Delineation of bedrock topography at Val Gagne, Ontario, using seismic reflection techniques'

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Abstract

Optimum offset shallow seismic reflection sections from the Val Gagne, Ontario, test site show excellent agreement with available borehole logs. Bedrock topography and structure within the overburden, including the delineation of occurrences of till, were interpreted from the seismic profiles. The results of this survey indicate that the optimum offset shallow reflection technique could be a valuable tool in exploration programs in northern Ontario and Quebec where overburden drilling is used for gold prospecting. With the seismic information available prior to drilling, drillsites could be selected to sample thick pockets of till or specifically located in the glacial-lee of buried bedrock highs in order to maximize the useful returns of each borehole.

Resume

Les profils de Val Gagne, en Ontario, obtenues au moyen d'une technique de sismique reflexion peu profonde a decalage optimal, concordent tres bien avec les diagraphies disponibles. A partir de ces profils sismiques, on a reconstitue la topographie et la structure de la roche en place a l'interieur du terrain de recouvrement et delimite les accumulations de till. Les resultats de ce sondage indiquent que la technique de sismique reflexion peu profonde a decalage optimal pourrait etre un outil d'exploration precieux dans le nord de l'Ontario et du Quebec, ou la prospection des gisements d'or s'effectue par forage dans des sediments meubles de recouvrement. Grace aux donnees sismiques recueillies avant le forage, on pourrait ainsi choisir les lieux de forage de facon a pouvoir prelever des echantillons des epaisses accumulations de till ou, plus particulierement, les etablir sur le versant des elevations de roche en place oriente dans la direction de l'ecoulement glaciaire, afin de tirer le maximum de chaque sondage.

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INTRODUCTION

With the development of digital enhancement engineering seismographs and the concurrent proliferation of microcomputers over the last decade, it has become possible to apply seismic reflection techniques, well established since the 1930s in the oil industry, to shallow engineering or groundwater problems. The Terrain Geophysics Section of the Geological Survey of Canada has been developing shallow reflection methods and software to process the data since 1980 (Hunter et a]., 1982a,b). The methods are now well established and have been tested in many areas of Canada (Hunter et al., 1984). This report describes a survey where this technique has been applied to a mining exploration problem to illustrate its potential usefulness in future exploration programs.

In the Matheson/Val Gagne area, east of Timmins, Ontario, gold prospecting has been inhibited by the thickness of the overburden. The area is covered by varying thicknesses of clay, silt, and/or sand, overlying pockets of till above the bedrock. The average depth to bedrock in 42 holes drilled in the area in 1984 by the Ontario Geological Survey (OGS) was 35 rn (Jensen et al., 1985). The standard current exploration procedure is to drill and sample any tills that are encountered above bedrock. The samples are then assayed for gold content, and, if this is significant, drilling continues in the "up-ice" direction in search of the "mother lode". Under ideal conditions drillholes would be positioned in the glacial lee of buried bedrock highs where thick occurrences of till are likely to be found, but without any prior knowledge of the subsurface structure, much of the initial exploratory drilling is blind. It is estimated that as many as 25% of such drillholes encounter no till (R.B. Barlow, personal communication, 1986) if no geophysical definition of the subsurface is available.

Our initial work in the Val Gagne area in 1985 was done at the request of R. B. Barlow of the Ontario Geological Survey. Prior to our seismic surveying he had carried out airborne and ground electromagnetic (EM) field and interpretation work that had demonstrated the utility of these methods for indicating the presence of till pockets coincident with bedrock valleys. This then provided regional overburden drilling targets. Although the lateral extent of till pockets could be outlined by various imaging techniques applied to the EM data, resolving the vertical section (i.e., precise depths and thicknesses) through one-dimensional sounding interpretation methods requires much further research. He suggested that collaborative efforts, using seismic reflection methods together with EM methods, would allow the possibility of further advancing the electromagnetic interpretation problem, while at the same time demonstrating the capability of the seismic reflection method for resolving the complex vertical stratigraphy of the Quaternary sections in the area.

Seismic tests in 1985, at various sites selected on the basis of EM surveys conducted by OGS, proved the feasibility of this approach. In 1986 we applied the "optimum offset" reflection technique on a production basis at a test site near Val Gagne, Ontario. Data from this test site are presented below, along with corroborative drillhole data from recent OGS drilling programs (OGS, 1986).

METHOD

The "optimum offset" shallow seismic reflection profiling technique has been described by Hunter et al. (1984). Under optimum conditions this technique allows an accurate and detailed delineation of the overburden-bedrock contact and of the structure within the overburden, even when the subsurface structure is fairly complex. The resolution depends on the frequency of seismic energy that can be returned from the target reflector to the surface. We have found that the best conditions occur when the near-surface materials are fine grained and water saturated. Such conditions exist throughout the clay belts of northern Ontario, which are also ideal for geophysical surveying in that there is minimal surface topography and good road access. Thus the Val Gagne test site, which is located in the clay belt north of Matheson, Ontario is an excellent area for the application of the optimum offset technique.

Each trace on an optimum offset profile is obtained using a geophone to record the ground motion in response to seismic energy that is produced at a predetermined source geophone offset. The final section consists of a series of such measurements made at a given geophone spacing.

Approximately 10 km of line has been shot at the Val Gagne test site, predominantly along roads (Figure 1). A source-geophone offset of 30 rn and a geophone spacing of 2.5 rn were used for Line I which was shot 'In 1985; Lines 100-600 were all recorded in 1986 with a source-geophone offset of 21 rn and a geophone spacing of 3 rn. The data were filtered in the field by high-frequency geophones (50 Hz for Line 1, 100 Hz for all other lines), and by the 300 Hz high pass analog filter on the seismograph. A 12-gauge "Buffalo gun" was used throughout the survey as the seismic source (Pullan and MacAulay, 1987). Shallow holes (I rn deep) were drilled in a ditch or at the edge of the roadway and filled with water before being used as shotholes.

The data were recorded on a Nimbus 121OF 12-channel engineering seismograph and stored in the field on a G724S digital tape recorder. 'Me records were transferred daily to an Apple Ile microcomputer and stored on floppy disk. Preliminary processing and plotting were carried out with the Apple system in the field office (Norminton and Pullan, 1986). Final plotting and a detailed velocity analysis were completed after all the data were collected.

Processing of the data involved: 1) shifting traces in time to line up the first arrivals (refractions from the top of the water table); 2) digital filtering (300-800 Hz bandpass); and 3) the application of an automatic gain control and time-varying gain tapers.

Depth scales were calculated after an analysis of multi-channel records which were recorded along with the optimum offset data. These records were used to obtain an estimate of average velocity as a function of depth; average

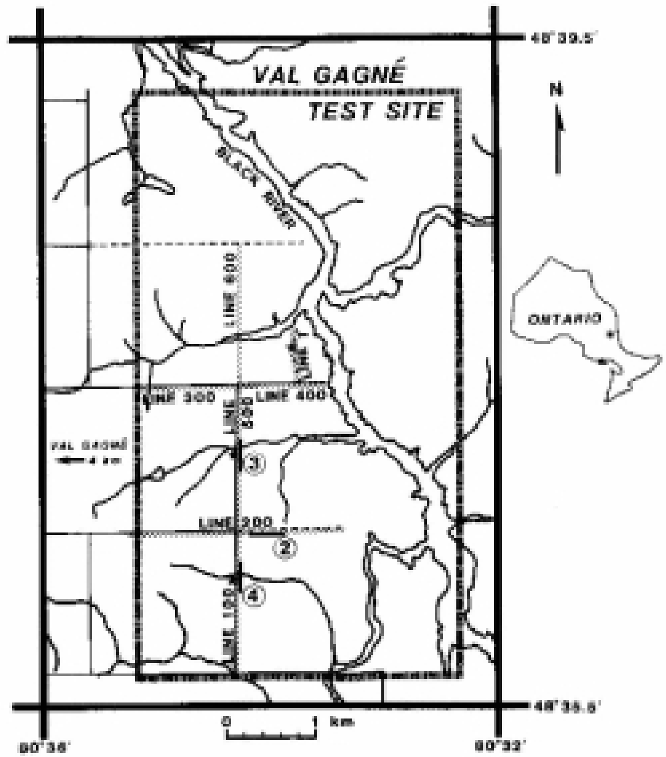

Figure 1. Map of the Val Gagne test site, indicating the location of seismic survey lines (hatched lines), drillholes (stars), and the sections shown in the following figures (solid lines related to circled numbers). Lines 100, 500, and 600 lie along the north-south baseline of the metric grid laid out for the test site; the east-west baseline is the southern limit of the site.

overburden velocities were in the range of 1500-1600 m/s. Depths are given with respect to the water table, as this is the datum on the seismic sections. Over most of the area, however, the water table is within I or 2 rn of the surface and the depths given below are essentially those from ground surface.

The complete suite of shallow seismic reflection sections from the Val Gagne test site is available in Gagne et al. (in press).

RESULTS

Figure 2a is a 400 rn section of the optimum offset profile along Line 200 which shows a buried bedrock valley The section is reproduced in Figure 2b with interpretation lines superimposed. This section demonstrates the potential of the optimum offset shallow reflection method to map fairly rugged subsurface structure. This buried valley is 200 rn wide, and the maximum relief on the bedrock surface is approximately 25 rn. The steep sides of the valley are an indication that the survey line transects the valley at close to right angles, but additional east-west profiles would have to be shot to the north and south to define the strike and lateral extent of this feature.

Within the overburden, there are several reflectors which are almost flat lying. From the logs of nearby drillholes (see below), it is believed that the overburden is essentially a clay unit. The reflectors within this unit appear to be "draped" over the bedrock topography, that is, they dip gently towards the centre of the bedrock valley and are arched up over the bedrock highs. This is attributed to the dewatering and compaction of the clays after deposition. 'Me draping effect can also be seen on the sections shown in the following figures, but it is more subtle because of the gentler bedrock topography

There is no indication of any substantial thickness of till in this bedrock valley. Instead, we interpret there to be a remnant of till overlying bedrock on the west side of the section, and possibly another one on the east (Figure 2b). This interpretation is based on the seismic signature of till layers encountered in boreholes nearby (see below).

The depth scale for this and the following two figures was calculated using an average velocity of 1525 m/s. Velocity analyses of multichannel records in the area indicate this to be a reasonable velocity for the clay unit.

Figure 3 shows a 350 rn section of the optimum offset profile along Line 100 centred on Sonic Drillhole 84-38 which was drilled by the Ontario Geological Survey in 1984 (Jensen et al., 1985; OGS, 1986). The bedrock dips gently to the north on this section, from a depth of approximately 30 rn at 230ON to a depth of 35 rn at 2600N. The overburden reflectors also dip gently to the north and again show the draping effect discussed in relation to Figure 2. According to the borehole log (OGS, 1986), the overburden consists of 9 rn of massive clay above 23.5 rn of varved clay. As the resolution in the upper 10 rn of the seismic section is poor, due to the nonzero source-geophone offset and the resulting wideangle reflections from shallow interfaces, it is not possible to resolve this contact on the section. The strong reflector on the seismic section at 28 ms corresponds to a significant increase in varve thickness which starts at a depth of 22 rn. The clay ends at a depth of 32 rn at a sharp contact with sandy till. The till is only 3 rn thick and overlies diabase bedrock.

On the seismic section, the top of till is the major reflector with a weaker reflection from bedrock below it. The interpretation of this section in Figure 3b is based on this till/ bedrock signature. We interpret there to be a continuous thin layer of till across this section north of 2300N. At the south end, a small bedrock high protrudes up into the clay unit. The till is believed to be thickest just north of 250ON where it fills a small hollow in the bedrock surface.

Figure 4 shows a 350 rn section of Line 100 centred on OGS Sonic Drillhole 84 - 39 (Jensen et al., 1985; OGS, 1986). This section is only I km south of the section shown in Figure 3. Again, the borehole log indicates a predominantly clay overburden with a contact between massive and varved clay at a depth of 13 rn. This interface is deep enough to be resolvable on the seismic section. The strong reflector within the overburden at a time of 30 ms is again attributed to a general increase in varve thickness which is logged at a depth of 24.4 rn. The clay overlies a I rn layer of till, below which there is 6.5 rn of sand above argillaceous siltstone. The till layer is too thin to allow resolution of both the top of till and the top of sand on the section. The seismic profile indicates, however, that the sand fills a small hollow (50 rn wide) in the bedrock surface (Figure 4b). Except for this pocket of sand and till, we interpret there to be only a thin layer of till, or sand and till, north of I 100N.

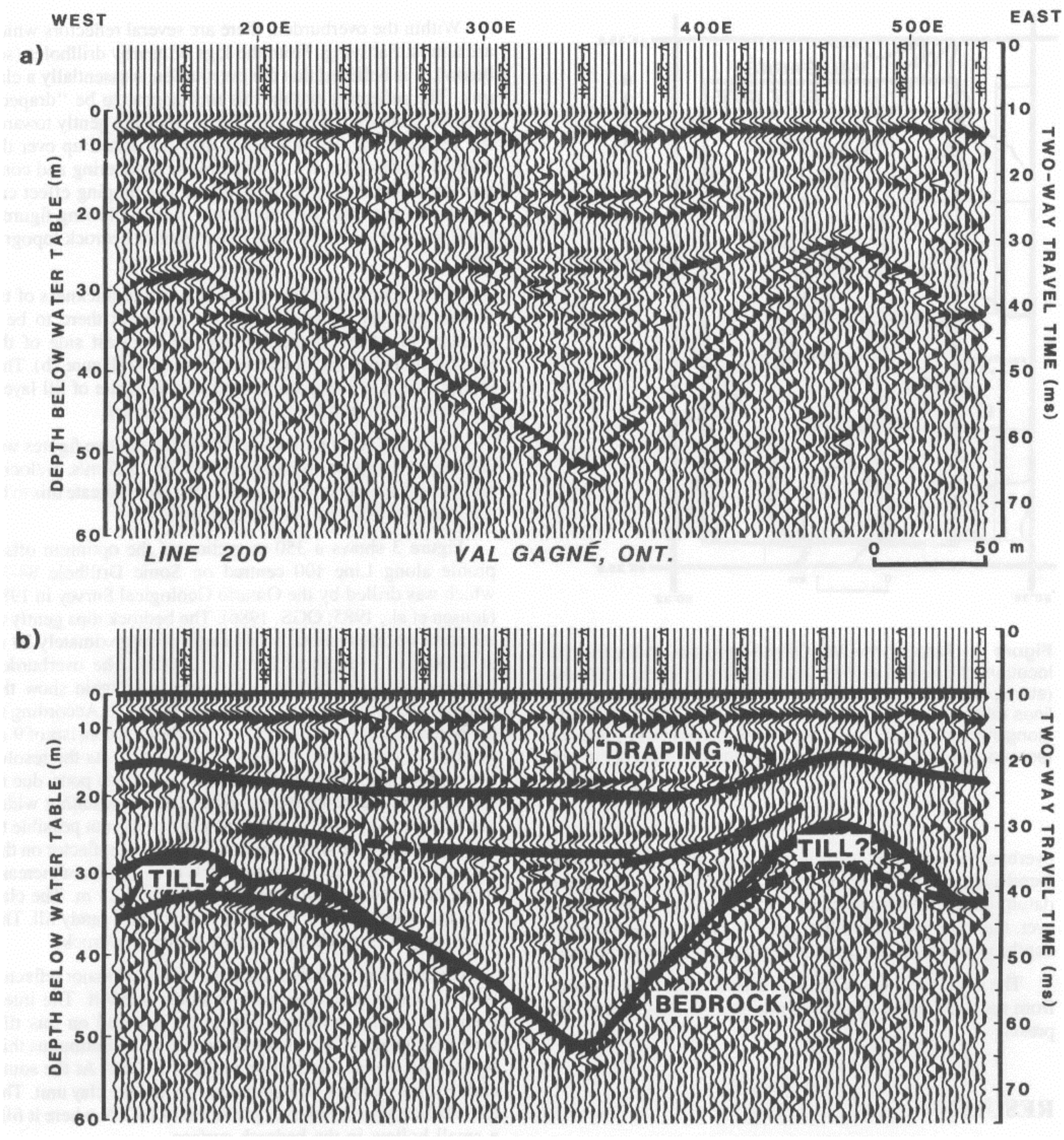

Figure 2.

a) Optimum offset seismic reflection section along Line 200 from 135E to 535E (i.e., with respect to the metric grid laid out for the test site).

b) An interpretation of Figure 2a, indicating bedrock topography, likely occurrences of till, and "draping" of overburden reflectors. See text.

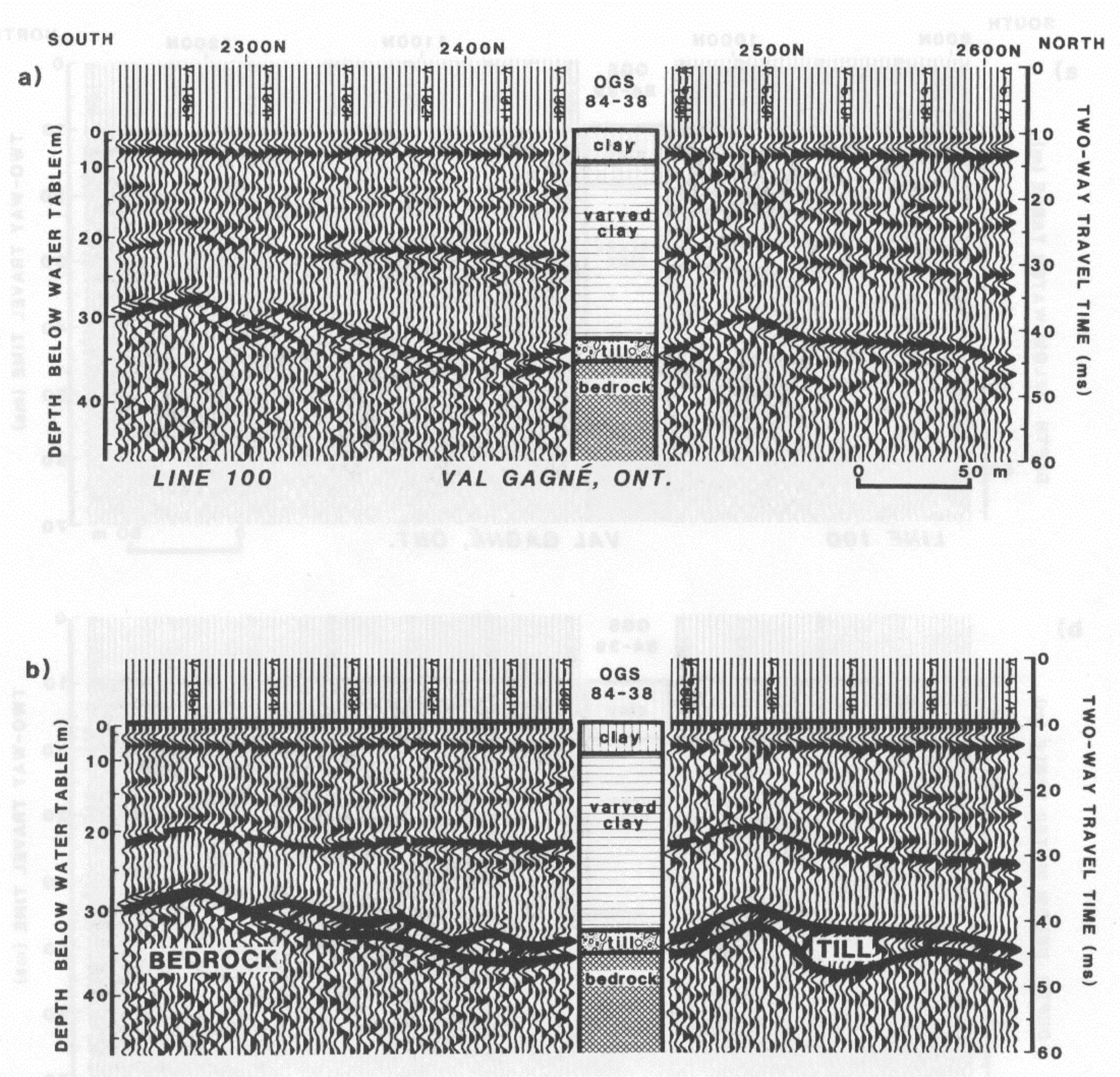

Figure 3.

a) Seismic reflection section along Line 100 from 2240N to 2610N. The section has been split at the site of OGS Sonic Drillhole 84-38, and a simplified drill log is shown there.

b) An interpretation of Figure 3a, outlining the likely extent and thickness of the till layer encountered in the borehole.

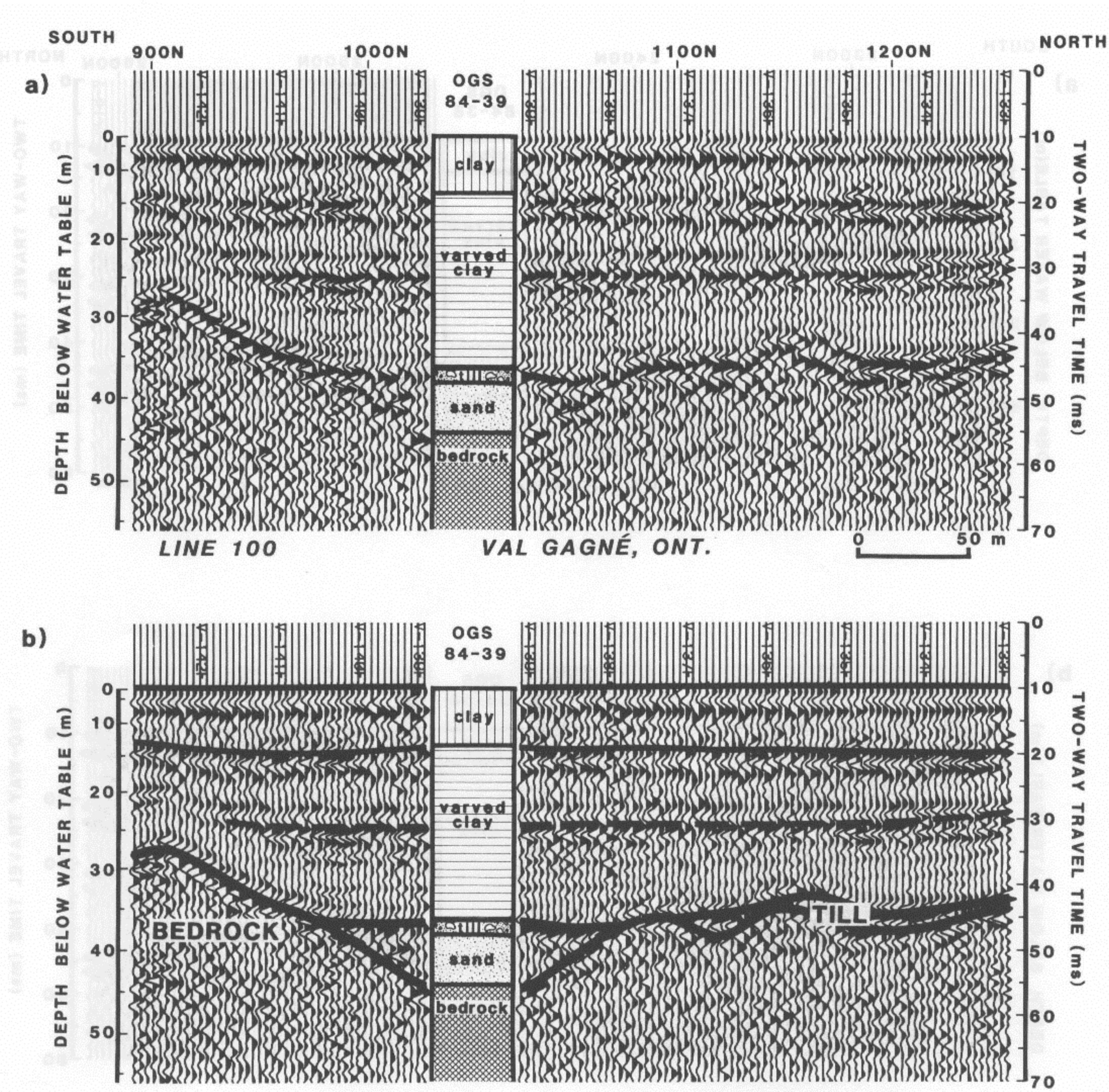

Figure 4.

a) Seismic reflection section along Line 100 from 890N to 1250N. A simplified drill log is shown at the location of OGS Sonic Drillhole 84-39.

b) An interpretation of Figure 4a, indicating the extension of lithological units north and south of the borehole, and likely occurrences of till.

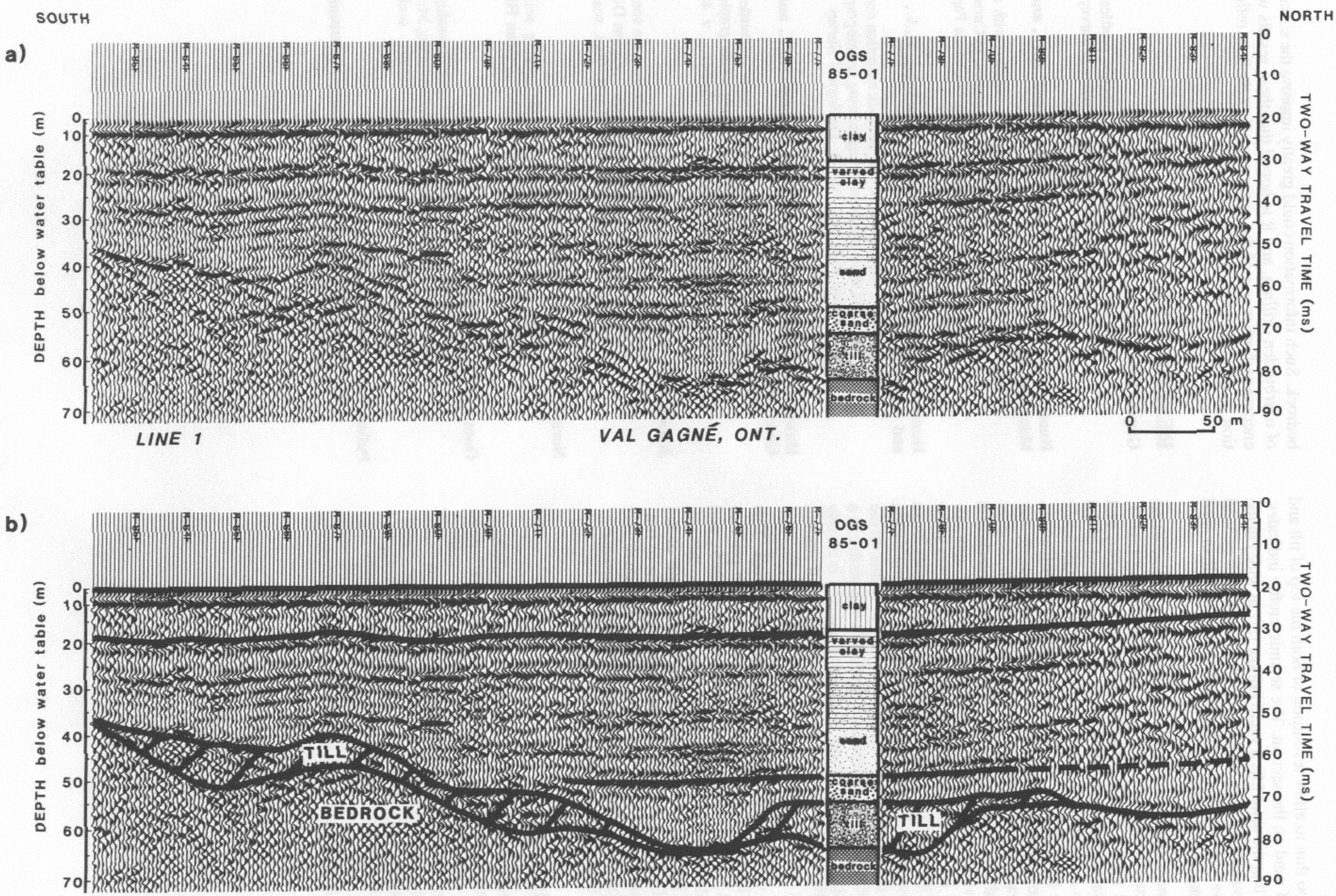

Figure 5.

a) Line 1 with a simplified drill log shown at the location of OGS Sonic Drillhole 85-0I.

b) An interpretation of Figure 5a, indicating the extension of lithological units north and south of the borehole, and likely occurrences of till.

The most significant bedrock depression that has so far been discovered on the Val Gagne test site is along Line 1, shown in Figure 5. This section is 660 rn in length, and bedrock varies from a depth of 37 rn at the south end of the section to a depth of 65 rn at the drillhole site (OGS Sonic Drillhole 85-01, R.B. Barlow personal communication, 1985). The essentially flat-lying overburden consists of clay grading into a thick sand unit. The contact between massive and varved clay occurs at a depth of 17 rn and this interface is clearly visible on the seismic section at a time of approximately 30 ms. A small amount of fine sand first occurs at the bottom of the varves at a depth of 17 rn, and this grades into a poorly layered sand from 40 to 50 rn depth. The top of the sand is an indistinct boundary and is not easy to define on the seismic section; however, there is a weak reflector visible at a depth of approximately 40 rn. Horizontal layering is clearly indicated throughout the clay/sand units with a small amount of draping visible.

At the drillhole, 15 rn of sandy till overlies bedrock. This pocket of till was identified on the seismic section prior to drilling (R.B. Barlow, personal communication, 1985), and the drillhole site was selected specifically to sample this till. Figure 5b shows another major pocket of till south of the drillhole. This section clearly demonstrates the value of running seismic profiles prior to drilling; had 85-01 been drilled 100 rn to the north of its location, only a minor occurrence of till would have been encountered in the hole.

DISCUSSION

The four short optimum offset seismic sections that have been presented above illustrate the potential benefit of this type of surveying, especially in combination with complementary electromagnetic techniques, to exploration programs in the clay belts of northern Ontario and Quebec. With some experience and drillhole control it is possible to delineate the subsurface bedrock topography, even when this is fairly rugged, to determine the structure and thickness of the overburden, and to define small occurrences of till overlying bedrock. Such information could greatly improve the success of overburden drilling, and it is hoped that these results will encourage further use of the optimum offset shallow reflection technique in this area.

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