GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

A bedrock depression, filled with sand, gravel and till, and overlain by glacial lake silt deposits, was delineated by test drilling about 1 1/2 miles southeast of Stenen, Saskatchewan. Charges of explosives were detonated at small intervals of depth in four of the drillholes to provide first arrival times for the construction of uphole wavefront diagrams. These diagrams show that there is a velocity inversion at the bedrock surface; the velocity in the till (6,000 feet per second) and the velocity in the sand and gravel (7,000 – 8,000 feet per second) both exceed the velocity in the shale bedrock (5,000 feet per second). Two correlation refraction profiles demonstrate the lack of secondary arrivals associated with the surficial deposits, the only consistent secondary arrivals being reflections from horizons within the bedrock. Therefore, the seismic refraction method cannot be used to map the bedrock surface in this area.

The relatively high velocity of the sand and gravel enables the location of this deposit to be determined beneath a continuous refraction profile. However, it is impossible to distinguish between head waves associated with the till and those associated with the deposit of sand and gravel using frequency and amplitude characteristics. Instead, there appears to be more correlation between the frequency spectrum and the shotpoint lithology. Finally, a continuous reflection profile was shot over the sand and gravel deposit and a time lead in the 'Second White Specks' reflection time observed. The maximum increase in the thickness of the sand, gravel and till section (170 feet) calculated from this time lead compares favourably with the estimated value (150 feet) from the drilling results.

A SEISMIC STUDY OF THE SURFICIAL DEPOSITS IN THE STENEN AREA, SASKATCHEWAN

INTRODUCTION

The use of the seismic method to map surficial deposits and underlying bedrock can be considered an established technique in many areas of Canada. Several examples of successful surveys for sites in Eastern Canada have been given by Hobson and Collett (1960). However, in the Canadian Prairies, seismic investigations are handicapped by the heterogeneity of the deposits and the considerable deviation from a layered model. Velocity contrasts at boundaries between deposits are small, or even non-existent, in most places, although there are some exceptions to this general rule. For instance, Hobson et al. (1964) have established a correlation between seismic velocity and particular deposits in a survey along the Red River Floodway. Nevertheless, interpretation of seismic data is usually difficult and results have been limited mainly to the mapping of the bedrock surface and the location of buried river channels, e.g. Hall (1962) and Lennox (1962). These limited results may also be incorrect. For example, the cross-section along a survey line in the Steelman area of Saskatchewan given by Hall (op. cit.) is not consistent with later drilling results obtained by Wyder (1968). In this example, the seismic boundaries do not correlate with any of the lithological boundaries and indicate that the real earth does not approximate to the seismic model. The conventional methods of interpretation of seismic surveys are therefore not reliable in such areas.

Similar problems have been encountered in other regions of the world and studies have been made of the possibility of using parameters other than velocity to assist the interpretation of seismic results. In some areas of the U.S.S.R., it has been shown that water-bearing sands can cause a seismic event to have a characteristic frequency spectrum. Thus, aquiferous sands may be distinguished from clayey layers with similar velocities, because of the generally higher frequencies associated with waves in the former deposits (Berzon et al.; 1959). Levshin (1961) has reported similar characteristics of seismic waves associated with the water-table.

In 1966, a seismic program was undertaken by the Geological Survey of Canada to investigate the possible application of these latter techniques to certain areas of the Canadian Prairies. Two areas in Saskatchewan

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Ms. received 24 July, 1968

and one in Manitoba were selected on the basis of availability of geological control; these were the Stenen and Frobisher areas of Saskatchewan and the Winkler area of Manitoba. This paper reports the results from the Stenen area. Reports on the other areas will follow.

Acknowledgments

The author wishes to express his appreciation to Mr. G.D. Hobson, Exploration Geophysics Division, for the opportunity to conduct this investigation and also for critically reading the manuscript. Grateful acknowledgment is given also to Messrs. G.B. Finlayson, J. French, and A. Ross, who acted as student assistants on the field crew.

Location

The survey area is in the east-central part of Saskatchewan, near the village of Stenen (62M, Section 9, Township 34, Range 3 west 2 meridian). The topography in the area is gently undulating, with a maximum relief of about 50 feet. All field work was confined to the road allowance, adjacent to Provincial Highway 49, along the northern edge of sections 32, 33 and 34 T33 R3 W2M, one mile south of Stenen (Fig. 1). This three-mile profile has a mean surface elevation of 1,650 feet above sea level.

GEOLOGICAL SETTING

About 3,000 feet of Paleozoic and Mesozoic strata lie above the Precambrian basement in this area; the general stratigraphic sequence is shown in Figure 2. An unconformity separates the Mesozoic strata from Upper Devonian formations. The Mesozoic strata have a dip of about 5 feet to the mile and the Paleozoic strata have a dip of about 15 feet to the mile, both dips being in the southwesterly direction. Wickenden (1945) has given a detailed account of the Mesozoic stratigraphy in the area.

The Stenen borehole of Canadian Oil and Gas Reserves Limited (Lsd. 11 Sect. 31 T34 R3 W2M), approximately 5 3/4 miles to the north of the project area, penetrated the top of the Lower Colorado Formation (equivalent to the base of the Favel Formation or 'Second White Specks' Formation) at 1,003 feet above sea level. The Blairmore Formation (equivalent to the Swan River Formation) is reported at 703 feet above sea level.

The bedrock in the area is covered by Pleistocene glacial deposits. Ground moraine, glacial lake-clay and silt and glacial sand and silt were mapped by Johnson _et al_. (1948).

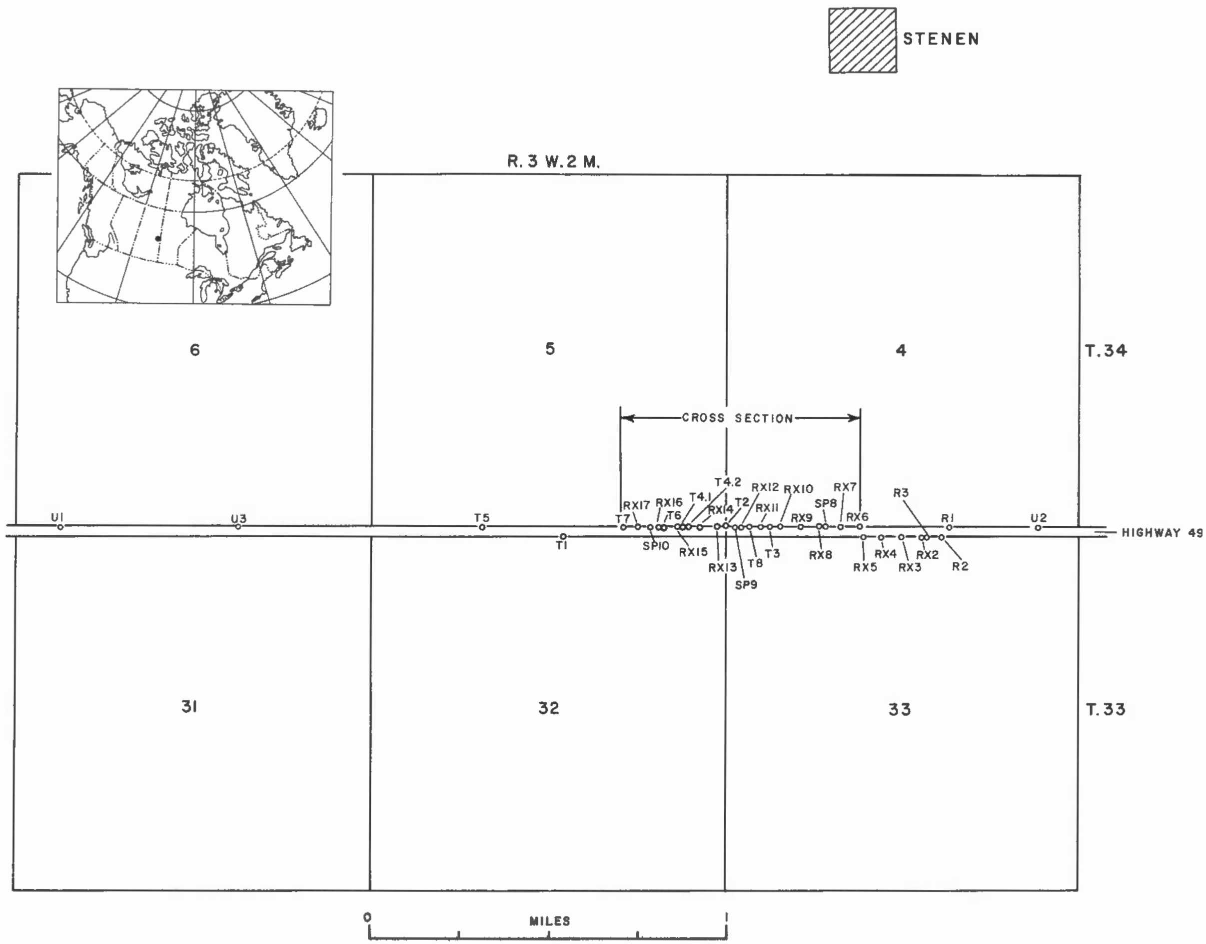


Figure 1. Location of seismic and drilling program, Stenen area, Saskatchewan

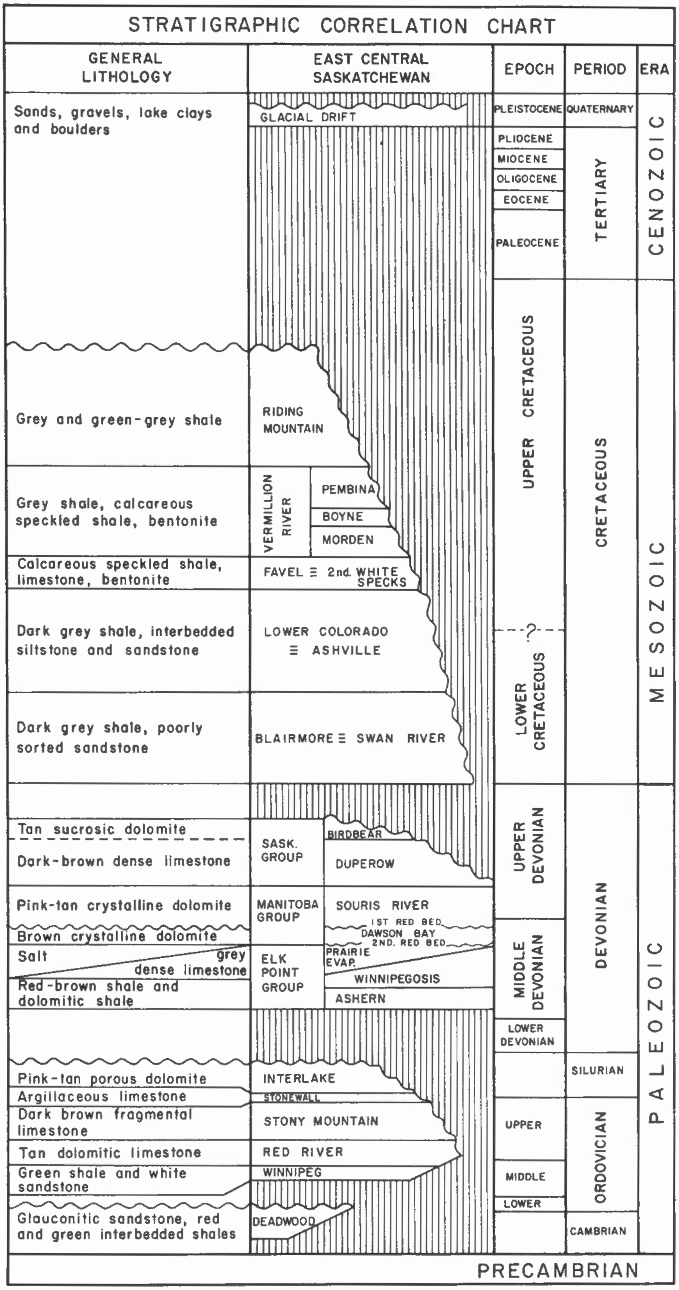


Figure 2. Stratigraphic correlation chart, Stenen area, Saskatchewan.

ESTABLISHMENT OF THE GEOLOGICAL CROSS-SECTION OF THE SURFICIAL DEPOSITS

Previous Work

One of the reasons for selecting the specific location along Highway 49 was the availability of detailed information on the surficial deposits from a previous seismic project (Burke *et al.*, 1966). Shotholes had been drilled at 1/4-mile intervals and logged. Lithological logs were based on detailed inspection of chip samples from roughly 10-foot intervals of depth and in some of the holes singlepoint electric logs were run to determine the drift-bedrock interface (J. Cherry, written communication, 1964).

The general sequence of deposits at the location is a grey, non-calcareous shale bedrock, covered by a grey, calcareous deposit of till, containing lenses of sand and gravel. On top of the till is a lacustrine deposit of clay, silt, or sand. The depth to bedrock varies from between 20 and 65 feet below the ground surface, except in shothole SP 9 (*see* Fig. 3). In SP 9, a deposit of coarse sand and gravel had been intersected at 60 feet below ground level and had not been bottomed at 135 feet below ground level.

The existence of this sand and gravel deposit was another reason for the selection of this location. Evidence for the westerly extension of this sand and gravel deposit was afforded by the relatively high subweathering velocity of 7,150 feet per second that was obtained along the seismic profile between shotpoints 9 and 10, compared to the subweathering velocities of between 5,100 and 6,050 feet per second for the other seismic profiles along Highway 49. The limited lateral extent of the deposit was confirmed by the logs of the two adjacent shotholes, SP 8 and SP 10. The log of SP 8 shows 12 feet of silt, 28 feet of till and 20 feet of bedrock shale and the log of SP 10 shows 28 feet of silt, 2 feet of gravel, 23 feet of till and 7 feet of bedrock shale (*see* Fig. 3).

Drilling results

Before the commencement of the seismic investigations, a test-hole, T2, was drilled 170 feet west of SP 9, in order to confirm the existence of the sand and gravel deposit. Not only was the deposit confirmed, but also a sharp bedrock depression was suggested when the till-bedrock contact was established at a depth of 172 feet below the surface. The sites of subsequent test-holes were chosen in an attempt to delineate the sand and gravel deposit and also to establish a profile of the bedrock surface. A cross-section illustrating the results is shown in Figure 3 and the lithological logs of the holes are tabulated in Appendix A.

The cross-section indicates a steep-sided depression in the bedrock with a horizontal extent of approximately 2,300 feet and a relief of 130 feet. A coarse sand and gravel deposit fills most of the depression. Two attempts were made to drill through the deposit at borehole T4, but both holes were abandoned due to difficult drilling conditions in the cemented gravel. The steep slopes of the sides (10 – 20 degrees) suggest that this depression was eroded by fast-moving water. It was probably a meltwater channel during a glacial retreat with the sand and gravel being deposited as an outwash deposit. Relatively thick layers of till on the slopes of the channel and below the coarse sand and gravel deposit suggest that the bedrock was eroded during an earlier retreat of the glacier rather than at the time when the actual deposition of sand and gravel occurred. Another possibility is that the channel represents a preglacial valley, which was later modified in shape by glacial action.

Six other boreholes were drilled to the west and east of the cross-section, to provide holes for uphole and refraction shooting. The lithological logs of all these holes may be found in Appendix A, together with the logs of all seismic shotholes.

SEISMIC INVESTIGATIONS

Introduction

The in situ seismic properties of subsurface materials are a complex function of many factors, including the elastic properties of the material, the water content and depth of burial. Therefore, seismic waves, spreading out from an explosion or other source, will be reflected from, and refracted by, many boundaries between materials of appropriately contrasting properties. Some of the reflected waves will be returned to the surface and recorded. The determination of the total travel time of the reflected wave, together with other information from the seismic record, allows the subsurface position of the boundary to be mapped. This procedure forms the basis of the seismic reflection method.

If there is an interface between two layers with contrasting velocity properties, and the lower layer has the higher velocity, then refracted seismic waves travelling near the upper surface of and within the lower layer will give rise to head waves. These head waves spread out through the upper layer and may be recorded at the surface. At a certain critical distance, the head waves will arrive at a geophone on surface at the same time as the direct wave travelling in the upper layer. This critical distance, together with the velocities in the two layers obtained from a time-distance plot, allow the position of the interface to be mapped. Such techniques form the basis of the seismic refraction method. The principles of seismic reflection and refraction methods may be found in standard textbooks, e.g. Dobrin (1960).

Many problems arise in the use of seismic methods for the investigation of surficial deposits. Domzalski (1956) in particular has considered the problems encountered in mapping the bedrock surface by seismic refraction techniques. He pointed out the disturbing effects of such factors as variations in shothole conditions, the inhomogeneity and anisotropy of the overburden, the irregularity and weathering of the bedrock and the much greater significance of errors in shallow surveys. Evison (1952) has also discussed the limitations of the conventional seismic techniques when applied to shallow problems. He showed that the resolving power of small-scale seismic investigations is severely limited by the relatively long duration of a shallow reflection event generated by a conventional explosive source. Burke (1967) has also reviewed the problems confronting seismic investigations in surficial deposits, and, in addition to the factors mentioned above, emphasized the fact that a large proportion of the energy from hammer or explosive sources is transformed in unconsolidated materials into various types of coupled and surface waves. Also the variation of velocity in lithologically identical deposits is shown to be another potential source of misinterpretation. Extreme care must therefore be taken in experimental procedure and interpretation of shallow seismic investigations.

Seismic Instrumentation

Twelve channels of seismic data were recorded through a Southwestern Industrial Electronics, P.T. 100 amplifier and filter section, coupled to a PMR-20 FM magnetic tape recording system and a VRO photographic recording oscillograph with conventional 'wiggly-trace' display. McManis (1961) and Hefer (1961) have given a detailed description of the amplifier and filter section. A GCU-3 Programmed Gain Control Unit was also used during playback of the magnetic tapes. Broad band recording (3-300 cps) was thus possible, with later playback through various levels of gain and filter settings.

Three types of vertical component geophones were available; Geospace HSl, 4.5 cps geophones, Geospace HSl, 85 cps geophones and S.I.E. 28 cps geophones. In addition, Geospace HSJ, 4.5 cps omnidirectional geophones were used for three-component recordings.

The PMR-20 FM magnetic tape recording system and the three-component geophones were available only during the later stages of the project thus placing some limitation on the extent of the investigations.

Field and Recording Procedures

The seismic investigations were carried out in four successive stages:

1. The establishment of a velocity model in the surficial deposits by uphole shooting.

2. The identification of the types of seismic waves which could be recorded in a refraction correlation spread.

3. The recording of seismic waves along a continuous profile of reversed, 300-foot, refraction spreads across the sand and gravel deposit.

4. The recording of seismic waves along a continuous profile of in-line, offset, reflection spreads.

1. Uphole Shooting

Uphole shooting was carried out in four boreholes U1, U2, U3 and U4 by detonating small charges at 10-foot intervals of depth. Meissner (1961) has shown that uphole shots yield more information if they are recorded using a complete spread of geophones rather than a single uphole geophone. The results can then be displayed in the form of uphole wavefront diagrams. The construction of these diagrams is accomplished by converting the wave path into a completely fictitious one, by exchanging the position of the shot and geophone. The time of arrival of a wave is plotted underneath the appropriate geophone location, at a depth corresponding to that of the shot (Fig. 4). Wavefronts are constructed by connecting points of equal travel time (isochrons). If changes in velocity occur mainly in the vertical or horizontal direction, the resultant representation approximates the actual wavefront diagram with sufficient accuracy for most purposes.

The initial uphole shooting was done in holes located to the west and east of the sand and gravel deposit, to determine the velocity in a normal section of silt, till and bedrock. Test U1 was conducted using geophone spacing of 55 and 110 feet, with total spread lengths of 660 and 1, 320 feet respectively, in order to obtain an overall picture of the subsurface velocities. A spread length of 1, 320 feet, with a geophone spacing of 110 feet, was used in test U2. A more detailed coverage of the near-surface deposits was obtained in test U3, using a spacing of 25 feet and a total spread length of 300 feet. Finally, test U4 was made over the sand and gravel deposit itself, in order to establish the modification of the velocity model which occurs at this location. Because the three-component geophones were not available for this part of the project, no attempt was made to identify shear or converted waves and plot them in a wavefront diagram, as reported by Berzon (1964) and by Meissner (1965).

2. Correlation Refraction Profiles, R1, R2 and R3

One 500-foot and one 800-foot correlation refraction profile were recorded at locations R1 and R2, east of the sand and gravel deposit (Fig. 1). The profiles consisted of colinear spreads of twelve, 4.5 cps, vertical-component geophones, with 10 feet between each geophone for the 500-foot

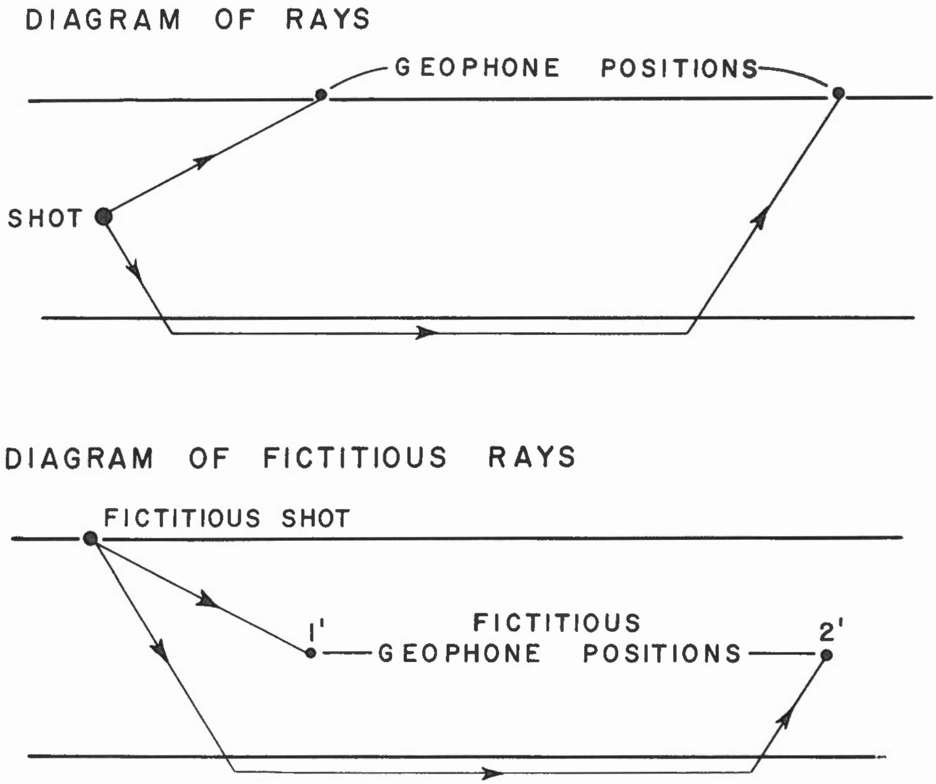


Figure 4. Theoretical basis of uphole wavefront method

profile, and 25 feet between each geophone for the 800-foot profile. Later in the project when three-component geophones were available, a 2,000-foot correlation refraction profile, R3, was recorded, with a three-component geophone every 200 feet, and vertical-component geophones in between at 25-foot intervals.

3. Continuous Profile of Reversed Refraction Spreads

A continuous profile of reversed refraction spreads (Fig. 3), each 300 feet long, was recorded across the sand and gravel deposit. The spreads consisted of twelve, 4.5 cps, vertical-component geophones, with 25 feet between each geophone. A constant charge size of 0.1 pound and a constant shot depth of 20 feet was maintained for each shot in an easterly direction. For the reversed shots in a westerly direction, difficulty was encountered in reloading the charge to a depth of 20 feet and shot depths were sometimes as shallow as 16 feet.

4. Continuous Profile of Inline, Offset Reflection Spreads

In an attempt to record a reflection from a shallow horizon in the bedrock, a continuous profile of 300 feet, inline, offset, reflection spreads was recorded along the same line as the reversed refraction spreads. Each spread consisted of twelve, 4.5 cps, vertical-component geophones, with 25 feet between individual geophones and was offset to a distance of 475 to 750 feet from the shotpoint to eliminate the interference of the reflected events by horizontally-travelling, low-frequency surface waves. For the first three spreads at the western end of the profile, the geophones were offset to distances between 325 and 600 feet, but difficulty was experienced in following the reflection, especially at the closer distances. All subsequent spreads were therefore offset with geophones between 475 and 700 feet.

RESULTS

Uphole Wavefront Diagrams U1

The generally uniform velocity conditions, which exist in the surficial materials in the survey area, are well illustrated by Figures 5 and 6, two wavefront diagrams. Below 20 feet, the shape of the wavefronts is characteristic of a direct transmitted wave, except in Figure 6 at the western end of the profile, where the bending back of the wavefronts between 20 and 80 feet, indicates the presence of some unidentified, low-velocity deposit. Generally, however, subsurface velocities determined by measurements along the normal to the wavefronts, show a decrease of about 1,000 feet per second with depth (a decrease from about 6,000 feet per second to 5,000 feet per second). There is a slight change in the slope of the wavefronts, at depths ranging between 50 to 70 feet below the surface, suggesting that the velocity decrease may be associated with a velocity discontinuity at the till-shale boundary. Because of the velocity inversion at this boundary, no head waves will be generated to arrive back at the surface, thus invalidating the application of seismic refraction methods for mapping the bedrock surface.

Above 20 feet, there is an abrupt change in the direction of the slopes of the wavefronts, which is characteristic of the replacement of a direct wave by a head wave. The contact between the silt and the till is interpreted as providing the velocity boundary for the generation of this head wave.

Uphole Wavefront Diagram U2

Velocity conditions similar to those in U1 are shown by Figure 7, with wavefronts characteristic of direct waves spreading out below 20 feet.

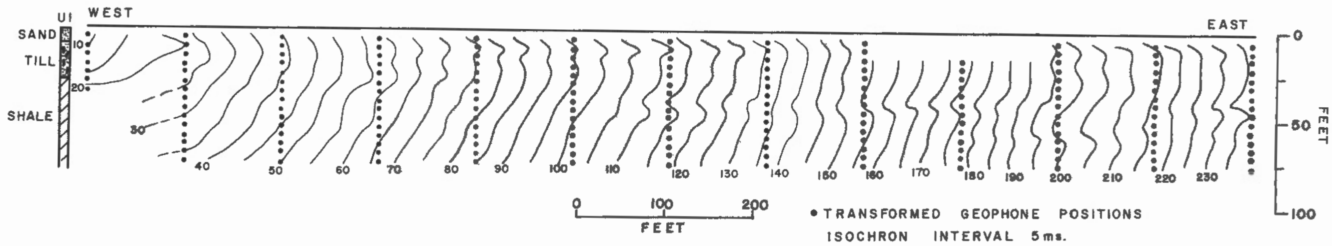


Figure 5. Uphole wavefront diagram, U1, 110 feet geophone spacing, Stenen area, Saskatchewan.

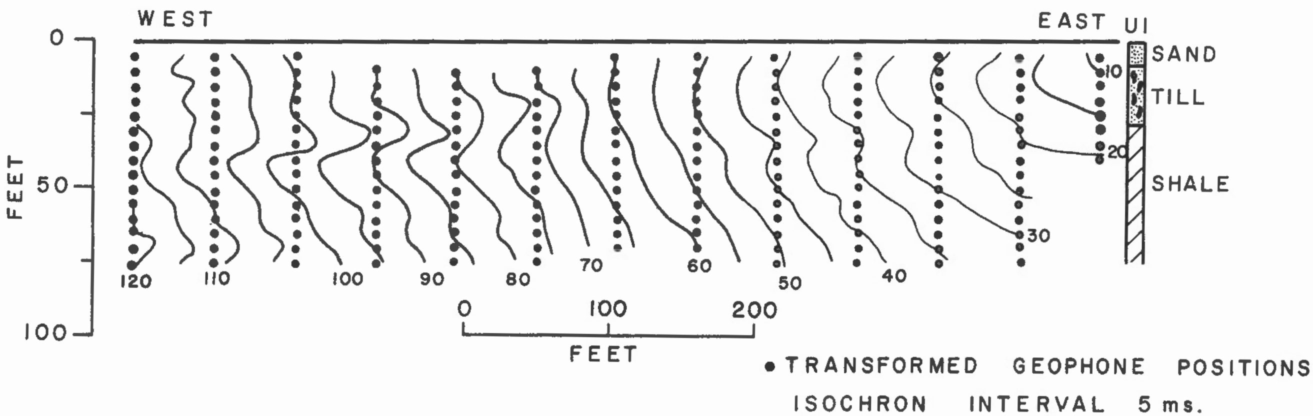


Figure 6. Uphole wavefront diagram, U1, 55 feet geophone spacing, Stenen area, Saskatchewan.

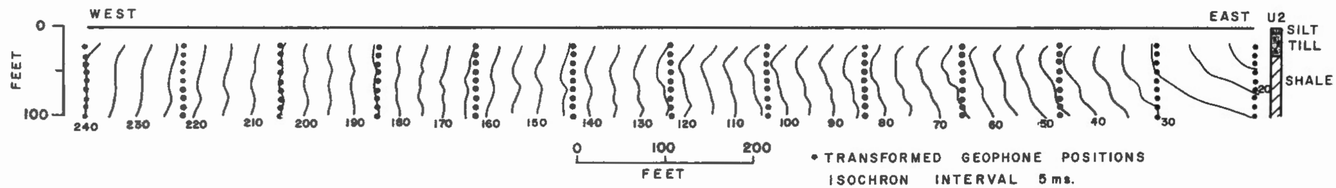


Figure 7. Uphole wavefront diagram, U2, 110 feet geophone spacing, Stenen area, Saskatchewan.

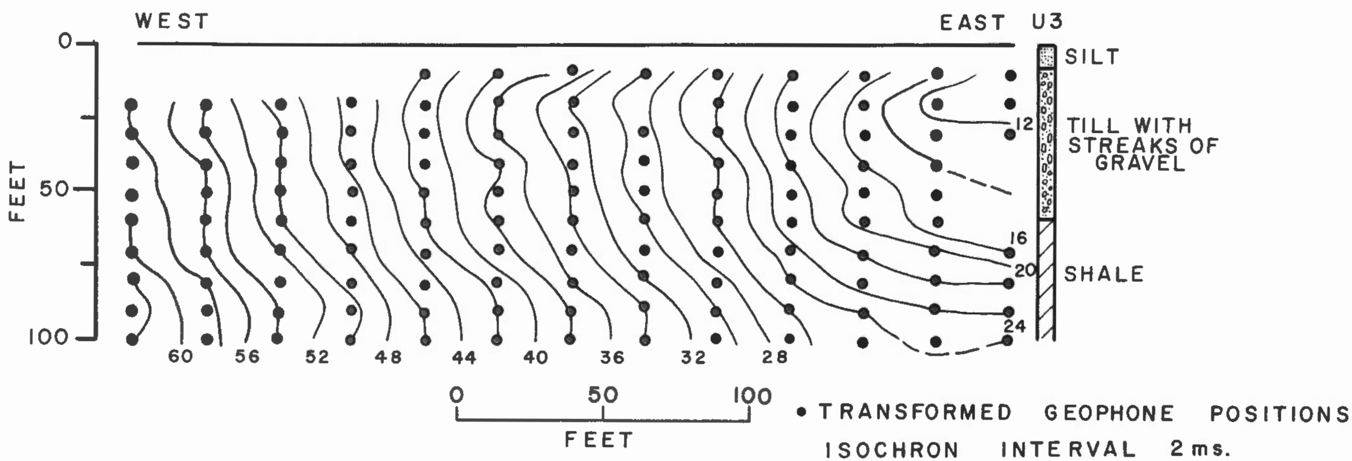


Figure 8. Uphole wavefront diagram, U3, 25 feet geophone spacing, Stenen area, Saskatchewan.

The change in the slope of the wavefronts at 50 feet below the surface again supports a velocity inversion from 6,000 to 5,000 feet per second between the till and the bedrock. The 6,000 feet per second velocity zone fades out in a horizontal direction, disappearing completely between 500 and 600 feet west of the shotpoint. This is to be expected because the till section is thin at this location (20 to 30 feet) and the attenuation of energy will be high due to the rapid leakage of the energy into the surrounding lower velocity materials.

No recordings were made for shots above 20 feet and there is no information on any head wave travelling along the silt-till boundary. This boundary is very shallow at this location (3 to 10 feet below the surface) and head waves would probably be difficult to identify, even from shallow shots within a few feet of the surface.

Uphole Wavefront Diagram U3

Figure 8 shows the velocity conditions in more detail for subsurface materials within 300 feet horizontally of a shotpoint, and 100 feet below the ground surface. The predominance of directly transmitted waves is confirmed, with a velocity inversion at 60 feet below the surface probably related to the bedrock-till contact. The presence of a head wave is again indicated by the abrupt change in the direction of the slopes of the wavefronts above 20 feet. This head wave corresponds to the silt-till interface. For depths between 20 and 100 feet in the hole, a plot of the times of first arrivals at the uphole geophone versus depth gives an average vertical velocity of 6,000 feet per second.

Uphole Wavefront Diagram U4

The wavefronts in Figure 9 were constructed from uphole shooting in test hole T2. The very sharp change in the direction of the slopes of the wavefronts at a depth of 30 feet is strong evidence for a marked velocity discontinuity at the silt-sand and gravel contact. Determination of velocity of the direct transmitted wave between 30 and 50 feet, gives values of approximately 8,000 feet per second. Shooting in the sand and gravel deposit was restricted to two depths because of the tendency of the hole to cave in for some distance immediately above the shot. Even so, the two sets of values obtained at 99 and 150 feet, support relatively high velocities of 7,000 to 8,000 feet per second for the sand and gravel deposit within 200 feet laterally of the shothole. Velocities appear to decrease to the order of 6,000 feet per second beyond this distance. The extremely high velocities of the sand and gravel deposit may be explained by cementation of the gravel in certain parts of the deposit, for which evidence was found in test hole T4. A plot of the uphole geophone time versus depth gives an average vertical velocity of 7,150 feet per second between 30 and 150 feet.

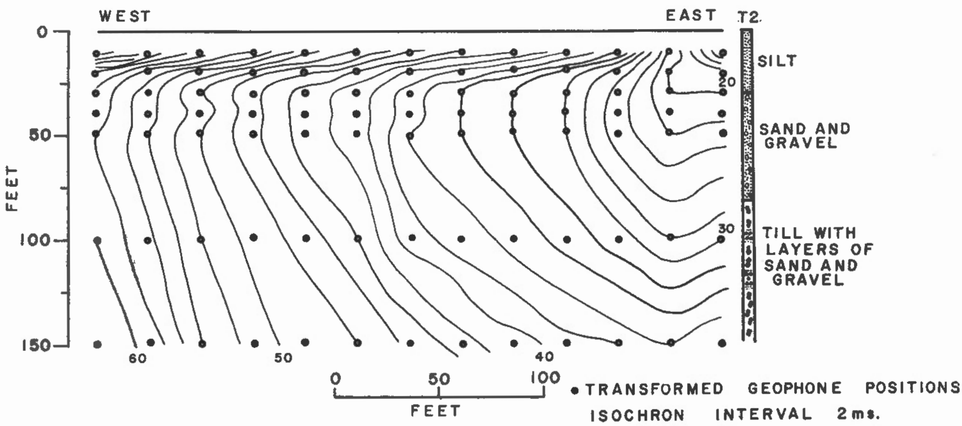


Figure 9. Uphole wavefront diagram, U4, in testhole T2, 25 feet geophone spacing, Stenen area, Saskatchewan.

The results from the uphole wavefront diagrams may be summarized as follows:

(a) Representative velocities for the main units investigated are:

Unit	Velocity (feet per second)
Silt	Variable
Till	6,000
Sand and gravel	7,000 - 8,000
Shale bedrock	5,000

(b) A head wave is associated with the silt-till or silt-sand and gravel boundary.

(c) The head wave may disappear as the distance from the shotpoint increases, due to the loss of energy from the thin, high velocity, till section. This will also apply to the 8,000 feet per second zone in the sand and gravel.

(d) The average vertical velocity through an 80-foot section of till and shale bedrock is 6,000 feet per second compared to an average vertical velocity of 7,150 feet per second through a section of mixed sand, gravel and till.

Correlation Refraction Profiles, R1, R2 and R3

Profiles R1 and R2 were recorded in an attempt to isolate the major wave groups associated with boundaries in the surficial deposits. A

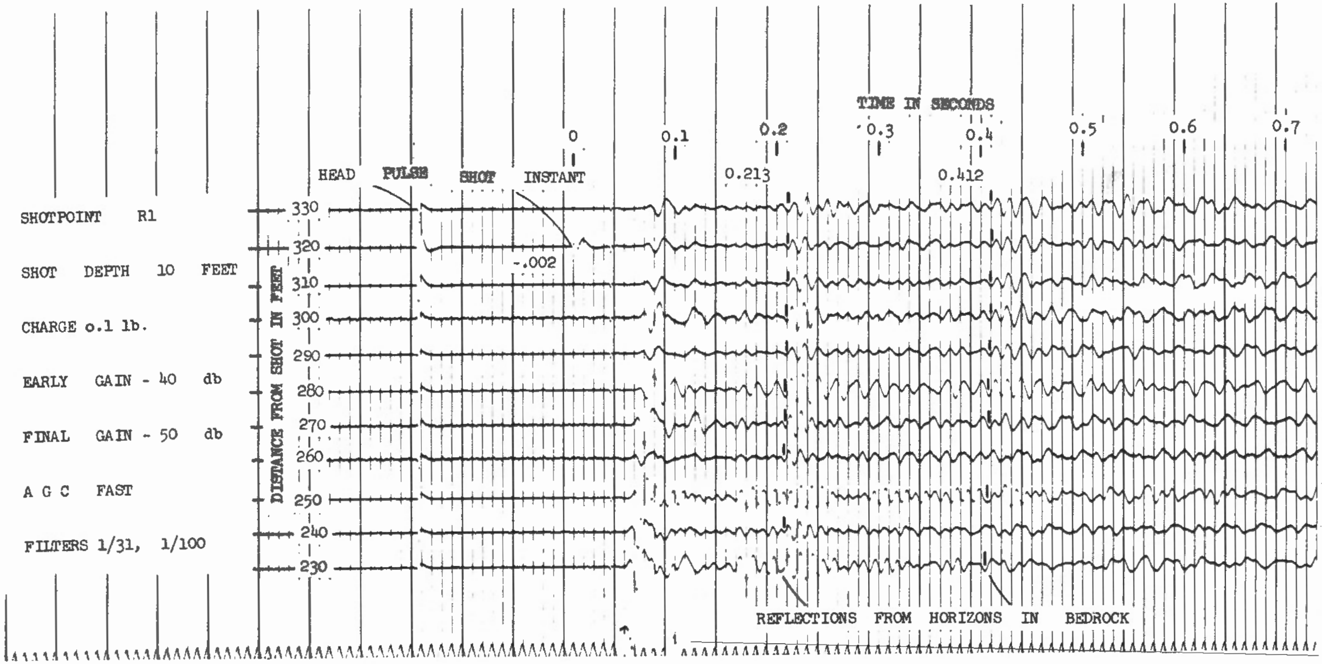


Figure 10. An example of seismic refraction record, profile R1, Stenen area, Saskatchewan.

sample record from profile R1 is shown in Figure 10. The absence of recognizable secondary arrivals associated with the surficial deposits is demonstrated by this record, only reflections from horizons in the bedrock being visible. All the records show a similar paucity of secondary arrivals, with the exception of the event at about 0.21 second which is a consistent arrival along both profiles. Surface waves were recorded intermittently, but were badly distorted because of their relatively low frequency compared to the frequency characteristics of the recording equipment.

The time-distance plot of first arrivals for profile R1 yields a velocity of 3,800 feet per second within 60 feet of the shotpoint and a velocity of 5,500 feet per second beyond (Fig. 11). Depths of 13 feet and 14 feet were calculated to the 5,500 feet per second layer, using the critical distance and intercept time methods. These depths are approximately the level of the water table as marked by the change from brown silty clay to blue silty clay at 10 feet in hole R2 (see Appendix A). The identification of the event at about 0.21 second as a reflection from a bedrock horizon is confirmed by the flat slope and hyperbolic character of its time-distance plot, also shown in Figure 11.

The time-distance plot of the arrivals for profile R2 (Fig. 12) is similar to that of profile R1. The first arrivals have a velocity of 5,300 feet per second beyond 50 feet, with the arrival time at 25 feet suggesting a lower velocity within this distance. The other major event is again the reflection from the bedrock horizon. On the basis of the above findings, it was decided to proceed with a continuous profile of 300 feet reversed refraction spreads, in an attempt to observe how the velocity and characteristics of the first arrivals changed over the sand and gravel deposits. These results are described below.

Towards the end of the project, three-component and 85 cps geophones became available. Refraction profile, R3, was then recorded, with a three-component geophone at 200-foot intervals. Two shots were recorded at each spread distance, one with the 4.5 cps geophones and one with the 85 cps geophones connected to the recording system. A sample record of a spread of 85 cps geophones and a three-component geophone at 375 feet is shown in Figure 13. The lack of secondary arrivals, other than the reflection event from the bedrock horizon, is again confirmed. One interesting observation from the three-component recording is the large amount of transverse movement of the first arrivals. It is probable that the transmission of energy in the relatively low velocity sediments does not take place wholly as a compressional wave, but is coupled to some Raleigh wave mechanism as described by Korschunov (1955). The three-component recordings for this area and the two other project areas is a subject of continuing investigation.

Continuous Profile of Reversed Refraction Spreads

A continuous profile of reversed refraction spreads each 300 feet long, with 25-foot spacing between 4.5 cps vertical-component geophones,

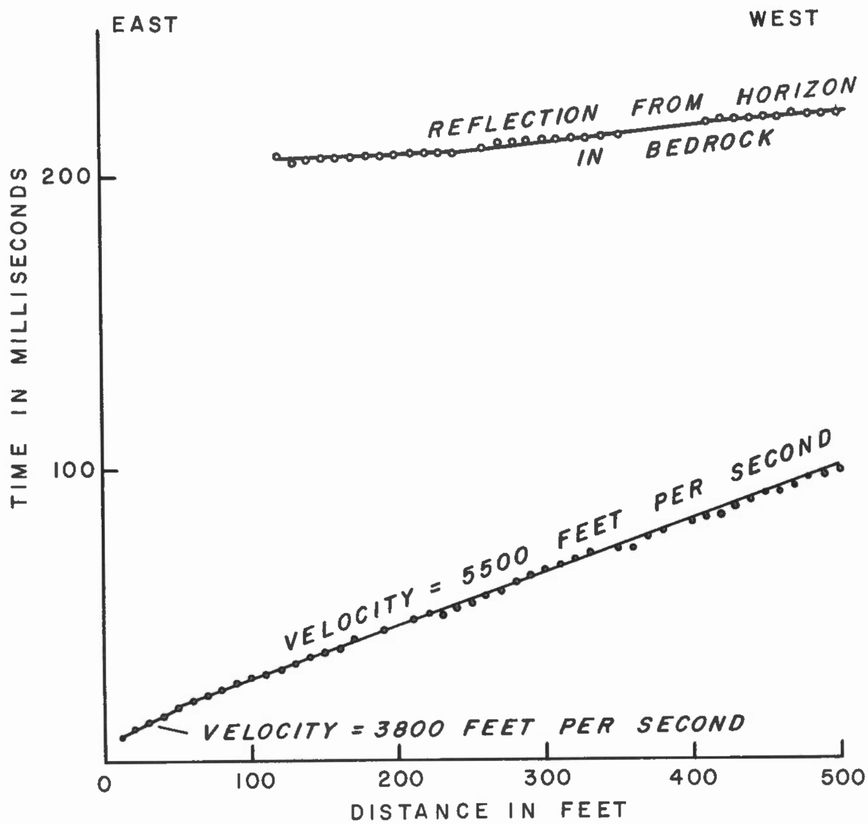


Figure 11. Time-distance plot, correlation refraction profile R1, Stenen area, Saskatchewan.

was recorded across the sand and gravel deposit. The time-distance plots of the first arrivals of energy are plotted in Figure 3, together with the calculated depths to the silt-till or silt-sand and gravel boundary, derived by using the critical distance method of computation.

The velocity determined for the layer below the silt shows a marked increase for the part of the profile which contains the sand and gravel deposit, that is, between boreholes RX16 and RX12 (Fig. 14). Where there are extensive thicknesses of sand and gravel, that is more than 50 feet, velocities lie in the range of 7,000 to 8,250 feet per second, but where only till is present, the range decreases to between 6,000 and 6,250 feet per second. It is impossible to correlate any definite velocities with the near-surface silt deposit, since velocities obtained are extremely variable in a range between 1,500 and 4,000 feet per second. The actual velocity in the silt at any location is probably influenced by the degree of saturation with water.

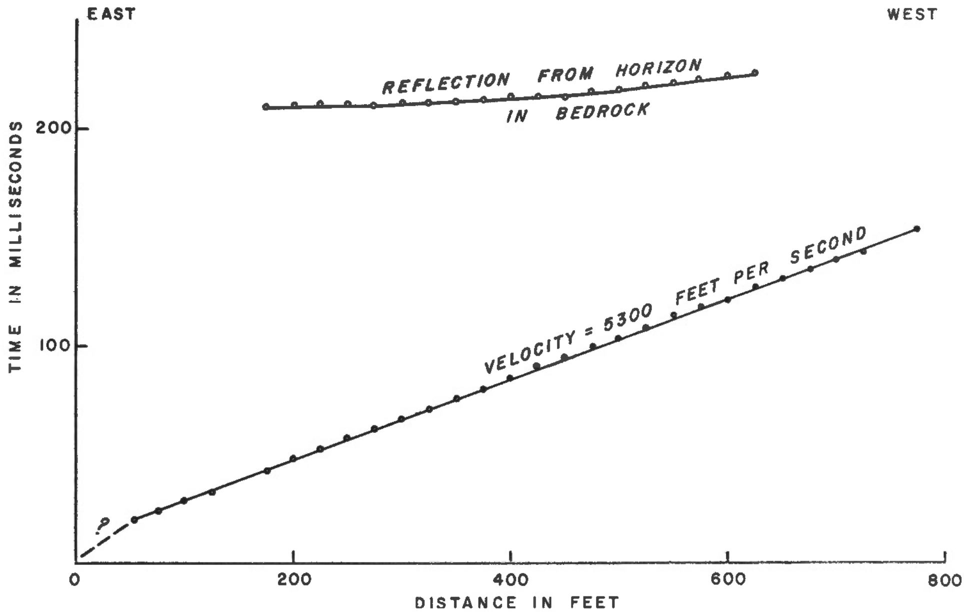


Figure 12. Time-distance plot, correlation refraction profile R2, Stenen area, Saskatchewan.

A frequency analysis of the first arrivals failed to demonstrate any significant difference between head waves related to the silt-till interface and those associated with the silt-sand and gravel interface. Apparent frequencies of the head waves were estimated by measuring the time between adjacent troughs and peaks on most of the records. A range of frequencies between 66 and 140 cps was obtained by this method, but no particular range of frequencies was correlatable with the head waves, either from till, or sand and gravel.

In addition to the qualitative frequency analysis reported above, power spectra were also computed from records obtained at locations RX9, RX12, RX14 and RX17. Each power spectrum was based on hand digitized data from the sixth trace on the seismic record, representing the arrival of the appropriate head wave at a distance of 150 feet from the shot. The trace was digitized at 1 millisecond intervals over an interval of 0.4 second. A plot of the results obtained is given in Figure 15.

The wave recorded at RX9, at a location east of the sand and gravel deposit, possesses the highest predominant frequency, 140 cps, with most of the energy being carried in a relatively narrow band between 100 and 160 cps. At one location, RX14, over the sand and gravel deposit a predominant frequency of 100 cps was determined, whereas at another location, RX12, a predominant frequency of 80 cps was obtained. Finally, from a recording made at RX17, west of the sand and gravel deposit, a predominant frequency

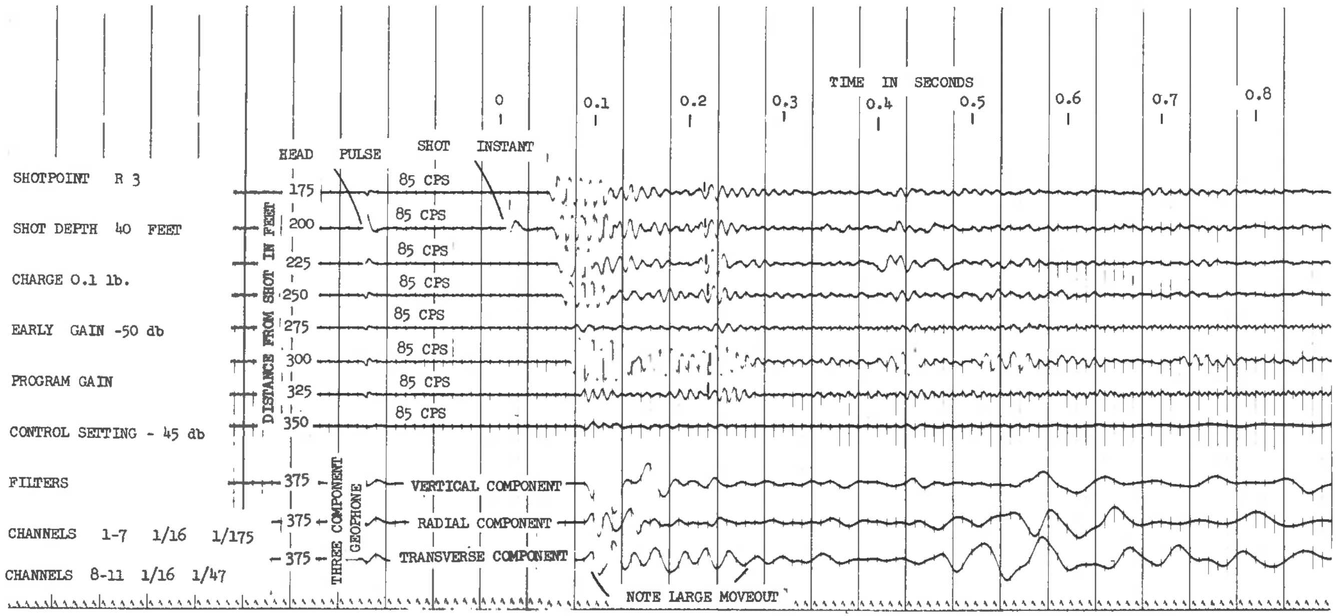


Figure 13. An example of a three-component record, Stenen area, Saskatchewan.

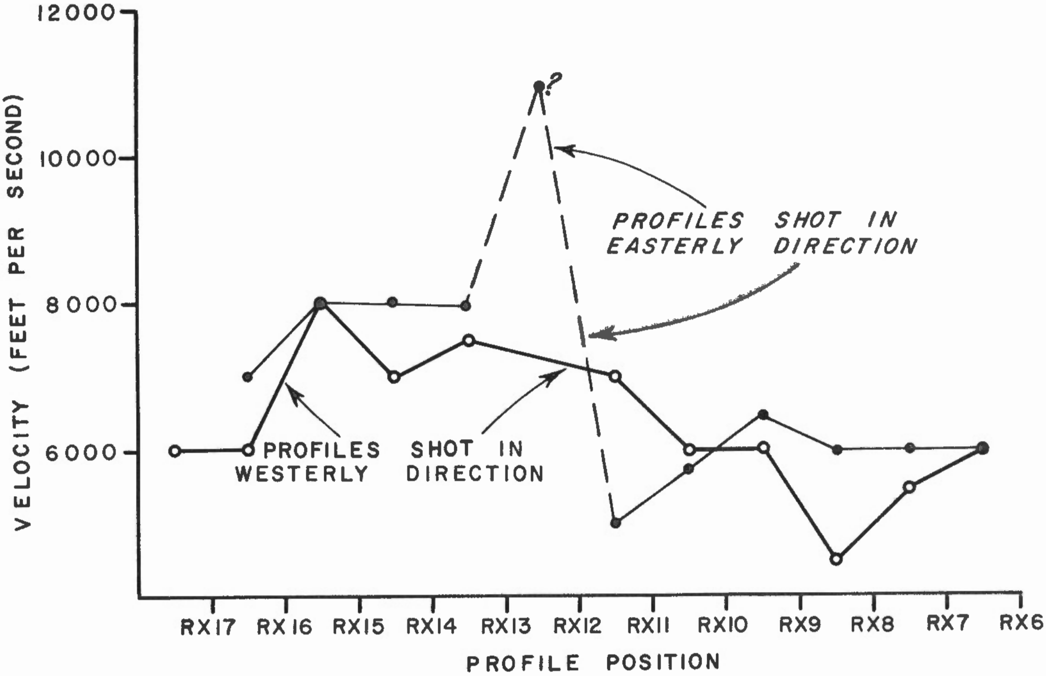


Figure 14. Velocities observed in the stratum underlying the silt. This layer may be either sand and gravel or till. Stenen area, Saskatchewan.

of 100 cps was obtained again. Most of the energy for all three of the last mentioned locations was in a frequency range between 40 and 140 cps, the spectra being almost identical in form.

The higher predominant frequency at location RX9, and the concentration of energy in the higher frequency range, is interesting and requires further explanation. One difference between this location and the other three locations is in the nature of the shooting medium. If the logs of the shotholes are consulted (Appendix A), it is found that the explosive for location RX9 was detonated in till, while at the other three locations, the explosive was detonated in either silt or gravel. Molatava (1964) found that spectra of waves generated by explosives in limestone or water-saturated sand or clay were characterized by higher frequencies than the waves from the same charge of explosive detonated in partially saturated clay or sand. In the present study, all shotholes bottomed in silt or gravel were completely dry when attempts were made to measure the depth to the water table on completion of the project. However, shotholes bottomed in clay or till had water still standing in them. The silt or gravel would therefore only be partially saturated in the vicinity of the shotpoint, whereas the till would be fully saturated. The higher frequencies at location RX9 are therefore more likely explained in terms of

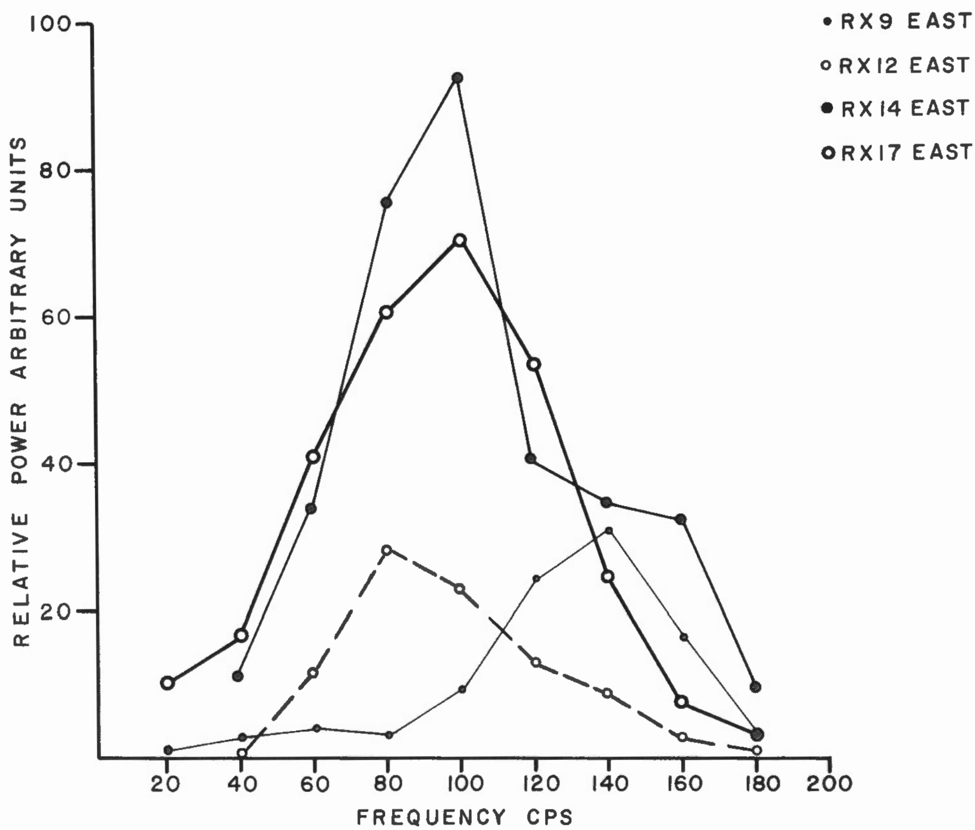


Figure 15. Power spectra for first arrivals recorded at four locations along (cross-section), Stenen area, Saskatchewan. Trace from channel number 6, 150 feet from shot point, analyzed in each case.

these changes in the shooting medium rather than by transmission characteristics of the till. This is supported by the fact that at location RX17, where the refractor is till, but the shotpoint is in silt, a similar concentration of high frequencies did not occur.

Continuous Profile of Inline, Offset Reflection Spreads

Because the reflection between 0.21 and 0.22 second seemed to be a persistent secondary event on the correlation refraction profiles R1 and R2, it was decided to record a continuous reflection profile across the sand and gravel deposit and examine the effects of the deposit on the time of arrival of the reflection. In order to record the reflection with the least interference from other arrivals, the spread was offset from the shotpoint. Two examples of seismic reflection records are shown in Figures 16 and 17. Location RX17 is west of the sand and gravel deposit while location RX12 is over the sand and gravel deposit.

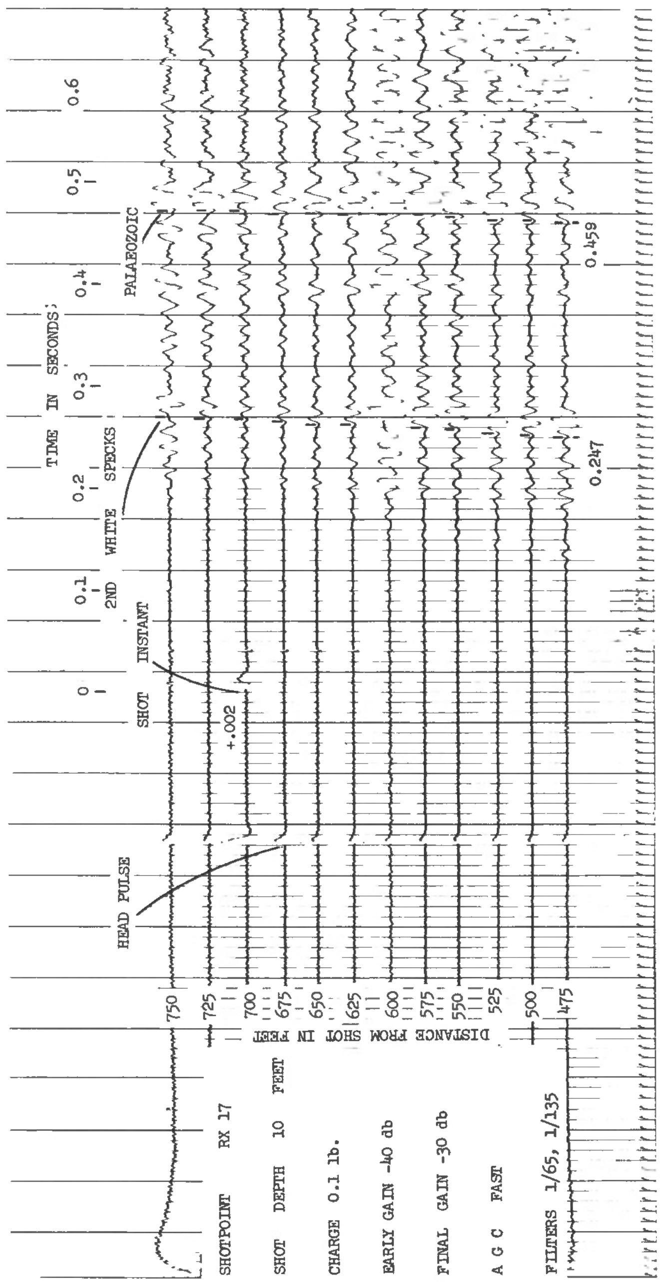


Figure 16. Seismic reflection record, Stenen area, Saskatchewan.

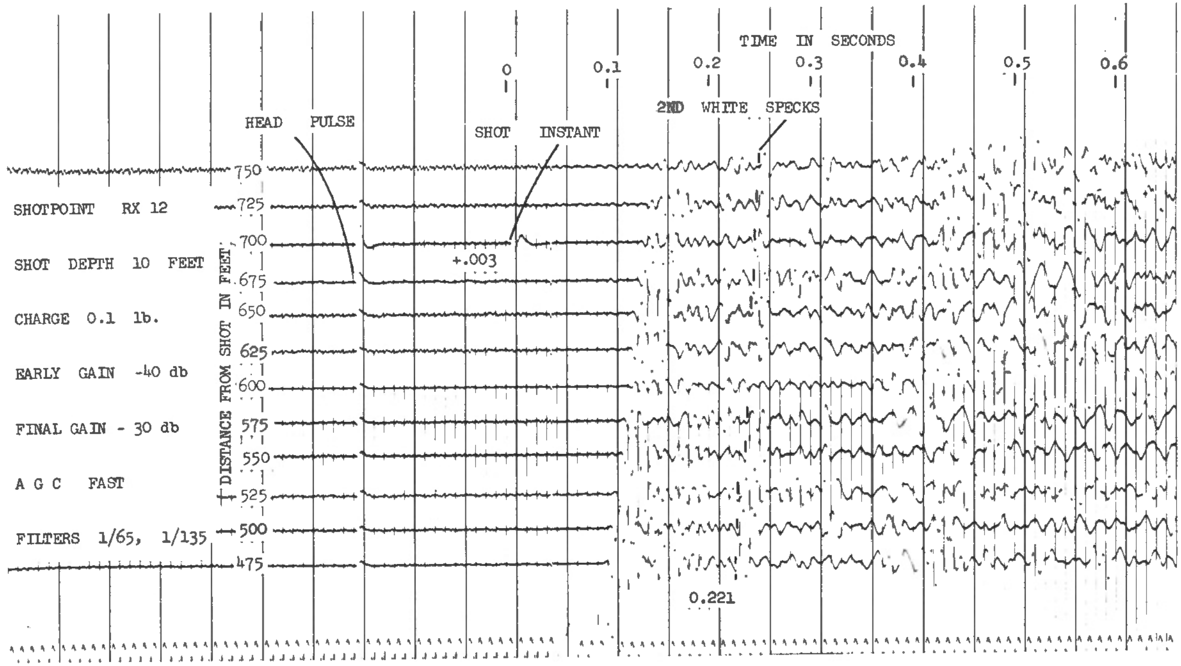


Figure 17. Seismic reflection record, Stenen area, Saskatchewan.

TABLE I.

Recorded Reflection Times, Continuous Profile of Inline, Offset Reflection Spreads

Shotpoint No.	Elevation of Shot	Height of shot with Reference to Datum Plane	Time Correction to Datum	Elevation to Geophone	Height of Geophone with Reference to Datum Plane	Time Correction to Datum	Total Time Correction	Actual Time of Reflection at Geophone	Corrected Reflection Time
	Feet	Feet	Millisecs	Feet	Feet	Millisecs	Millisecs	Millisecs	Millisecs
RX 6	1636	-19	+14	1660	+5	-4	+10	-?	
RX 7	1640	-15	+12	1664	+9	-7	+5	-?	
RX 8	1651	-4	+3	1667	- +12	-9	-6	235?	229?
RX 9	1652	-3	+2	1668	+13	-10	-8	230	222
RX 10	1657	+2	-2	1662	+7	-5	-7	229	222
RX 11	1658	+3	-2	1668	+13	-10	-12	231	219
RX 12	1649	-6	+5	1667	+12	-9	-4	221	217
RX 13	1657	+2	-2	1666	+11	-8	-10	226	216
RX 14	1656	+1	-1	1669	+14	-11	-12	230	218
RX 15	1657	+2	-2	1672	+17	-13	-15	233	218
RX 16	1660	+5	-4	1674	+19	-14	-18	242	224
RX 17	1662	+7	-5	1677	+22	-17	-22	247	225

An average velocity of 5, 900 feet per second to the reflector and depths ranging between 675 and 700 feet (975 to 950 feet above sea level), were calculated from three T^2/X^2 plots. Correlation with the Stenen borehole of Canadian Oil and Gas Reserves Limited suggests that the top of the Favel Formation, or the 'Second White Specks', is the most likely reflector at this depth.

The recorded reflection times, for geophones 475 feet away from the shotpoint, are given in Table 1. These times have also been corrected to a datum of 1, 655 feet above sea level using the relative elevations obtained by series levelling. The time corrections were calculated using a velocity of 1, 300 feet per second to represent the near-surface material. This velocity was obtained from the uphole survey in borehole T2 for the uppermost 20 feet. A velocity pull-up is indicated by the smaller reflection times over the sand and gravel deposit in the centre of the profile. There is a time lead of 9 milliseconds in the corrected reflection time for record RX13 compared to record RX17. Assuming all of the time lead to be associated with the increased section of sand and gravel, and that the average velocities through the surficial deposits are represented by the values obtained in uphole shooting, the increase in thickness of the mixed sand, gravel and till section is of the order of 170 feet. This is in good agreement with the estimated 150 feet based on the borehole control.

CONCLUSIONS

1. A bedrock depression, filled with a deposit of sand and gravel, was located. The most likely origin of this depression is a meltwater channel formed during a retreat of the glacier.

2. A velocity model for the surficial deposits in the survey area was established by the construction of uphole wavefront diagrams for the first arrivals. A direct, transmitted wave predominates in most of the diagrams, with a generally lower velocity (5, 000 feet per second) for the bedrock section than for the till section (6, 000 feet per second). The velocity was highest in the sand and gravel deposit, where velocities of 7, 000 to 8, 000 feet per second were obtained. A head wave was identified in the diagrams, at depths varying between 10 and 30 feet, and was associated with the silt-till or silt-sand and gravel interface.

3. With the exception of surface waves, no secondary arrivals propagating solely in the surficial deposits could be identified in correlation refraction profiles.

4. A continuous profile of short reversed refraction spreads across the sand and gravel deposit yielded results which showed a marked increase in velocity over the sand and gravel deposit. The velocity in the sand and gravel appears to vary between 7, 000 and 8, 000 feet per second, whereas a

velocity of 6,000 feet per second is more typical in the till. Depths calculated from the time-distance plots of the first arrivals (critical distance method) correlate well with the silt-till boundary or the silt-sand and gravel boundary, the latter boundaries being interpolated from the drilling results.

5. No correlation was established between the frequency content of the seismic wave and the medium through which it was propagated. Instead, the frequency content seemed to be a function of shotpoint lithology, higher frequencies being obtained from a shot placed in till than from shots in silt and gravel.

6. There is a small time lead associated with the reflection time from the 'Second White Specks' Formation in the velocity of the sand and gravel deposit. Calculation of the increased thickness of the mixed sand and gravel and till section, on the basis of the time lead of 9 milliseconds, and average vertical velocities based on uphole geophone times, gives a value of 170 feet, which is in approximate agreement with the estimated values of 150 feet from the drilling results.

7. A large movement on the traverse component of the three-component geophone was noted for the first arrival. This is possibly due to the coupling of the compressional wave to some kind of Rayleigh wave mechanism.

REFERENCES

Berzon, I.S., Vassil'ev, Yu. I., and Starodubrovskaya, S.P.
1959: Wave refraction by aquiferous sands; Bull. Izv. Acad. Sci., U.S.S.R., Geophys. Series No. 1 (English Edition), pp. 17-29.

1964: Some results of a study of seismic waves from well shooting; Bull. Izv. Acad. Sci., U.S.S.R., Geophys. Series No. 9 (English Edition), pp. 793-806.

Burke, K.B.S.
1967: Problems of seismic prospecting for groundwater in surficial deposits; Paper presented to Canadian Centennial Conference on Mining and Groundwater Geophysics, Niagara Falls, October, 1967.

Burke, K.B.S., Gendzwill, D., and Sawatsky, H.
1966: Seismic investigation of the Stenen magnetic anomaly; Sask. Res. Council, Report P-66-2.

Dobrin, M.B.
1960: Introduction to geophysical prospecting, 2nd ed., McGraw-Hill Book Co., New York.

Domzalski W.
1956: Some problems of shallow refraction investigations; Geophys. Prospecting, vol. 4, No. 2, pp. 140-166.

Evison, F.F.
1952: The inadequacy of the standard seismic techniques for shallow surveying; Geophysics, vol. 17, No. 4, pp. 867-875.

Hall, D.H.
1962: Groundwater studies in southern Saskatchewan from seismic surveys for oil; Sask. Res. Council, Report P-62-1.

Hefer, F.W.
1961: The use of photo-resistive cells as losser elements in a transistorized seismic amplifier; Geophysics, vol. 26, No. 5, pp. 550-559.

Hobson, G.D., and Collett, L.S.
1960: Some observations with a hammer refraction seismograph; Can. Mining Met. Bull., vol. 53, No. 581, pp. 674-681.

Hobson, G.D., Scott, J.S., and van Everdingen, R.D.
1964: Geotechnical investigations, Red River Floodway, Winnipeg, Manitoba; Geol. Surv. Can., Paper 64-18.

Johnson, W.A., Wickenden, R.T.D., and Weir, J.D.
1948: Preliminary map, surface deposits, southern Saskatchewan; Geol. Surv. Can., Paper 48-18.

Korschunov, A.
1955: On surface waves in loose materials of the soil; Geophys. Prospecting, vol. 3, No. 4, pp. 359-379.

Lennox, D.H.
1962: Geophysical methods of locating aquifers in the prairies; Nat. Res. Council Can., Proc. Hydrology Symposium No. 3, Groundwater, pp. 251-300.

Levshin, A.L.
1961: Determination of groundwater level by the seismic methods; Bull. (Izv.) Acad. Sci., U.S.S.R., Geophysics Series, No. 9, (English Edition), pp. 857-870.

McManis, L.B.
1961: Proposed standards for seismic amplifiers ..... and what they mean to field records; Geophysics, vol. 26, No. 5, pp. 543-549.

Meissner, R.
1961: Wave-front diagrams from uphole shooting; Geophys. Prospecting, vol. 9, No. 4, pp. 533-543.

1965: P- and SV-waves from uphole shooting; Geophys. Prospecting, vol. 13, No. 3, pp. 433-459.

Molotava, L.V.
1964: The relationship between the frequency spectra of seismic vibrations and explosion conditions; Bull. (Izv.) Acad. Sci., U.S.S.R., Geophys. Series (English Edition), pp. 1059-1072.

Wickenden, R.T.D.
1945: Mesozoic stratigraphy of the eastern plains, Manitoba and Saskatchewan; Geol. Surv. Can., Mem. 239.

Wyder, J.E.W.
1968: Geophysical and geological study of surficial deposits near Frobisher, Saskatchewan; unpubl. Ph.D. thesis, Univ. Saskatchewan.

APPENDICES

APPENDIX A

Hole No.	Location of Holes Elevation (ASL) Feet	Distance east of southwest corner sec. 6 T 34 R 3W 2M Feet
U1	1656	660
U3	1659	3300
		Distance east of southwest corner sec. 5 T 34 R 3W 2M
T5	1670	1650
T1*	1677	2860
T7	1675	3740
RX 17	1672	3980
SP 10	1670	4140
RX 16	1670	4280
T6	1676	4290
RX 15	1667	4580
T4.1	1664	4620
T4.2	1664	4630
RX 14	1666	4880
RX 13	1667	5180
T2	1668	5280
		Distance east of southwest corner sec. 5 T 34 R 3W 2M
SP 9	1661	120
RX 12	1659	200
T8	1667	330
RX 11	1668	500
T3	1668	660
RX 10	1667	800
RX 9	1662	1100
RX 8	1661	1400
SP 8	1660	1450
RX 7	1650	1700
RX 6	1646	2000
RX 5*	1645	2000
RX 4*	1643	2300
RX 3*	1642	2600
RX 2*	1643	2900
R3*	1643	2900
R2* (RX 1)	1643	3200
R1	1642	3300
U2	1646	4620

All holes except those marked with * are in the northern ditch of Highway 49.

APPENDIX B

Logs of Holes

Refraction Shotholes

R1	No log available	
R2 (RX 1)	0 - 10	Brown silty clay
	10 - 26	Blue silty clay
	26 - 28	Medium-coarse gravel
	28 - 40	Dark grey shale
R3	0 - 10	Brown silty clay
	10 - 21	Blue silty clay
	21 - 31	Blue clay
	31 - 40	Dark grey shale

Reflection Shotholes

RX 1	Same hole as R2	
RX 2	0 - 12	Brown silty clay
	12 - 21	Blue silty clay
	21 - 33	Blue clay
	33 - 40	Dark grey shale
RX 3	0 - 12	Brown silty clay
	12 - 20	Blue silty clay
RX 4	0 - 9	Brown silty clay
	9 - 20	Blue till with coarse gravel streaks
RX 5	0 - 4	Brown silty clay
	4 - 12	Brown till with some rocks
	12 - 20	Blue till with coarse gravel streaks
RX 6	0 - 4	Brown silt
	4 - 12	Brown till with coarse gravel streaks
	12 - 15	Blue stony till
	15 - 21	Coarse gravel
	21 - 27	Blue till with sand and gravel streaks
	27 - 40	Dark grey shale
RX 7	No log available	
RX 8	0 - 10	Brown silt
	10 - 14	Brown sandy silt
	14 - 20	Blue till with gravel streaks

RX 9	0 - 17	Brown silt
	17 - 20	Brown till with gravel streak
RX 10	0 - 20	Brown silt
RX 11	0 - 15	Brown silt
	15 - 20	Brown sand
RX 12	0 - 13	Brown silt
	13 - 20	Brown sandy silt
RX 13	0 - 20	Brown silt
RX 14	0 - 19	Brown silt
	19 - 20	Coarse gravel
RX 15	0 - 20	Brown silt
RX 16	0 - 19	Brown silt
	19 - 20	Blue silt
RX 17	0 - 20	Brown silt
Testholes		
T1	0 - 2	Brown silt
	2 - 10	Fine to medium gravel
	10 - 29	Brown, silty till with gravel streaks
	29 - 40	Dark grey till with gravel streaks
	40 - 45	Fine to medium gravel
	45 - 58	Dark grey, sandy till with sand and gravel streaks
	58 - 160	Dark grey shale
T2*	0 - 30	Brown silt
	30 - 40	Coarse gravel with streaks of silt
	40 - 82	Coarse sand and gravel
	82 - 117	Dark grey till with streaks of medium to coarse gravel
	117 - 132	Dark grey, sandy till with streaks of coarse gravel
	132 - 137	Dark grey till with boulders
	137 - 172	Dark grey till with streaks of sand
	172 - 200	Dark grey shale
T3*	0 - 30	Brown silt
	30 - 44	Dark grey, sand till with streaks of coarse gravel
	44 - 60	Dark grey shale

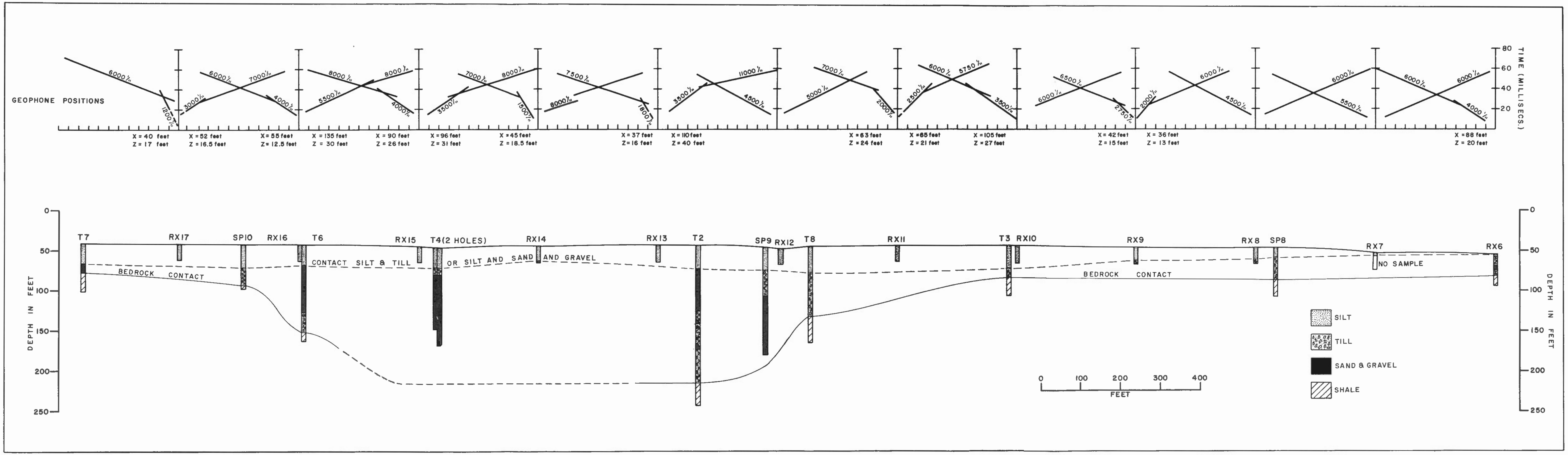
T4.1	0 - 26	Brown silt
	26 - 35	Brown sandy till
	35 - 79	Coarse sand and gravel
	79 - 83	Boulders
	83 - 100	Very coarse, cemented gravel with streaks of till and medium gravel
T4.2	0 - 26	Brown silt
	26 - 35	Brown sandy till
	35 - 78	Coarse sand and gravel
	78 - 83	Boulders
	83 - 120	Very coarse, cemented gravel with streaks of fine to medium gravel
T5*	0 - 10	Brown silt
	10 - 13	Brown, sandy till
	13 - 24	Dark grey, sandy till
	24 - 34	Brown, medium sand
	34 - 70	Dark grey, stony till
	70 - 75	Brown shale
	75 - 100	Dark grey shale
T6	0 - 19	Brown silt
	19 - 26	Blue silt
	26 - 81	Coarse sand and gravel with streaks of till
	81 - 105	Dark grey, stoney till
	105 - 120	Dark grey shale
T7	0 - 25	Brown silt
	25 - 34	Medium to coarse gravel
	34 - 60	Dark grey shale
T8	0 - 29	Brown silt
	29 - 34	Blue silt
	34 - 37	Medium to coarse gravel
	37 - 90	Dark grey, stony till
	90 - 120	Dark grey shale
Uphole Testholes		
U1*	0 - 14	Brown sand
	14 - 18	Dark grey, sandy till
	18 - 25	Dark grey till with streaks of coarse gravel
	25 - 55	Dark grey till with streaks of fine sand
	55 - 150	Dark grey shale

U2*	0 - 4	Brown silt
	4 - 13	Brown, sandy, stony till
	13 - 23	Dark grey, stony till
	23 - 30	Dark grey, sandy till with fine gravel streaks
	30 - 100	Dark grey shale
U3*	0 - 7	Brown silt
	7 - 10	Brown stony till
	10 - 22	Dark grey, stony till with fine gravel streaks
	22 - 37	Dark grey till
	37 - 57	Dark grey till with coarse gravel streaks
	57 - 100	Dark grey shale
U4 (T2)	Same log as T2 above	

<u>Logs of Shotholes Drilled on Previous Project Based Upon Written Communication by J. Cherry, 1964</u>

SP8	0 - 12	Brown silt
	12 - 35	Brown and grey till with gravel streaks
	35 - 40	Grey till
	40 - 60	Dark grey shale
SP9	0 - 30	Silt with some fine sand
	30 - 32	Gravel
	32 - 43	Grey stony till
	43 - 60	Grey till with gravel streaks
	60 - 135	Gravel and coarse sand
SP10	0 - 28	Brown silt
	28 - 35	Mixture of silt and till and gravel streaks
	35 - 53	Grey till
	53 - 56	Dark grey shale

* Holes marked with * were E - logged (Single point resistivity and S.P.).



GEOPHONE POSITIONS
TIME (MILLISECS.)
X = 40 feet Z = 17 feet
X = 52 feet Z = 16.5 feet
X = 55 feet Z = 12.5 feet
X = 135 feet Z = 30 feet
X = 90 feet Z = 26 feet
X = 96 feet Z = 31 feet
X = 45 feet Z = 18.5 feet
X = 37 feet Z = 16 feet
X = 110 feet Z = 40 feet
X = 63 feet Z = 24 feet
X = 65 feet Z = 21 feet
X = 105 feet Z = 27 feet
X = 42 feet Z = 15 feet
X = 36 feet Z = 13 feet
X = 88 feet Z = 20 feet
DEPTH IN FEET
T7 RX17 SP10 RX16 T6 RX15 T4(2 HOLES) RX14 RX13 T2 SP9 RX12 T8 RX11 T3 RX10 RX9 RX8 SP8 RX7 RX6
CONTACT SILT & TILL OR SILT AND SAND AND GRAVEL
BEDROCK CONTACT
NO SAMPLE
SILT
TILL
SAND & GRAVEL
SHALE
0 100 200 300 400
FEET