Application of High Resolution Reflection Seismic to Surface Minable Oil Sands

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ABSTRACT

During the last decade, a number of geophysical methods have been successfully used to aid in the exploration and development of surface mineable oil sands (Rozenberg et. al., 1985). It is only more recently that high resolution reflection seismic methods have been applied.

This paper presents typical results from a high resolution seismic survey which was included as part of the mine and tailings siting studies during the 1989 winter program for the OSLO Project. The objectives of the reflection seismic survey were:

i) definition of deep Pleistocene channels
ii) definition of basal zone stratigraphy
iii) definition of the Devonian surface
iv) definition of Devonian stratigraphy
v) definition of structures within the Cretaceous and Devonian

The results of the reflection seismic survey show that the method was able to meet the survey objectives. The application of high resolution reflection seismic when used in conjunction with electrical methods provides a cost effective method of targeting drill hole locations and interpolating subsurface conditions between drill holes.

INTRODUCTION

The purpose of the paper is to present a case history of how high resolution reflection seismic and electrical geophysical methods were successfully used as an aid in the exploration and definition of geological features in and around the OSLO oil sand mining project. The techniques employed provide a cost effective method of targeting core hole locations and interpolating subsurface geology between drill holes at considerable savings to the owner.

The OSLO oil sand project is located about 40 miles north of Fort McMurray, Alberta in and around Township 95 of Range 8 West of the 4th. (see Figure 1). Mine and plant facilities, while not finalized, might be located as illustrated in Figure 2.

BACKGROUND GEOLOGY

Regional Geological Setting

The Devonian Waterways Formation developed in a relatively shallow warm water marine environment. The sediments are composed of both skeletal and micritic carbonates and light greenish/grey calcareous clay. A major Devonian low trends northwards through Township 95, Range 8. Salt removal from the underlying Middle Devonian Elk Point Group and subsequent collapse of the overlying Beaverhill Lake Group is believed to have played a major role in controlling the initial geometry of the drainage basins developed on the Paleozoic erosional surface. Normal faults possibly extending into the Pre-Cambrian basement complex, which may have been active as late as lower McMurray time, are also thought to have played a role in the development of these early drainage basins.

A regional airphoto interpretation suggests that most structural lineaments trend north-south and northwest-southeast. These sets are parallel to some field-measured joint sets in the McMurray and Waterways Formations (Babcock & Sheldon, 1976).

The McMurray Formation represents the sediment infill of a paleo-drainage system which developed on the Devonian erosional surface. The quartzose sands of the McMurray Formation were derived from the Proterozoic Athabasca sandstone east of the study area.

Continental fluvial sands were deposited in the deepest parts of the basin (Devonian lows). On Lease 31, several of these sands are water saturated and over pressured. The coarse fluvial sands are often flanked and/or overlain by finer grained floodplain and overbank deposits which commonly onlap the Devonian highs. Onlapping of the continental deposits onto Devonian highs and an increase in the occurrence of muddy marsh deposits towards the top of the continental succession is indicative of a decrease in channel activity and an overall fining upwards trend. This suggests a stagnation of the basin's drainage system in response to an overall rise in sea level.

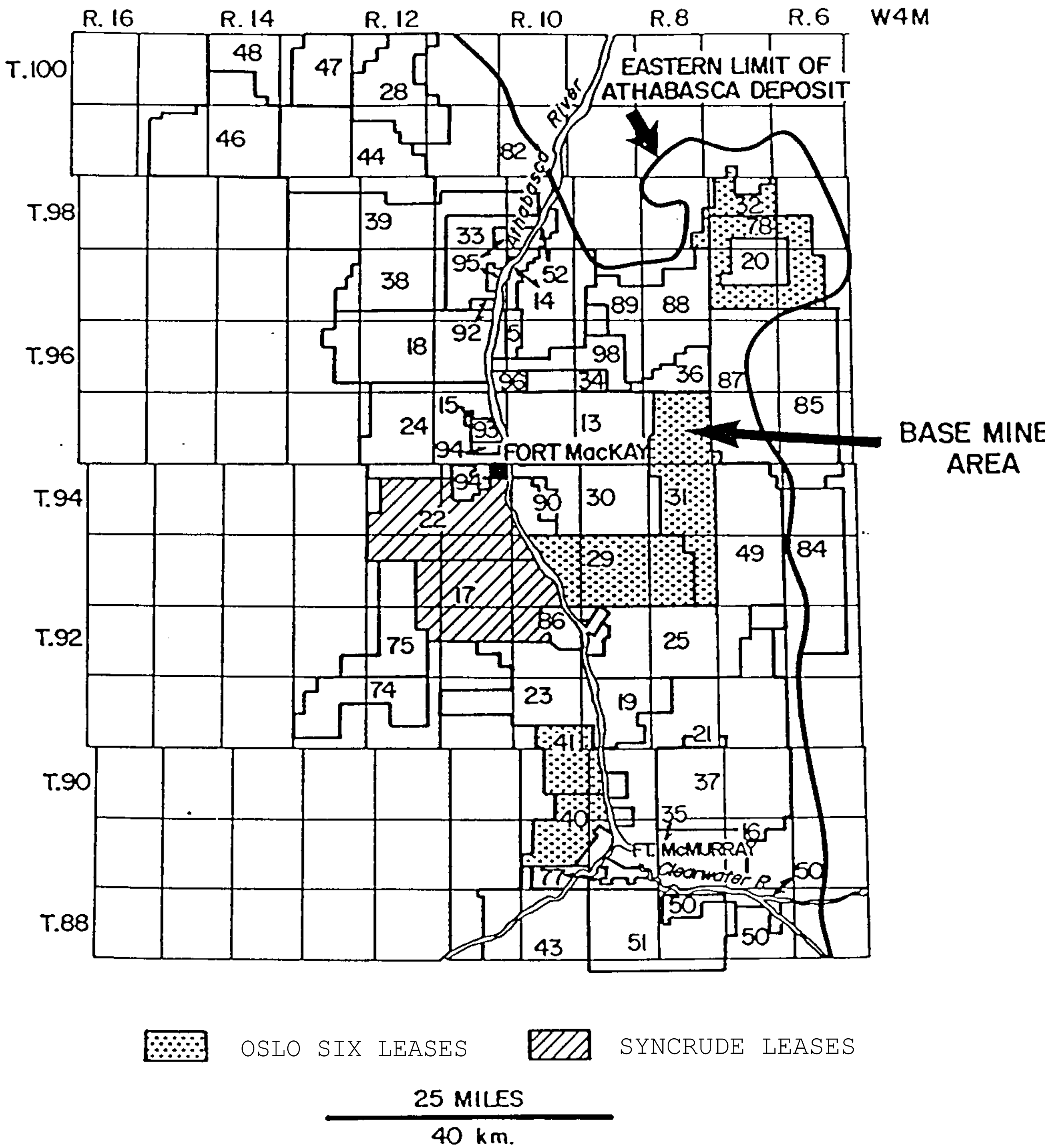

Figure 1 - Location Map

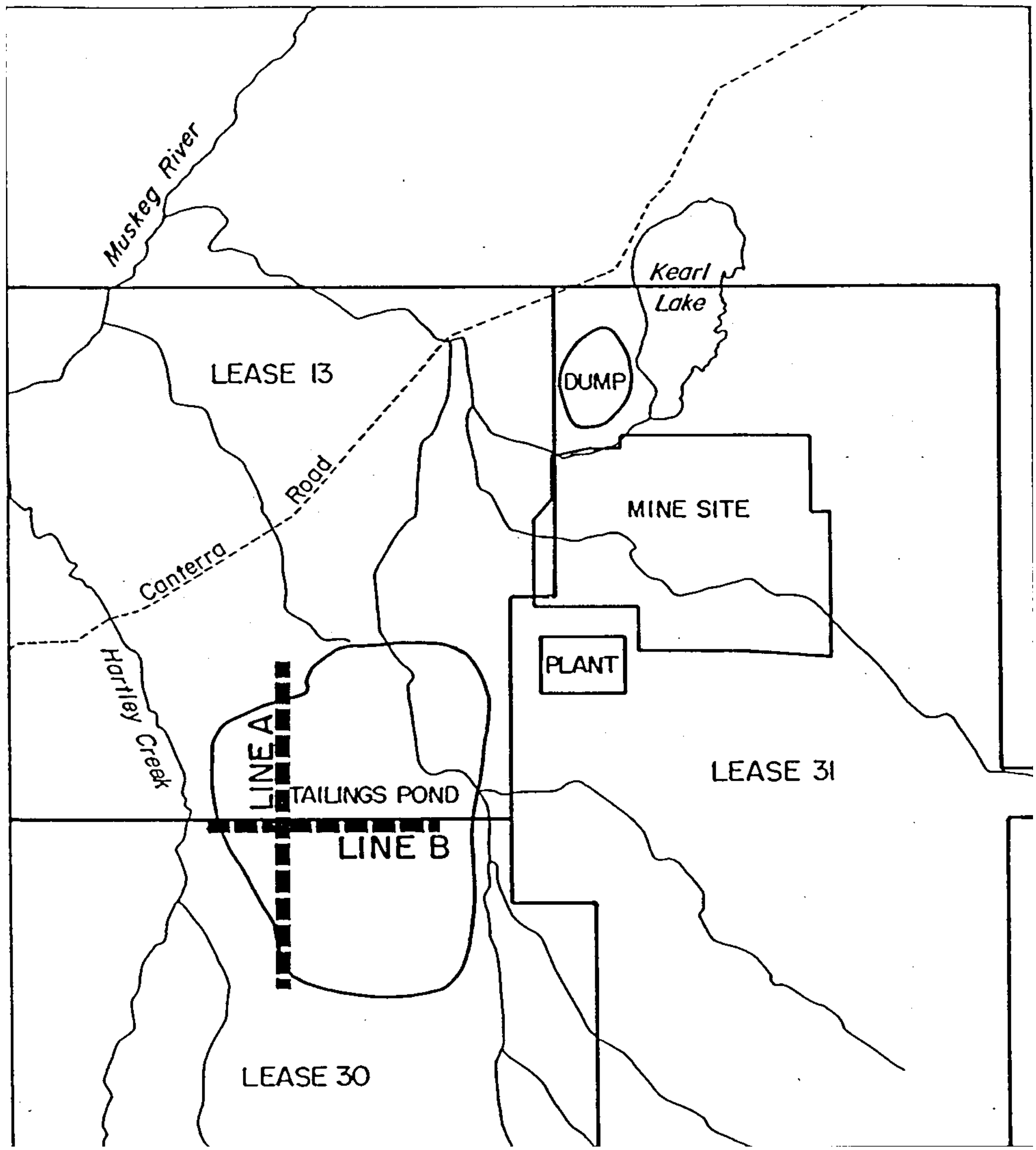

Figure 2 - Survey Line Location Map

Later interplay of transgressive and minor regressive cycles by a boreal sea flooding from the north formed an estuary in the drainage basin. Fluvial or continental marsh sedimentation prevailed in the upper reaches of the partially drowned valleys, while estuarine processes influenced by tidal currents formed the bulk of the sediments deposited within the lower part of the estuary. Lateral migration of tidal channels into marsh, tidal flat and older tidal channel deposits, account for the dynamic juxtaposition of depositional environments and the complex stratigraphy exhibited in the middle McMurray member. Towards the end of McMurray time a strong transgressive pulse flooded the estuary and sedimentation became more coastal and open marine in nature.

The McMurray Formation in the proposed mine area can be divided into three main environmental megafacies which are, in ascending order, continental, peritidal and marine. These groups are portrayed in a regional setting on a schematic cross-section enclosed as Figure 3. Facies within these three key environmental groups have been identified on the basis of grain size, texture, and sedimentary structures as well as through lateral and vertical facies relationships. The facies types and their inherent characteristics have a direct bearing on the oil saturation, fines content, geometry and quality of the orebody.

A major transgression of a boreal sea during Early Cretaceous (Albian) time is marked by the basal Wabiskaw Member of the Clearwater Formation and terminates the McMurray sedimentation. Where preserved, the Clearwater consists of the Wabiskaw Member and previously undifferentiated Clearwater silty clays and clays. Commonly these clays are of the low density swelling type. Indurated siltstone and ironstone lithologies also occur within the Clearwater Formation.

Lying unconformably above the Cretaceous sediments is the Pleistocene glacial and glacio-fluvial geological units. In the study area the Pleistocene consists predominantly of tills, sourced mainly from the McMurray oil sand Formation, the Grand Rapids Formation, and a small percentage derived from the Clearwater Formation. A number of localized glacio-fluvial sands and gravels from meltwater channels and a glacio-lacustrine silty clay unit are also present. All units are to some extent discontinuous or localized.

Pleistocene meltwater channels, although prominent as subsurface features, do not have any surficial expression and can be more accurately defined as buried valleys. Channel depths can exceed 60 metres and widths of one kilometre are not unusual. The paleo-valleys are typically filled with glacio-fluvial sands and gravels, and glacial tills. North-South trending valleys with intersecting tributaries occur within the study area.

Holocene and recent sediments consisting of water saturated organic "mineral" soil, muskeg,. peat, minor occurrences of Holocene lake bottom sediments, as well as fluvial and aeolian silts and sands complete the stratigraphic sequence.

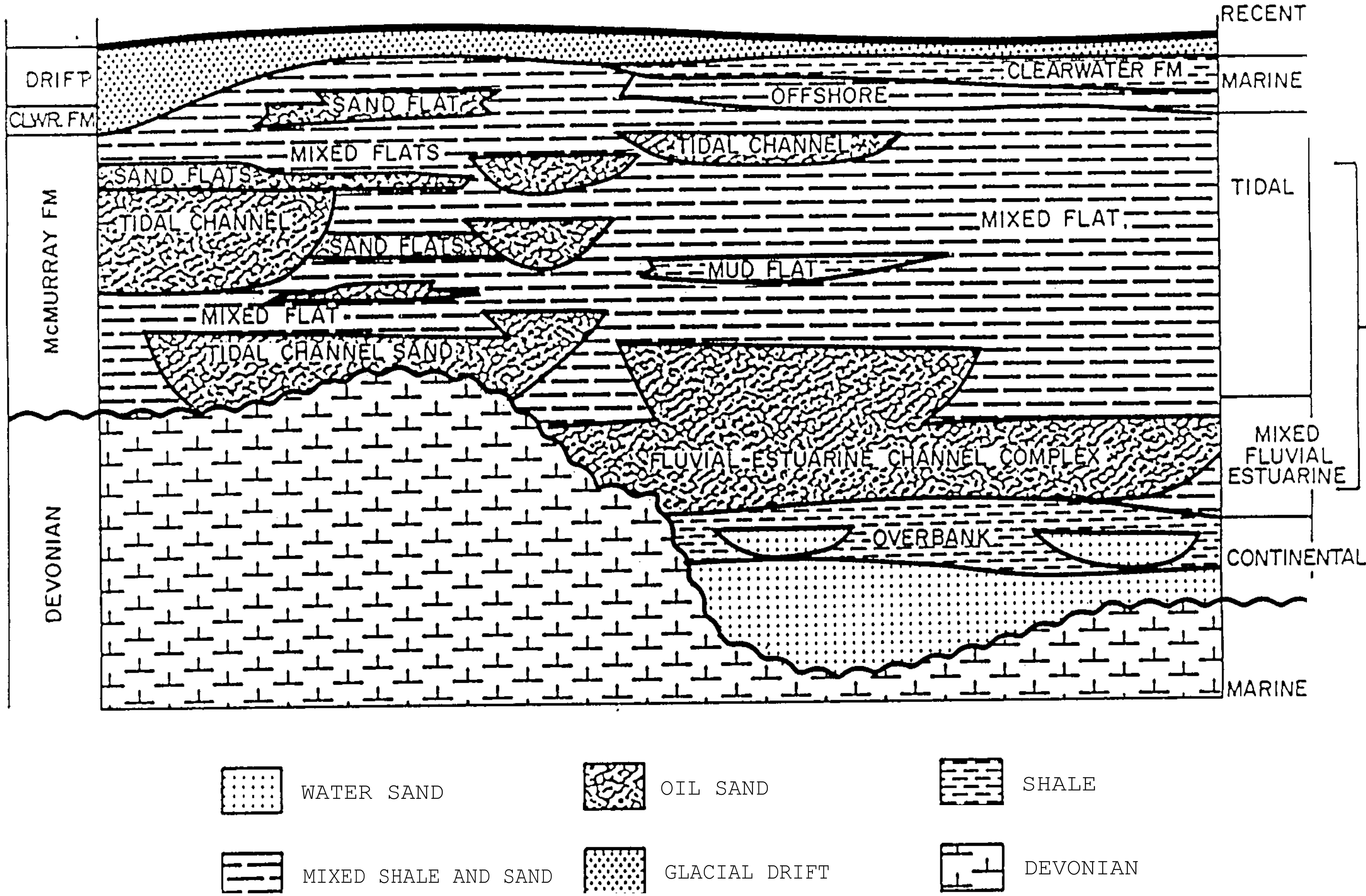

Figure 3 - Schematic Geologic Section

THE PROBLEM

From an oil sands mining prospective, geologists must map features having the potential to affect mining activities, such as ore thickness and grade, steeply dipping structures, thickening of the overburden top waste units, etc. For example, in terms of the underlying Devonian stratigraphy, a mining operation may require information on the Methy Formation, the presence or absence of salts in the Elk Point Group (Prairie Evaporite), the presence or absence of faulting and, if present, its timing and extent, and Devonian paleotopography. In the McMurray Formation, thickness and depositional structures, oil sand quality and the top McMurray paleotopography are of particular interest.

Features in the overburden such as the presence or absence of Clearwater shales, buried Pleistocene valleys, lacustrine clays, glacio-fluvial sands and gravels, and muskeg thickness are also of considerable interest.

No one geological or geophysical method can successfully distinguish and cost effectively map all of the above information. As Explorationists, we know the old "tried and true" method of drilling holes on an ever closer spacing to obtain the level of confidence we need in our interpretation; but drilling costs are high in the north.

The cost for an average core hole, complete with access clearing, analyses, description and including the fixed costs, is approximately $30,000 per hole. From a cost perspective, effective targeting of drill holes rather than high density drilling is a more desirable method. Also, as Explorationists we know that whatever method we choose, it must have adequate and constant verification with well designed drilling programs.

THE SOLUTION

Recent advances in technology have helped to control the upfront exploration and development data gathering costs. While geophysical methods have been present in the industry for some time, it is only in recent years that they have been applied to oil sands exploration and development. An important part of the successful application of geophysical techniques has been the integration of different geophysical techniques, as no one method will provide all of the answers required by the explorationist. By using a combination of high resolution reflection seismic and electrical geophysics to establish targets for core and auger drilling, most of the required information can be mapped and the results verified, thus maximizing the efficiency of the exploration budget.

DESCRIPTION OF GEOPHYSICAL METHODS

The use of ground based geophysical studies for surface mineable oil sand exploration has increased significantly over the last ten years. These studies have been characterized by the combined use of electrical and

refraction seismic techniques to satisfy interrelated and often complex mapping objectives (Isherwood et al, 1987 and Rozenburg et al, 1985). Preliminary studies by Sartorelli et al, 1986 have indicated that high resolution reflection seismic techniques are useful for surface mineable oil sand exploration.

Since 1982, surface electrical and refraction seismic surveys have been carried out on the OSLO Leases. A program, utilizing recent advances in the acquisition and processing of high resolution reflection data, was carried out during the winter of 1989. Table 1 shows the geophysical techniques used to date, and the corresponding survey objectives for the geophysical program on the OSLO Leases.

TABLE 1

Fixed frequency electromagnetic profiling	- type and thickness of overburden - depth to conductive Clearwater Formation - permafrost distribution
Transient electromagnetic soundings	- presence of Clearwater Formation - top of resistive McMurray Formation - basal zone - anomalous features within Devonian
Refraction seismic profiling	- depth to water table - depth to Devonian
Reflection seismic profiling	- deep Pleistocene channels - basal zone stratigraphy - depth to Devonian - Devonian stratigraphy

DATA ACQUISITION

In the planning of the reflection seismic survey, careful consideration was given to the source and geophone attributes, the source-receiver geometry and the type of recording instrumentation to ensure optimum results. A one day test was carried out at the beginning of the program using a variety of Shot hole depths and charge sizes to determine the best source parameters: In addition, consideration was given to the shallow electrical data which provided information on type and thickness of Pleistocene sediments. Table 2 shows the acquisition parameters which were used to carry out the survey.

TABLE 2 - Data Acquisition Parameters

Instrumentation	-	Geometrics ES2420, 96 channel
Sample Rate	-	0.25 millisecond
Record Length	-	1.0 second (4000 samples per trace)
Antialias Filter	-	720 hertz
Low Cut Filter	-	20 hertz
Notch Filter	-	out
Format	-	SEG-D
Geophones	-	OYO, 28 hertz
Geophone Array	-	No array, geophones clustered at stations
Geophone Station Interval	-	5 metres
Array Geometry	-	(240 metre - 5 metre - shot - 5 metre - 240 metre)
Shot Size explosive equivalent	-	primacord @ 12.5 or 25 gram
Shot Hole Depth	-	5 or 8 metres
Shop Point Interval	-	20 metres
Fold Coverage	-	12

All refraction seismic data were recorded with a Geometrics, 12 channel signal enhancement seismograph. Each spread consisted of 12 geophones placed at 50 metre intervals with overlapping end shots providing continuous ground coverage. One kilogram sticks of Forcite (40%) were used to generate energy at six shot locations along each spread.

Fixed frequency EM measurements were made using Geonics EM31 and EM34-3 conductivity meters. Six effective depths of exploration were probed by varying the mode of instrument operation, as shown below.

Instrument		Effective Depth Of Exploration	Station Interval
EM31(VG)	- vertical loop mode at ground level	2.0 m	25 m
EM31(HZ)	- horizontal loop mode at hip level	4.0 m	25 m
EM31(HG)	- horizontal loop mode at ground level	5.0 m	25 m
EM34(20V)	- vertical loop mode 20 m loop separation	11.5 m	50 m
EM34(40V)	- vertical loop mode 40 m loop separation	23.0 m	50 m
EM34(40H)	- horizontal loop mode 40 m loop separation	50.0 m	50 m

Transient electromagnetic soundings, using the Geonics EM37 system, were conducted at intervals of 200 metres along the survey lines. A transmitter loop size of 60 x 60 metres was utilized to meet the exploration depth objective of about 150 metres.

OSLO CASE STUDY

Since oil sand mines, plant facilities and tailings pond structures are generally unforgiving in the design, accuracy and completeness of data is a must. Verification of the interpreted subsurface geology by core and auger drilling is a given. Geophysics is used to target drill hole locations and aid in the interpolation of the subsurface geology between drill holes. Costly drilling is augmented by less expensive geophysical data to provide a more complete picture of the subsurface.

In the shallow surface mineable oil sand areas, the use of reflection seismic methods is in its infancy. Geologists working in these areas have not, until recently, had the benefit of reflection seismic data to assist in interpretations and selection of drilling targets. For the most part, they have had to rely on the more conventional drilling. Geological sections were compiled based on a straight line interpolation of boundaries between drill holes, which can be shown is not always the case. From a technical perspective, geophysics has the benefit of continuous data along specific lines. When calibrated with drill hole data, geophysics adds a whole new dimension to geological interpretation.

To effectively accomplish the merging of geophysical and geological data, a team of geologists and geophysicists was assembled. This resulted in the preparation of cross-sections which incorporated both the geological and geophysical data. Inconsistencies and interpretation problems were dealt with and resolved by team members.

To illustrate the effectiveness of surface geophysical methods portions of two lines are presented. The location of these lines in relation to the proposed tailings pond site is shown in Figure 2.

Line Al

The geological section for Line Al, compiled prior to the 1989 exploration program is shown in Figure 4. Figure 4 shows the paleotopography of the Devonian surface to be gently undulating, and the facies within the McMurray Formation appear fairly continuous and relatively flat lying. The reflection seismic section for Line Al presented in Figure 5, indicates significant additional structural features on this line. The geological section based on all drilling and geophysical data presented in Figure 6, indicates a major Devonian high between station 950 and 1500. It also appears that the continental sediments of the McMurray are absent above the Devonian high. There is evidence in the reflection seismic profile to suggest that there may be normal faulting associated with the Devonian high. There is no evidence however that this faulting has affected the upper Cretaceous sediments.

In the vicinity of stations 200 and 600, there appears to be evidence of collapse structures. At station 600, there is no expression of the

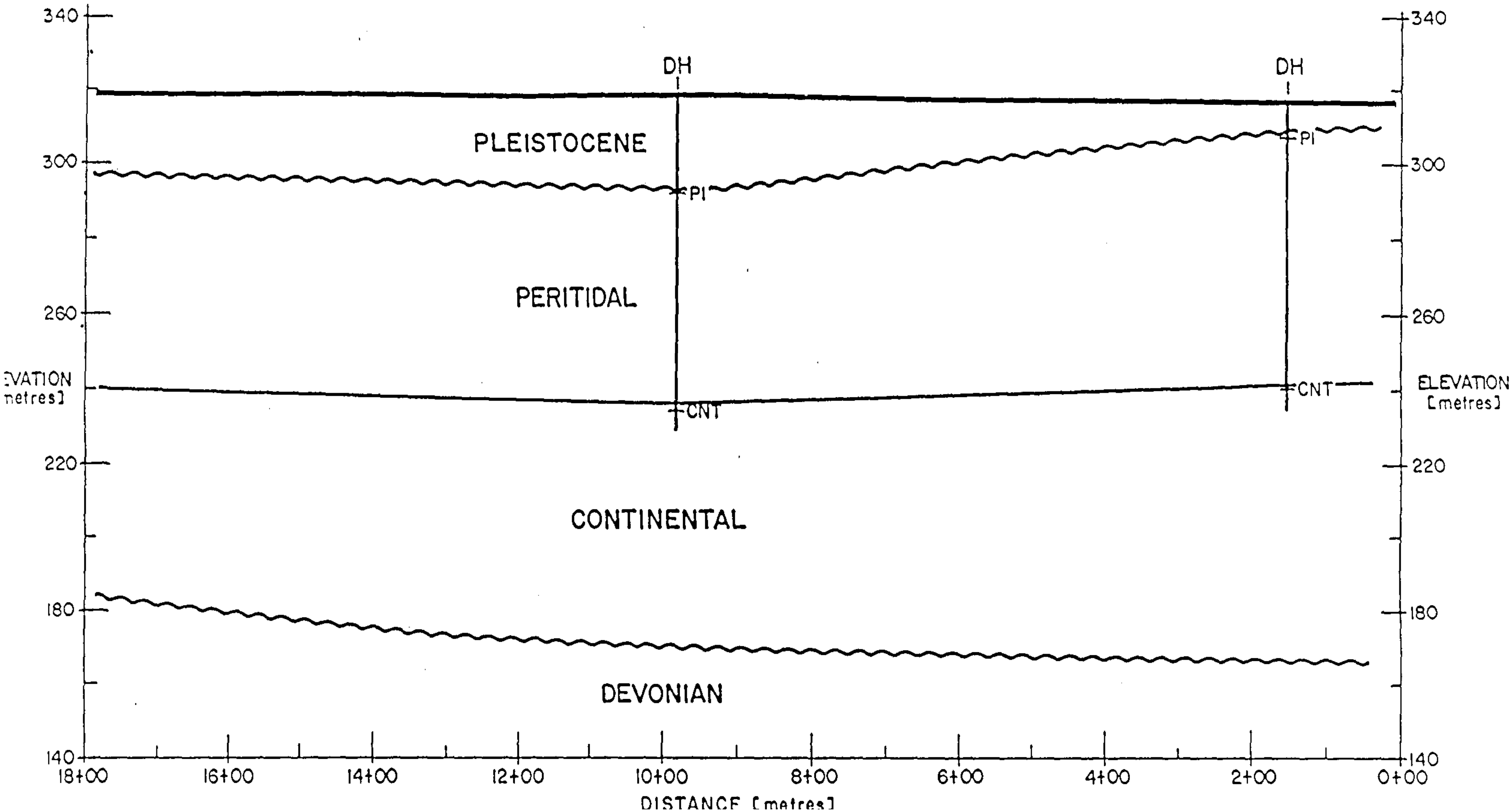

Figure 4 - Geologic Section (Pre 1989) - Line Al

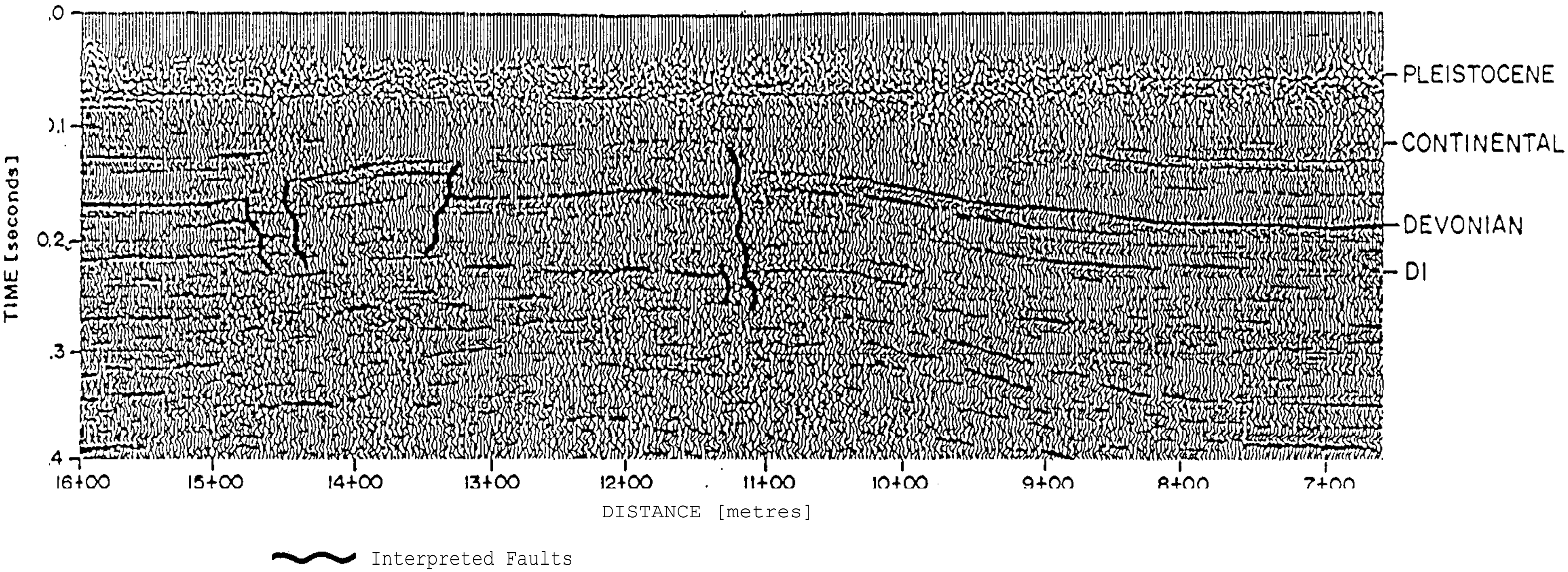

Figure 5 - Seismic Section - Line A1

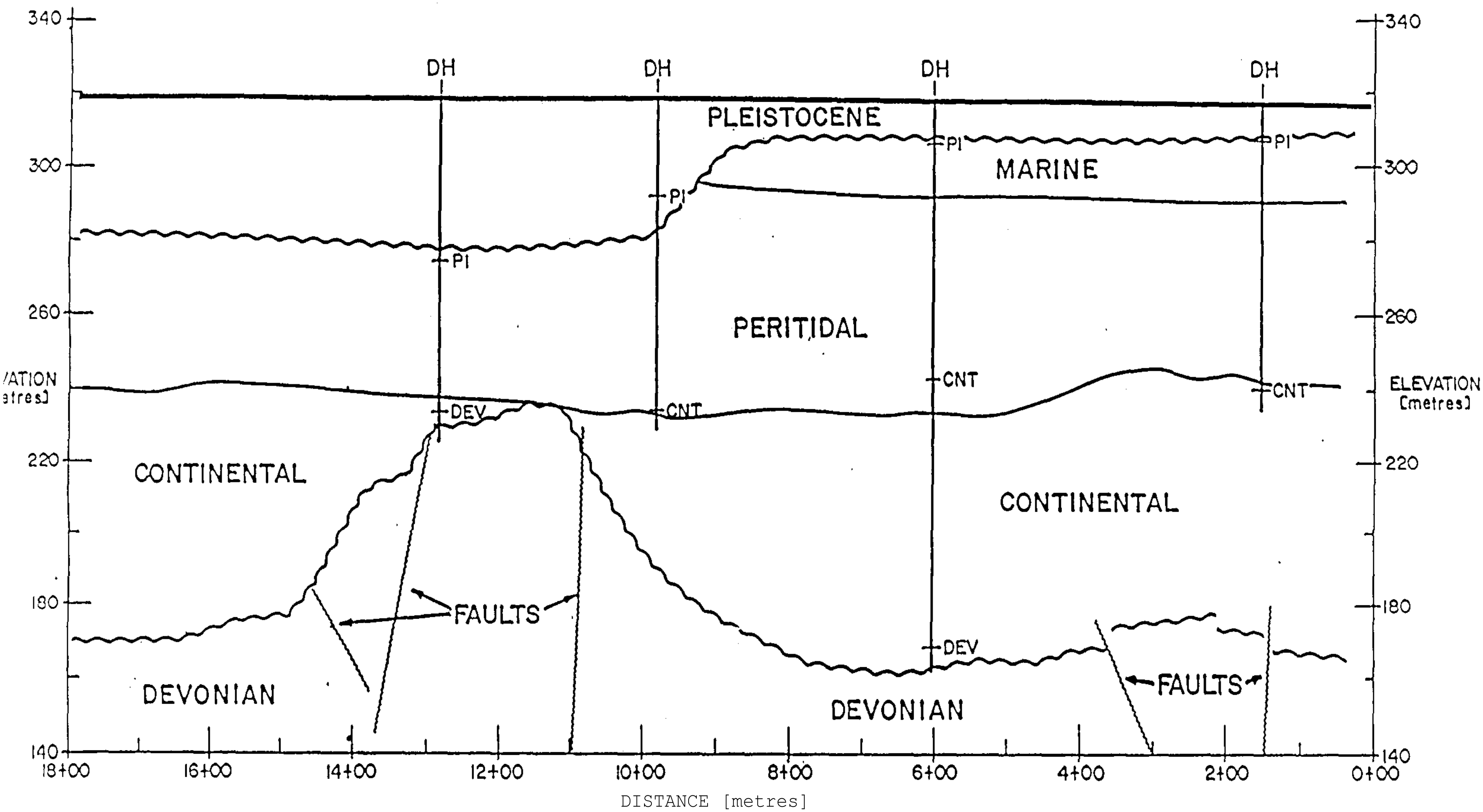

Figure 6 - Geologic Section (1989) - Line Al

collapse structure above the Devonian reflector. A sagging of the sediments up to the top of the continental sediments exists above the possible collapse structures at station 200 suggesting a lack of activity on the structure since Early Cretaceous (120 my) time.

Other boundaries which have been mapped using geophysical methods include the top of Cretaceous, rich versus lean oil sands in the peritidal sediments and stratigraphy within the continental sediments. A drill hole was located on the Devonian high during the 1989 exploration program confirming the geophysical interpretation. The combination of drilling and surface geophysics has enabled the explorationist to better target drilling locations and better interpolate between drill holes.

Line A2

Line A2 is an extension of Line A1 (Figure 2). The geological section compiled prior to the 1989 exploration program for Line A2 is shown in Figure 7. The geologic section shows a flat lying Devonian. The Cretaceous sediments are also flat lying. A Pleistocene channel is located to the east of station 3000.

The reflection seismic section for Line A2 is presented in Figure 8. The section confirms the initial geologic section indicating a relatively homogenous section. The geologic section incorporating all of the drilling and geophysical data is presented in Figure 9. There is virtually no major differences between this section and the initial geologic section.

Line B

The pre-1989 geologic section for Line B is shown in Figure 10. The Devonian surface shows a gradual decrease in elevation from east to west along the line. The Pleistocene sediments are thinnest in the central portion of the line and show a slight thickening to the west and east along the line.

The reflection seismic section for Line B is shown in Figure 11. The section shows that there is a major Devonian high along the central portion of the line which may be associated with normal faulting. The interpreted geophysical data indicates that to the east of the Devonian high, the elevation of the Devonian surface is approximately 15 to 20 metres higher than to the west of the high. It should be noted that the thickness of the Devonian sediments above a relatively continuous reflector within the Devonian remains constant to both the east and west of the Devonian high.

The continental sediments are present over the entire line length. Very steep dips are associated with the continental sediments on the west flank of the Devonian high.

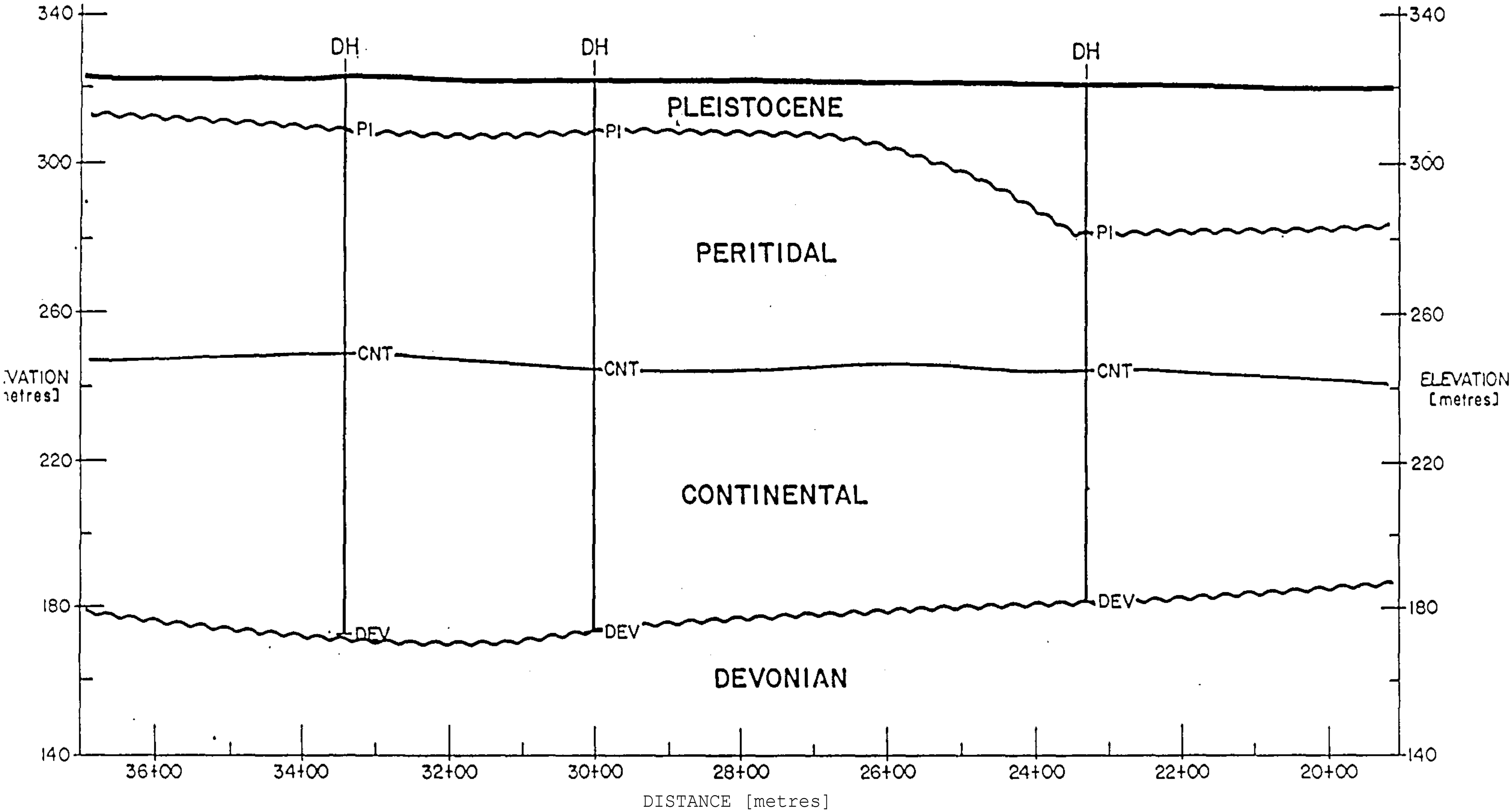

Figure 7 - Geologic Section (Pre 1989) - Line A2

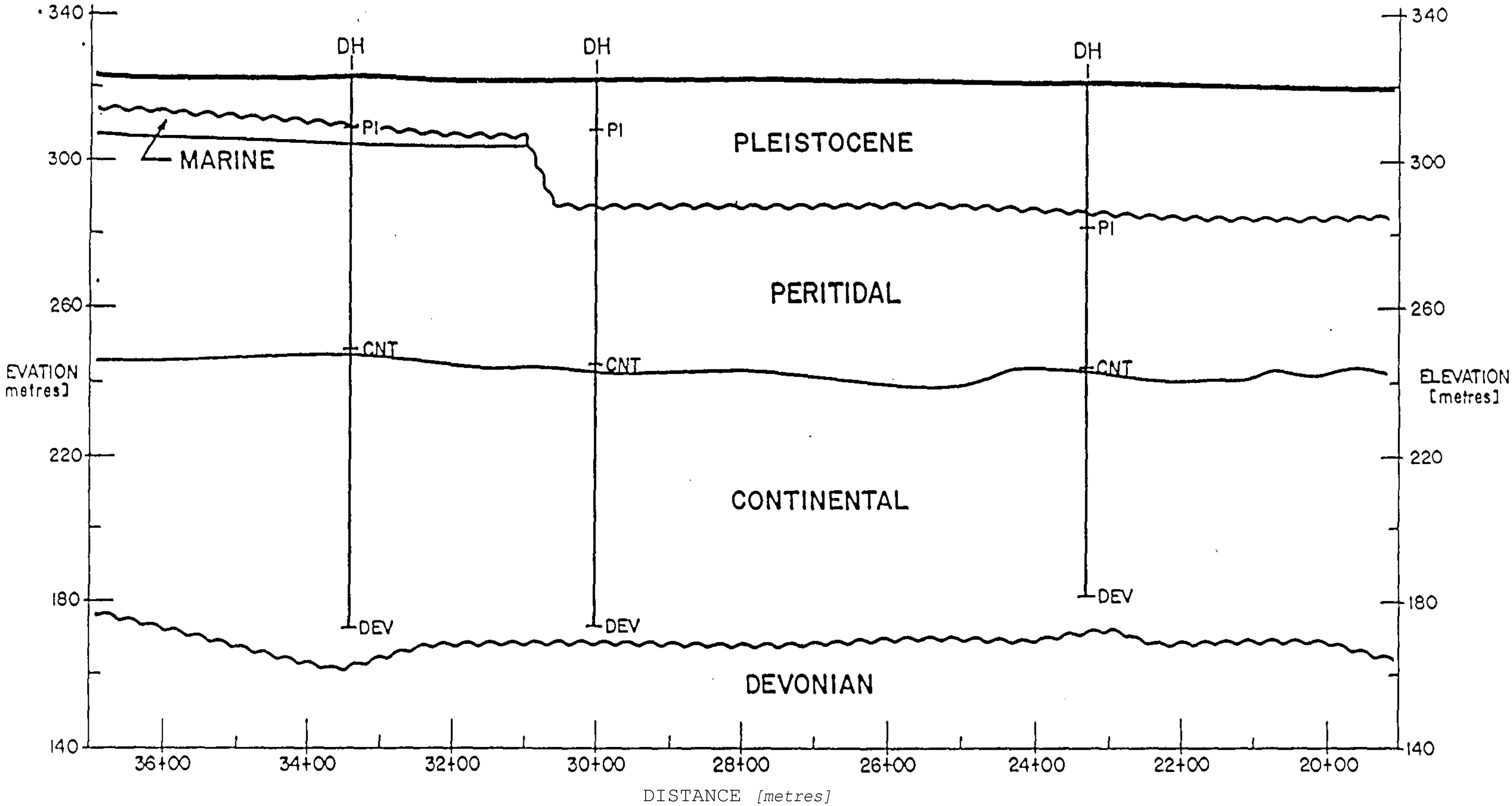

Figure 9 - Geologic Section (1989) - Line A2

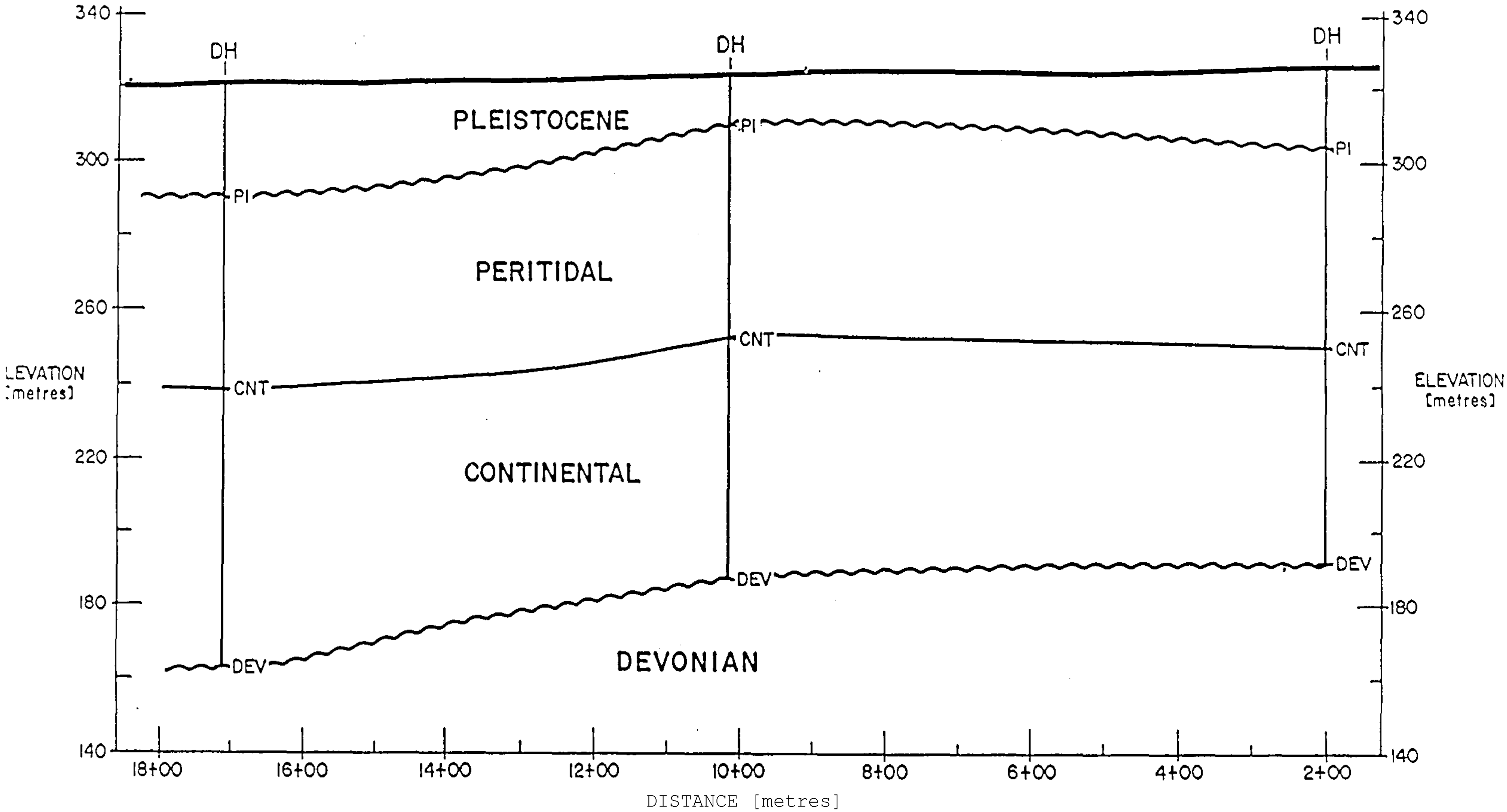

Figure 10 - Geologic Section (Pre 1989) - Line B

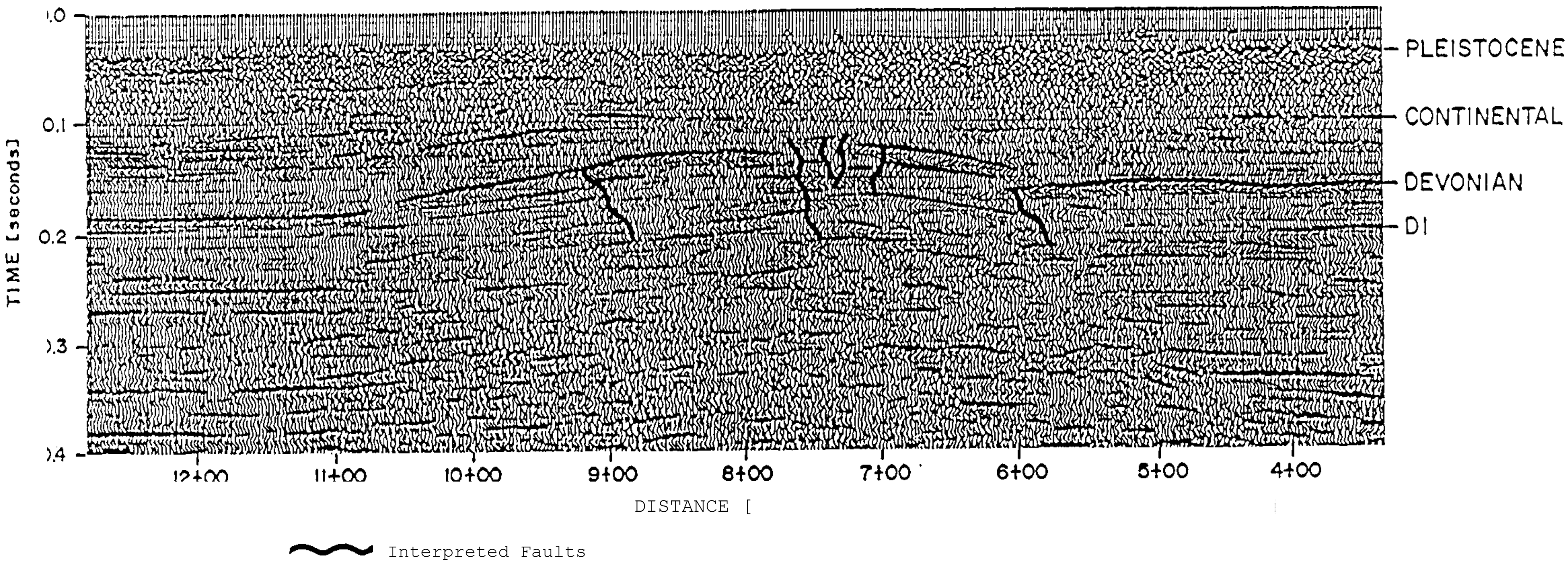

Figure 11 - Seismic Section - Line B

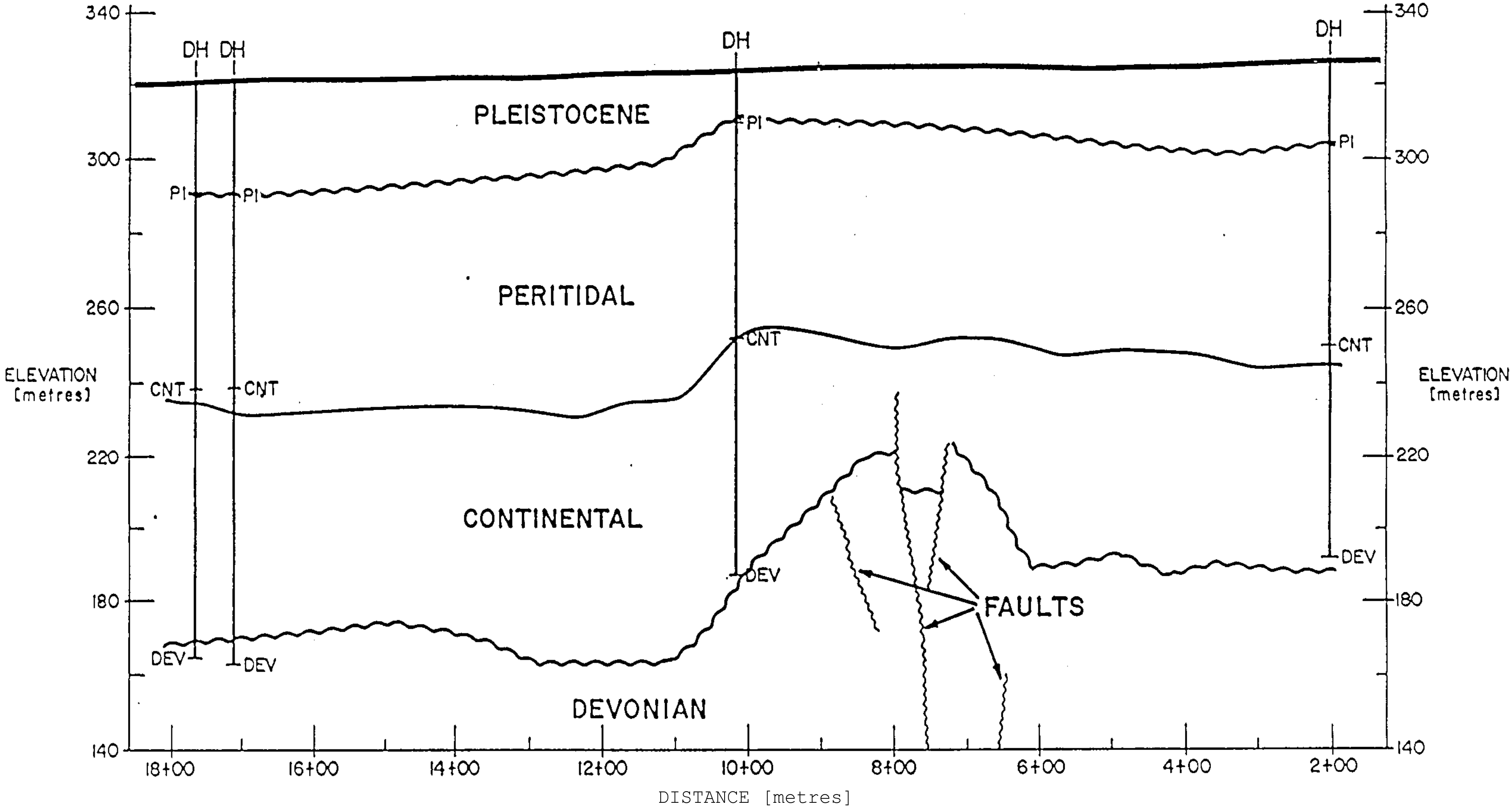

Figure 12 - Geologic Section (1989) - Line B

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