Testing of Shallow Seismic Reflection Technique, Cape Breton Island (NTS 11F/10, 11F/11 and 11F/14)[1]

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Introduction

In September and October 2000, the Geological Survey of Canada conducted shallow seismic reflection tests at 79 sites in south-central Cape Breton Island (Fig. 1). The seismic tests were carried out to provide estimates of the depth to bedrock and to determine whether this method could be used to find and outline areas of thick overburden which might be further explored for industrial mineral resources. The sites were chosen to prove the effectiveness of this method in areas where borehole information was available, and to provide information in areas where borehole control is lacking.

This work comprises one component of a federal-provincial Targeted Geoscience Initiative (TGI) project aimed at stimulating resource development in Cape Breton Island. This project will improve the geoscience knowledge base relating to both the Carboniferous bedrock and the overlying Mesozoic and Cenozoic sediments in the area.

Shallow Seismic Reflection Method

Land-based seismic methods are geophysical techniques that use measurements of the time taken for acoustic energy to travel from a source on the surface through the subsurface and back to a series of receivers on the ground (Fig. 2). Energy is refracted or reflected at boundaries where there is a change in acoustic impedance (the product of material density and seismic velocity). Because contrasts in acoustic impedance are generally associated with lithologic and/or stratigraphic boundaries, seismic techniques can be used to obtain subsurface structural information.

Shallow seismic reflection methods (targeting subsurface structure within a couple of hundred metres of the ground surface) depend on the detection of high-frequency energy reflected from shallow velocity discontinuities. The ability of a particular site to transmit high-frequency energy is a major factor in determining the quality and the ultimate resolution of a shallow reflection survey. Data quality and resolution are critically dependent on the surface conditions, with the best results usually associated with fine-grained, water-saturated surface materials, and the poorest results with coarse-grained, dry surface sediments.

An overview of the application of land-based seismic methods to delineating the structure of unconsolidated sediments and the underlying bedrock surface can be found in Pullan and Hunter (1999).

The seismic reflection testing program discussed in this paper was designed to evaluate the quality of reflected energy (frequency and signal strength) that could be obtained in the area, to determine the depths from which reflection signals could be recorded, and to obtain an estimate of the depth to bedrock at each site. As well, these data will be a factor in determining appropriate sites or areas for future drilling programs, and in establishing recording parameters (e.g. source, source-receiver geometry, recording timescale) and potential survey lines for follow-up production CMP (common midpoint) profiling.

Data Acquisition

At each test site, data were acquired using an array of 24 geophones (Mark Products 50 Hz in marsh cases) at 5 m spacings (active spread length = 115 m; Fig. 3), generally deployed alongside roads. Wherever possible the geophones were planted in the bottom of ditches in order to improve the high-frequency response resulting from coupling to water-saturated sediments. The energy source was an in-hole “Buffalo gun” (Pullan and MacAulay, 1987), which fires a 12-gauge blank charge into the ground from 1 m below surface in a narrow-diameter, drilled hole (tamped with water). The data

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[1] A contribution to the Targeted Geoscience Initiative (TGI) project: Geological Mapping for Mineral Development in South-central Cape Breton Island; Project Leader Peter Giles, Geological Survey of Canada (Atlantic)

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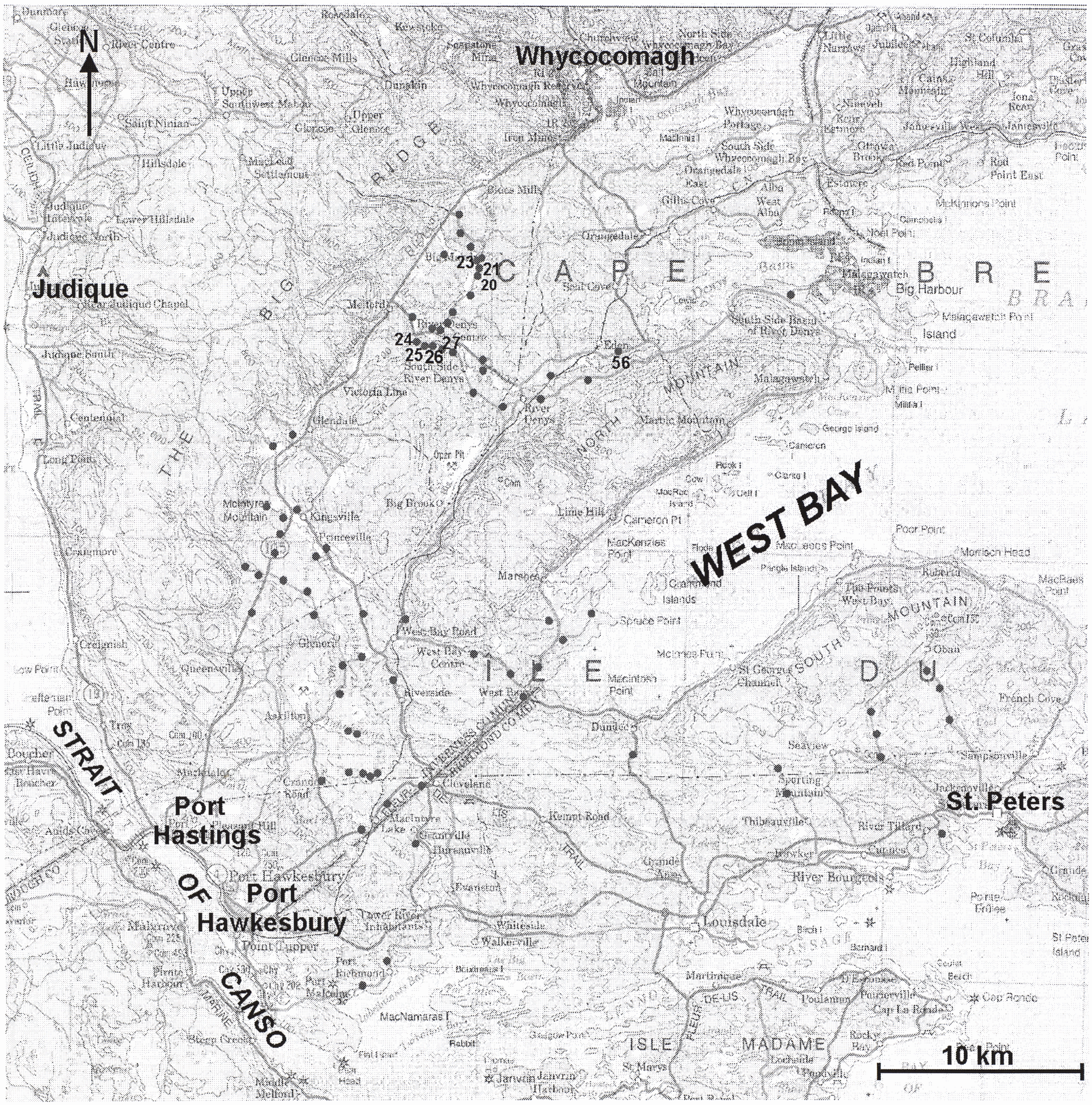


Figure 1. Map showing the seismic test site locations (dots) in southern Cape Breton Island (base is 1:250 000 scale topographic map NTS 11F). Data from the numbered sites are discussed in this preliminary report.

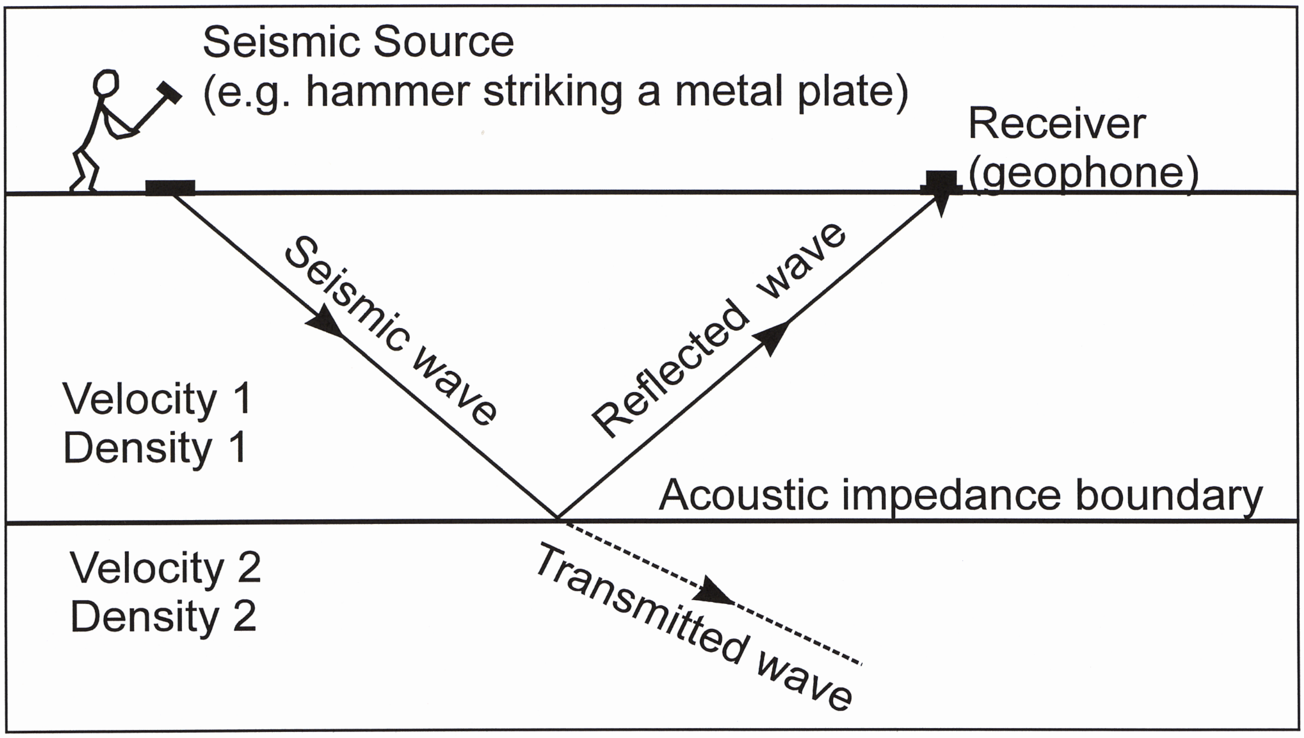


Figure 2. Schematic illustration of the basic premise of seismic reflection methods (from Pullan and Hunter, 1999). Seismic energy produced on the ground surface travels from the source down to an acoustic impedance boundary where it is partially transmitted and partially reflected back towards the surface. The resulting ground motion at the surface is recorded by a receiver (geophone) as a function of time.

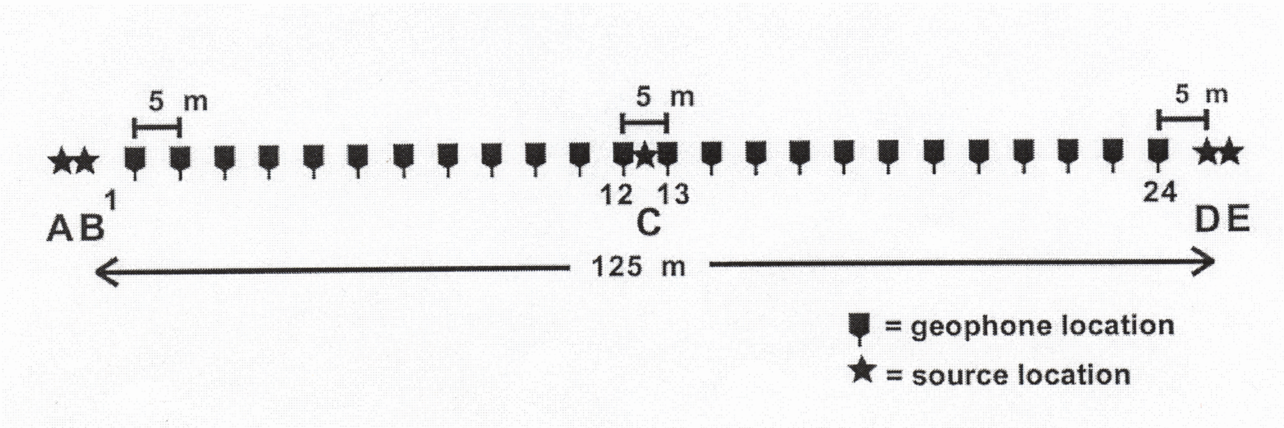


Figure 3. Diagram of geophone array deployment and shot locations for the acquisition of the test site data. The geophone spread consists of 24 receivers (geophones) spaced 5 m apart. Data were recorded for shots located in the centre of the geophone spread and at 5 and 7.5 m off each end of the array. (Note: at some sites additional records were recorded from shots at 47.5 and 50 m off the end of the array).

were recorded on a Geometrics Strataview RS-48 engineering seismograph, for shots fired at the midpoint of the array, and at 5 m, and 7.5 m off each end of the array (Fig. 3). At some sites, additional records were acquired with shots at 47.5 m and 50 m off the end of the array. Example suites of field records for both a shallow bedrock (bedrock refraction) site and a deeper bedrock site (bedrock reflection) are shown in Figure 4.

Results

The data collected during this testing survey are analyzed as follows:

(1) Refraction analysis of first arrival times to estimate near-surface velocity structure. In cases where refractions from the bedrock surface are observed, the first arrivals are used to estimate depth to bedrock.
(2) High-pass digital bandpass filtering of records to attempt to reduce groundroll and enhance reflection events.
(3) For sites where reflections from the bedrock surface and possibly intra-overburden horizons are evident, a low-fold, common-midpoint (CMP) seismic section is produced.

Refraction Analyses

Seismic refraction methods involve the measurement of the time of first arrival of seismic energy at a series of source-receiver separations. As the source-receiver separations increase, energy that has been critically refracted from deeper (and necessarily higher-velocity) horizons overtakes the shallower refractions and becomes the first arrival. The arrival times and source-receiver distances are used to determine layer velocities and depths to the refracting horizons. Velocity contrasts must also be large for an interface to be definitively identified in a layered-model refraction analysis.

At many test sites, bedrock was within 20-25 m of the ground surface and could be identified by high-velocity refraction arrivals. An example is shown in Figure 5 (Site 56). The upper panel of this figure is a plot of the front end (0-50 ms) of the five records obtained at the site; the central panel shows the picked first arrival times on a time-distance plot; and the lower panel shows the resultant layer velocities and depth interpretations for a simple two-layer model. The high-velocity "breakover" (change in the slope of the first arrival times) is interpreted to represent the bedrock surface (bedrock velocity = 3800 m/s) beneath 10-15 m of unconsolidated sediments (1650 m/s).

The depth to bedrock has been estimated by refraction analyses at approximately one-half of the 79 test sites surveyed. At these sites, bedrock is too shallow to be observed clearly as a reflection event.

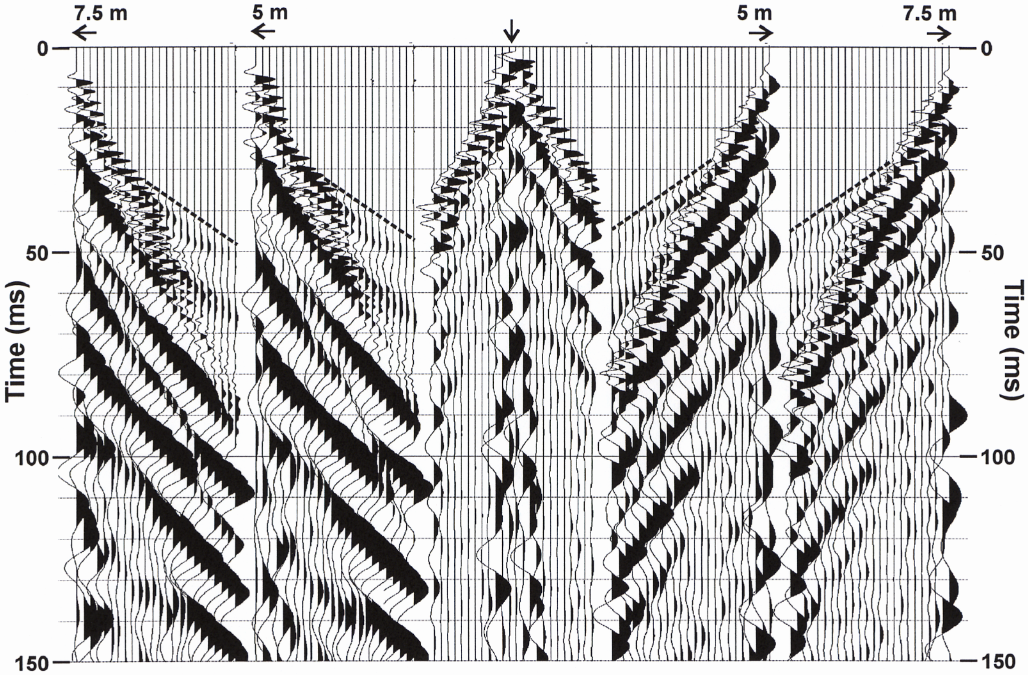
Digital Filtering

The records obtained at each site were digitally filtered in an attempt to enhance high-frequency reflection events (which appear as hyperbolic features on field records) and attenuate interfering energy such as groundroll. Figure 6 shows the record suite from Site 24 after digital filtering and application of an automatic gain control (AGC). In this case, filtering was able to enhance (sharpen) the high-amplitude reflection events seen on these records, and to essentially remove the groundroll (low-frequency, low-velocity signal observed on the near-offset traces in the raw field records). The difference in the hyperbolic moveout of the bedrock reflection observed in the records obtained from opposite ends of the spread indicates that the bedrock surface is dipping beneath the site (see below).

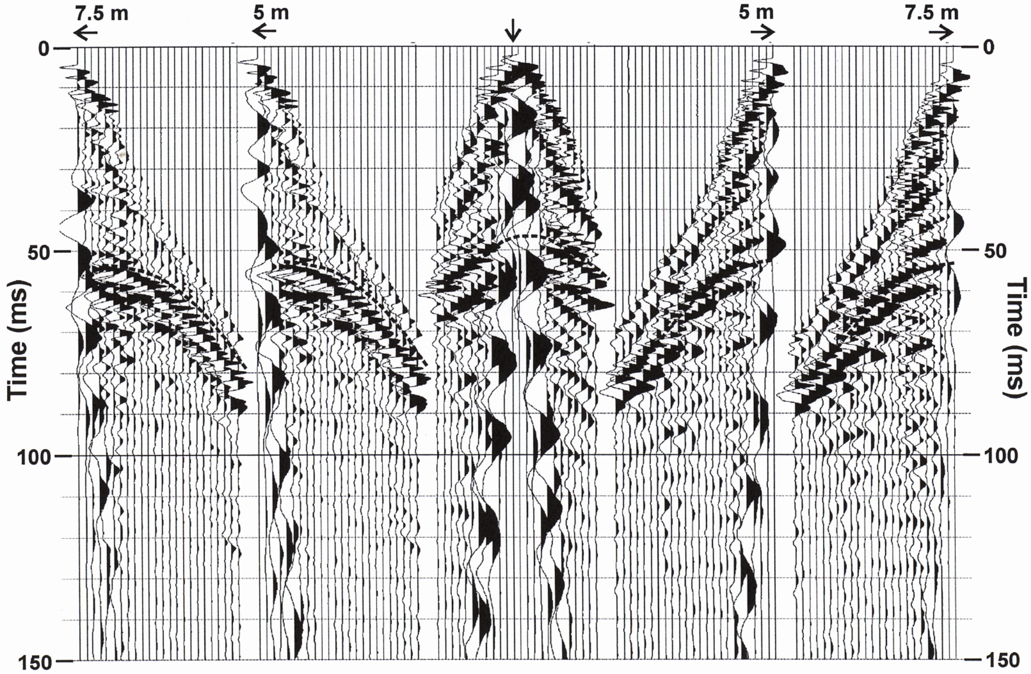
CMP Processing

A suite of records obtained with the test spread source-receiver geometry can be utilized to produce a low-fold, common-midpoint (CMP) seismic section over a limited subsurface area, and where the signal-to-noise ratio is good this can be a very effective means of providing a reconnaissance assessment of the subsurface structure (e.g. Pullan *et al.*, 1995). Processing includes digital filtering, muting of groundroll and refraction first arrivals, sorting into CMP gathers, velocity analyses, normal moveout corrections, and final stack (1-2 fold). Figure 6 shows the raw and filtered field files obtained at Site 24, along with the resulting low-fold CMP section that was produced from these data. The section shows a high-amplitude reflection that dips steeply to the east from ~40 m in the west to ~60 m depth at the east end of the section (depths are calculated using the stacking velocities). Above this reflection are lower amplitude events which dip less steeply; at 45 m depth there is an event which can be seen to pinch out against the high-amplitude reflection to the west.

A composite of four sections along a 1.5 km east-west line in the River Denys area is shown in Figure 7. It outlines a >100 m deep buried valley that is on the order of 1-1.5 km wide. Site 25 shows the deepest structure with a reflection dipping to the east at 80-110 m depth. Below this eastward-dipping reflection are indications of deeper events dipping to the west. It is not known whether these represent overburden sediments or structure within the bedrock.



Site 56: Raw field records, showing bedrock refraction.



Site 26: Raw field records, showing high-frequency reflections to an estimated depth of ~55 m.

Figure 4. Two example suites of raw field files. The source-receiver geometry for each panel of five records is shown in Figure 3, and the source offsets and direction are indicated above each record. No automatic gain control has been applied, but plots are trace-normalized. The upper panel shows the records obtained at Site 56 where a clear refraction "breakover" to higher velocities (bedrock) is observed (dashed line). The lower panel shows the records obtained at Site 26 where high-frequency reflections can be clearly seen as hyperbolic events (dashed line). The large-amplitude reflection at ~ 55-60 ms (near-offsets) is interpreted as the bedrock surface.

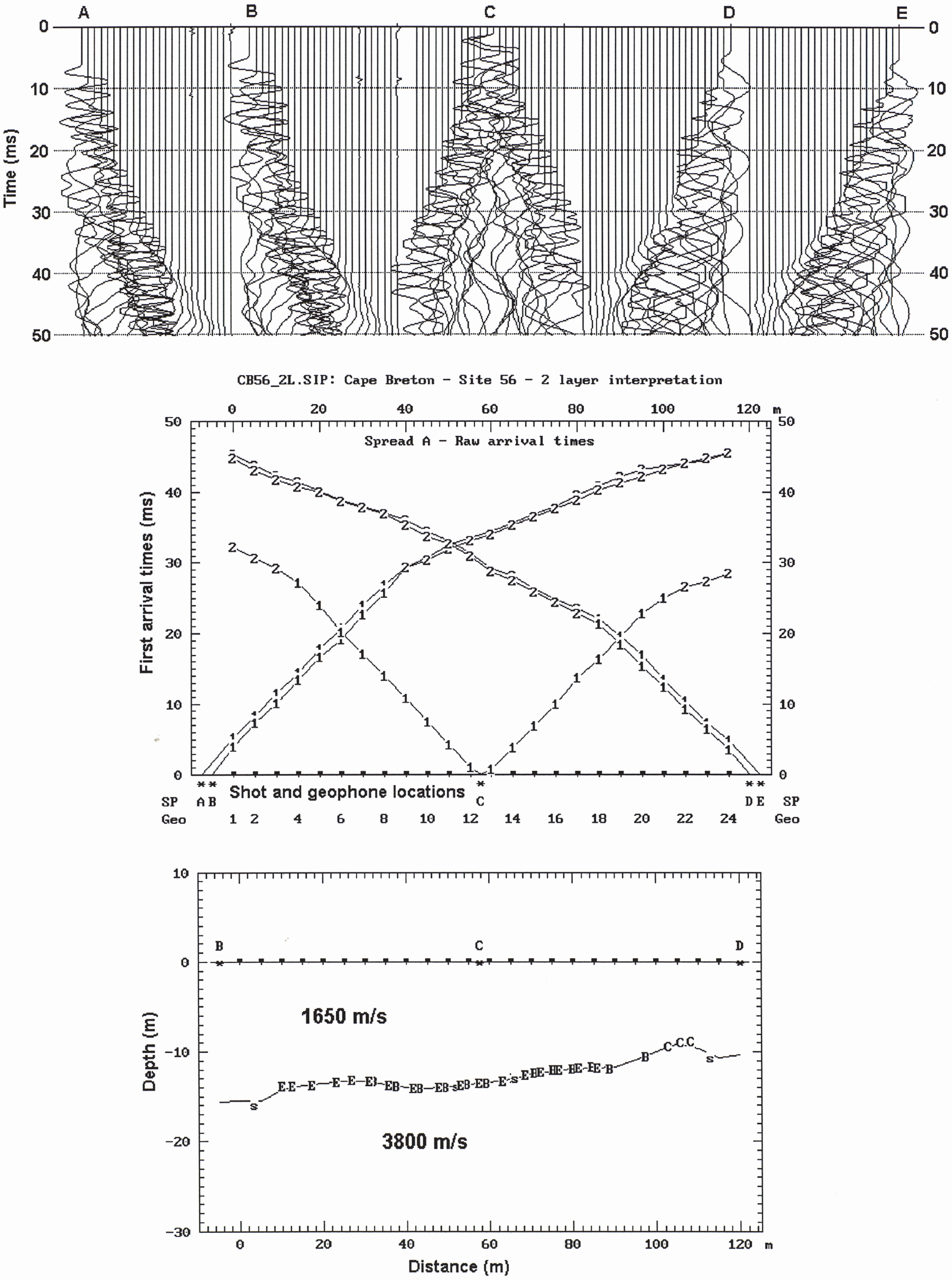


Figure 5. Refraction analysis for Site 56. The upper panel is a plot of the front end (0-50 ms) of the five records obtained at the site; the central panel shows the picked first arrival times on a time-distance plot; and the lower panel shows the resultant layer velocities and depth interpretations.

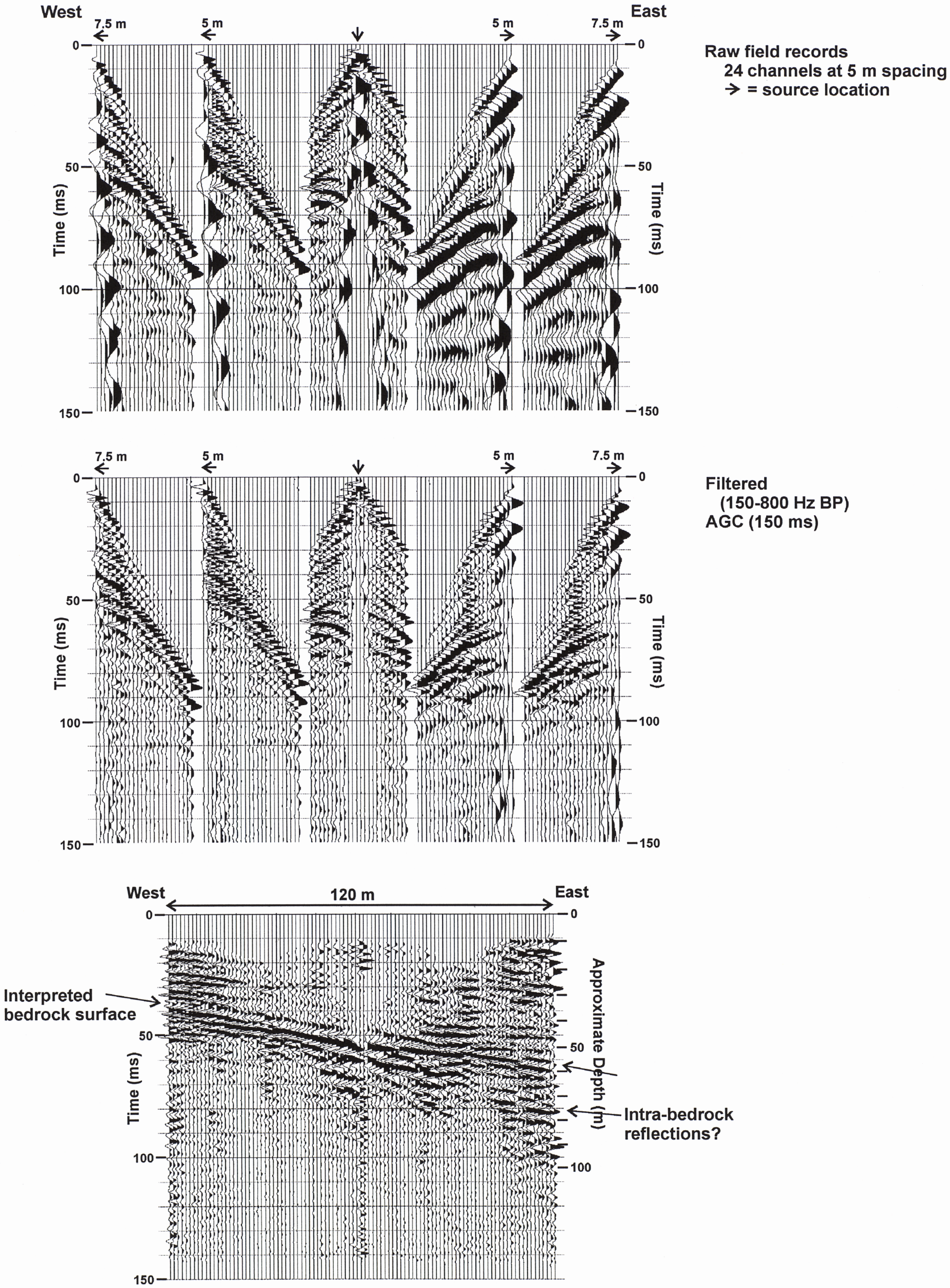


Figure 6. An example of the raw (upper panel) and filtered (centre panel) field records from Site 24. These records have been processed to produce the 96-trace seismic reflection section (1-2 fold) shown in the lower panel. This section shows the subsurface structure beneath the geophone spread used to acquire the test spread data.

Figure 8 shows three north-south sections at Big Marsh, approximately 4 km northeast of Figure 7. These sections outline another buried valley which again reaches depths of >100 m. Site 23 shows steeply dipping events which are interpreted as diffractions from a bedrock high (fault?) to the north (a test site only 250 m to the north indicated very shallow bedrock).

Drilling in the River Denys buried valley has recently been completed, with boreholes drilled at test spread sites 23 (Fig. 8) and 25 (Fig. 7). Cores at both sites reveal that the valley is filled with massive brown, Quaternary silty clay (50-70 m thick at site 23) overlain by <20 m of till and coarse gravel. At site 25, drilling was halted due to a pressurized artesian aquifer underlying the surface till at 31 m. This contact is apparent on the seismic test spread (Fig. 7).

This preliminary analysis of some of the seismic test sites shows that seismic methods can be effectively used in this region to estimate depths to bedrock, and clearly indicates that the buried bedrock topography is rugged and complex in some areas.

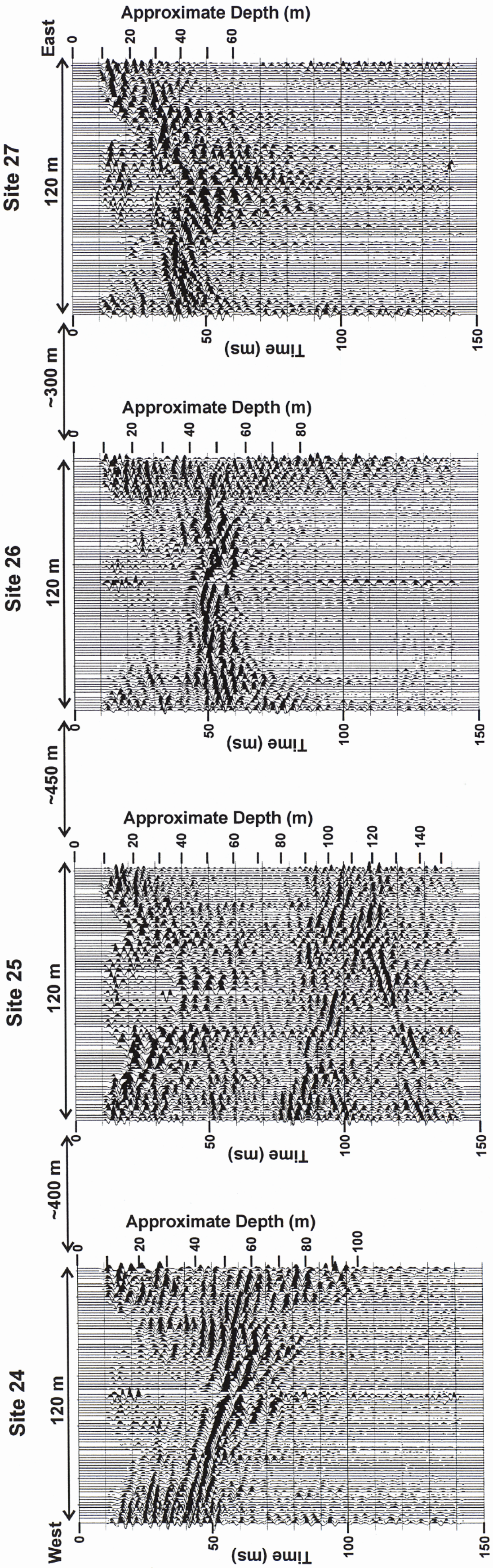


Figure 7. Four east-west sections across a >100 m deep buried valley in the River Denys area. The bedrock surface is interpreted as the high-amplitude event that dips steeply to the east at Site 24 and rises to ~30 m below ground surface at the east end of Site 27. The deep westward-dipping events at Site 25 may represent overburden sediments or structure within the bedrock.

References

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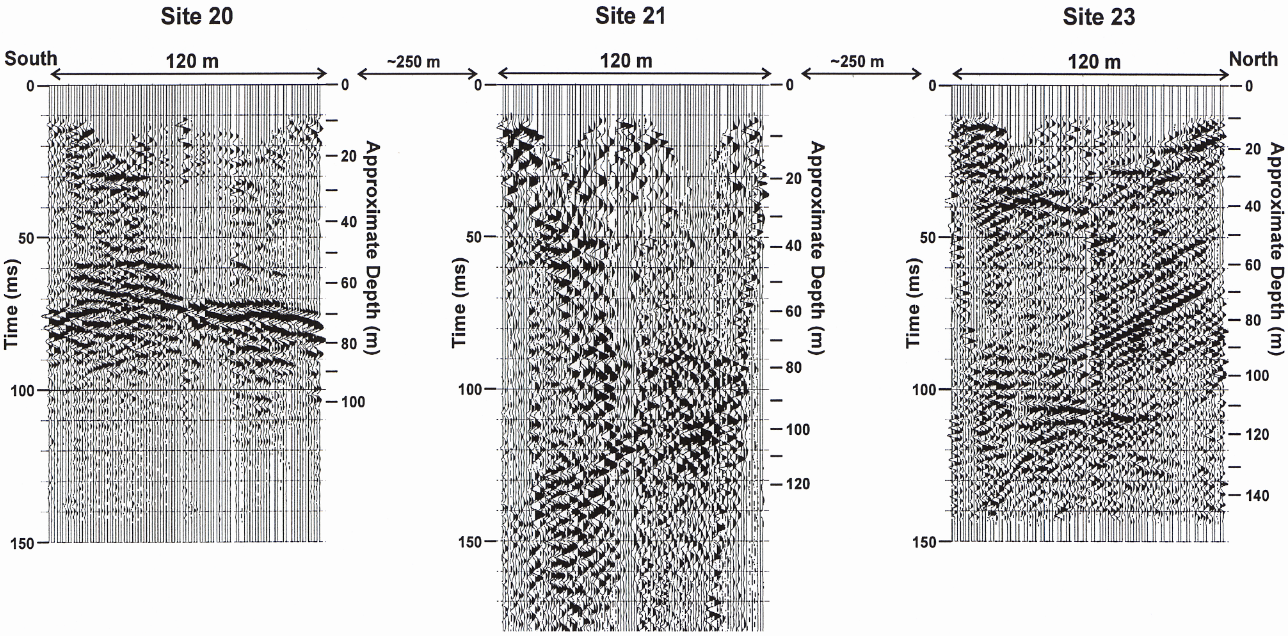

Figure 8. Three north-south sections at Big Marsh (~4 km northeast of Fig. 7). These sections outline part of another buried valley >100 m deep. The dipping events observed at Site 23 are interpreted to be diffractions from a bedrock high (fault?) immediately to the north.