TOUR OF THE HIGHVALE
OPEN PIT COAL MINE
JUNE 2, 1985
CIM-CSPG CONFERENCE

FIELD TRIP GUIDEBOOK NO. 1

THE PETROLEUM SOCIETY OF CIM AND
CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS
JOINT CONFERENCE
EDMONTON, ALBERTA 1985

Prepared by:
M.M. Fenton, C.W. Langenberg, C.E. Jones, M.R. Trudell,
J.G. Pawlowicz[1], J.A. Tapics and D.J. Nikols[2]

Open File Report 1985-7

---

[1]Alberta Research Council, 4445 Calgary Trail South,
Edmonton, Alberta, T6H 5R7

[2]TransAlta Utilities Limited, 110-12th Avenue, Calgary, Alberta, T2P 2M1

TABLE OF CONTENTS

LIST OF FIGURES

List of Figures (continued)

TABLE

ACKNOWLEDGMENTS

The authors wish to thank TransAlta Utilities Limited and particularly Harry Laleune, John Tapics and Dennis Nikols both for assistance during the field trip and permission to use data collected at the mine.

The background geology information used in the first part of this guidebook comes from a highwall stability study undertaken by the Terrain Sciences and Alberta Geological Survey Departments of the Alberta Research Council with joint funding by TransAlta Utilities Limited and ARC. The information on reclamation comes from research carried out by the Terrain Sciences Department under the sponsorship of the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with funding derived from the Alberta Heritage Trust Fund and the Alberta Research Council.

The authors thank K. Gates and M. Tatchyn for typing of the report, C. Day for preparing some of the illustrations and S. Moran for editing the manuscript. E. Wijnen and G. Felix of the University of Amsterdam are thanked for making measurements on glaciotectonic structural elements available to W. Langenberg.

INTRODUCTION

The Highvale Mine is situated about 80 km west of the City of Edmonton (figure 1) near the south shore of Lake Wabamun. Access is westward from Edmonton on Highway 16, and southward via a provincial road just east of Lake Wabamun. The route is paved except for a gravelled portion through the Paul Band Indian Reserve. Geologic investigations were conducted in three areas: Pits 02, 03 and 04 (figure 2).

The Highvale Open Pit Coal Mine, which is owned by TransAlta Utilities Limited and operated by Manalta Coal Limited, was initially opened to supply thermal coal to the Sundance Generating station. Current production is from three pits and supplies both Sundance and the nearby Keephills generating stations.

The bedrock overburden in many places in the Plains of western Canada has been thrust by Pleistocene glaciers (Moran et al, 1980, Fenton 1983a, and Fenton and Andriashek 1978). Regional surficial mapping of the Wabamun map sheet (Andriashek et al, 1979) revealed much of the bedrock in the Lake Isle-Lake Wabamun-Saskatchewan River area had been glacially disturbed and deformed. This deformed bedrock material is weaker than the undeformed bedrock. As a result, highwalls cut into this sediment have greater tendency to fail than those cut into undisturbed bedrock.

Many of the highwall failures in Pits 02, 03 and 04 are likely related to the glacially thrust bedrock material. The implications of highwall failure are serious since temporary benches excavated in the highwall serve as transportation corridors and a working foundation for overburden stripping equipment. In addition to the risks posed to men and equipment such failures also result in potentially sizable additional costs resulting from the rehandling of overburden materials, disruption of mining schedules and outright loss of potentially mineable coal.

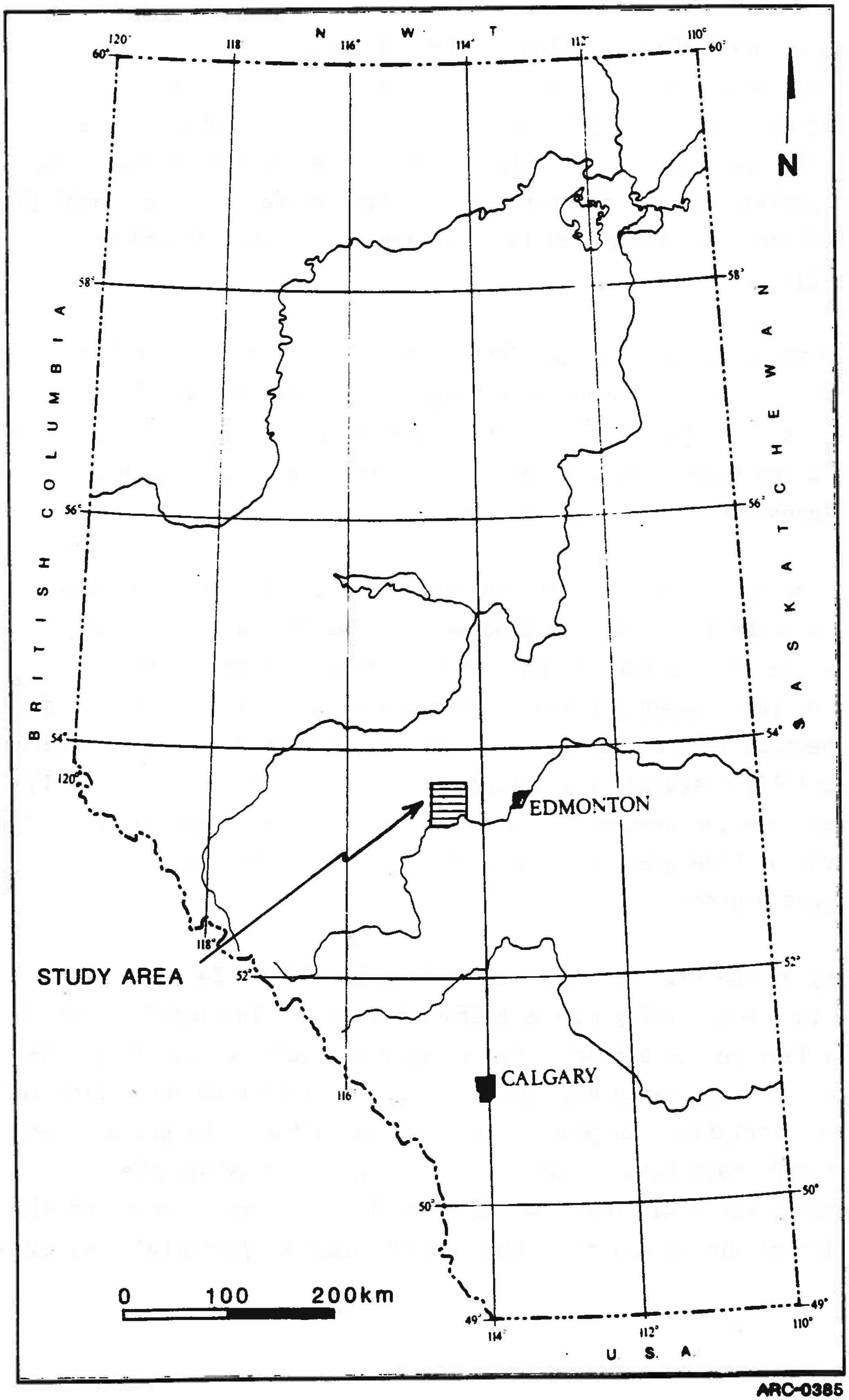

Figure 1. Location of study area.

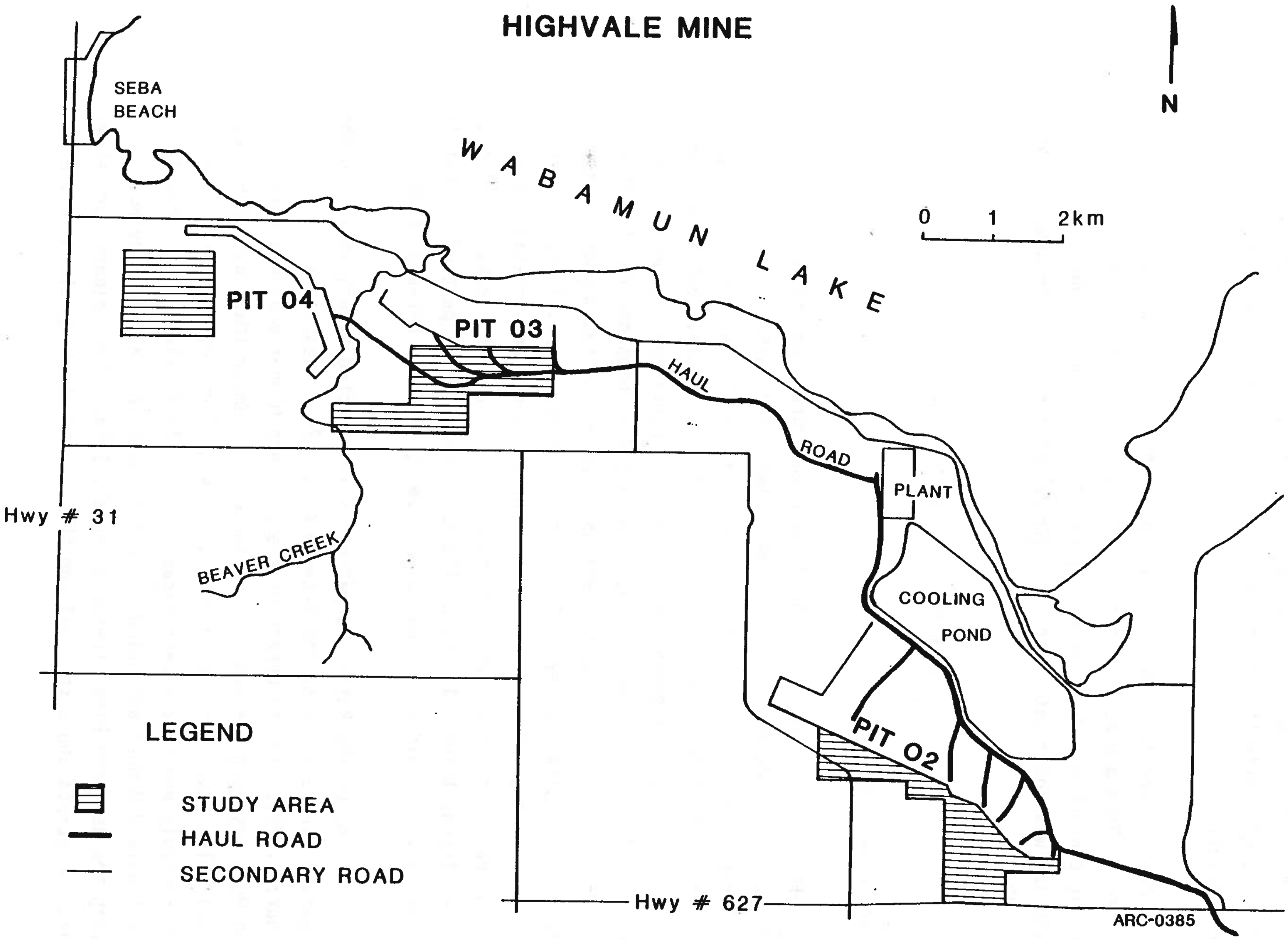

Figure 2. Highvale Mine showing the three study areas.

Foreknowledge of the location, structure, dimensions and hydrology of these glacially thrust masses is of value in mine planning management.

Preliminary investigations at the Highvale Mine in 1983 (Fenton, 1983b and Fenton et al, 1983) had indicated that glacially thrust bedrock material was widespread and that the presence of this material was contributing to the highwall failure near the east end of Pit 03.

GENERAL GEOLOGIC SETTING

Bedrock Geology

The bedrock geology of the Wabamun Lake area consists of Upper Cretaceous and Paleocene non-marine coal-bearing rocks (figures 3 and 4). The coal being mined at the Highvale Mine belongs to the Ardley Coal Zone (Holter et al, 1975). The Ardley Coal Zone forms part of the Scollard Member of the Paskapoo Formation, as defined by Irish (1970) and Carrigy (1970). Gibson (1977) proposed to elevate the Scollard Member to Scollard Formation, a usage not recommended by the Alberta Geological Survey (J.R. Nurkowski, pers. comm., 1984). The Battle Formation which is situated below the Paskapoo Formation is a mauve-gray weathering, dark brownish gray to purplish black, bentonitic shale (Irish, 1970). The Keephills Tuff, which forms part of the Battle Formation, is a widespread marker horizon (Irish and Harvard, 1968).

The top of the Battle Formation is intersected by drillholes in the Highvale Mine area at depths between 45 and 75 m (Maslowski Schutze 1984). The thickness of the Scollard Member measures between 23 and 28 m assuming the coal at the top of the member (Maslowski Schutze, 1984). The exact position of the Cretaceous-Tertiary boundary has not been established in the Lake Wabamun area. It is likely somewhere in the Scollard Member and below the Ardley Coal Zone as shown by work along the Red Deer River (Lerbekmo et al, 1979). Preliminary work shows that the strata above the coal and the coal at the Highvale Mine are of

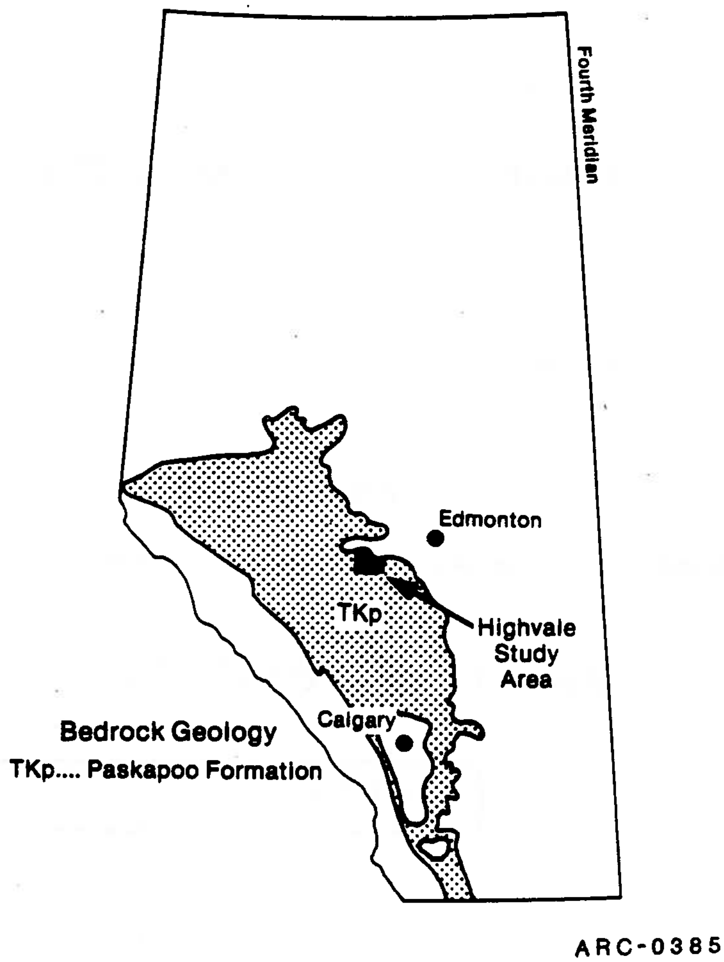

Figure 3. Bedrock geology map of region (after Green, 1972).

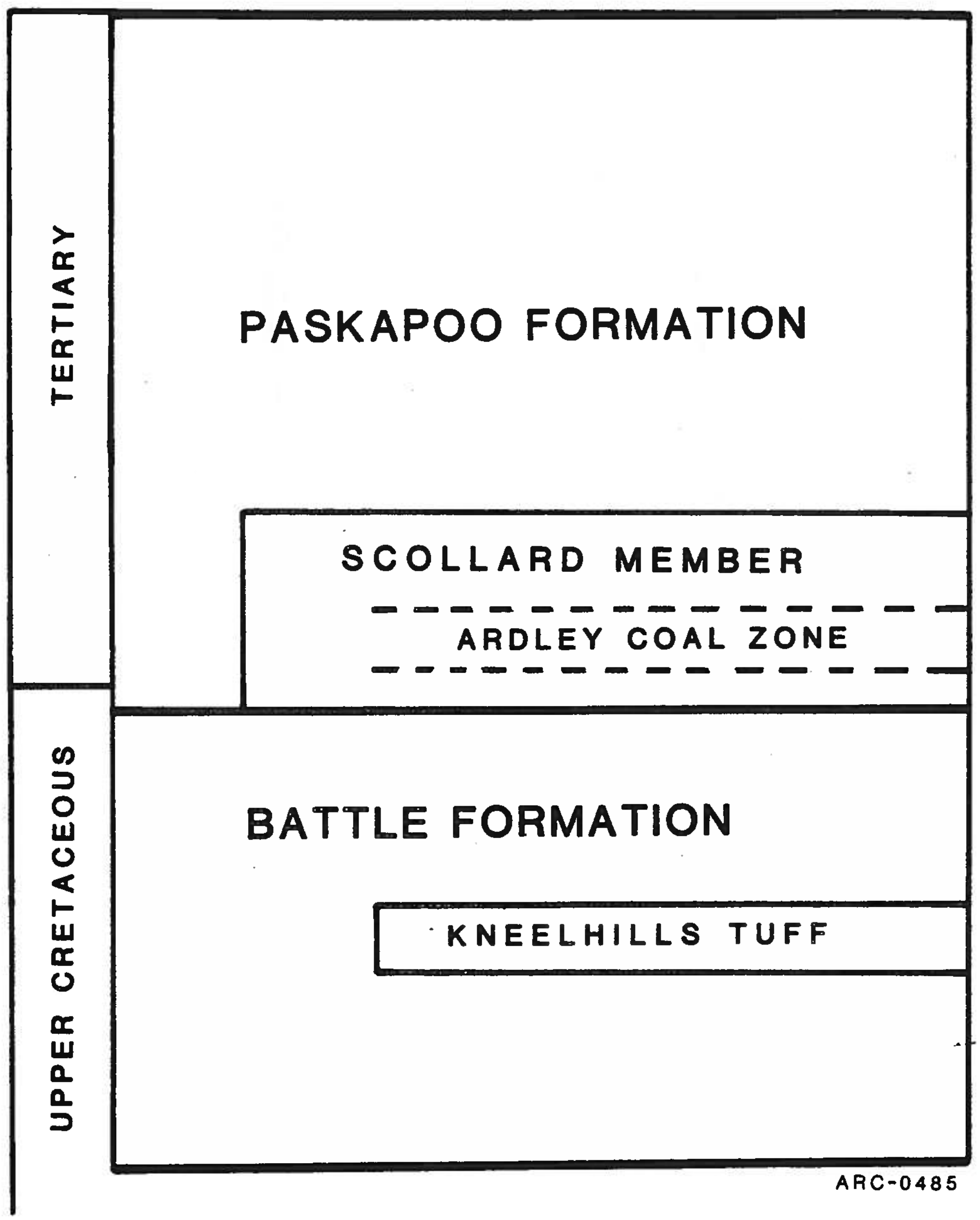

Figure 4. Bedrock stratigraphy, Highvale Mine.

lower Paleocene age based upon the Angiosperm pollen Tricolpites angululuminosus and Tricolpites bathreticulatus (Singh, pers. comm., 1984). This coal was designated as Lower Ardley 'B' by Holter and others (1975) and could be correlated with seam 14 of Gibson (1977).

The Ardley Coal Zone is about 15 m thick in the study area. Six distinct and laterally continuous seams can be distinguished. They are separated by shale and bentonite partings with a cumulative thickness of about 5 m, leaving a cumulative thickness of coal of about 10 m. The coal dips between 4 and 10 m per kilometre to the southwest.

Surficial and Glaciotectonic Geology

The surficial deposits overlying the bedrock include extensive areas of glacially deformed bedrock material, as much as 50 m thick in places (Fenton, 1983b and Fenton et al, 1983) overlain by a comparatively thin discontinuous cover of till, glaciolacustrine clay and glaciofluvial silt, sand and gravel (Andriashek et al, 1979, Fenton and others op. cit.). Some areas mapped as lacustrine clay are now known to be glacially crushed and fragmented mudstone and shale.

Fenton (1983b) prepared a glaciotectonic map of the mine that showed extensive areas of glacially thrust sediment.

Data Sources

Geologic data have been collected through outcrop study, air photo interpretation, surface geophysical methods, rotary coring, hollow stem auger coring to obtain oriented A-casing and downhole geophysical logging. A number of piezometer nests have also been set.

POWER PLANT AND MINING OPERATIONS

The province of Alberta contains 80 percent of Canada's known coal reserves. Of these reserves a large percentage of the coal can be easily recovered as it is close to the surface and can be surface mined in the conventional fashion. The area in the vicinity of Wabamun Lake hosts two coal mines that supply low sulfur sub-bituminous coal to three "mine-mouth" power plants (figure 5). The Whitewood and Highvale Mines produced 11.6 million tonnes of coal in 1983. The Whitewood Mine supplies coal to the Wabamun Power Plant which began production in 1956 as a gas fired plant and was later converted to coal. The Highvale Mine is Canada's largest coal mine; the coal production has increased from 1.1 million tonnes in 1970 to 9.6 million tonnes in 1983 (figure 6). Coal production from the Highvale Mine 1983 coal production represented 24 percent of total Canadian coal production in 1983. Coal production peaked at 11.4 million tonnes in 1984 production and is expected to maintain that level. Highvale Mine supplies coal to the Sundance and Keephills Power Plants. At currently planned production levels the coal reserves will be depleted in 54 years (from 1983) (Tapics, 1984) (figure 6).

Table 1. Wabamun Lake power stations

Power Plant	Supply Mine	Year Opened	Number of Units in Operation (1983)	Total Power Output (1983)
Wabamun	Whitewood	1956*	4	569.0 MW
Sundance	Highvale	1970	6	1987.0 MW
Keephills	Highvale	1983	1**	377 MW

* Originally gas fired converted to coal 1964.
** A second unit came onstream in 1984.

The Sundance Power Plant is the largest electrical generating station in Western Canada with a net capacity of 1987 MW. The two generating units at the Keephills Plant came onstream in 1983 and 1984. The coal being used to fire the three power plants near Wabamun Lake is of such a grade that it would not be economically feasible to transport the coal more than 10 km; thus the "mine-mouth" power plants utilize a resource that may otherwise have been overlooked.

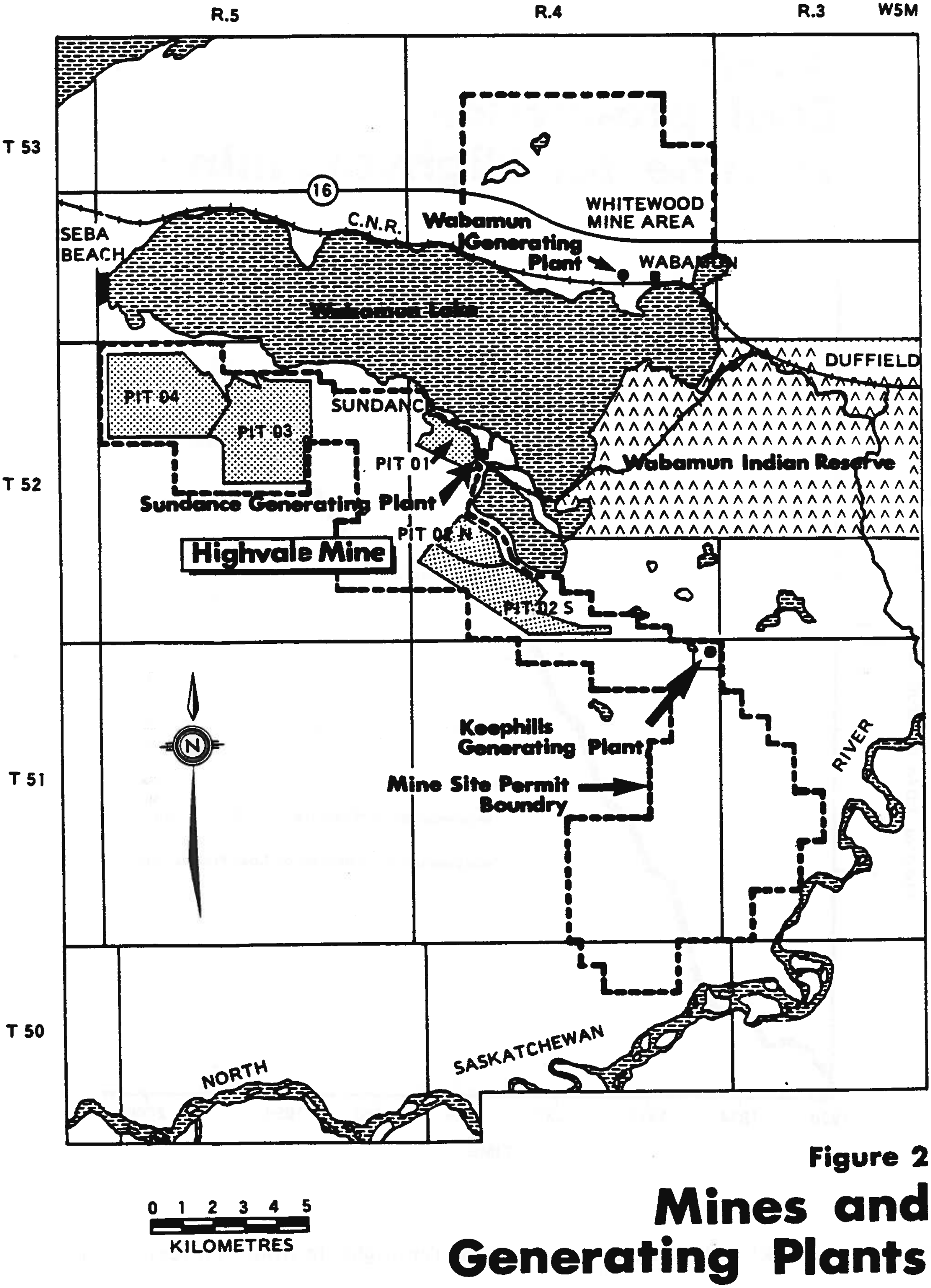

Figure 5. Mines and generating plants (Tapics, 1984)

Annual Coal production vs time for Highvale mine

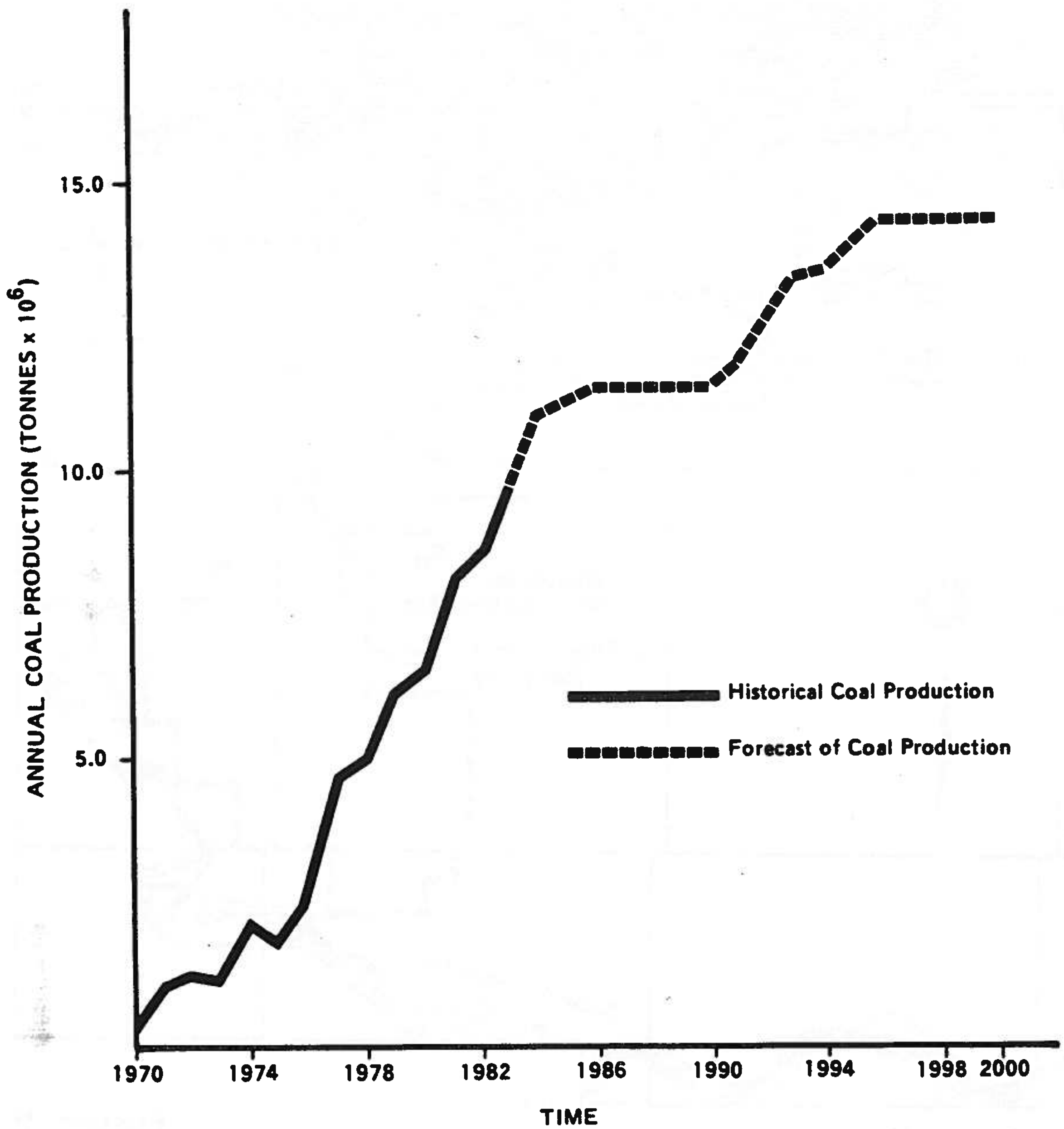

Figure 6. Annual coal production v.s. time for Highvale Mine (Tapics, 1984).

Mining Operations

The Highvale Mine consists of three active dragline pits that utilize three walking draglines varying in bucket size from 38.2 to 68.8 m^3. The newest and largest dragline has one of the two longest booms in operation in the world today. Major mining equipment includes five cable shovels, one front-end loader, sixteen bottom-dump coal haulers and four rear-dump ash haulers.

The mining process at the Highvale Mine begins with large scrapers that salvage and stockpile the topsoil and subsoil for later use in reclamation. The remainder of the overburden material above the coal seams is removed by the walking draglines and put into spoil piles adjacent the pit. Electric shovels and front-end loaders load the exposed coal onto bottom-dump coal haulers. Presently only seams one and two require blasting prior to loading; the remainder only require ripping prior to loading. The partings between the coal seams are removed utilizing scrapers, shovels, loaders and rear-dump trucks (figure 7). The partings are buried in the pit after mining has been completed. The coal is hauled by truck a maximum of 10 km to the plants where the coal is stockpiled near a conveyor system.

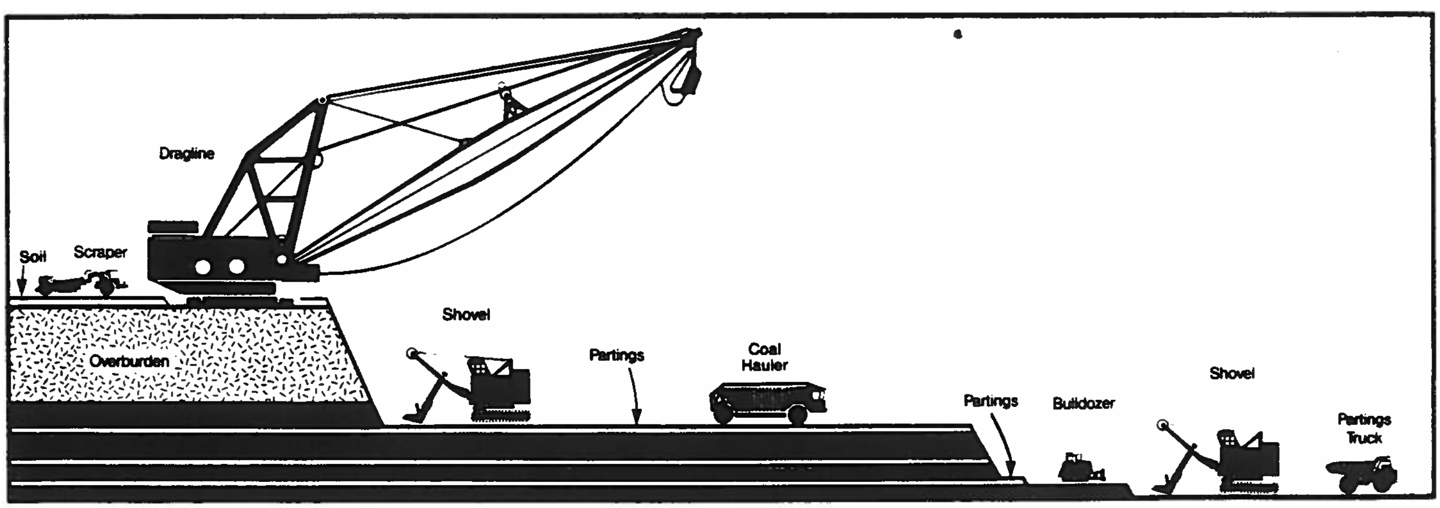

Figure 7. Production in a typical surface mine (Anon, 1984).

The gravity fed conveyor system moves the coal to the bunker. From the bunker the pulverizers crush the coal to a fine powder that is blown by huge fans into the combustion chamber of the boiler. The coal is ignited and the heat transforms water to superheated steam that turns the turbine shaft, which is attached to the electrical generator.

Environmental Factors

The coal in Alberta has a very low (approximately 0.2 percent) sulfur content, thus the problem of acid rain prominent in Eastern Canada is not nearly as large an issue in Western Canada. Historically there has not been a sulfuric acid problem around Wabamun Lake but to insure immediate detection if these conditions should change there are a number of monitoring stations around the plant sites.

Fly ash can be an environmental problem. Therefore the power plants at Wabamun Lake are equipped with an electrostatic precipitator that removes more than 99 percent of particulates or fly ash. The fly ash is disposed of in a variety of ways:

1) Fly ash is sold for use as a partial cement replacement in concrete.

2) Fly ash from Sundance Plant is hauled back to the mine and buried in the open pits.

3) Keephills Plant has a closed ash system that carries ash via water to lagoons where the ash settles and the water is re-used.

The Highvale Mine has changed drastically as the coal production has increased. The changes in mine operation will become more evident as increased stripping ratios, haul distances and reclamation standards require alternative methods of material handling (Tapics, 1984). A number of overburden removal alternatives have been examined so that after 1988 the mining process will change to allow for additional overburden stripping capacity (Tapics, 1984).

PIT 03

Geology

This section presents some of the results of the 1984 investigations carried out for TransAtla Utilities under a cost shared agreement between the Alberta Research Council and TransAlta.

The following text focuses on the portion of Pit 03 in the vicinity of ramps 3-1 and 3-2 (figure 8).

The general stratigraphy in the area of Pit 03 consists of till, overlying a thick sandstone sequence, overlying a thinner mudstone sequence which, in turn, overlies a coal unit consisting of six coal seams. A mass of thrust bedrock material overlies the till in the western two-thirds of the area (figure 9). A more detailed description of the stratigraphy exposed in the highwall can be found under the following section discussing the stratigraphy of the failure site.

Geologic studies reveal the area to be deformed. The schematic cross-section (figure 10) shows the general structural setting near ramp 3-1. The bedrock sequence has been folded and faulted by compression and thrusting directed generally toward the south. Large scale folds and faults have been exposed in the east face of the pit and the small pit southeast of ramp 3-1 and small scale deformation features are common (Fenton et al. 1983 and Nikols, 1985).

The base of the disturbance is a shear plane. This plane has been observed to rise stratigraphically southward from a position that involves deformation of seams 1 and 2, approximately 600 m north of the haul road, to a position immediately above seam 1, about 400 m north of the haul road and further southward to a position a few metres above seam 1 near the haul road. The shear plane is believed to die out at some point south of the haul road. Where the shear plane immediately

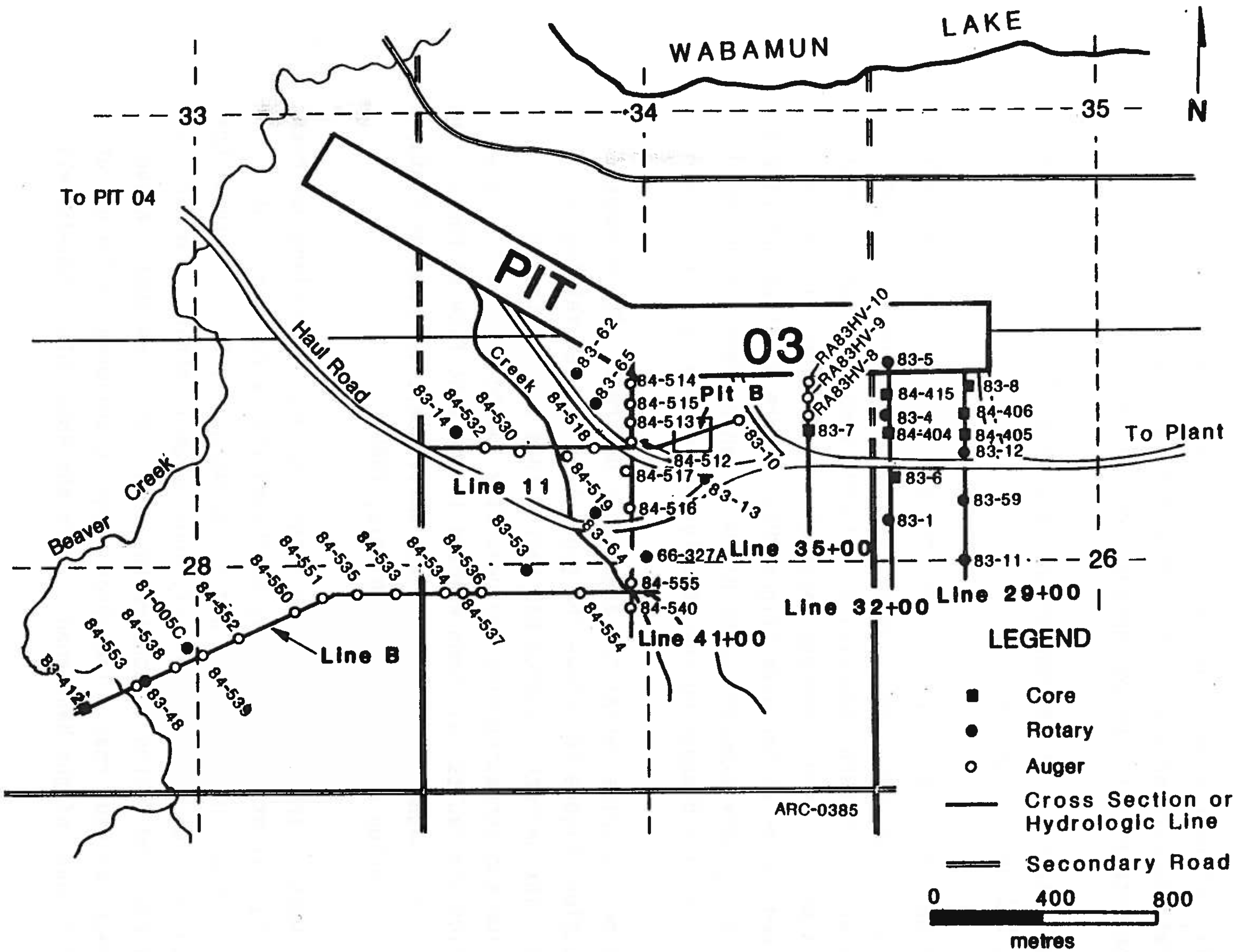

Figure 8. Location of boreholes and cross-sections, Pit 03, Highvale Mine.

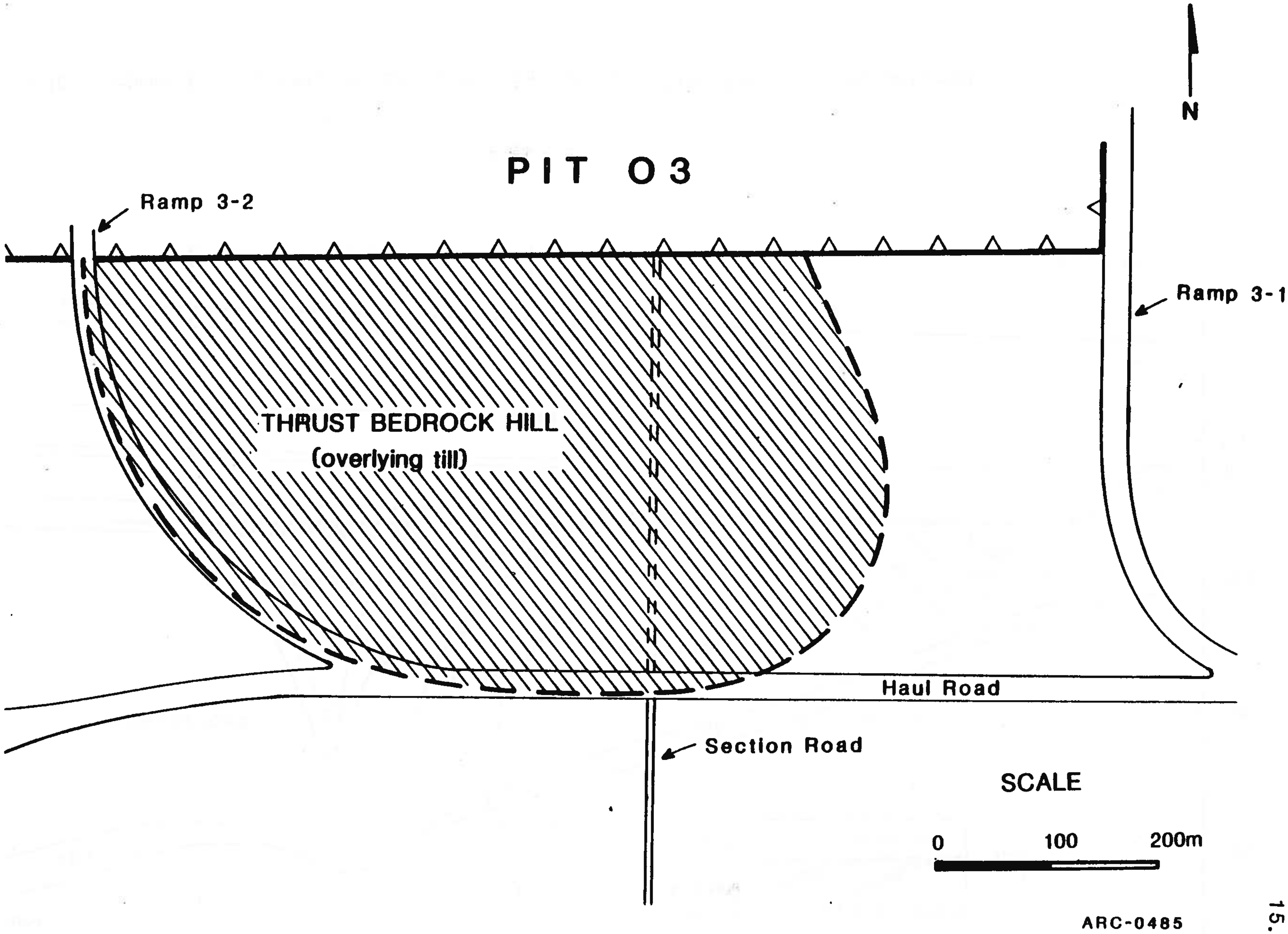

Figure 9. Location of thrust bedrock hill, south of Pit 03.

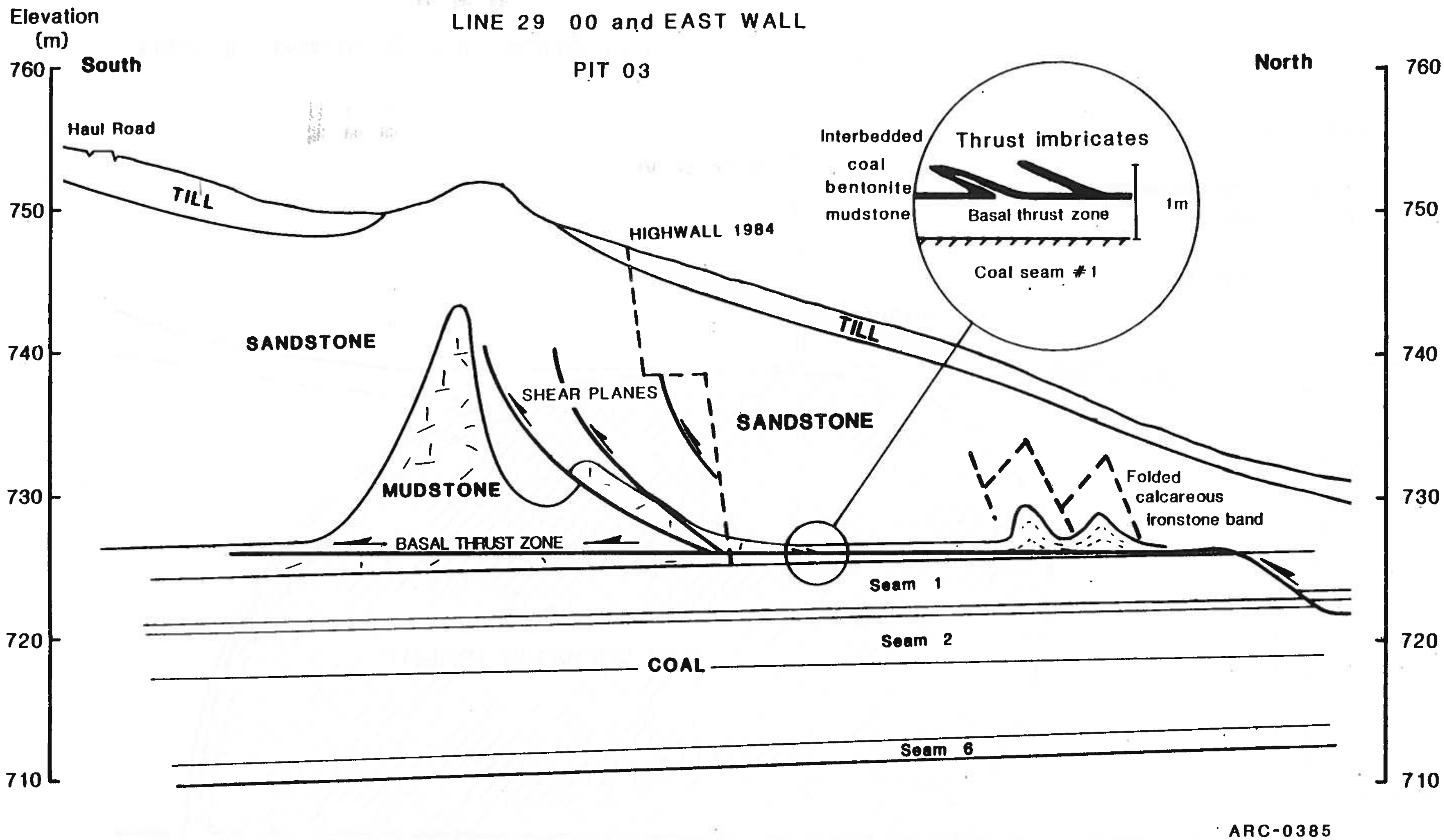

Figure 10. Schematic cross-section along ramp 3-1 and test line 29+00 showing deformation.

overlies seam 1, the movement has been along a 30 to 60 cm thick layer of mudstone with bentonite and coal laminae and is well illustrated by small folds in the coal laminae.

Detailed data on the glaciotectonic structures were collected from the three locations of good outcrop available during the summer of 1984. These sites are all situated where the north-south cuts have allowed the structures to be viewed in a direction generally parallel to the direction of glacial advance and, therefore, parallel to the structural grain of the area. Earlier research had shown that the glaciers advanced in a southerly direction (Fenton et al., 1983). These outcrops are located in Pits A and B and along ramp 3-1 (figure 11). The highwall of Pit 03, although an extensive exposure, is oriented east-west and consequently does not allow the viewing of any of the large structures in a down glacier direction; the only data comes from measurements of smaller scale structures exposed in the cut made the preceeding summer (Fenton et al., 1983).

The measurement of the glaciotectonic structures (that is, fold axes and thrust planes) are summarized in figure 12. In Pit B, both folding and faulting indicate a glacial advance in the direction N160°E, as shown by the orientation of the mean fold axes with a trend of N70°E and a plunge of 3° and the dip direction of the mean thrust plane of about N340°E (requiring a thrust direction of N160°E, figure 12).

The exposures along ramp 3-1 show varying orientation of the thrust planes, but an average dip direction of N17°E can be calculated, indicating a thrust direction of N197°E. The average dip is 40°. The mean orientation of the fold axes has a trend of N92°E and a plunge of 10°. Assuming slightly oblique movements by the glacier along the thrust planes produced the folds, the glacial advance direction is N182°E (figure 12).

Note that the orientation of the mean thrust plane, N17°E, is close to that of the glacial shear plane on which a major failure of July 1, 1984 took place, about N20°E (direction is approximate because the

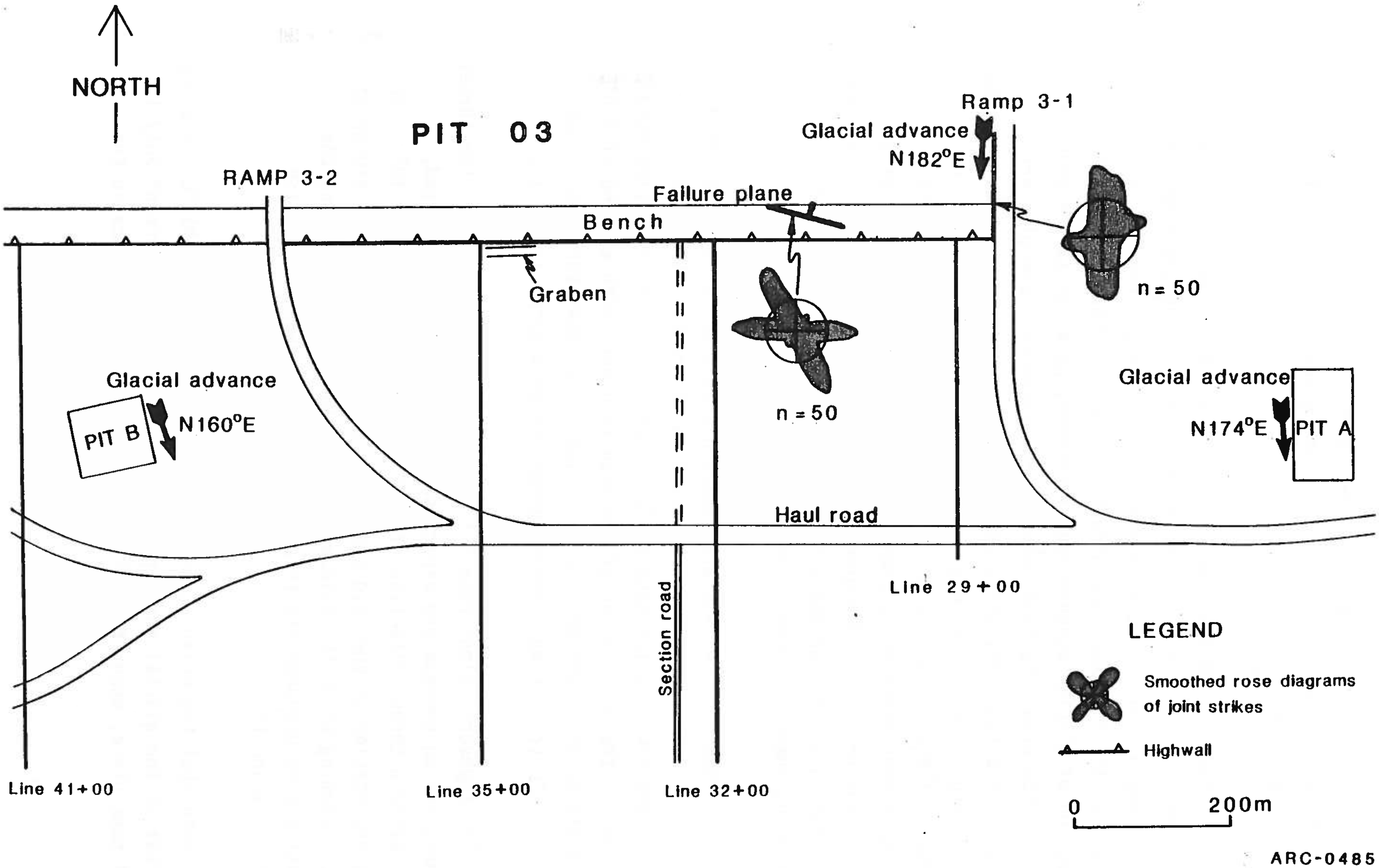

Figure 11. Sites of structure observations southeast part of Pit 03.

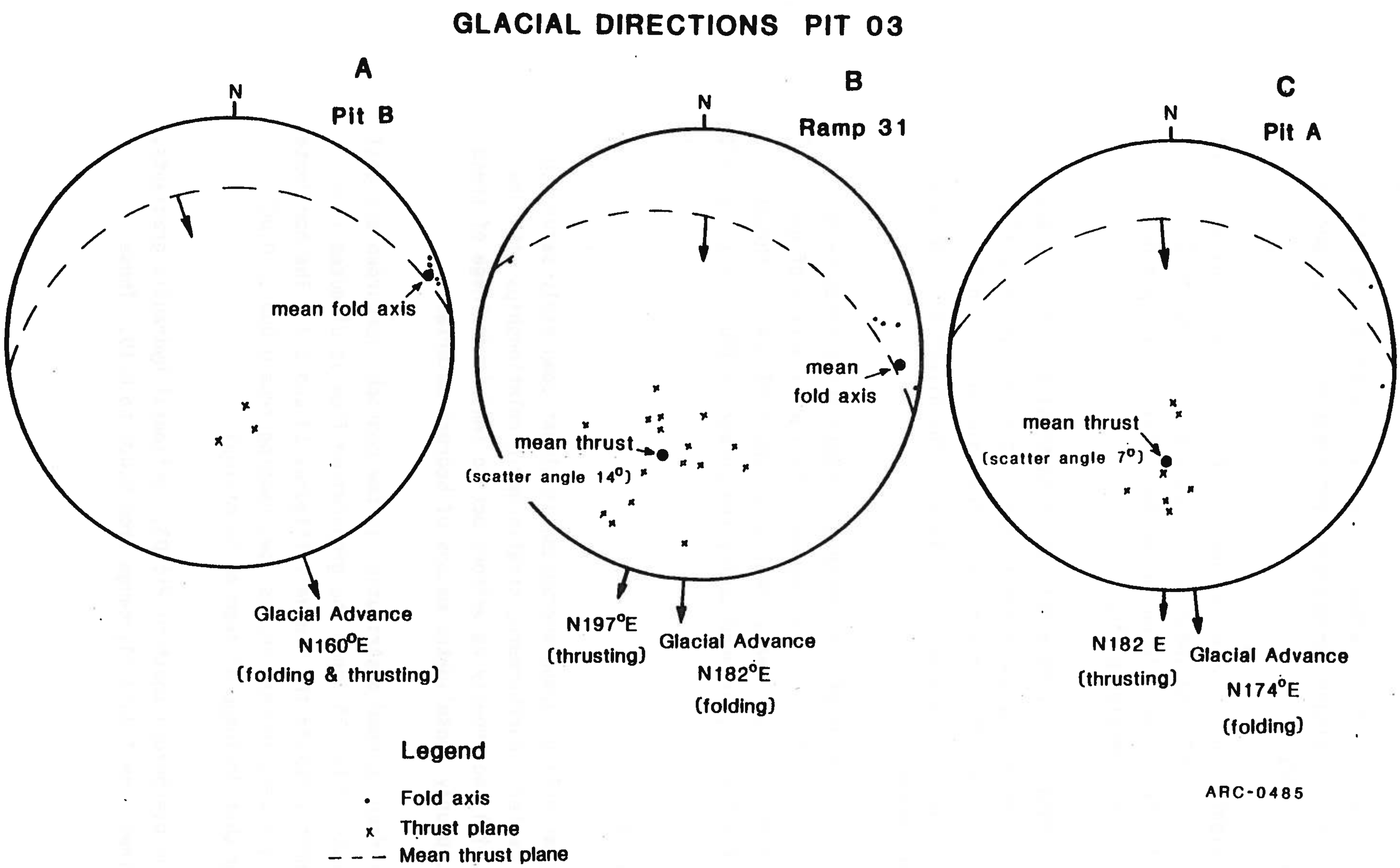

Figure 12. Stereonets showing the orientation of structures in the east part of Pit 03

failure plane was slightly curved). The orientation is also close to the direction of a slight topographic high visible on aerial photos which trends N110°E.

The orientation of the mean thrust in Pit A has a dip direction of N2°E and a dip of 49° and indicates a thrust direction of N182°E (figure 12). The large fold on the western wall of this pit has a plunge of 4° in direction N70°E.

The eastern wall shows a fold trending in direction N96°E and plunging 4°. Averaging these two trends we obtain a possible glacial advance direction N174°E (figure 12). The movements along the thrust plane are assumed to be slightly oblique to the direction of glacial flow in this model.

The directions of glacial advance at these three sites range between N160°E and N182°E. This agrees with the direction of about N170°E obtained from the measurement of a number of smaller thrust planes in the highwall exposed during the summer of 1983 (Fenton et al., 1983, p.26).

Groundwater Conditions

The glacially deformed overburden is almost completely saturated with groundwater. Furthermore, stratigraphic relationships with the overlying till and underlying bedrock act to inhibit drainage of these saturated, poorly consolidated masses of bedrock material.

The hydraulic head distribution in the bedrock overburden and coal seam #6 south of Pit 03, show the groundwater flow is directed from south to north, toward the highwall (figures 13 and 14). The horizontal hydraulic gradient in seam #6, is low, ranging from 0.003 to 0.009, suggesting that drainage of seam #6 is minimal.

In the overburden south of Pit 03, horizontal hydraulic gradients, as determined from figure 14, range from 0.009 to 0.10. These

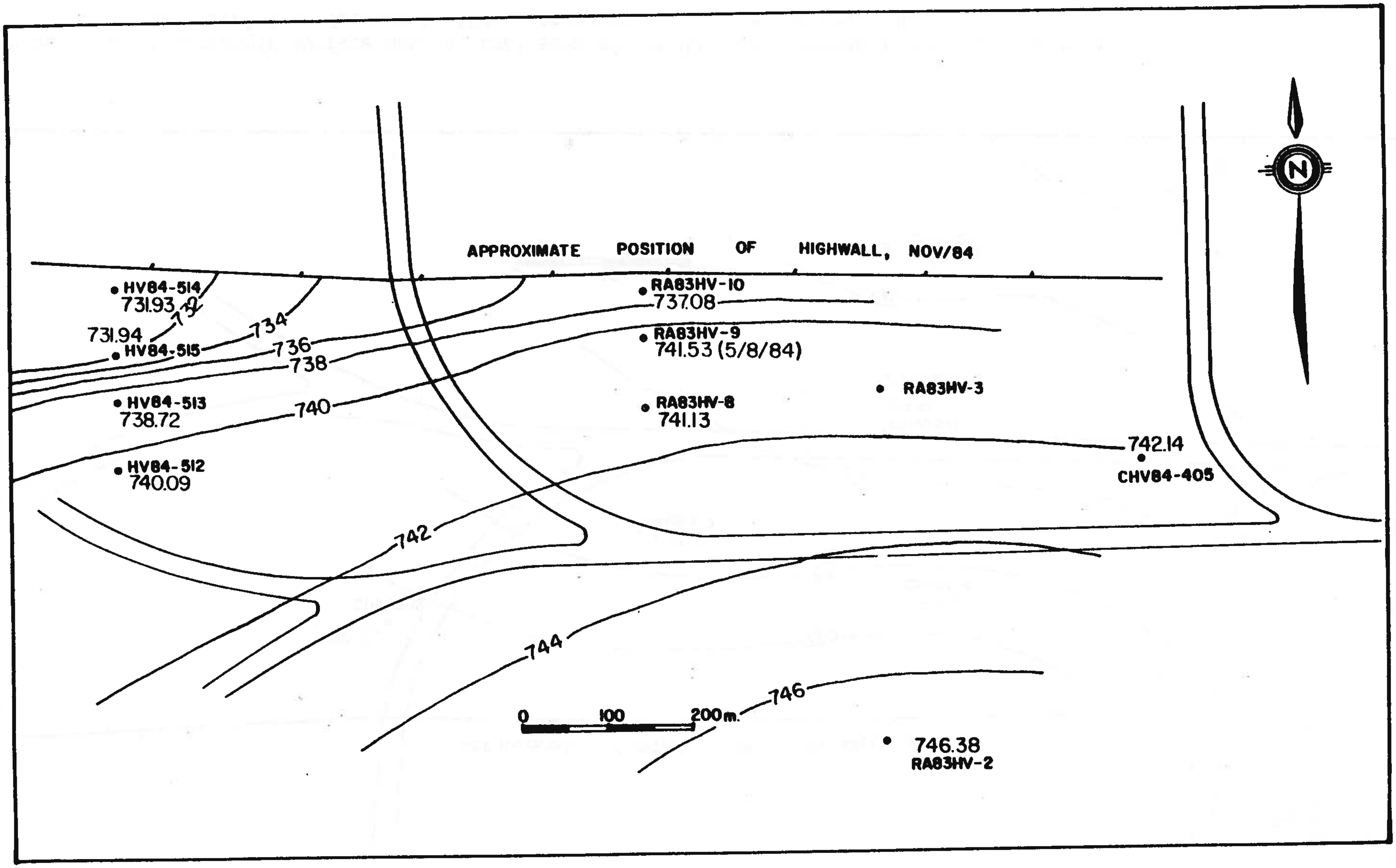

Figure 13. Water table map for the Pit 03 area. Water elevations in meters above sea level from October 5, 1985 measurements. contour interval 2m.

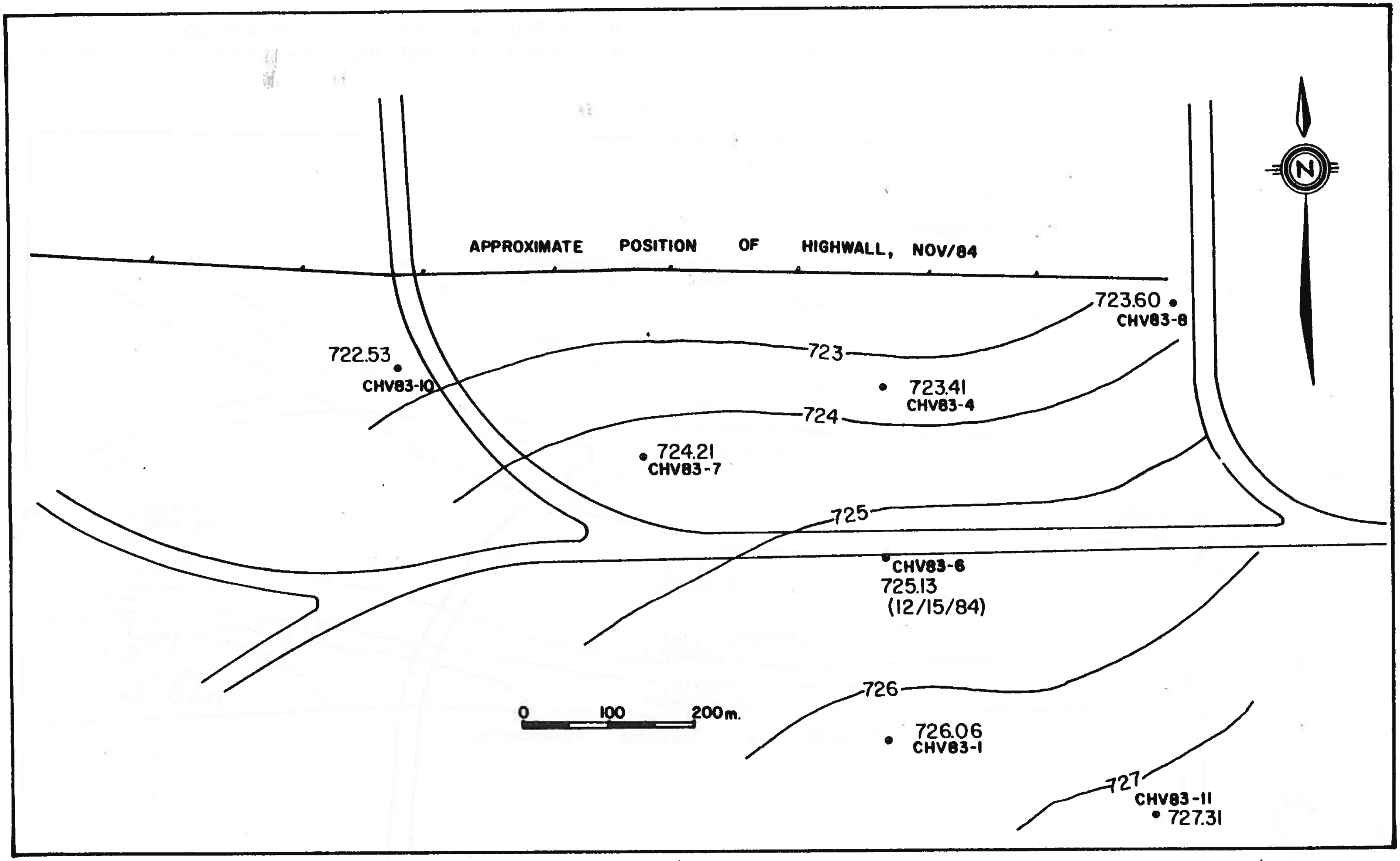

Figure 14. Piezometric surface map for coal seam #6 Pit 03 area. Hydraulic head values in metres above sea level from October 5, 1984 measurements. Contour interval 1m.

relatively steep gradients (compared to those in seam #6) indicate that some drainage of the overburden is occurring (or has already taken place) within approximately 100 m of the highwall. The drainage is incomplete, however.

The hydrogeologic cross-section for Line 32+00, about 300 m west of ramp 3-1, (figure 15) shows that at sites CHV83-4 and RA83HV-3, located approximately 80 m south of the highwall, there is evidence of only very limited drainage in both the overburden and seam #6. The water level in piezometer RA83HV-3 in the overburden sandstone has declined by only 0.6 m since October 1983, leaving 20 m of saturated overburden at that site. Sites farther from the highwall (HV83-6, CHV83HV-2 and CHV83-11) show no decline in waterlevel; in fact, small increases have been detected at RA83HV-2. Consequently, in the vicinity of Line 32+00 the overburden remains poorly drained, and there has been no evidence of any improvement in drainage conditions since September 1983.

Highwall Stability Problems Between Ramps 3-1 and 3-2

Geology

This section contains information relating directly to the highwall failures during 1984 and includes data on the geology, groundwater and conditions prior to and during failure and the styles of the failure.

Current observation of the highwall began about March and continued until October 1984. This period covered the excavation of a new bench, the development of the conditions prior to the start of a major failure on July 1, 1984 and the conditions subsequent to this event.

The stratigraphy exposed in the cuts above and below the bench (figure 16) show a relatively thin (0 to 3 m) till unit, overlying a thick sandstone unit. The till is overlain by thrust bedrock material in the western portion. The sandstone rests directly on the mudstone in the east half of the area. The mudstone overlies a unit, about 1 m thick consisting of mudstone with laminae of bentonite and coal. This

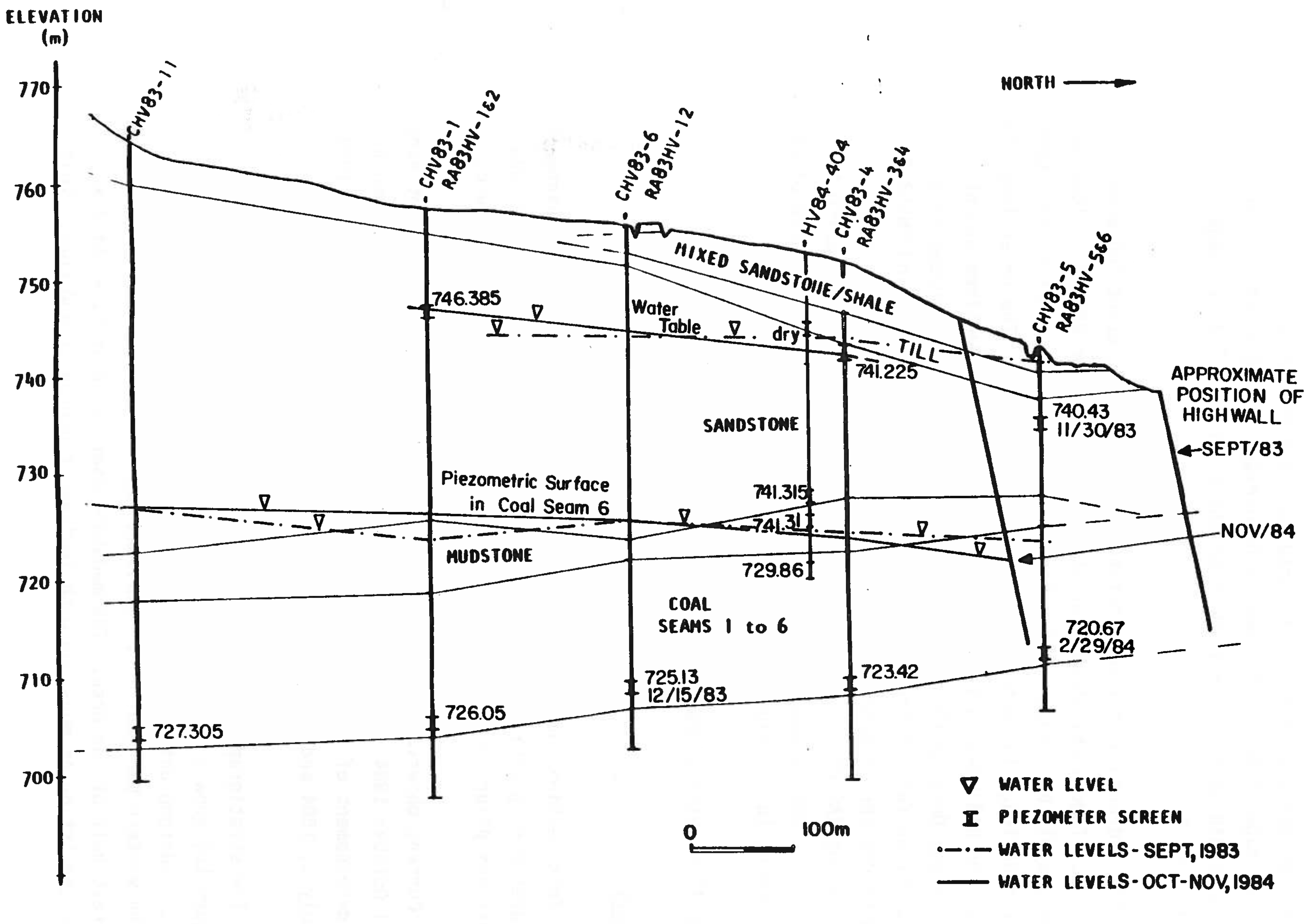

Figure 15. Hydrogeologic cross-section for line 32+00. Hydraulic head values in metres above sea level from October - November 1984, except where noted.

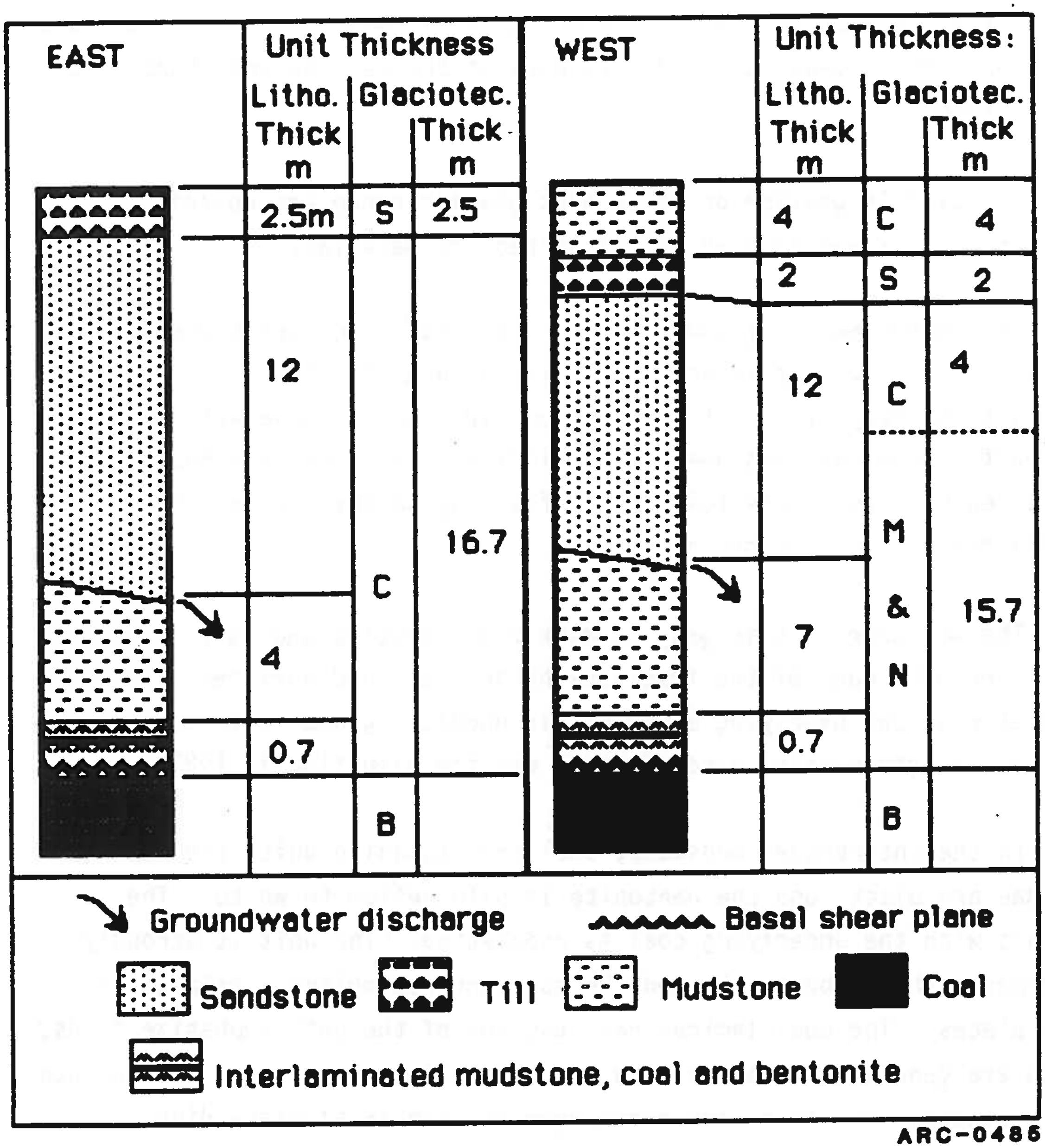

Figure 16. Lithologic and glaciotectonic units exposed in the south wall of Pit 03 between ramps 3-1 and 3-2.

unit contains the basal shear plane produced by the glaciotectonic deformation.

The mass of thrust bedrock material, which core holes show overlies the till in the western two-thirds of the area, was not observed because spoil or debris always covered this part of the section when that area was visited.

The till is grayish brown to dark grayish brown and contains abundant clasts and sheared lenses of bedrock material.

The sandstone is yellowish brown where oxidized, and bluish gray where unoxidized. The generally massive nature of this unit commonly prevents the recognition of deformation structures. Observations from the wall of ramp 3-1 and nearby pits indicate the sandstone has been subjected to large scale folding and faulting so that large blocks remain relatively undeformed.

The mudstone unit is gray to dark gray, massive and is highly fractured with many of the fractures having polished surfaces. The contact with the overlying sandstone is undulating and is in most places the site of groundwater discharge, as was the situation in 1983.

In the interbedded mudstone, coal and bentonite unit, the coal laminae are black, and the bentonite is pale yellow to white. The contact with the underlying coal is undulating. The unit is strongly deformed with the bentonite and the mudstone resembling a melange in many places. The coal laminae near the top of the unit emphasize folds, which are generally less than one metre in height and extend upward into the mudstone. The folds are overturned and the axial plane dips northward. The bentonite is believed to be the basal shear plane of the glacially displaced bedrock material because the underlying coal shows no evidence of deformation.

Failure

Highwall failures in Pit 03 have been occurring between ramps 3-1 and 3-2 since at least April 1983.

Surface and subsurface data indicate the failure is a composite type with four types of failure contributing to the overall result. These four are exfoliation or spalling, block rotation, block slide and mass wasting or disintegration of the large failed blocks.

The surface manifestation of the failures is shown in figure 17. The first exfoliation consists of the falling away of sheets or slices of the sandstone about one to three metres thick. The vertical fractures are a series of cracks, likely due to stress release, that trend approximately parallel to the face and develop over the area between ramps 3-1 and 3-2 extending into the area at least 50 m back from the upper edge of the pit face. The fracture extends to depths of more than 4 m and width increases with time.

The rotational slumps vary in size but are generally 50 to 100 metres long, roughly semicircular in plan, with the direction of rotation approximately northward. One slump, which occurred on July 1, 1984, was observed within 12 hours of failure. Here the slump appeared to have moved along a pre-existing surface because (1) the direction of dip of the surface was about N20°E degrees and of the slickensides caused by the rotation are oriented about N334°E (2) the surface along which the rotation occurred was observed to pass under small undisturbed or abandoned masses of the "failed sediment" that were left adhering to the surface after the failure. This strongly suggests the surface predated the failure. The surface is likely an example of the fractures described by (Fenton et al., 1983) and is believed to be a glacial shear plane.

The fourth, and minor type of failure is referred to here as mass wasting. This is a sequel or product of the first three and occurs in

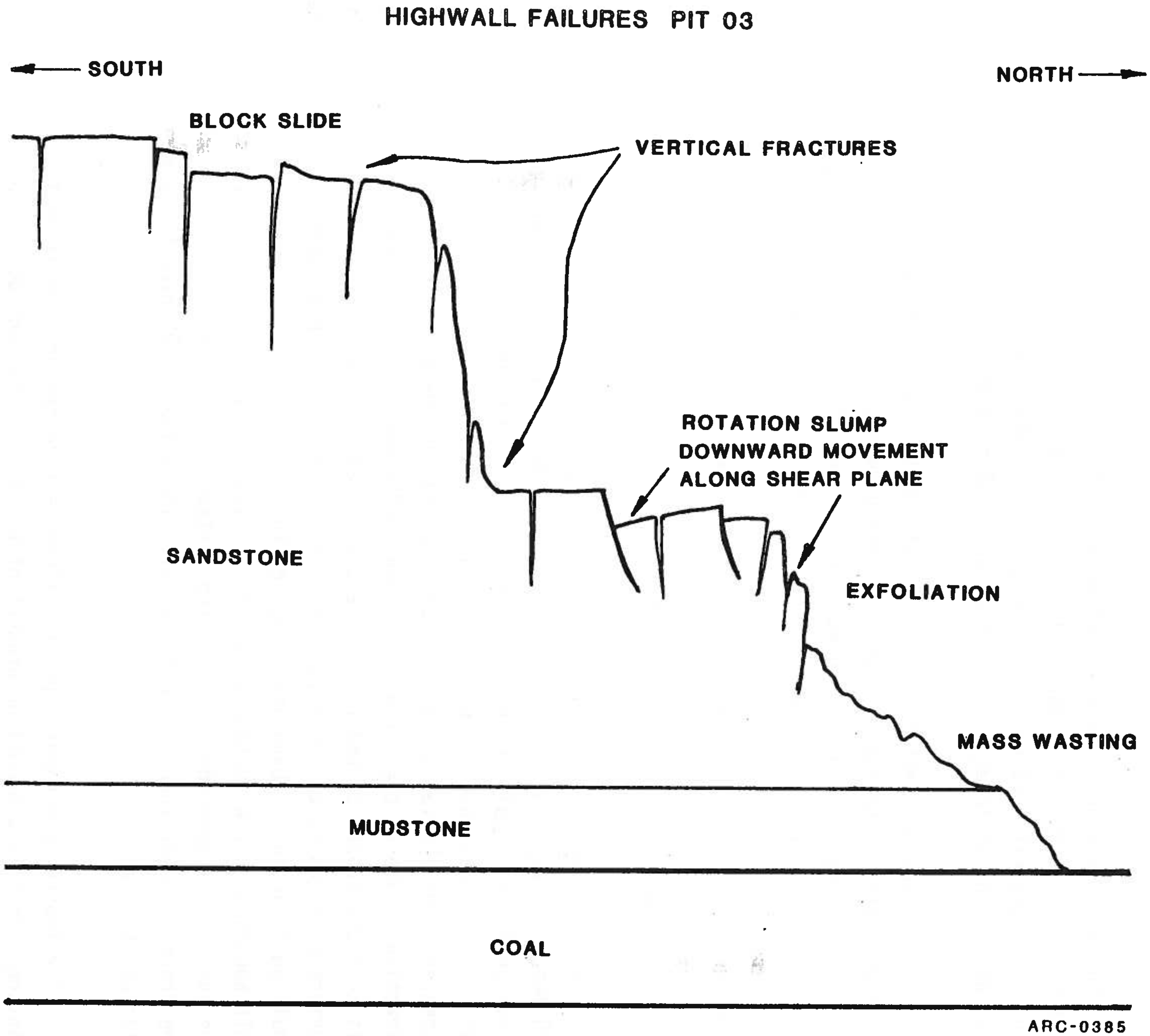

Figure 17. Schematic drawing of observationsl data on the failure at the east end of Pit 03 highwall.

the debris that collects at the bottom of the slope after failure. This failure consists of the gradual dissintegration or reduction in size of the sandstone blocks produced by the three previous types of failure. This tends to produce a relatively low angle ramp of disaggregated sandstone that extends out onto the coal seam and forms the toe of the collapsed mass.

The chronological observations cover the period from late March to October and demonstrate the composite nature of failures in the highwall. The interaction of exfoliation, rotational failure, mass wasting and likely block slide combine to produce instability and failure along the entire length of the area between ramps 3-1 and 3-2. Following the initiation of a new cut by the dragline a near vertical slope remains sitting in a metastable position. This undergoes failure with time and this failure progresses along the face of the cut.

The exfoliation of slices of the sandstone is the first type of failure to occur. This was observed within a week of the dragline making the cut. Another relatively similar type of failure was observed in the folded siltstone unit exposed in the western half of the cut examined in March. The folding of the siltstone had been by bedding plane slip and slabs of siltstone were becoming detached and sliding down the upper, north-dipping limb of the fold onto the bench. The volume of failed sediment was small, however. This process is not believed to be a major contributor to the highwall failure. This siltstone was subsequently removed by the next cut and is discussed nowhere else in this report.

The vertical fractures appeared some time after this. The exact time these fractures began to manifest themselves is unknown because the observation periods in March, April and May were rather far apart. By late May, however, many of these fractures were present in the bench above the coal, the wall between the bench and the surface and for at least 50 m south of the pit edge. These last were about one metre wide and over three metres deep. By late June, narrow failures, with a maximum width of about 3 m, had extended along a major portion of the bench and to within about 100 metres of the portion of the bench being excavated by the dragline.

The failed blocks of sandstone at the base of the bench continued to undergo mass wasting and form a ramp extending out onto the coal. This ramp was removed at least ounce, in the area between ramp 3-1 and a point half way to ramp 3-2. This fresh face revealed groundwater being discharged at the contact of the mudstone and sandstone units and sliding of the sandstone over the mudstone.

The exfoliation and growth in the width and the abundance of the vertical fractures continued until July 2, 1984 when a relatively large rotational slump occurred about 150 m west of ramp 3-1. The failure was not observed during formation but occurred during a 12 hour period between observations. The northern side of this failure was much farther from the edge of the bench than the earlier small rotational slumps and extended to within three metres of the cut on the southern side of the bench. The failed area included an access trail created by light trucks driving to the dragline and rendered the bench essentially inaccessible to the east-west movement of equipment. As stated previously this failure moved along a pre-existing surface, likely a glacial shear plane. The failure surface was wet at the time of failure, although dessication cracks had started to form on the exposed portion of the surface when the authors reached the failure site.

After July 1, the excavation of the northern half of the bench continued westward. Large-scale failures also spread westward along the remaining portion of the bench and kept pace with the excavation. Some are known to be rotational failures. Others, in which the slip plane was too deep to be observed were likely both rotational slumps and block slides. The debris extending out over the coal at the base of the bench was not removed when the authors were present so that the continued northward movement of the sandstone at the contact with the mudstone unit could not be observed. This likely continues, however.

The vertical fractures on the surface above the bench continued to grow in frequency, width and length extending the area of failure westward. A piezometer set in July had to be abandoned when intersected by the fracture system. Northward movement, likely due to block slide along the sandstone mudstone contact, was manifest on this surface at one site east of ramp 3-2 by a down dropped graben about 5 m wide and 30 m long in which the surface remained horizontal but subsided about 4 m below the surface to the north and south. The vertical fractures along the margin of the graben extended downward at least another 4 m.

Any model to explain the failures in the highwall of Pit 03 between ramps 3-1 and 3-2, must take in account the above observations summarized in figure 17: the highwall failure is composite, the product of a series of smaller failures of a variety of types consisting of exfoliation, mass wasting at the toe, rotational slump, and block slide. The last two types are of major importance because they involve the failure of large volumes of sediment and the destruction of the bench and adjacent land surface.

The rotational slumps, particularly the large ones are likely the result of remobilization of pre-existing glacial shear planes (figure 18). Some, particularly the small ones may form spontaneously as a result of the low strength of the sandstone. Groundwater contributes at least to the remobilization of the relict shear planes.

The block failures are believed to be caused by elevated water pressures at the contact of the sandstone and fractured mudstone units compounded by the saturated and weakened condition of the overlying sandstone, the latter conditions produced by the glacial thrusting and saturation. The dip of the contact toward the pit undoubtedly also contributes to the block sliding (figure 10). The vertical fractures manifesting the block slide may be the result of the slide itself but are more likely due to opening of pre-existing joints, or perhaps a combination of joints and shear planes (figure 18).

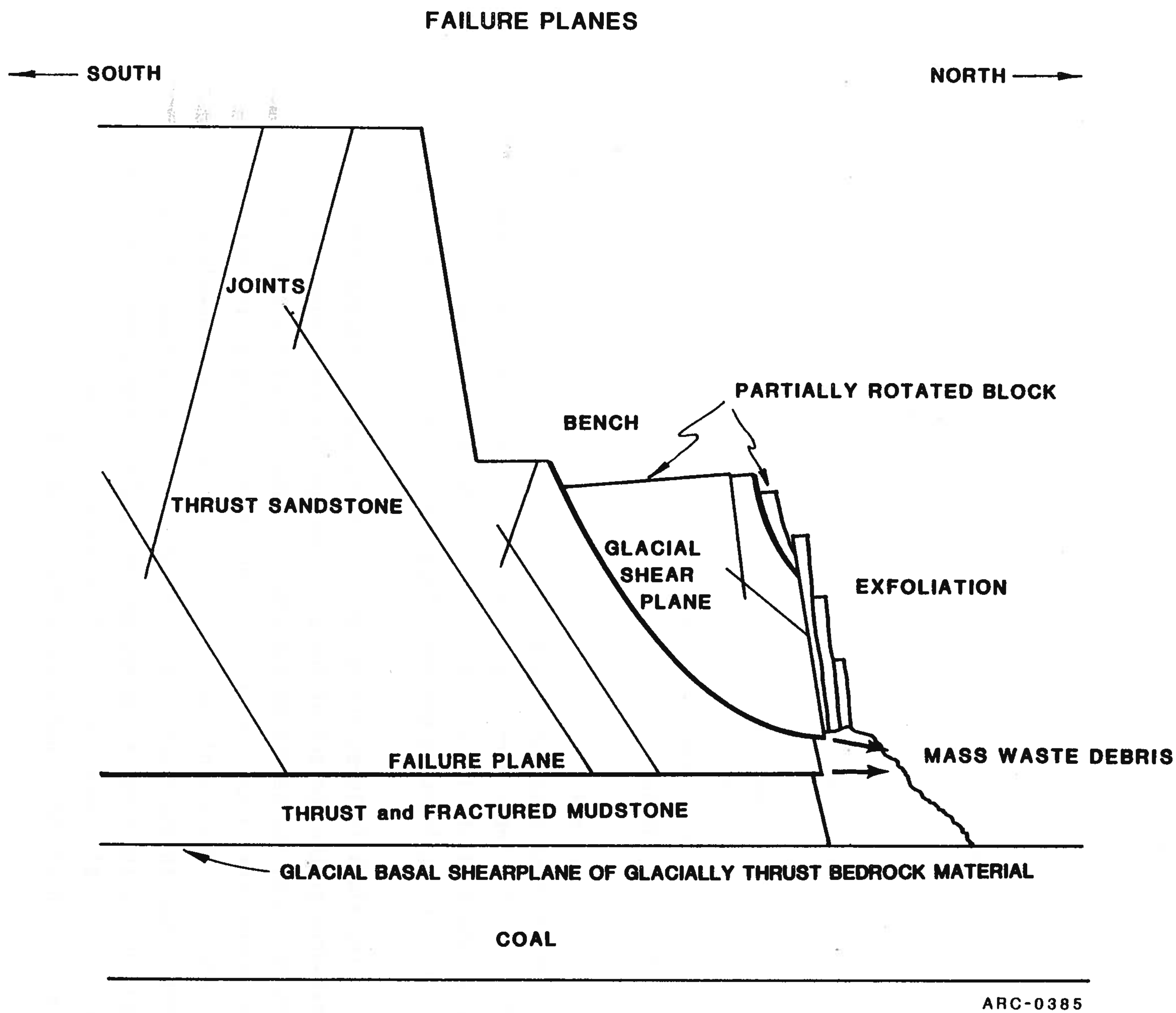

Figure 18. Model for the failure east end of Pit 03 highwall.

In summary the proposed model of deformation initially involves exfoliation of the newly exposed face and mass wasting of the spalled block deposited at the base of the cut followed by the development of vertical fractures, manifesting a combination of stress release and block slide. Later, within about two months for the 1984 failures, small and later larger rotational slumps develop combined with greater movement of the block slides to produce massive and widespread failure in the bench and adjacent land surface.

RECLAMATION

The reclamation of prairie coal mines is a concern because of the disruption of farmland by mining. As a result reclamation research is one of the major programs undertaken by the Council. The Highvale Mine and the surrounding region was chosen as one of the investigation areas. The Plains Hydrology and Reclamation Project (PHRP) research was carried out under the sponsorship of the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with funding derived from the Alberta Heritage Trust Fund and the Alberta Research Council.

The ARC began the (PHRP) study of the Highvale Mine area in 1982. The primary objective of the project has been to assess the potential for salinization of reclaimed soils over a period of time. The cast overburden or mine spoil becomes saturated within a relatively few years of placement, especially where surface ponds are present in the post-mining landscape. The chemical quality of this water is significantly degraded relative to the water in the coal prior to mining as a result of dissolution of salts in the replaced overburden. The reservoir of salt available in the spoil is so great that water containing abundant salt will likely be produced for thousands of years. Whether this salty water will reach the soil or plant rooting zone is a function of the hydrology within the reclaimed landscape.

The dominant factors influencing the hydrology of mine spoil in the plains appear to be (1) the fine texture and low permeability of the spoil itself, (2) the absence of the subdrain produced by the coal in an unmined setting and (3) the apparent absence of fractures in spoil material below the water table. As a result of these characteristics of mine spoil, steady-state water-table position is expected to be much closer to the land surface than in the premining case. Where the water-table position is within some small distance of the land surface, salt can be transported upward by capillarity and transpiration of plants resulting in soil salinization. Research began during 1983-84 to quantitatively assess the critical depth to the water-table for capillary action to transport of salts into the soil zone.

The investigation of the premining hydrogeology at the Highvale Mine study area is based on the study of approximately 420 piezometers installed in unmined material. Approximately 380 of these piezometers were installed by Monenco Limited (Montreal Engineering Limited) for TransAlta Utilities Limited and fourty-two were installed by the Alberta Research Council, Plains Hydrology and Reclamation Project. Ten stratigraphic units were instrumented as shown in the generalized stratigraphic column for the Highvale area (figure 19).

The principle topographic features of the Highvale region include Lake Wabamun (elevation 732.2 m above sea level) and a northwest-southeast trending escarpment that reaches an elevation of approximately 800 m above sea level, situated from 3 to 5 km south of the lake. In the south central part of the area is a dry lake bed at an elevation of approximately 745 m above sea level. This lake, which was called Low Water Lake before it was drained, is approximately 10 km long and 4 km wide (elongated in a north-south direction).

In the southeast part of the study area is an upland with elevations as much as 840 m above sea level, which drops off toward the North Saskatchewan River in the south, Lake Wabamun in the north, and Low Water Lake in the west.

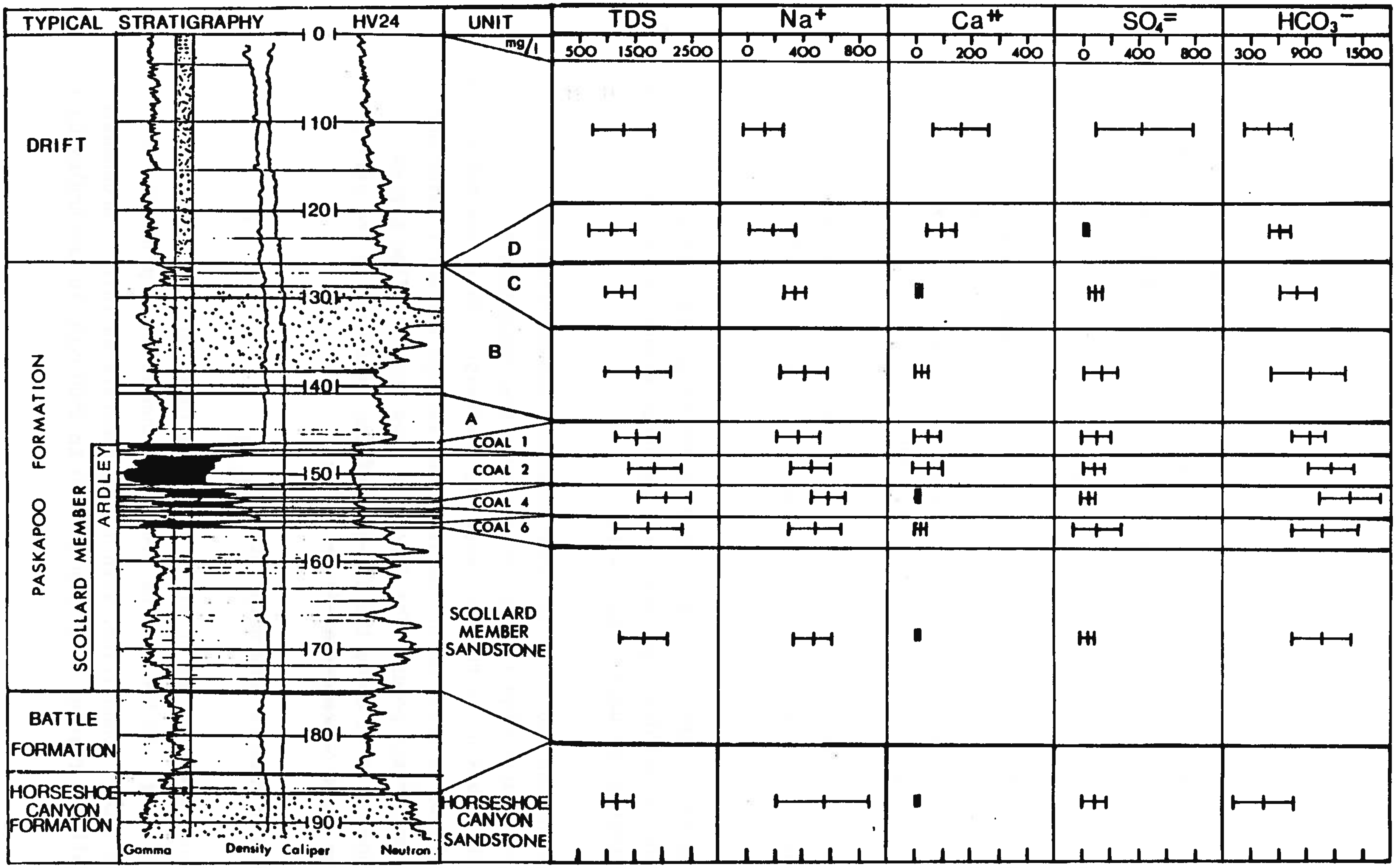

FIGURE 19. Generalized stratigraphic column and vertical trends in groundwater chemistry. Depths in metres, concentrations in mg/L.

Groundwater Flow Patterns

1) The regional groundwater-flow pattern illustrated by figure 20 has two principal components - one from the uplands in the southwestern part of the study area north toward Lake Wabamun and the other from the uplands in the east-central part of the study area southeast toward the North Saskatchewan River.

2) Over most of the area vertical hydraulic gradients are directed downward, representing recharge conditions. Groundwater discharge conditions are present at the sub-crop of the Ardley Coal Zone and overburden sandstone just to the south of Lake Wabamun.

3) The North Saskatchewan River is the regional groundwater drain for both shallow and deep bedrock aquifers in the southern part of the study area.

4) Low Water Lake is in some places a discharge area for shallow bedrock and drift groundwater. In other places it is a source of recharge for bedrock aquifers.

5) In the sandstone of the Upper Horseshoe Canyon Formation groundwater flow is from the sub-crop area southeast of Lake Wabamun, to the southwest and southeast. This flow pattern is related to recharge of the sandstone through the drift cover and from surface ponds. The discharge area for this flow system appears to be along the sub-crop of the sandstone in the valley of the North Saskatchewan River.

Groundwater Chemical Characteristics

1) Groundwater in the drift is highly variable both in composition and salinity. In the shallow bedrock, groundwater is primarily of Na^{+}-HCO_3^{-} composition, with low to moderate salinity. Groundwater salinity reaches a maximum of 2000 to 2500 mg/L in the Ardley Coal

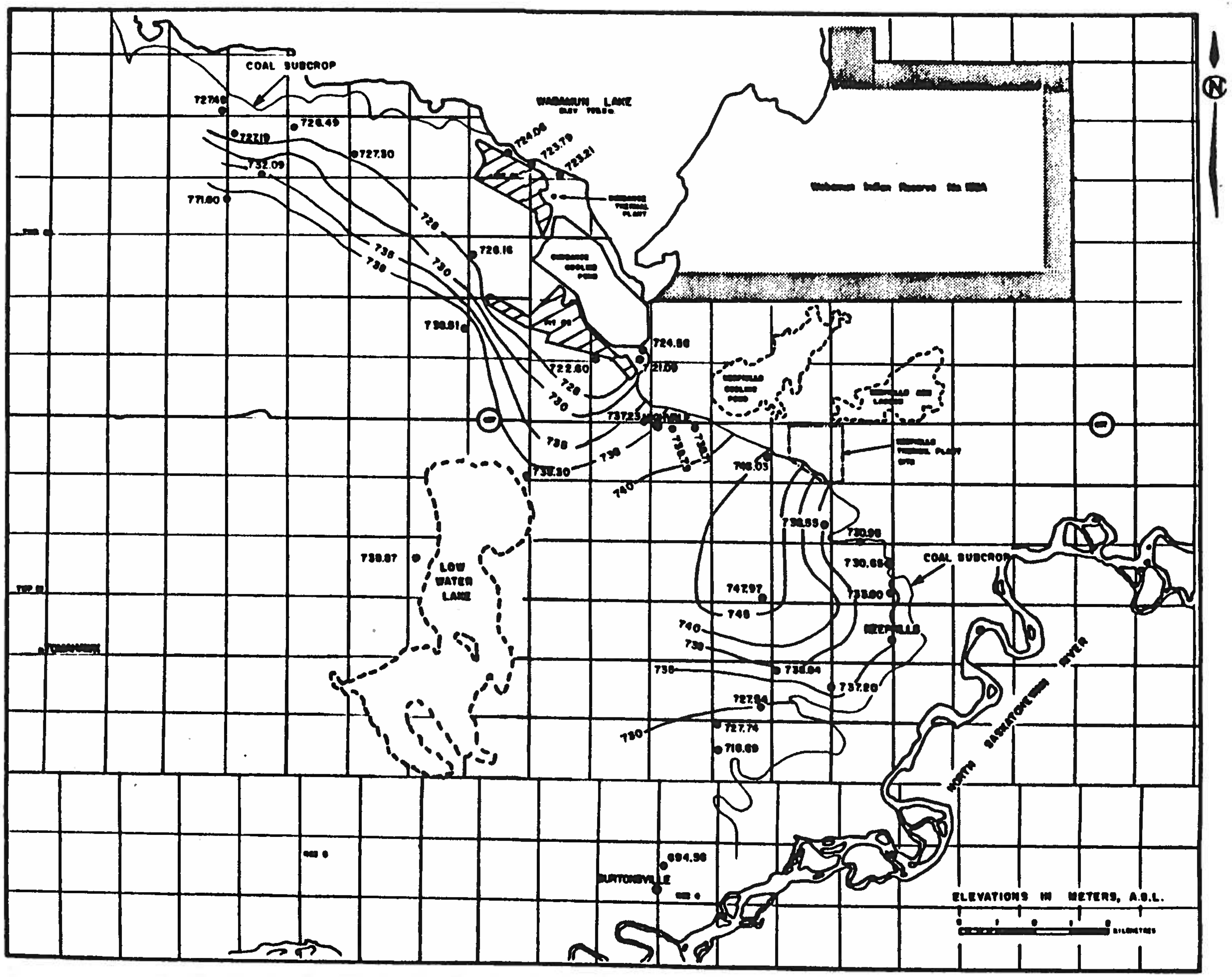

FIGURE 20. Piezometric surface map for coal seam #6. Water elevations in metres above sea level. Contour interval variable.

Zone, and declines somewhat with increased depth. Sandstone beds in the Upper Horseshoe Canyon Formation, which at approximately 100 m depth are the deepest stratigraphic unit studied, contain Na^+-HCO_3^- groundwater of low to moderate salinity.

2) Groundwater in all stratigraphic units is slightly undersaturated to saturated with respect to calcite and dolomite and undersaturated with respect to gypsum. Ion exchange characteristics of all stratigraphic units except the drift show a strong tendency for dissolved calcium to be exchanged for adsorbed sodium, giving rise to a sodium-dominated groundwater composition.

Spoil Hydrology and Hydrogeochemistry, Highvale Mine, Pit 01

The reclaimed portion of Pit 01 was instrumented in 1982 with 49 piezometers at 13 sites.

At least a portion of the spoil at Pit 01 is saturated at all sites except HV-1 and HV-5, which are situated at the north end of the pit. In all cases the elevation of groundwater in the reclaimed spoil is higher than the elevation of Lake Wabamun. The water table in the reclaimed spoil at Pit 01 is from 5.5 to 12.8 m in depth below ground surface; at most of the sites the water table is from 7.5 to 8 m depth, with the shallowest depths associated with the large pond near Site HV-11 greater depths occur around the perimeter of the pit. A water-table map for Pit 01 (figure 21) indicates that a groundwater mound is present in the west-central portion of the pit. This mound is associated with ponding of water and recharge derived from the ponds. Groundwater flow at the water table has two principal components, northward, toward Lake Wabamun and southward toward the inactive mine pit that is present below the old highwall.

The very high water table in unmined material at site HV-13, just west of Pit 01, indicates that there is a very strong potential for the spoil in Pit 01 to receive lateral inflow from the overburden sandstone to the west of the pit.

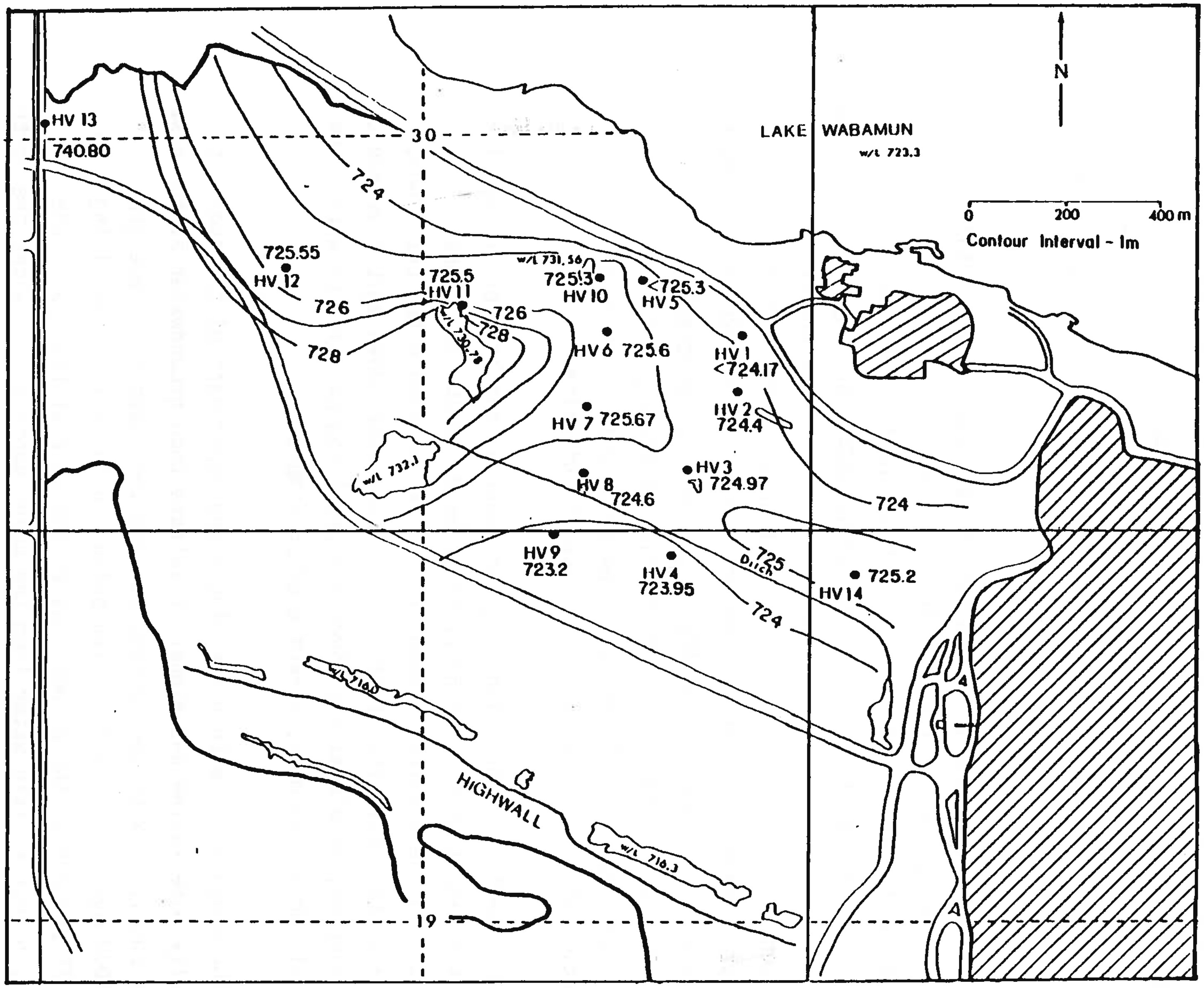

FIGURE 21. Water table map for Highvale Mine Pit 01 site. Water elevations in metres above sea level.

Water samples have been collected for chemical and isotopic analyses from 23 wells in the spoil at Pit 01. Sodium is by far the dominant cation in most samples, while the dominant anion is either bicarbonate or sulfate. In general, the salinity of the spoil groundwater is related to its position within the spoil; in addition the higher salinity samples tend to be dominated by sulfate. Figures 22 and 23 are north-south and east-west cross sections illustrating the major chemical constituents of the spoil groundwater.

At the base of the spoil six out of ten samples have total dissolved solids in the range of 2000 to 3000 mg/L. At all sites except those along the north end of the pit (HV-2, HV-6, HV-10) the water at the base of the spoil is a Na^{+}-HCO_3^{-} or Na^{+}-HCO_3^{-}-$SO_4^{=}$ type, with sodium exceeding 90 percent of the cation component and bicarbonate exceeding 60 percent of the anion composition. Along the north end of the pit at sites HV-2, HV-6 and HV-10, the water is more saline (3200 to 6900 mg/L) and has a larger component of $SO_4^{=}$ (as much as 70 percent). At site HV-9 the water at the base of the spoil is extremely alkaline (pH = 11.9) and is a Na^{+}-OH^{-}-$CO_3^{=}$ type water with 4 100 mg/L TDS, reflecting the in-pit burial of fly ash at this site.

The chemical composition of groundwater at the base of the spoil (with the exception of site HV-2, HV-6, HV-9, HV-10) is virtually identical to the premining composition of water within the coal zone, but the average salinity of the spoil groundwater, 2648 mg/L (average of seven samples) is almost 2.5 times the premining salinity of water from the coal zone, 1138 mg/L, (average of 25 samples).

The groundwater within the middle and upper part of the spoil is generally more saline and higher in sulfate than groundwater at the base of the spoil. Six of twelve samples from the upper spoil are greater than 4000 mg/L in total dissolved solids, with sulfate comprising from 55 to 75 percent of the anions. As at the base of the spoil, the more saline, higher sulfate water from the upper spoil occurs along the north end of the Pit 01, at sites HV-2, HV-6, HV-10 and also HV-7. Somewhat less saline water (TDS 3 460 mg/L) is present at site HV-9, south of the

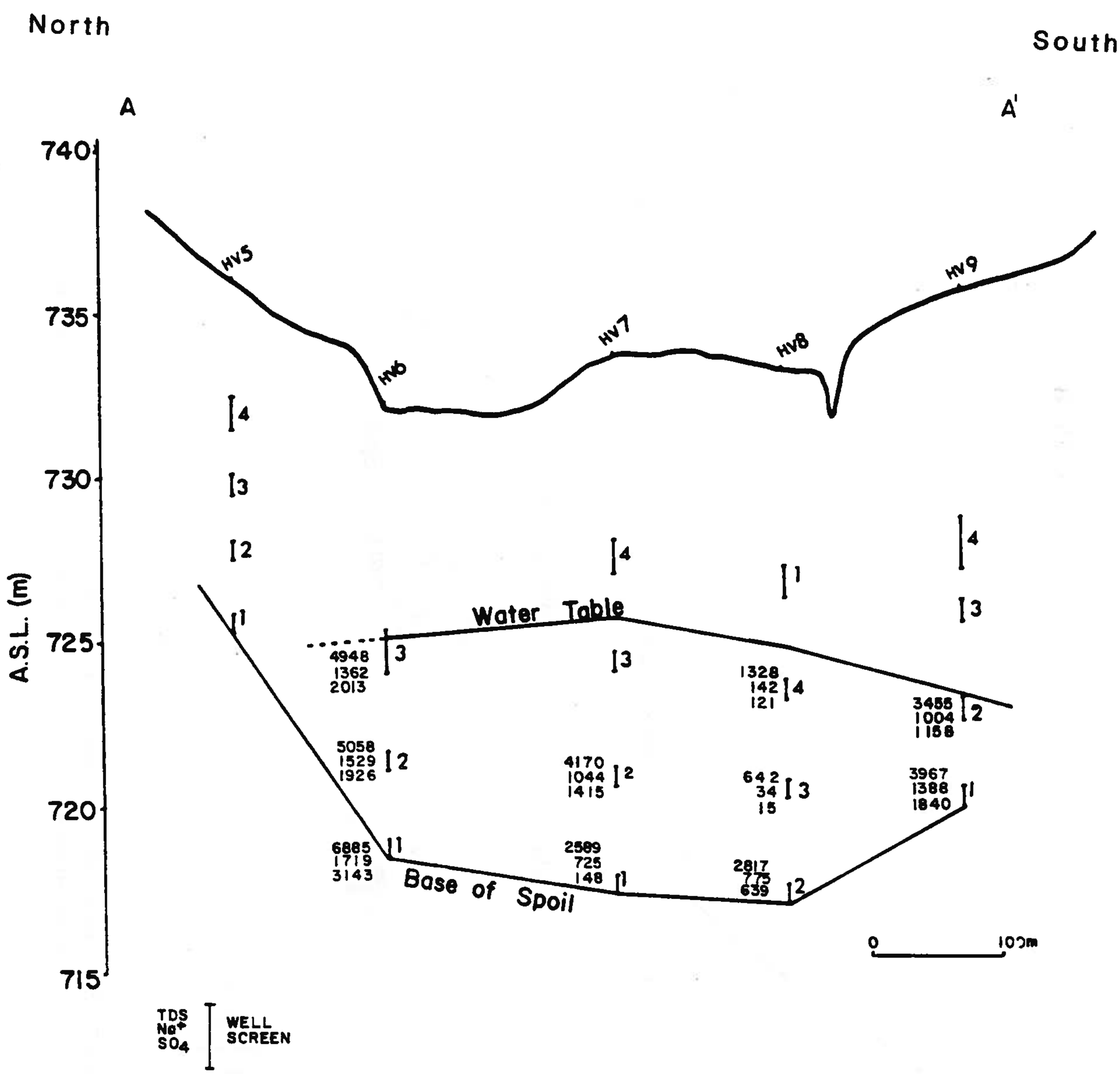

FIGURE 22. Total dissolved solids (TDS), sodium and sulfate concentrations (mg/ℓ) in spoil groundwater. Cross section A-A', Highvale Mine Pit 01 site.

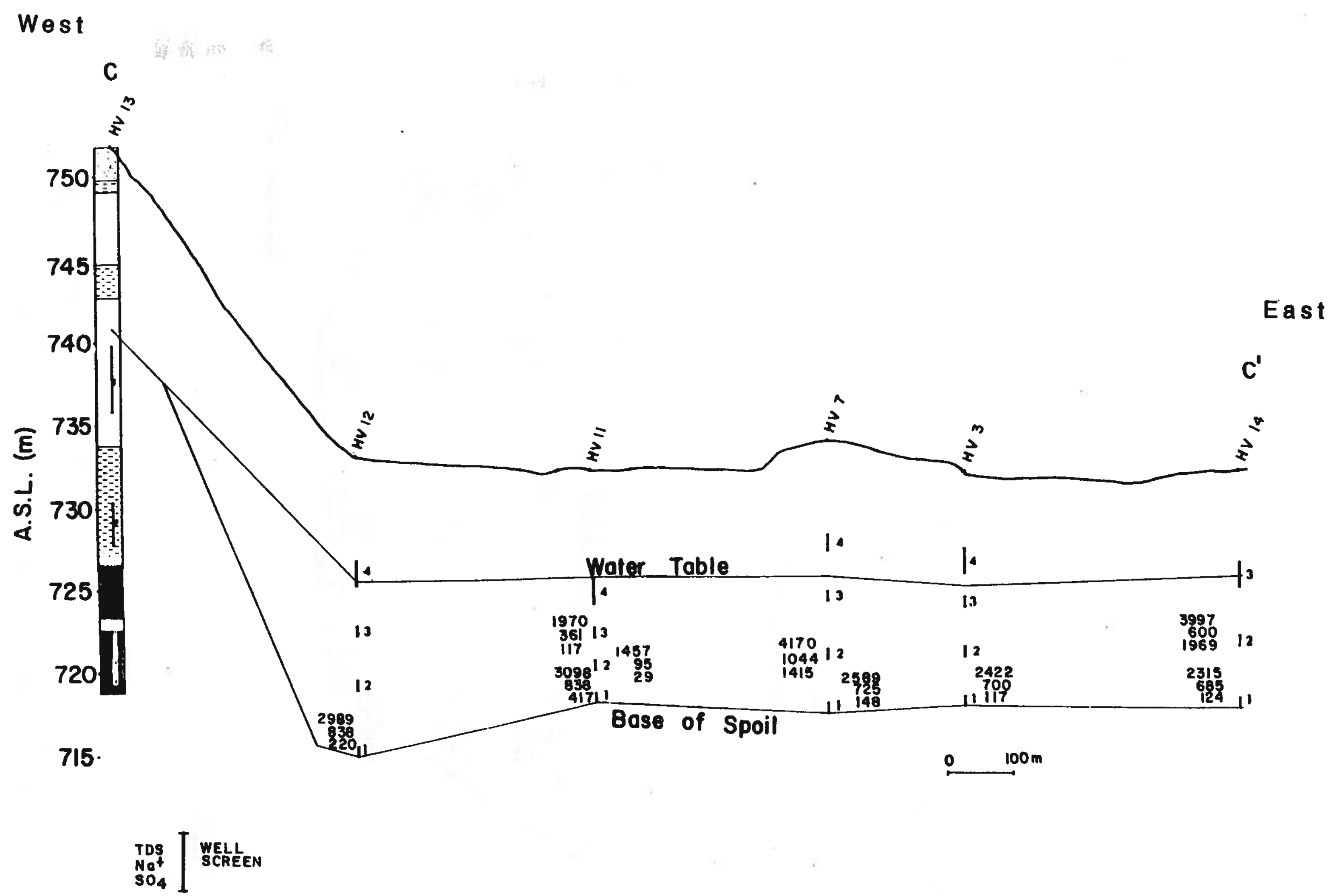

FIGURE 23. Total dissolved solids (TDS), sodium and sulfate concentrations (mg/ℓ) in spoil groundwater. Cross section C-C', Highvale Mine Pit 01 site.

drainage ditch; and the shallow wells at site HV-8 and HV-11 contain significantly less saline water (640 to 1 970 mg/L TDS) than elsewhere in the spoil.

ROAD LOG EDMONTON TO HIGHVALE

Distance (km)	
6 km	Intersection of 170 Avenue and Highway 16 near the western outskirts of Edmonton. Surficial deposits are composed of clayey sediment of glacial Lake Edmonton. In this part of the city, they are about 30 m thick.
3.8~6 km	Winterburn Corner. West of this point the highway crosses the Lake Edmonton pitted delta.
~8.4 to 10.2	Crossing the Acheson Devonian oilfield. Production is obtained from the Nisku and Leduc Formations of the Upper Devonian Winterburn Group.
15.8	Overpass over the main line Canadian National Railways. The topographic low marking the bedrock channel of the pre-glacial North Saskatchewan River may be seen to the north where it is occupied by Big Lake.
20.6	Spruce Grove. The north-south trending ridge on the horizon to the west is the highest point of the Lake Edmonton pitted delta. The elevation of this ridge is more than 100 m higher than the elevation of the City of Edmonton.
30.6	Entering the main part of the pitted delta. Looking eastward one can get an appreciation of the large build up of sediment in the delta. Note that the kettle holes do not normally contain water because of the high permeability of the lake silt.
37.6	Highest point of the pitted delta on Highway 16. This area has the most rugged topography of any part of the pitted delta. Deltaic sediment here is over 100 m thick.
42.7	Junction of Highway 43 to Whitecourt and Valleyview. This point marks the western edge of the Lake Edmonton pitted delta. The topographic depression approximately 1/2 km to the west is a small glacial spillway that drained meltwater towards the southwest during the final draining of

Lake Edmonton. The western bank of the spillway is a hummocky-dead-ice moraine.

51.2 Junction with road to Kapasiwin. Turn south and just south of the overpass take the road leading to the Highvale Mine and the Sundance Generating Station. Route traverses high to moderate relief hummocky terrain composed of sandy to clayey lacustrine sediment. High relief may be due in part to buried glacially thrust masses of bedrock. Powerlines leading from the generating stations are visible. Some of the transmission towers have been chosen as nesting sites by large hawks or eagles.

STOPS AT HIGHVALE MINE

The descriptions of the stops within the mine are brief because within an active mine the exposure may change daily. We will point out the important features currently exposed when we visit each stop (figure 24).

Stop 1: Reclamation Pit 01

The stop is located on the north side of the mine on the east-west gravel road about 1 km west of the mine entrance (figure 25). The purpose of this stop is to view the reclaimed land and the monitoring sites.

The reclaimed area ranges in elevation from 713 m ASL in the central portion to 737 m along the northern edge. To the south of our stop the land surface drops 15 m to Lake Wabamun, at an elevation of 723 m.

Looking to the south is Pit 01 of the Highvale Mine, an area of approximately 140 hectares mined during 1970-76. The area north of the haul road was reclaimed by 1981, and instrumented by the Plains Hydrology and Reclamation Project in 1982. At the far southern

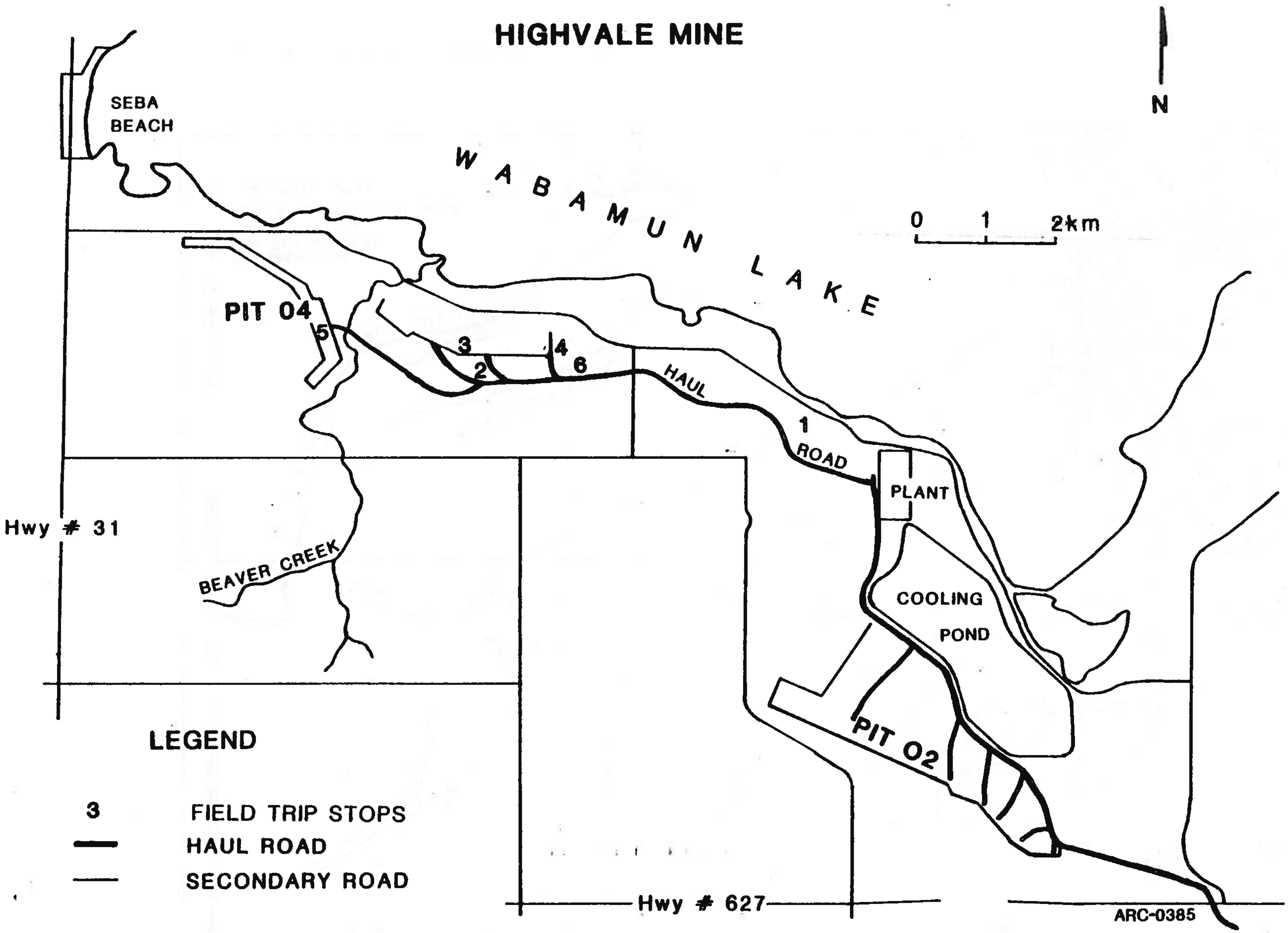

Figure 24. Map of Highvale Mine with field trip stops.

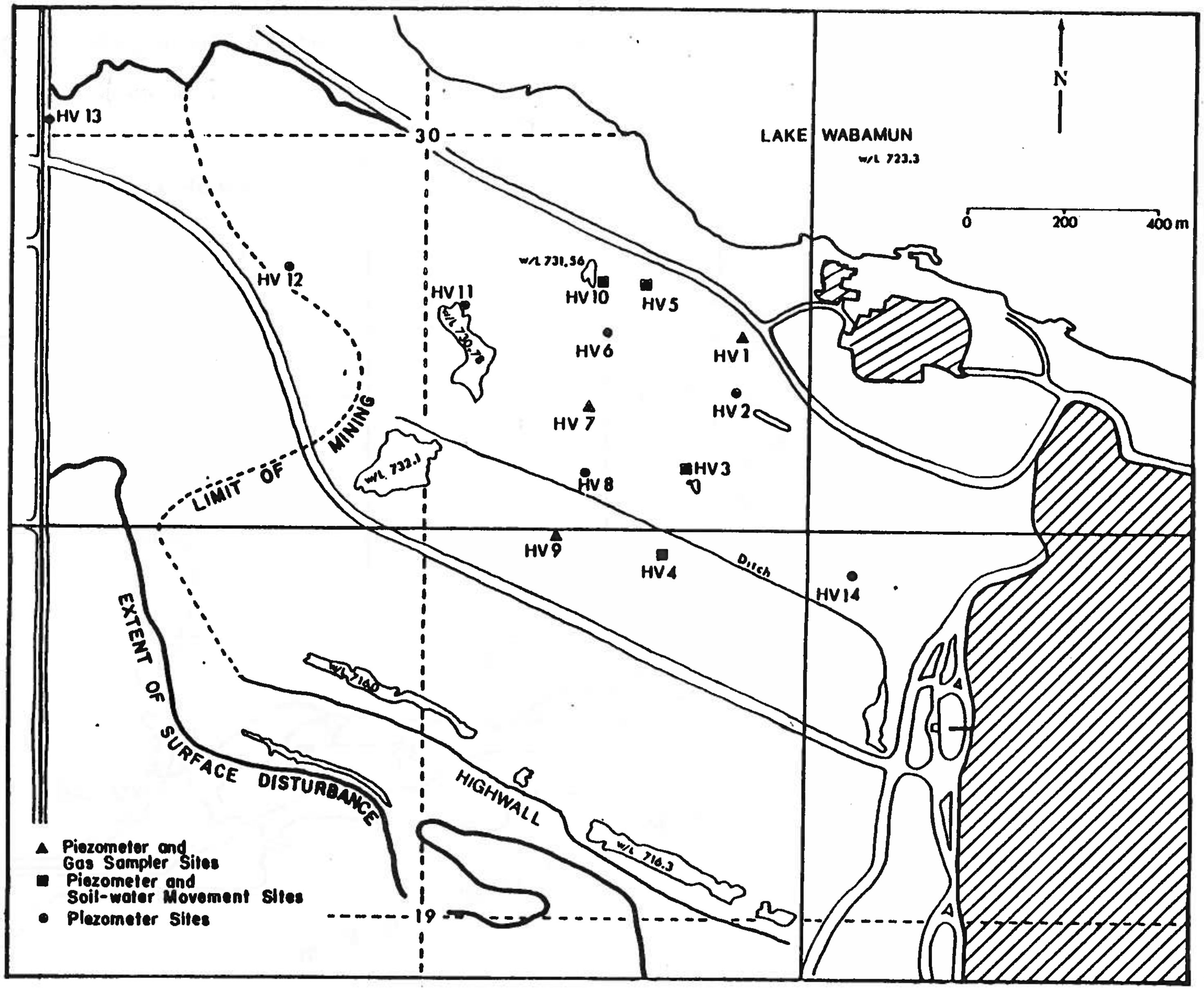

Figure 25. Map of Pit 01 showing groundwater instrumentation.

end of Pit 01 remains an inactive pit, which is an emergency coal supply and ash relief dumping area for the Sundance Power Plant.

Some of the instrumentation sites are visible with the most prominent feature being the white pipes of the piezometers. Information on the study is contained in the background information provided earlier in the guidebook.

Stop 2: Pit B

The east wall of Pit B offers a very good view of glaciotectonic structures (folds and faults). The wall is perpendicular to the trend of the folds and consequently one sees the true profile of the folds. A sketch of the face is given in figure 26. Three lithologic units can be distinguished in the deformed Paleocene rocks. They are, starting from the bottom, and in this case from the left: a lower unit of massive sandstone with two prominent ironstone layers; a middle unit of interbedded sandstone, mudstone and siltstone; and an upper unit of massive sandstone containing some coalified trees. The stratigraphic top of the sequence was determined from crossbedding in the massive sandstone.

The folding is well outlined by the contact between the upper and middle units (sandstone and the interbedded unit). The direction of the fold axes is very consistent with a trend of N70°E and a plunge of 3° (figure 12). The lower unit with the ironstone layers is overturned with the axial-plane of the fold dipping 40° in a direction N340°E. The folds (as indicated by the orientation of the axial plane) suggest a movement direction of N160°E. The incompetent middle unit forms a zone of disharmony as shown by the straightness of the ironstone layers. Three north dipping thrust faults can be seen (their poles are plotted on figure 12). They show the same sense of movement in a direction N160°E. Two other faults are dipping to the south. They are so-called "back thrusts" and are indicative of layer-parallel shortening. All faults are clay filled.

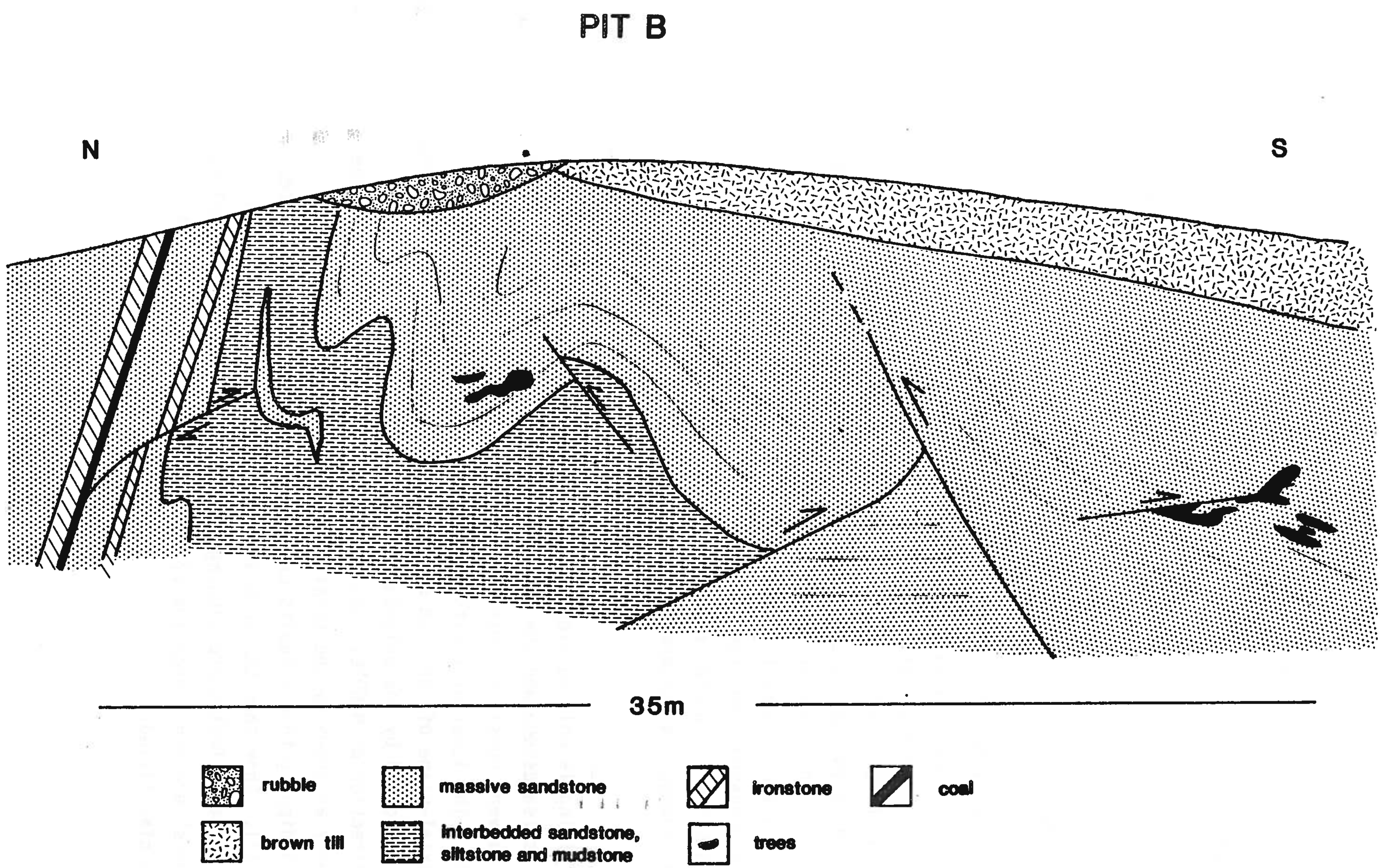

Figure 26. Sketch of Pit B face.

In summary this outcrop indicates that the glacier advanced in a direction N160°E in this particular area. This direction is slightly oblique to the directions determined in Pit A and ramp 3-1.

Stop 3: Mine North of Pit B

Proceed northward from Pit B toward Pit 03. On the upper bench a dark glacial till can be observed on top of glacially deformed Paleocene sandstone. An anticline is outlined by some calcite cemented layers. The trend of the fold axis is east-west.

Descend into the main pit. The coal is not yet mined at this particular spot. We are standing on the contact of the Paleocene Ardley Coal and its overburden. At the bottom we see a mudstone overlain by a thin coal seam containing a 10 cm thick bentonite layer. This bentonite layer can be followed along the entire highwall of the pit. The thin coal seam is overlain by two (and in places three) fining upward units of sandy siltstone and mudstone. The bottom part of the lowermost unit is extensively rooted.

This overburden sequence is in places glacially deformed. North dipping thrusts have sheared off thin layers of coal. Some listric normal faults displace the layering. They are probably a result of loading caused by ice and overburden. Notice some well developed joint planes in the overburden.

Stop 4: Highwall Failure East End Pit 03

This stop will examine the area at the east end of Pit 03. The purpose is to view the highwall failures in progress and comment on the types and causes of the failures.

The geology is from the top of seam 1 upward: about ~1 m of interlaminated mudstone, coal and bentonite, ~3 to 4 m of fractured mudstone; ~12 m of sandstone and ~0 to 2 m of till. All the sediment has been deformed by glacial thrusting; the basal shear plane is just above the coal.

The overburden is saturated to within a few metres of the surface, the hydraulic gradient is northward into the pit. Permeability is low and therefore drainage is slow to nonexistent.

Additional comments can be found in the background information provided earlier in the guidebook.

Deformation initially involves exfoliation of the newly exposed face and mass wasting of the spalled block deposited at the base of the cut followed by the development of vertical fractures, manifesting a combination of stress release and block slide. Subsequently small and later larger rotational slumps develop and greater northward (pitward) movement of the block slides, causes further opening of existing vertical fractures and the creation of others. The result is massive and widespread failure in the bench and the adjacent land surface to the south. The large rotational slumps can occur within a period of less than 12 hours.

Stop 4a. Upper Bench

The most prominent feature is the rotational slumps. One slump is likely due to remobilization of a pre-existing glacial shear plane. Evidence for this is: (1) the slide is oriented at an angle to the face rather than parallel to it; all other slumps are parallel to the face. (2) the block movement has been diagonally across the shear plane rather than vertically down it. (3) the slide surface consists of about 1 cm of clay rich fault gouge between sandstone masses unlike the other slumps. the other slumps are oriented parallel to the face and are sandstone slipping vertically over sandstone without the fault gouge.

Stop 4b. Coal Bench Below Stop 4b (Weather Permitting).

The most important feature exposed in the face is the groundwater discharge visible at the contact between the sandstone and the underlying fractured mudstone. Much of the movement associated with the block failure is believed to be along the sandstone mudstone contact. The mudstone does not become involved in the failure until much later in the process.

The basal glacial shear plane is likely just above the coal where a 3 cm bentonite layer is visible. This plane is difficult to recognize at a distance because the face is perpendicular to the direction of glacial thrusting.

Stop 5: Dragline

Four draglines are present on the mine site. We will examine one not currently in operation, likely "The Lady of The Lake" in Pit 04.

Stop 6: Pit A (Time Permitting)

The west wall of Pit A offers another good perpendicular view of glaciotectonic structures. A sketch of the exposure is given in figure 27. The main lithology present is massive sandstone of the Paskapoo Formation. The layering in this sandstone is steeply dipping in the south part of the pit as indicated by a hard, well cemented layer. In the north part the dip is gently to the north.

In the central part of the exposure an anticline is outlined by the layering. The massive sandstone weathers easily because of a lack of cementation and as a result the layering is not always clearly visible. Two clay filled thrust faults occur near the core of the anticline. Their straightness indicates that they formed in a late stage of the folding process.

On the north limb of the anticline the lower-most lithologic unit, consisting of interbedded sandstone and mudstone, is thrusted southwards along several north dipping clay filled faults. The orientation of the mean thrust plane has a dip direction of N2°E and dip of 49° (figure 12). The anticline has a fold axis with a plunge of 4° in direction N70°E. The anticline could also be measured on the east wall of the pit. Here the fold axis is trending in direction N96°E with a plunge of 4°. Averaging these two trends one can obtain a possible glacial advance in direction N174°E. The direction of movement is indicated by the orientation of the north dipping axial plane and the sense of fault movements (figure 27). In this model the movements along the thrust planes are assumed to be slightly oblique. Alternatively these observations could be explained with separate phases of shortening in different directions. However, because of a lack of overprinting relationships, we prefer the single phase movement model.

PIT A

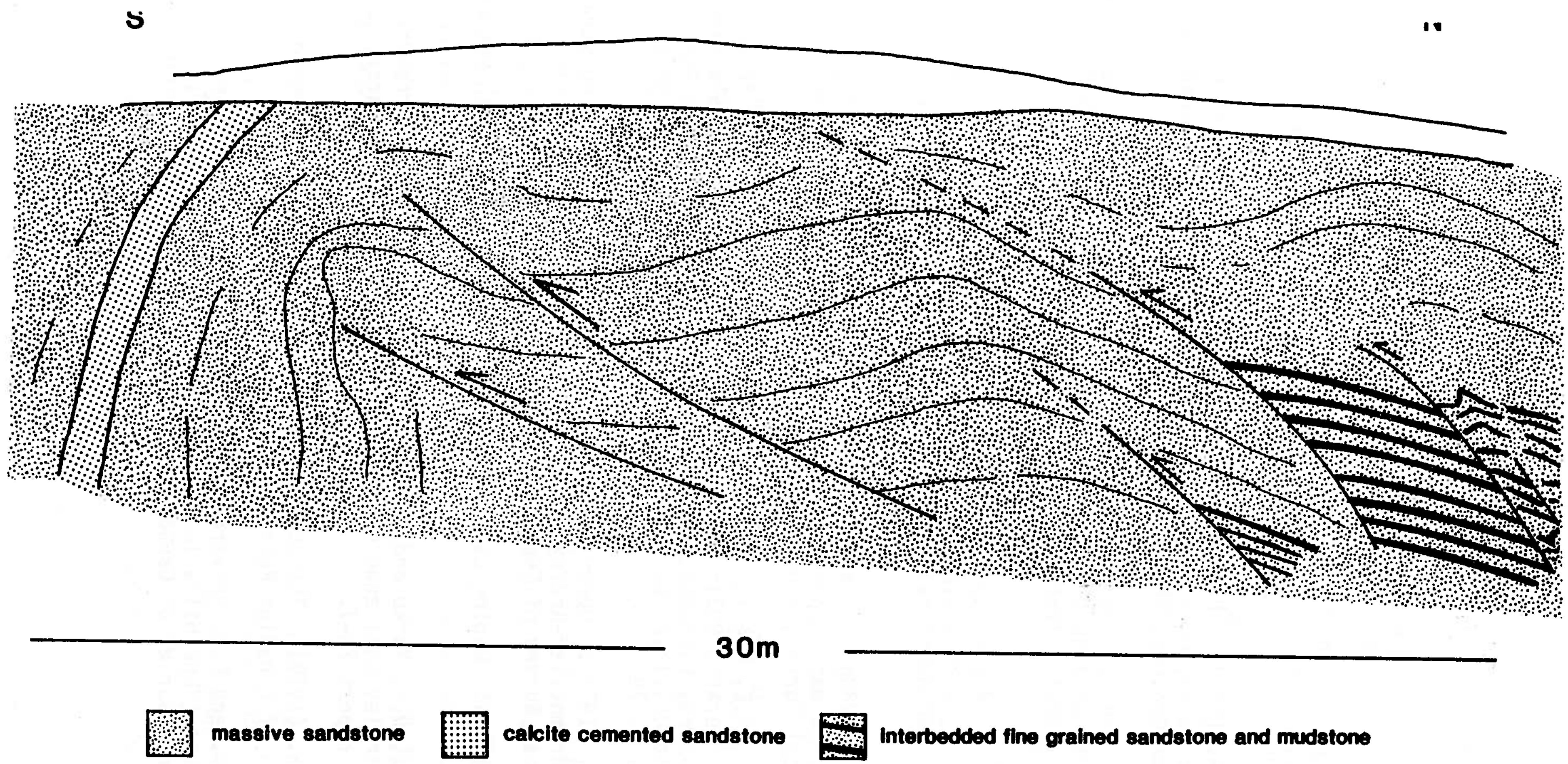

Figure 27. Sketch of Pit A face.

REFERENCES

Anonymous (1984): Mining Information Brochure, TransAlta Utilities Limited, 13 p.

Andriashek, L.D., C.P. Kathol, M.M. Fenton and J.D. Root (1979): Surficial Geology - Wabamun Lake NTS 83G. Alberta Research Council Map.

Carrigy, M.A. (1970): Proposed revision of the boundaries of the Paskapoo Formation in the Alberta Plains: Bulletin of Canadian Petroleum Geology, 18, pp. 156-165.

Fenton, M.M. and L.D. Andriashek (1978): Glaciotectonic features in the Sand River area northeastern Alberta, Canada: Abstracts 5th Biennial meeting American Quaternary Association, Edmonton, Alberta, p. 199.

Fenton, M.M. (1983a): Deformation terrain mid-continent region: Properties, subdivision, recognition: Geological Society of America, North-Central Section, Program with Abstracts, v. 15, n. 4, p. 250.

Fenton, M.M. (1983b): Preliminary Glaciotectonic Map, Highvale Mine: Unpublished map prepared for TransAlta Utilities by Alberta Geological Survey, Alberta Research Council.

Fenton, M.M., C.E. Moell, J.G. Pawlowicz, G. Sterenberg, M.R. Trudell and S.R. Moran (1983): Highwall Stability Project, Highvale mine study report, December, 1983: unpublished report prepared for TransAlta Utilities by Alberta Geological Survey, Alberta Research Council, p. 70.

Gibson, D.W. (1977): Uperr Cretaceous and Tertiary Coal-bearing strata in the Drumheller-Ardley region, Red Deer Valley, Alberta: Geological Survey of Canada Paper 76-35.

Green, R. (1972): Geological map of Alberta. Alberta Research Council map.

Holter, M.E., J.R. Yurko and M. Chu (1975): Geology and coal reserves of the Ardley coal zone of central Alberta: Alberta Research Council report 75-7.

Irish, E.J.W. (1970): The Edmonton Group of South-Central Alberta: Bulletin of Canadian Petroleum Geology, 18, pp. 125-155.

Irish, E.J.W. and C.J. Harvard (1968): The Whitemud and Battle Formations ("Kneehills Tuff Zone"), a stratigraphic marker: Geological Survey of Canada Paper 67-73.

Lerbekmo, J.E., C. Singh, D.M. Jarzen and D.A. Russell (1979): The Cretaceous Tertiary boundary in south-central Alberta - a revision based on additional dinosaurian and microfloral evidence, Canadian Journal of Earth Sciences, 16, no. 9, pp. 1866-1869.

Maslowski Schutze, A. (1984): Geology of the Highvale study site: Plains Hydrology and Reclamation Project: Alberta Research Council internal report.

Moran, S.R., Lee, Clayton, R.LeB Hooke, M.M. Fenton and L.D. Andriashek (1980): Glacier-bed landforms of the prairie region of North America: Journal of Glaciology. v. 25, n. 93, p. 457-476.

Nikols, D. (1985): October, 1985 Calendar, Canadian Society of Petroleum Geology.

Tapics, J.A. (1984): The Highvale Mine - Developments in the next ten years: 86th Annual General Meeting of CIM - 1984, paper no. 78.