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GROUND-PENETRATING RADAR: A TOOL FOR DELINEATING AGGREGATE-RESOURCE DEPOSITS

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ABSTRACT

Ground-penetrating radar (GPR) was tested in two gravel quarries on the Avalon Peninsula to determine its usefulness in evaluating the aggregate-resource potential. In Mercer's Pit, near Tors Cove, GPR profiles showing irregular, discontinuous reflections are interpreted as aggregate deposits that extend to depths of >30 m. Boulders are common at depth (identified on the profiles by numerous individual diffractions). Analysis of a peat bog, near Mercer's Pit, shows a prominent contact: the hummocky surface of the gravel deposit (continuous, high-amplitude reflections) underlying a much weaker reflective zone of peat. At Snow's Pit, near Bay Roberts, a series of overlapping diffractions at depth are interpreted as representing bedrock that varies from 5 to 15 m below the surface. Directly overlying the bedrock are aggregate deposits (irregular, discontinuous reflections) that contain few boulders (the radar profiles show few individual diffractions).

The GPR system was found to be an effective tool for delineating the extent and volume of subsurface aggregate resources. It provides a detailed view of the subsurface and large amounts of information are gathered quickly and easily. It can be used to revise volume calculations of quarries already in operation, and the gathered data can better estimate the volume of potential new deposits. As well, it can be used to plan pit development and to analyse prospective areas with virtually no environmental impact on the land surveyed.

INTRODUCTION

Aggregates are a prerequisite for road building, and domestic and public construction projects all over Newfoundland and Labrador. The demand for aggregate is thus continuous and widespread. To enable the effective and economical use of aggregates, it is important to locate aggregate resources close to the source of the demand, as their value decreases with increasing distance of transport. Therefore, an aggregate-resource company needs to locate a high-quality, economic aggregate deposit near an area where aggregate is in demand. In the past, these aggregate-resource companies have relied, in part, on aggregate-resource maps produced by the Geological Survey of Newfoundland and Labrador to locate and outline the surficial extent of potential deposits; however, little was known about the depth of the deposit. Test pits dug by backhoe are used to give some idea of deposit thickness prior to development, but they give an incomplete picture. As a result, companies involved in aggregate extraction are not able to fully define the volume of their deposits, and this limits the value of any economic feasibility study.

Over the last several years, there have been advances in ground-penetrating radar (GPR) technology that have made this instrument a tool, having excellent potential, for determining the extent and depth of an aggregate resource. The method is non-invasive and it can be used in areas where an operator does not yet own or have rights to, without any damage to the property. This is especially important near urban areas.

A GPR unit sends electrical signals into the ground and records the wave energy that is reflected back to the surface (*see* Davis and Annan, 1989, for a detailed explanation). The system works best in clean sands and gravels – the typical grain sizes of high-quality aggregate deposits. Grain size, porosity, pore-water salinity or contamination, moisture content and organic content all influence the electrical conductivity of a soil, which in turn affects the quality and character of the radar response. Penetration depth and reflection quality are poor in more conductive materials such as saturated silt, clay and saline sediments, as most of the wave energy is not reflected back to the surface (Davis and Annan, 1989). Unsaturated gravel, sand and organic deposits provide the best conditions for GPR analysis (Moorman *et al*., 1991). Fortunately, these materials are common in the province, and even the till deposits tend to be sandy, rather than clay-rich.

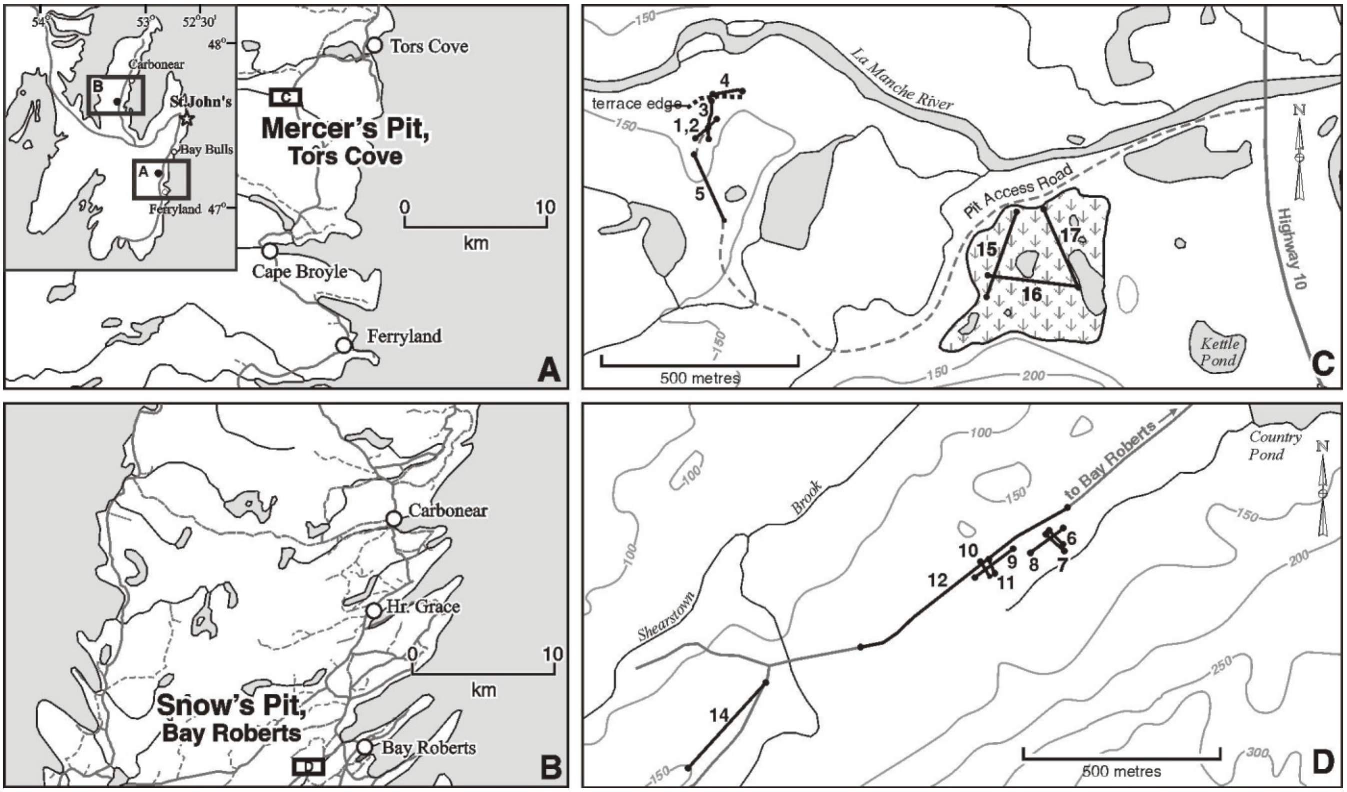

Figure 1. *Location map of active gravel pits analyzed in this study.*

GPR can detect bedding, boulders and bedrock at depth (5 to 35 m), providing lateral, as well as vertical, information about a deposit. In ideal circumstances, it also can identify the location of the water table. Excavation for aggregate cannot continue beneath the water table. If the water table is identified above the bedrock surface, it is an important limiting factor for the extent of the economic viability of the deposit. Bedding style may give some idea of the depositional environment of a deposit and may allow prediction of grain-size changes laterally and with depth (Jol *et al.*, 1998). Boulders at depth are shown by individual diffractions on the radar profile. The sediment/bedrock interface is commonly easy to detect, as the electrical properties of gravel and bedrock are quite different.

The objective of this study is to test the GPR in active gravel pits and assess its effectiveness in determining deposit thickness and economic viability. A similar study using the GPR system proved useful for this purpose in Alberta, despite penetration depths of less than 5 m (Fisher *et al*., 1995).

METHODS

A late-model 1000 V GPR unit (the Ramac X3M) was rented and tested in an operating gravel pit near Bay Roberts and in a smaller, recently opened gravel pit in Tors Cove (Figure 1a-d). Two shielded 100 MHz antennae (a transmitter and a receiver) were towed in a skid box behind the surveyor, and distances were measured with a wheel towed behind the antennae (Plate 1). For geological work, the 100 MHz antennae provide a good compromise between range,

Plate 1. *Ramac X3M ground-penetrating radar and operator. The shielded antennae are towed in a skid box and data is collected on a weather-resistant computer carried in a harness by the operator. Horizontal distances are measured by a calibrated wheel attached to the antennae.*

Table 1. Processing parameters used on each radar profile

Line Number	Profile Number	DC Removal	Automatic Gain Control	AGC Window	Upper Band Pass	Lower Band Pass	Time Varying Gain Linear	Time Varying Gain Exponential	TVG start point (ns)	Subtract Mean Trace	Velocity (m/ms)	Running Average
1	82302	370	6000	70	110	75	7	8	440	80	120	
2	83044	250	8000	35	110	60	8	8	392	75	120	
3	83800	125	6000	99	110	80	5	5	340	100	120	
4	85732		8000	80	110	90	127	19	129		120	
5	91412		9000	80	120	60	67	9	98		120	3 X 3
6	91445		8000	15	120	90	180	14	157	100	120	
7	92348	133	8000	40	120	80	10	22	374	80	120	3 X 3
8	92743	114	6000	20	100	80	7	0	276	100	120	3 X 3
9	93357	152	5000	40	120	85	0	9	176	100	120	
10	94131	171	8000	30	120	85	0	7	171	100	120	
11	94545	172	7000	48	110	80	0	20	321	70	120	
12	95801	250	8000	15	120	90	0	4	105		120	
13	110554	230	5000	40	105	80	19	9	138	75	120	
14	120611	402	8000	45	133	90	10	0	167	100	120	
15a	95624		6000	20	120	80	80	10	217	100	90	
15b	95624		6000	20	120	50	80	10	217		90	
16a	101115		5000	60	120	80	55	10	113	100	90	
16b	101115		5000	60	120	50	55	10	113		90	
17a	101829		7000	30	120	80	25	12	119	100	90	
17b	101829		7000	30	120	50	25	12	119		90	

resolution and ease of use in the field (Davis and Annan, 1989). Reflection information was recorded at 30 cm intervals along the surface and profiles up to several hundred metres long were acquired for this study in less than two days. Using an unshielded antennae, a common midpoint (CMP) survey can be done to determine actual wave velocities in the sediments and as a result, depths can be calculated accurately. However, because the shielded antennae configuration has a fixed antenna separation, this type of survey could not be carried out (a CMP survey involves moving the antennae farther and farther apart). As a result, sediment velocities in this study were estimated, and depth calculations are therefore subject to error. In wet sediments (bogs, for example), a wave velocity of 90 m/µs was used and in dry sediments, the velocity was set to 120m/µs.

The unit has three depth settings. The shallow setting gives high resolution but low penetration depths (about 10 m) and the deep setting gives the best penetration depth (35 m) at the expense of resolution. A medium setting is a compromise between the two (about 25 m). Generally, the deepest setting is tested, and the other settings may be chosen if penetration is not good in that area or if detail is more desirable than depth.

Data was plotted using Ramac GroundVision software. A variety of filters was applied to each profile (Table 1). The data may also be processed with migration software (Gradix) to remove diffractions, but this was not done for this study.

GPR profiles represent a vertically exaggerated, 2-D slice of the subsurface. Lines that are run perpendicular to each other, or in a grid pattern, can give an idea of the 3-D aspect of the deposit. The 2-way travel time (in nanoseconds) is shown on the left side of each profile and the estimated depth is shown on the right (e.g., Figure 2). The horizontal distances along the profile, however, are accurate and are shown at the top of each line.

RESULTS

MERCER'S PIT

Mercer's Pit, in Tors Cove (Figure 1a) has only recently begun operations and as a result, open areas suitable for GPR analysis were restricted. The geophysical lines were run in a cleared gravelly area, where brush and topsoil have been removed, and in recently cut-over areas that contain brush and stumps. The latter included an upper and a lower terrace flanking La Manche River (Figure 1c). Lines were also run along the road near the pit and on a bog near the gravel-pit access road (Plate 2). Excavations in the pit reveal discontinuous beds of sand, silty sand and pebble/cobble gravel. Large boulders (>1 m in diameter) are also present, but are less common.

Lines 1 to 4 were recorded in the active and prospective pit areas (Figure 2). Line 1 was run at a medium-depth setting and reflectors were seen clearly to a depth of 25 m. The

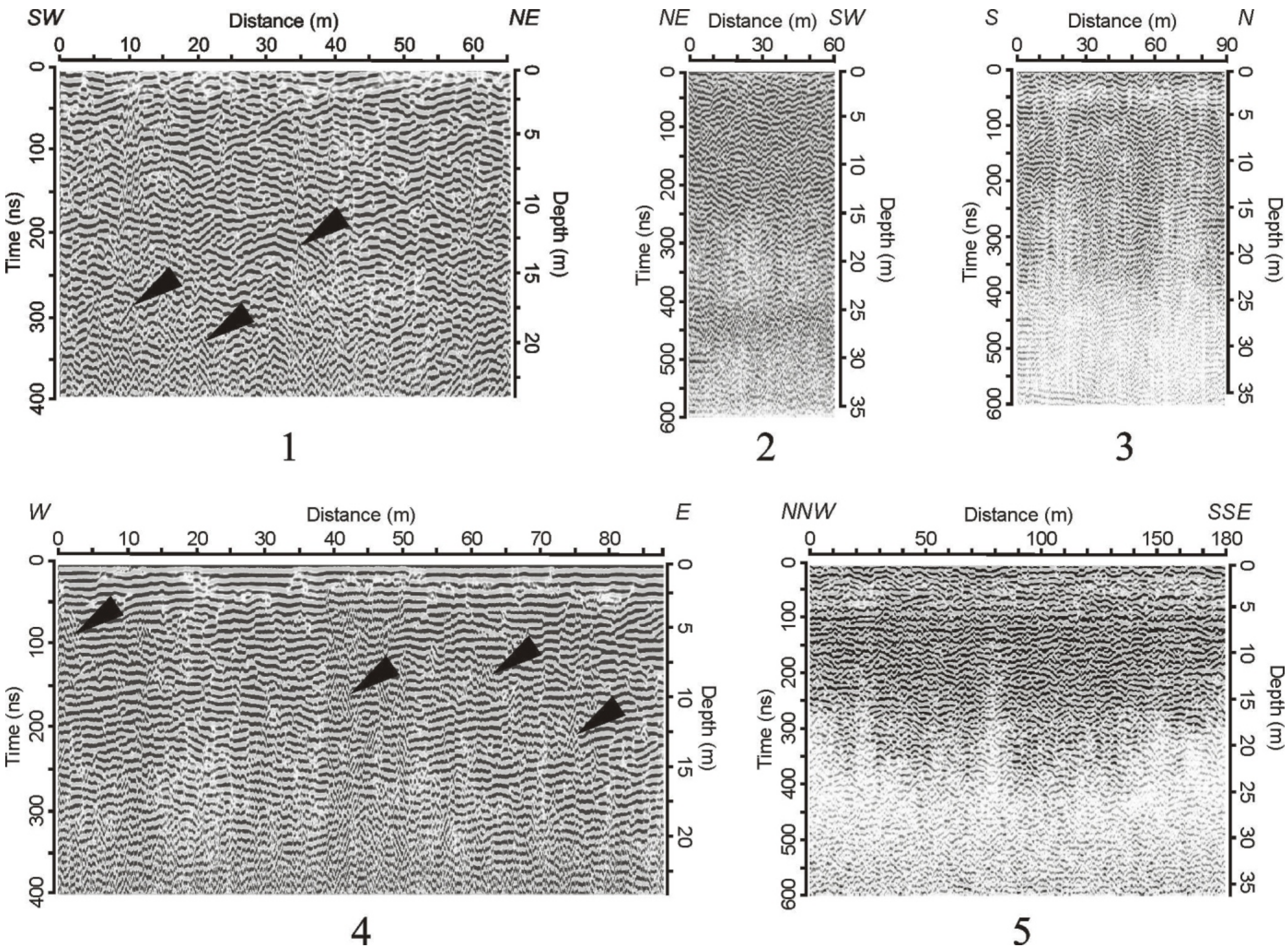

Figure 2. *Radar profiles from the active pit area at Mercer's Pit. Arrows show localized diffractions caused by the presence of boulders. Line numbers are shown below each profile.*

Plate 2. *Collecting GPR data in a bog.*

line was run again (line 2) at the highest depth setting. Note the compressed horizontal distance on this profile due to the greater depth setting. Line 3 is oriented perpendicular to lines 1 and 2. On lines 2 and 3, undulating reflections are interpreted as showing irregularly bedded gravel to depths of 30 m, and possibly 35 m, below the surface. Pit excavations substantiate this type of bedding in the upper 5 m. Line 1 shows the reflectors in more detail. The reflections are strong (high in amplitude) and display irregular, dipping and horizontal bedding. They also tend to be discontinuous. This style of bedding is common in fluvial and glaciofluvial environments (Benn and Evans, 1998). At 58 m distance on line 3, the line passes from a cleared gravel area into a cut-over area that contains tree stumps (Plate 3). This transition produced no noticeable difference in the data. Line 4 was acquired on a cut-over terrace, 5 to 10 m below the terrace on which the upper lines were run. It appears to show gravel over 20 m thick at this lower elevation. Higher quality data were recorded in a boggy area (from 80 to 86 m, line 4) on the lower terrace. This is probably a result of better ground coupling and less signal attenuation. Line 5 was run along the road leading to the pit. It shows similar results to

Plate 3. *Running GPR in a cut-over area.*

lines 2 to 4, with probable gravel deposits to a depth of >30 m. A few diffractions at depth indicate the presence of scattered boulders. These are more visible on lines 1 and 4.

Lines 15-17 were run across a bog, 700 m southeast of the quarry on the deepest setting (Figures 1 and 3). Penetration was good and the quality of the reflections is high in this environment. The prominent, continuous reflectors at depth could be either the bedrock surface or the upper surface of a gravel deposit. These reflectors are overlain by weaker, discontinuous, undulating reflectors. On lines 15a, 16a and 17a (Figure 3), the mean trace was subtracted during processing to remove the multiples of the air wave and ground wave (the first arrivals in all GPR profiles, mostly removed by processing in this study). However, on lines 15b, 16b and 17b (Figure 3), the multiples can be instructive. They only occur in the beds above the major reflector at 5 to 10 m depth. It is probable that this zone is a saturated peat deposit. In this area, (lines 15a-17a), the profiles are nearly devoid of reflections, allowing the multiples to become more visible. The anaerobic zone of peat bogs has been shown to be nearly transparent on GPR profiles (Nobes and Warner, 1992). It is not completely transparent here, but it is certainly weak compared to the reflections in the deposits below.

Below the major reflector are horizontal and irregular discontinuous reflections similar to those in lines 1-4; a few diffractions that likely represent boulders are present in this area. This zone is thus interpreted as a gravel deposit at least 10 m thick, with a highly irregular upper surface.

SNOW'S PIT

Snow's Pit is located just southwest of Country Pond, about 3 km southwest of the town of Bay Roberts (Figure 1b). Profiles were run in the operating part of the gravel pit (which has been excavated several metres below the original surface), in a prospective quarry area, along the road by the pit, and in a hummocky field (Figure 1d).

Lines 6 to 8 were surveyed in the active part of the pit, while lines 9 to 11 were run in a grassy area reserved for future excavation. The latter site is about 10 m higher in elevation than the former. All of the profiles were acquired using the medium depth setting. Lines 6 to 8 show that there is 10 to 15 m of aggregate beneath the pit floor (Figure 4). The stronger and more continuous reflections at these depths may represent the bedrock surface. Diffractions are uncommon, indicating a lack of boulders and therefore suitable grain sizes for an aggregate deposit. Lines 9 to 11 are somewhat different: they show many diffractions at depth. While these could indicate the presence of many boulders below 5 to 10 m depth, it is more likely that they represent vertically or nearly vertically bedded sedimentary bedrock. The laterally continuous and overlapping nature of the diffractions is suggestive of a rugged bedrock surface, rather than a few dispersed boulders; the interpreted bedrock surface is shown by the heavy line (Figure 4). The bedrock identified at about 10 m below the surface means that the prospective pit area contains more limited reserves than the active pit area. The existing gravel pit has a further 5 to 10 m of gravel remaining after initial excavations.

Line 12 was run along the road adjacent to Snow's Pit (Figure 1d). Here, bedrock appears to be present at 10 to 15 m depth (continuous, overlapping diffractions), and it is overlain by what looks to be irregularly bedded gravels without many large boulders present (strong, undulating, discontinuous reflectors with few diffractions). The interpreted bedrock surface is shown by a black line (Figure 5).

Line 14 was run along a grassy road in a field that overlies a potential aggregate resource (Figure 1d). The GPR was attached to a truck, which tows the unit more smoothly over the ground surface than a human operator. The ground surface is hummocky in this area, however, the GroundVision program does not allow topographic correction. As a result, line 14 is incorrectly displayed as having a planar surface (Figure 6). A number of large, overlapping diffractions are present on this profile, as on line 12. The laterally continuous diffractions are likely caused by reflections from a jagged bedrock surface (interpreted with a dark line). This area contains 5 to 10 m of gravel and/or sand.

CONCLUSIONS

In this study, a number of sediment types and features were identified using ground-penetrating radar. Gravelly sediments are characterized by strong, undulating discontinuous reflections, while peat bogs exhibit weak, nearly trans-

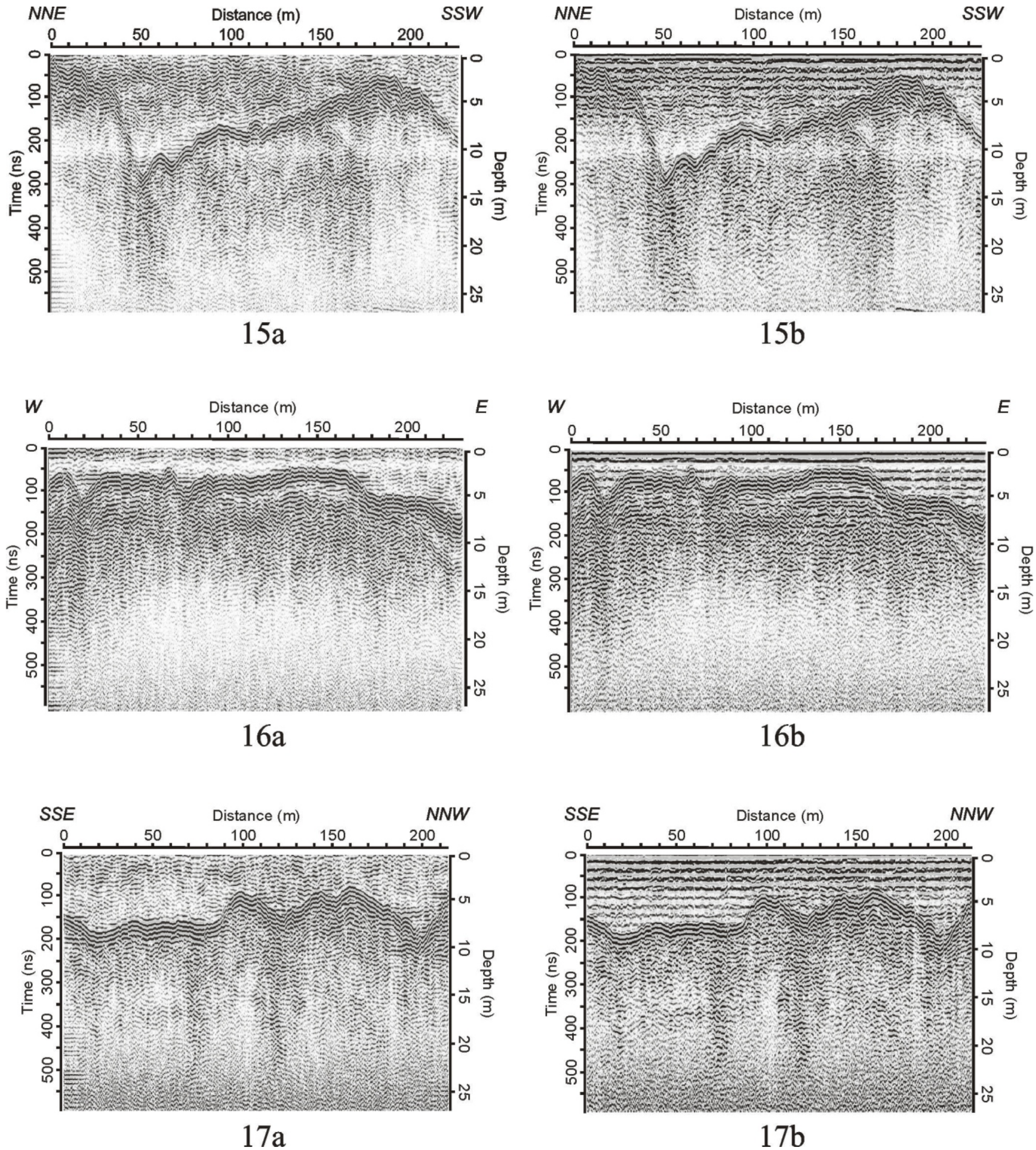

Figure 3. *GPR profiles run across a bog near Mercer's Pit. The profiles on the left were processed to remove multiples of the air and ground waves. The same profiles on the right show these multiples. Line numbers are shown below each profile.*

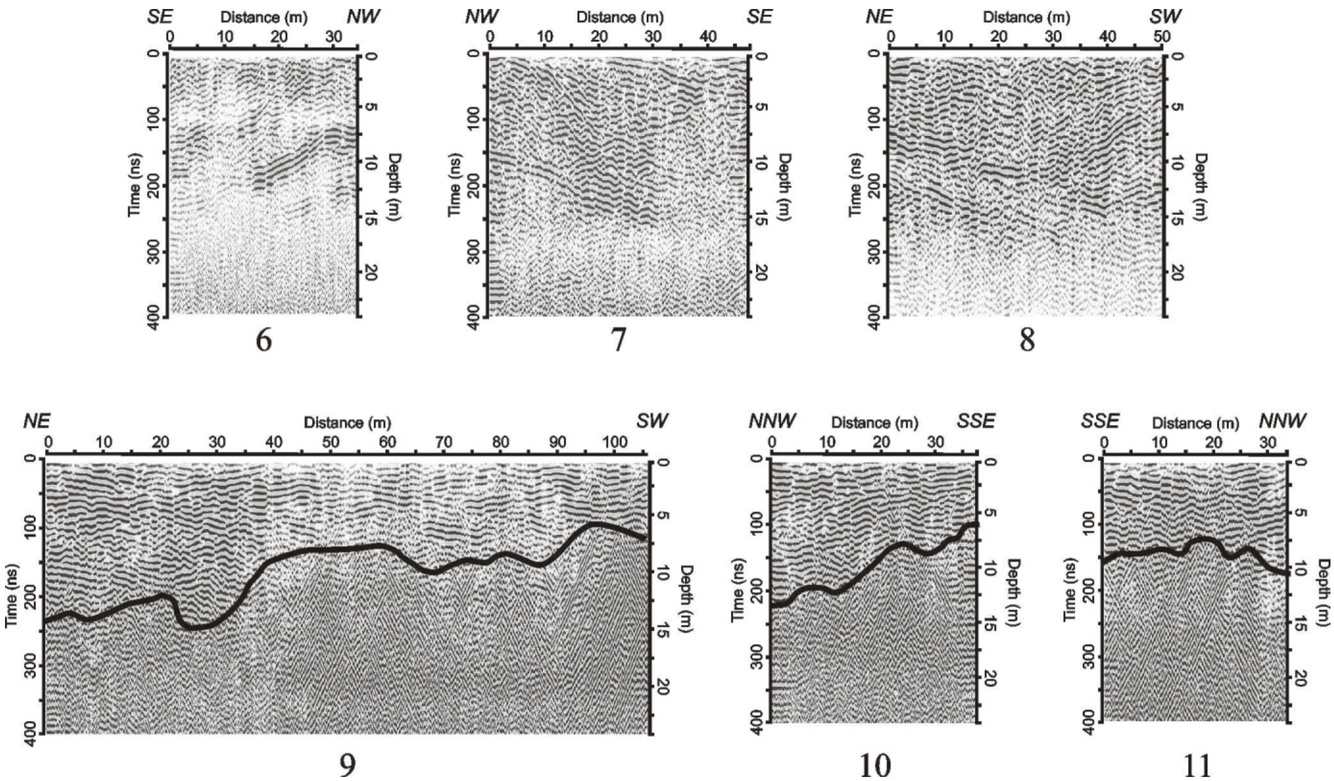

Figure 4. *Radar profiles in Snow's pit. The bedrock/gravel interface is shown as a black line. Line numbers are shown below each profile.*

parent reflections. Boulders produce individual localized diffractions, while a series of continuous, overlapping diffractions is interpreted as the bedrock surface. A skilled and experienced professional is required to gather, process and interpret this type of data.

GPR is an efficient tool for determining the extent and nature of aggregate resources, even those that may exist beneath bogs. A grid of radar profiles run in a prospective area would have excellent potential for providing operators with a 3-D impression of a particular deposit, which can be used to estimate deposit volume and potential. The need for test pits is thus lessened considerably. The method is also non-invasive, and can be used in areas not yet owned or leased by the quarry operator.

The system cannot differentiate between gravel and sand. However, it can identify the presence or absence of boulders within a deposit. It does not work in environments that contain high amounts of silt, clay or saline-contaminated ground water near the surface (although such zones within a potential deposit can be identified by the poor level of penetration in those areas).

GPR can be used to revise estimates of aggregate volume in operating quarries, which could prolong the life of the quarry, and to produce initial volume estimates for potential new deposits. For example, the volume of Mercer's Pit is estimated to be up to 500 000 m^3 through air-photo interpretation and site observations (estimated deposit thickness 5 m). Recalculation based on the GPR data in this report gives a new estimate of 2.8 million m^3.

GPR can also be useful in planning quarry development. At Snow's Pit, for example, extending the pit westward into the prospective pit area may be less favourable than expanding it in a different direction, where deposits may be thicker.

The following are the advantages and disadvantages of using ground-penetrating radar to evaluate aggregate resource potential:

Advantages

1. Generates detailed profiles of subsurface, including location of bedrock
2. Gathers a large amount of information quickly
3. Reaches depths of over 30 m (backhoe reaches 3 to 5 m)
4. Provides more accurate estimates of deposit volume
5. Can be used to plan quarry development
6. Identifies boulders in sediment
7. Reduces number of backhoe test pits required and can

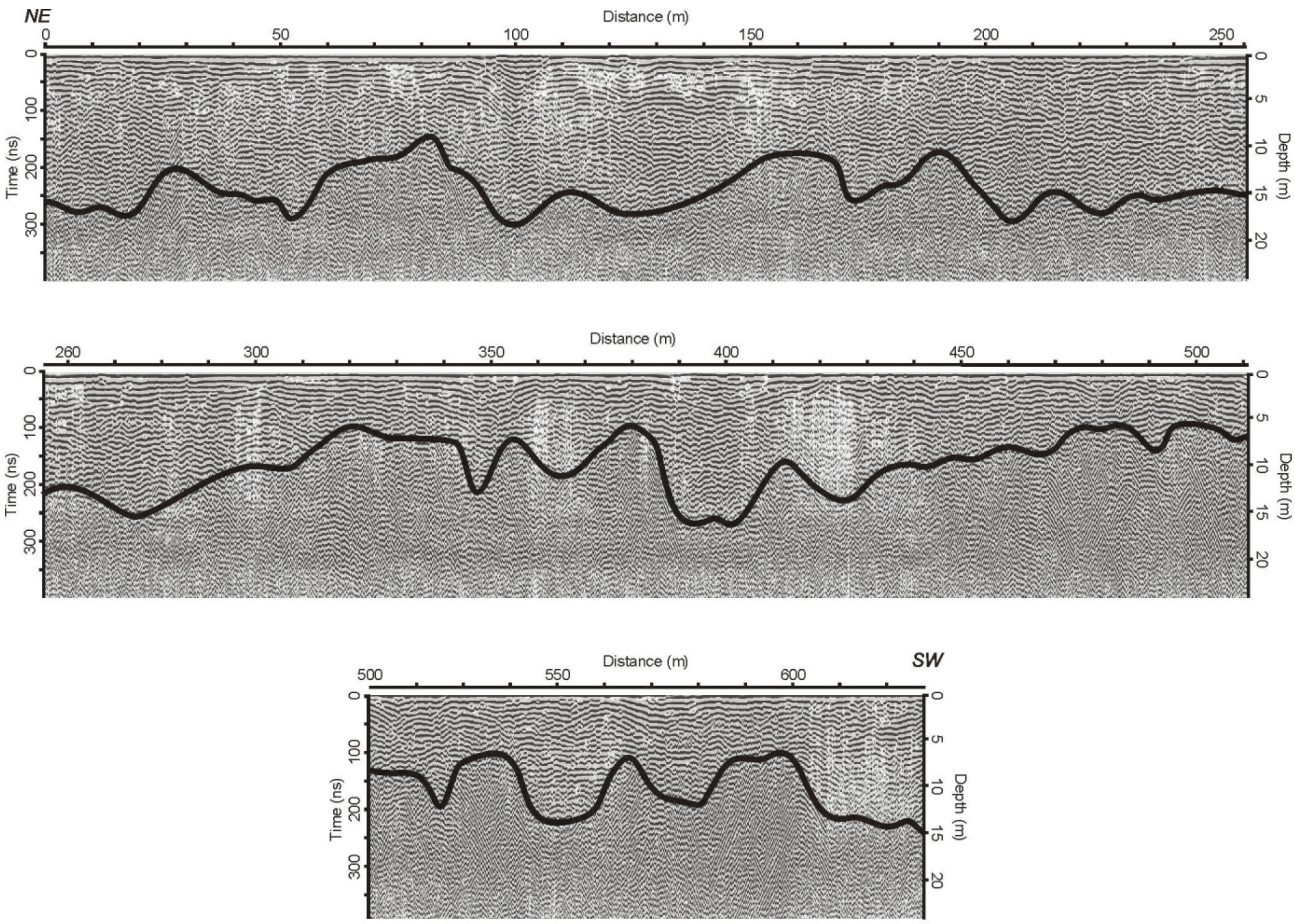

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Figure 5. *Radar profile from road by Snow's Pit. Bedrock surface is identified as a black line. Line number is shown below profile.*

help test pits to be located more strategically
8. Can be used on bogs
9. Non-invasive (backhoe is not)
10. Easy to use
11. Easy to transport (backhoe is not)

Disadvantages
1. Does not give grain-size/aggregate quality information (backhoe test pits are still needed)
2. Saline-contaminated areas, or areas with high silt/clay content will generate poor to unusable results
3. Cost of skilled professional and equipment can be relatively high (but cost of backhoe can also be high and backhoe will not gather nearly as much information)
4. Requires a cleared linear path for one profile or a cleared area for a grid of profiles
5. Cannot be used in heavy rain/snow conditions (electrical connections are weak points)

REFERENCES

Benn, D.I. and Evans, D.J.A.
1998: Glaciers & Glaciation. Arnold, London, 734 pages.

Davis, J.L. and Annan, A.P.
1989: Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy. Geophysical Prospecting, Volume 37, pages 531-551.

Fisher, T.G., Jol, H.M. and Smith, D.G.
1995: Ground-penetrating radar used to assess aggregate in catastrophic flood deposits, Northeast Alberta, Canada. Canadian Geotechnical Journal, Volume 32, pages 871-879.

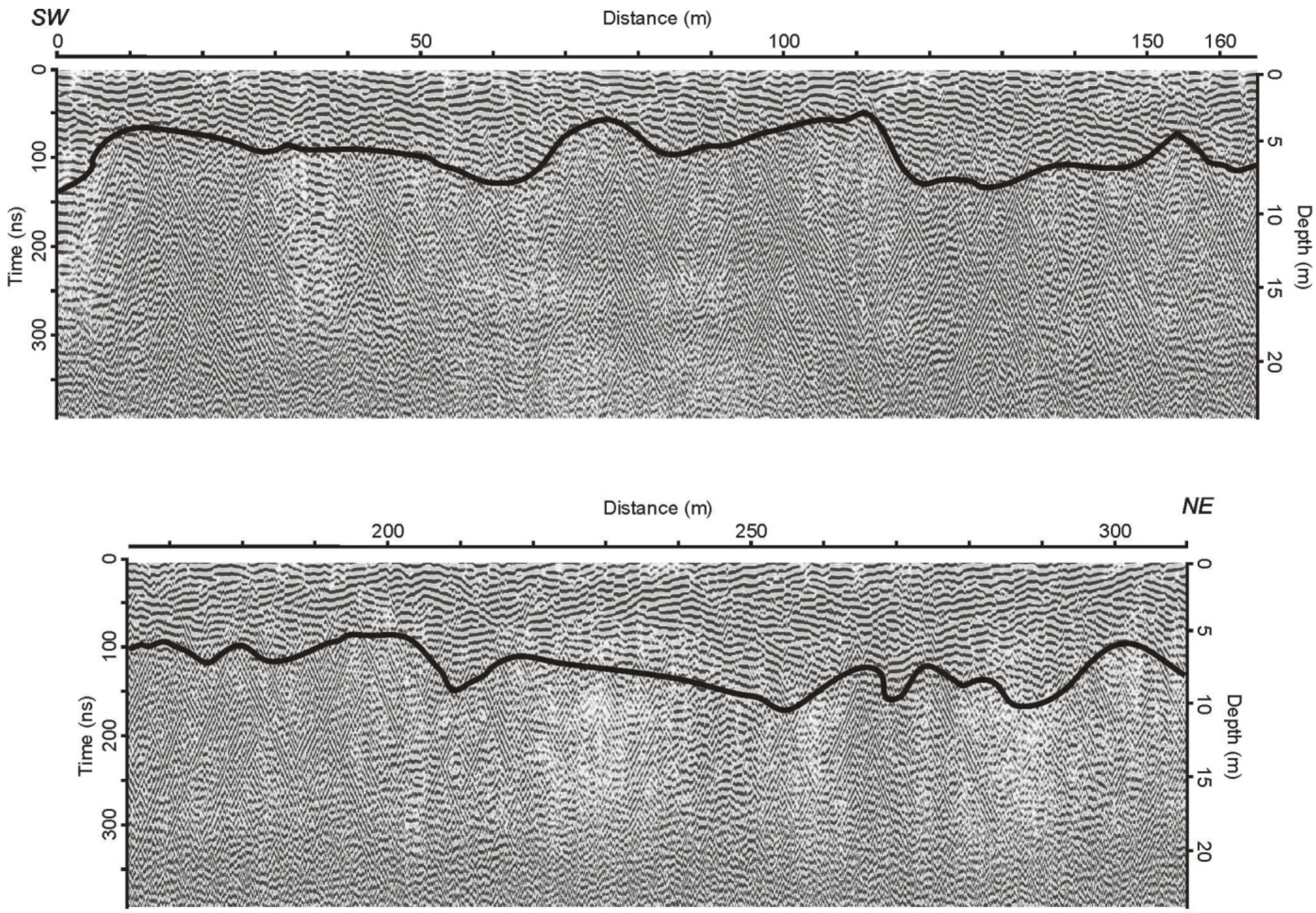

Figure 6. *Radar profile from a prospective excavation site near Snow's Pit. The dark line marks the bedrock surface, which is shown by overlapping diffractions. Line number is shown below profile.*

Jol, H.M., Parry, D. and Smith, D.G.
1998: Ground penetrating radar: applications in sand and gravel aggregate exploration. *In* Aggregate Resources; A Global Perspective. *Edited by* P.T. Bobrowsky. A. A. Balkema, Rotterdam, Netherlands, pages 295-306.

Moorman, B.J., Judge, A.S. and Smith, D.G.
1991: Examining fluvial sediments using ground penetrating radar in British Columbia. *In* Current Research, Part A. Geological Survey of Canada, Paper 91-1A, pages 31-36.

Nobes, D.C. and Warner, B.G.
1992: Application of ground penetrating radar to a study of peat stratigraphy: preliminary results. *In* Ground Penetrating Radar. *Edited by* J.A. Pilon. Ottawa, Geological Survey of Canada Paper 90-04, pages 133-138.