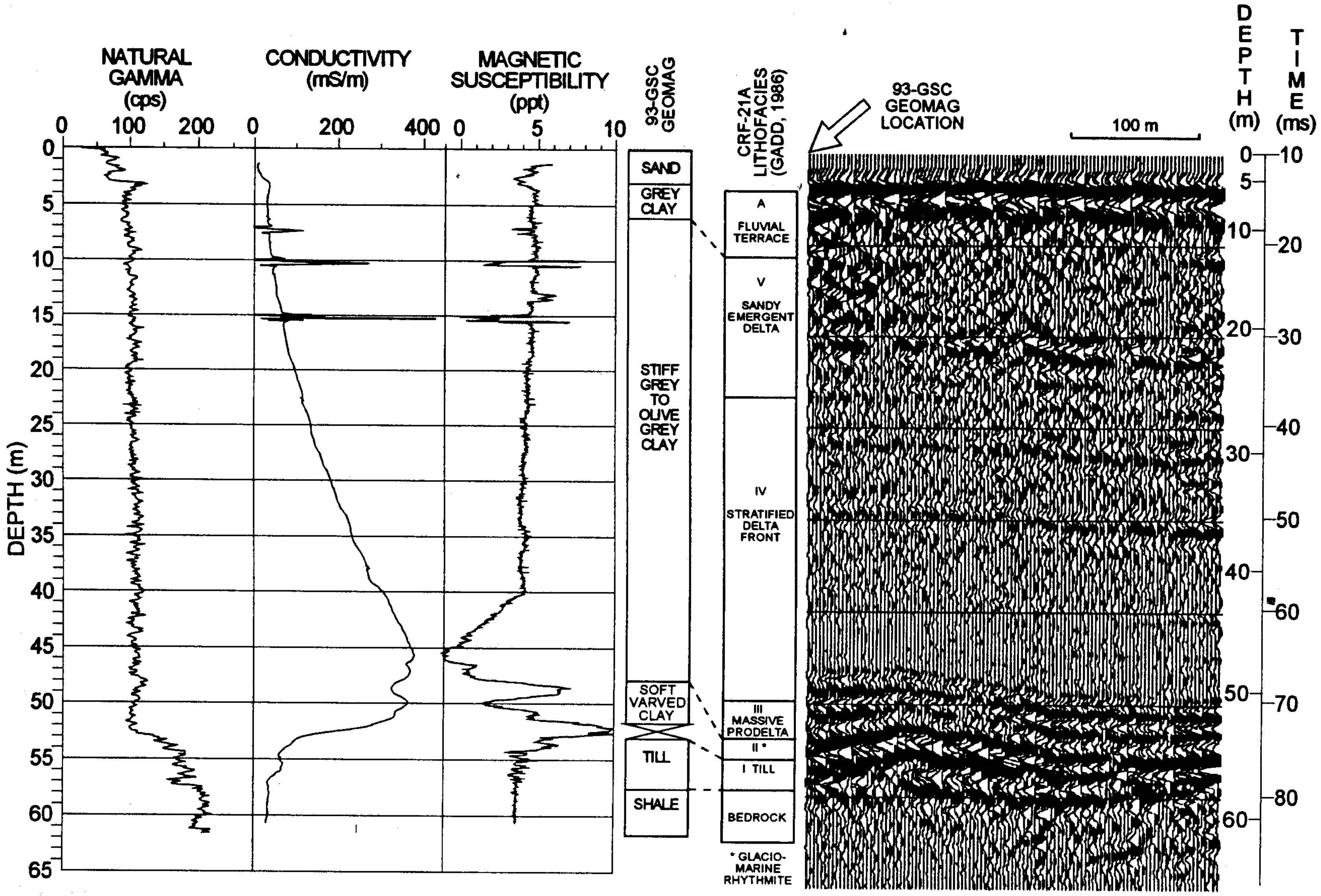

Figure 2. EM-39 borehole logs and high resolution seismic section at the Anderson Road borehole. Mis-ties between log depths and the calculated seismic section depth, particularly at shallow depths, are due to the 12 m offset between source and receiver. The lithofacies classification from a borehole CRF-21A is from Gadd (1986).

overall susceptibility of a lithology is dependent only on the amount of ferrimagnetic mineral, such as magnetite, pyrrhotite, and ilmenite, present in the material.

The gamma tool detects the decay of uranium, thorium, and potassium in the environment, although for practical purposes the tool provides a qualitative measurement of the abundance of clay in the strata surrounding the borehole. Low gamma readings are an indication of coarse grained sediments, and high gamma readings are attributable to fine grained materials; although it is important to consider the provenance of the strata when interpreting the results.

RESULTS

Figure 2 shows the southern-most 324 m of the 1600 m seismic line shot in the ditch adjacent to Anderson Road. An abbreviated lithological log and the results of the EM-39 logging are superimposed at the borehole location to allow comparison of the data. In addition, the figure shows Gadd's (1986) stratigraphic log for borehole CRF-21A, drilled nearby, adjusted to the same bedrock elevation as the new hole.

A reflection event at 79 ms two-way travel time is interpreted to represent the top of bedrock. The calculated depth to bedrock from ground level, based on an average overburden acoustic velocity of 1500 m/s (below the water table), is 58 m. Bedrock consists of very dark grey Ordovician shale, probably of the Carlsbad Formation. It is characterized on EM-39 logs by a high gamma count, low conductivity, and very uniform magnetic susceptibility.

The prominent reflection, at 73 ms (53.5 m, calculated) is interpreted, on the basis of sample and EM-39 logs, to represent the top of ice contact deposits consisting of olive grey to pinkish grey clayey silt with shale clasts and garnet-rich gneiss cobbles. EM-39 logs show low conductivity, variable magnetic susceptibility, and a gamma count which increases from 100 counts per second at the top of the till to 175 counts per second at the bottom. This gamma count is high for a till, and is probably due to the elevated level of radioactivity inherent in the Precambrian material incorporated in the till and to a significant component of radioactive Paleozoic bedrock.

A moderate amplitude reflection event at 66 ms two-way travel time (48 m, calculated), followed by a pair of high amplitude 'rings', marks the top of a clay unit overlying the till. Samples of clay below this contact are recorded as being slightly softer than those above, and some loss of sample due to wash-out indicates less cohesion and more permeability. Conductivity is very high, perhaps because of provenance and mineralogy, or due to the infiltration of saline water from the unit above it. The gamma log indicates that this unit may have a slight fining upward trend, and the magnetic susceptibility is highly variable in this interval. In a nearby borehole, Gadd (1986) assigned this unit to a glaciomarine or glaciolacustrine rhythmite facies of the Leda clay, deposited during an early, freshwater phase of the Champlain Sea.

An acoustically transparent unit exists from 59 to 66 ms two-way travel time (43 to 48 m, calculated). Conductivity is very high at the base of the unit and, if it is interpreted in terms of pore water chemistry, indicates a salinity of approximately 3000 ppm, slightly lower than estimates of salinity based on foraminiferal assemblages in the western basin of the Champlain Sea (Rodrigues, 1987). This unit may correspond to the massive prodelta facies of Gadd (1986). The magnetic susceptibility log shows a uniform and rapid increase upward through this interval. Such a change may indicate a mineralogical change in the sediment due to provenance, subareal weathering environment, depositional environment, or diagenesis.

The reflections above this unit, at 49, 41, 36, and 31 ms (35, 29, 25, and 21 m, calculated), exhibit uniform characteristics and appear to characterize a common lithological unit. The reflections are parallel and conformable. Subordinate reflections visible within each sequence are not well defined. The gamma log records minor coarsening upward sequences throughout this unit. The magnetic susceptibility log shows a slight step-wise increase upward through the unit. This may be correlated with Gadd's (1986) stratified delta front facies. Conductivity declines upward through this sequence, coinciding with Rodrigues' (1987) observation of declining salinity upward through the Leda clay, and perhaps corresponding to the more proximal shift in the depositional environment.

The unit bounded by prominent reflections at 15 and 31 ms (7 to 21 m, calculated), is quite different from underlying units in that it does not exhibit the same amount of internal organization. On the gamma log this unit may be differentiated from that underlying it by the frequency of the changes in the count rate, perhaps due to the thickness of the bedded units. According to the gamma log, the sediment gradually fines downward, to 19.5 m below ground level (approximately 30 ms two-way travel time), where it becomes slightly coarser and the gamma counts begin to fluctuate with greater frequency. This boundary is also recorded by a minor change in magnetic susceptibility. The conductivity log maintains a decrease upward, and if its response is due primarily to the salinity of connate water, then the trend toward declining salinity is again in agreement with Rodrigues (1987). This unit corresponds stratigraphically with Gadd's (1986) sandy emergent delta facies in the nearby Mer Bleue borehole, but the lithology of this unit appears to be predominately silty clay. This unit contains three conductivity and magnetic susceptibility anomalies, at 7, 10, and 15 m, probably not related to borehole lithologies. Each anomaly spans approximately 1.5 m of depth, and none appear on the gamma log. The origin of the anomalies is unknown at present. A positive magnetic susceptibility anomaly at 13 m may be related to a mineralogical change in the sediment.

The seismic record cannot be used to delineate structure in the very shallow subsurface (above 15 ms, or 7 m depth) because of the interference between shallow reflections and refracted wave arrivals. Lithologically the surficial unit consists of 3 m of grey or oxidized sand with minor rhythmic clay overlying 3 m of grey clay containing some brown organic material and featuring some rounded pebbles of mixed lithology at its base. It is not known yet how much of the surficial material may be fill used to landscape the site, although given the terrain in the immediate vicinity it is unlikely that the fill is more than 1 m thick. The clay unit shows the continuation of the upward diminishing conductivity trend, followed by an abrupt reduction in the conductivity corresponding to the sandy surficial layer. The gamma log marks the upward transition from clay to sand at 3 m with a significant drop in the count rate which would result from a decline in the amount of clay in the surrounding strata. The magnetic susceptibility also decreases in the sandy zone, marking lower concentrations of magnetic material, perhaps through oxidation. Gadd (1986) suggests that this type of lithology represents overbank flooding of proto-Ottawa River floodplains and terraces during progradation into the regressing Champlain Sea.

SUMMARY

A 62 m borehole drilled to bedrock just east of Ottawa, passed through 57.5 m of unconsolidated sediments. Gamma, conductivity, and magnetic susceptibility logs show good correlation with a high resolution, shallow seismic reflection survey at the site. Cores taken during drilling will be extruded and analyzed at Carleton University. The detailed litho-stratigraphy that will be available may explain the conductivity and magnetic susceptibility anomalies at 7, 10, 13, and 15 m below ground level.

Excluding the relatively nonconductive till and bedrock at the bottom of the hole, the conductivity increases, at an increasing rate, with depth. Assuming that the log is reacting primarily to pore water chemistry (i.e. that there is not an increasing concentration of conductive minerals with depth), it indicates increasing salinity with depth. The conductivity at the base of the clay unit suggests a salinity of approximately 3000 ppm. Whether the conductivity trend confirms the decrease, through time, of the salinity of the Champlain Sea determined from foraminiferal assemblages, or marks dilution of saline water by fresh ground water, is unknown.

The gamma log and the seismic record indicate that the 47 m thickness of Leda clay in the borehole may be subdivided into four units. According to Gadd's (1986) lithofacies analysis, these units mark the postglacial immersion of the site in a glaciolacustrine setting, followed by marine incursion by the Champlain Sea. The subsequent regression is recorded in the vertical progression from deep water marine sediments to deltaic overbank deposits.

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REFERENCES

Gadd, N.R.

1986: Lithofacies of Leda clay in the Ottawa basin of the Champlain Sea; Geological Survey of Canada, Paper 85-21.

1987: Quaternary evolution of the Ottawa area; in Quaternary of the Ottawa Region and Guides for Day Excursions, (ed.) R.J. Fulton; International Union for Quaternary Research, XII[th] International Congress, p. 75-80.

Pullan, S.E. and Hunter, J.A.M.

1990: Delineation of buried bedrock valleys using the optimum offset shallow seismic reflection technique; in Geotechnical and environmental geophysics, Volume III: Geotechnical, (ed.) S.H. Ward; Society of Exploration Geophysicists, p. 75-87.

Pullan, S.E. and MacAulay, H.A.

1987: An in hole source for engineering seismic surveys; Geophysics, v. 52, p. 985-996.

Rodrigues, C.G.

1987: Late Pleistocene invertebrate macrofossils, microfossils and depositional environments of the western basin of the Champlain Sea; in Quaternary Geology of the Ottawa Region, Ontario and Quebec, (ed.) R.J. Fulton; Geological Survey of Canada, Paper 86-23, p. 17-23.

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