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CONSULTING GEOTECHNICAL ENGINEERS

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IN ASSOCIATION WITH
PD-NCB CONSULTANTS LTD.
&
WRIGHT ENGINEERS LTD.

REPORT NO. 4
HAT CREEK GEOTECHNICAL STUDY
INTERIM CONCLUSIONS

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SUMMARY

The geotechnical study described in this interim report was carried out as part of a feasibility study on the mining of the Hat Creek No. 1 coal deposit down to an elevation of 2400 feet.

The results obtained to date indicate that:

a. The rock types in which the ultimate pit slopes will be mined are generally very weak and steep slopes are unlikely to remain stable for long periods of time.

b. High groundwater levels exist in the proposed open pit area and the low permeability of the rock mass will make drainage difficult and expensive.

c. One active landslide and several areas of previous landslide movement have been identified in the pit and waste dump areas and special precautions will have to be taken to stabilise these landslide materials.

As a result of these conditions it is concluded that:

a. Overall final slope angles of 15° to 16° should be used as a basis for the determination of stripping ratios for the evaluation of the cost of mining this deposit.

b. Drainage of surface water collected in small lakes and ponds on the western side of the deposit will be necessary in order to improve the stability of the landslide debris.

c. Sub-surface drainage will be required in critical areas such as the access ramp slopes and it may permit significant steepening of the slopes in other areas. The cost and economic benefits of a large scale sub-surface drainage program should be evaluated as part of the detailed mine design studies.

d. Small scale bench failures will be a regular occurrence during the mining of this deposit but these failures will generally be slow moving and are not expected to pose a threat to men and equipment in the mine. The mine design proposed by PD-NCB Consultants is considered ideal because it has been designed to accommodate such small scale bench failures.

e. The waste dump site in Houth Meadows is unsuitable for large volumes of materials and it is recommended that carefully engineered berms be placed across the toe of this waste dump area and that the poor materials and landslide debris from the western side of the open pit be placed in this dump area. The dump face should be established at a slope of approximately 1 in 10.

Adequate capacity for disposal of better quality waste materials exists in the Medicine Creek valley.

The size of the Hat Creek coal deposit and the complexity of the geological history of the area precludes the possibility of a precise pit design, and it is strongly recommended that provision be made for on-going design studies during the life of the pit. The recommendations presented in this report are believed to provide a reliable basis for feasibility studies. Experience suggests that knowledge gained during early phases of mining provides the most reliable basis for slope design in a rock mass such as that being considered at Hat Creek. It is probable that significant improvements in slope angle can be achieved if the mining program is flexible enough to accommodate these improvements.

1.0 INTRODUCTION

1.1 Scope of Study

In May, 1976 the proposal submitted to BC Hydro by Golder Associates in association with PD-NCB and Wright Engineers for the geotechnical study of the Hat Creek No. 1 Coal Deposit was accepted. The scope of the study was as follows:

To assess the feasibility of the mining of the Hat Creek coal deposit down to elevation 2,400 ft. with respect to the following questions:

1. the stability of the ultimate pit slopes,
2. the stability of the access ramp and the operating benches,
3. the stability of the surficial materials, particularly those mudslides already identified,
4. the location of suitable waste dump sites,
5. the stability of the waste dumps, and
6. ground water conditions within the surficial deposits, the coal, and other deposits forming the mine and adjacent pit slopes, and an assessment of their probable drainability.

1.2 Method of Study

In order to complete the geotechnical feasibility study the following activities were undertaken:

1. A diamond drilling program to investigate the nature and distribution of those rocks which would be present in the open pit slopes and to obtain samples for testing.
2. Installation of piezometers to establish the pattern of ground water flow within the coal deposit and the surrounding rock.

3. In situ permeability testing to assess the representative permeabilities of the materials.
4. Execution of a pumping test to assess the drainability of the materials.
5. Installation of slope indicators to permit measurement of subsurface horizontal displacement, and determination of rates of movement of existing slides and to locate slide planes.
6. In situ index testing of materials.
7. Laboratory testing to assess the strength characteristics of various rock types.
8. Analyses of the stability of ultimate pit slopes and access ramp slopes.

The field work was commenced at the beginning of June, 1976 and was largely completed by the end of August, 1976. A total of 10,072 ft. of diamond core drilling was completed in 20 holes, 999 ft. of rotary drilling in 7 holes for permeability testing, 957 ft. of rotary drilling in 5 holes for slope indicator installation and 2,280 ft. of rotary drilling in 5 holes for pump testing. In addition 2,178 ft. of percussion drilling in 29 holes was carried out to comparatively shallow depths in surficial deposits. The hole locations are shown on Drawing 1.

1.3 Relationship to Other Studies

The Geotechnical Study is part of the PD-NCB Mining Study the conclusions of which are contained in the PD-NCB Report No. 2 entitled "Preliminary Report on Hat Creek Openpit No. 1", dated March, 1976. Golder Associates provided an earlier input to that study.

Close liaison was maintained with PD-NCB throughout the study and all implications for any aspects of the mining were communicated to them.

There was much inter-action with Dolmage-Campbell and Associates, especially on site, as both organizations were investigating different aspects of the geology of the coal deposits. Piezometers were installed in holes drilled under Dolmage-Campbell's direction, and samples were also taken from their cores for testing. Their co-operation is gratefully acknowledged.

Discussions were held with Integ-Ebasco, Wright Engineering, Monenco, and Acres on those aspects of common interest. Samples taken by Golder Associates in the course of the early BC Hydro auger hole program were made available to Acres to assist them in their sampling program.

There was considerable contact with the BCH Hat Creek Project team during the study, and acknowledgement is made for the considerable help and assistance provided to us.

2.0 GEOLOGY

2.1 Geological Setting

The area being considered lies in the southern extension of the Interior Plateau province of British Columbia and is bounded by the Coastal Range Mountains to the west and the North Cascade Mountains to the southeast. The rocks of the Hat Creek area consist broadly of sedimentary and volcanic rocks of Jurassic and Cretaceous age uplifted by fold and fault movements during the formation of the mountain chain. Granitic rocks were intruded into the sedimentary rock sequence during that period and much of the rock mass was metamorphosed.

Tertiary sediments were subsequently deposited in basins formed within the folded areas and volcanic material was extruded both simultaneously and subsequent to the sedimentation. In comparatively recent time the area has been mantled by surficial deposits.

2.2 Stratigraphy

The Tertiary basin formed of Coldwater Formation sediments occupies the lower slopes of the Hat Creek valley upstream of Marble Canyon (see Drawing 2). The margins of the basin surrounding the Hat Creek valley are formed of older rocks. Many of these rocks are overlain by volcanic rocks but the exact relationships are not clear and some of the volcanic rocks ~~may~~ either pre-date ~~or be contemporaneous~~ with the Coldwater Formation.

A thick sequence of limestones, known as the Marble Canyon Formation outcrops to the north and northwest of Hat Creek, as well as forming the Cornwall Hills to the east. A sequence of mixed rocks including greenstones, cherts, argillite, quartzite and limestones outcrops to the east of Hat Creek. In the southwest flat-lying volcanic rocks form the edge of the basin. Intrusive granodiorite forming Mount Martley occupies the area in the west. Other than in the escarpment immediately east of Hat Creek, the volcanics are poorly exposed, and their lack of outcrop and extreme variability make their stratigraphical relationships difficult to determine.

The Coldwater Formation comprises three main units as shown below and on Drawing 3:

1. Siltstones with claystones and tuff bands, often bentonitic. Sandstones may be developed towards the basin margins.

2. Coal with thin siltstone or claystone interbeds. The coal has been divided into four zones by Dolmage-Campbell from A-D in descending order.

3. Sandstones, conglomerates, siltstones and some claystones. They are highly variable in character especially near the margins of the basin and often tuffaceous.

The lower unit is predominantly green or grey in colour and because of the variation in facies, correlation between drillholes is generally not possible. The grading and composition of the coarser clastic beds is much dependent on their location within the basin and their relation to the source of detrital material. However, the high proportion of tuffaceous material in some rocks indicates that volcanic activity probably occurred during sedimentation in the basin.

The zones in the coal are based primarily on the presence of interbeds and purity of the coal. Although four zones are recognizable over most of the central part of the basin, they are less distinct towards the margins and give out into carbonaceous sediments which are extremely difficult to correlate. Tuff bands are developed at some horizons and may occasionally be bentonitic although are not normally so.

The upper unit of the Coldwater Formation consists of a very regular sequence of siltstones and more occasionally claystones. The grain size of the rocks is variable and often not easy to determine. Tuff bands, very often altered to montmorillonite, are present at regular intervals throughout the sequence; when more data are available it may prove possible to use these for purposes of correlation. Towards the edge of the basin sandstones and conglomerates interdigitate with the fine-grained beds.

Glacial and Recent surficial materials cover the whole site and effectively mask all outcrops. To the east of Hat Creek itself a channel was eroded during glacial times to a maximum depth of some 400 ft. below the present floor of the valley. This channel has been filled by a sequence of dense sands and gravels and hard tills. A thin veneer of glacial materials covers most of the slopes west of Hat Creek. Thin alluvial deposits are present in the bottom of the valley overlying glacial deposits.

Slide zones of various ages are present on the west bank of the valley and represent instability in both the surficial material and in the Coldwater Formation. One shallow flow slide in excess of one mile in length is currently moving; other slides are of doubtful current stability; most are stable under present conditions.

2.3 Structure

The Coldwater Formation rocks form a truncated elongate basin with a north-south axis which has a low point towards the southern end of the coal body. The structure plunges steeply at angles of up to 40° towards the centre of the basin. It is likely that it has resulted both from the prolonged subsidence which must have operated during the formation of the coal, and the subsequent history of folding.

Many faults exist within the Hat Creek area but few can be substantiated by field evidence well enough to be regarded as definite. However, drilling has indicated that the coal is cut-off to the south by a northeast trending structure termed the Finney Fault. This fault must have a throw in excess of 2,000 ft. It is highly likely that a fault with a similar trend cuts off the coal at the north of the deposit; carbonaceous siltstones and sandstones to the northwest are brought against thick coal to the southeast.

Folding or faulting with a near-northerly trend affects the basin in the northeast in the vicinity of Hat Creek developing a sub-basin in this part of the pit.

Other faults undoubtedly exist but their effect on the coal and related beds is too small to be picked up with the drilling spacing as carried out at present.

Discontinuities in the Coldwater Formation rock cores have been recorded but they are generally widely spaced. Considerable brecciation has been recognized and shearing is not uncommon.

Regional structures may be recognized from the aerial photographs and have a predominant northeast to southwest trend. However, a major fault runs down Marble Canyon trending to the southeast and it is likely that the volcanic rocks to the east and west of the valley are faulted along the north-south trending structures.

2.4 Geology of Waste Dump Areas

The original planned locations for the waste dump areas for the 600 ft. pit were to the northwest in Houth Meadows, and to the north on the sides of the Hat Creek valley. This report recommends that large dumps be considered in the Medicine Creek area previously reserved for the waste from the 1,500 ft. pit. Initial investigations have shown that Houth Meadows is generally underlain by soft slope outwash material overlying stiff glacial materials. Major instability exists to the south and southwest of that valley. The ridge separating Houth Meadows from Hat Creek is formed by the Marble Canyon and Coldwater Formations overlain by glacial till. The limited dumps to the north of the pit would be founded on fluvioglacial sands, gravels and silts.

There is little exposure in the Medicine Creek area. Greenstones underlie the east of the area and Coldwater Formation is likely to be present further west. However, the thick glacial cover precludes further comment without the results of additional drilling. Nonetheless very little existing instability exists and there is no reason to anticipate that further slides will be found.

3.0 HYDROLOGY

3.1 Instrumentation

The emphasis of the geohydrologic investigation to date has centered on the installation and reading of piezometers placed in cored holes drilled both for the Golder Associate program as well as the Dolmage-Campbell program. In most cases one piezometer was installed at full depth with the rig on site and another was installed at a shallower depth after the drill had moved. Approximately 40 holes were instrumented and both pneumatic and standpipe-type piezometers were used.

In order to determine the in situ permeabilities of representative materials six 6 in. diameter air-flush rotary holes were drilled and piezometers placed in them at selected intervals of depth. All such holes were drilled adjacent to existing cored holes to facilitate interpretation. Falling head tests were carried out in these holes and permeabilities calculated.

A further check on the permeability of the rock mass was achieved by conducting a pumping test in the Coldwater sediments. A single 8 in. production well and three 6 in. diameter observation wells were drilled with the rotary air-flush rig. The observation wells were instrumented with 3 pneumatic piezometers per hole to monitor piezometric pressures during pumping. The purpose of the test was to assess the drainability of the sediments particularly in the fine grained siltstone-claystone sequence. A secondary objective was to determine the effect, if any, of the Finney Fault on the local hydrological picture.

3.2 Regional Hydrology

Based on the results of the above program, the regional hydrological aspects of the Hat Creek Valley as they relate to mining the No. 1 deposit can be summarized as follows.

1. The claystones, siltstones, sandstones and conglomerates of the Coldwater Formation are largely impermeable but the coal is significantly more permeable.
2. Tertiary volcanics on the upper portions of both east and west valley sides are expected to be permeable and the west side especially might provide significant inflows into the pit, unless it is externally dewatered.
3. The coal deposit itself can be regarded as relatively permeable and will probably drain quite easily, possibly providing significant pit inflows.
4. The fluvioglacial sands and gravels within the surficial deposits of the area are considered to be relatively permeable.

3.3 Hydrology of Proposed Pit Area

3.3.1 Piezometric Levels

The network of piezometer installations throughout the area of the proposed open pit have indicated the following general points.

1. Piezometric levels within all rock and surficial units are high (usually within 100 ft. of the ground surface). Local variations in piezometric levels (i.e., the Dry Lake area) have yet to be explained by existing geological data.
2. Lows in the ground water table on the east bench appear certainly to be related to the depth of the surficials in this area but other aspects, such as flow patterns in the material will require further detailed analysis.
3. It appears quite possible that artesian conditions either contribute to, or result from, the presence of an active slide plane in the northwest corner of the deposit. High piezometric levels in addition to artesian water flows during drilling are evident in several holes in this area.
4. Based on a limited number of deep piezometers it seems that piezometric elevations at depth are not significantly different from the more shallow data.
5. High water flows up to 40 gal/min. were observed in some air-flush rotary holes drilled in surficial deposits. These sediments have permeabilities in the range 10^{-3} to 10^{-4} cm/sec. There is little evidence of a significant alluvial deposit in the present Hat Creek watercourse.
6. Outcrops of massive limestone occur to the northeast and southeast of the valley. While the limestone is probably highly water bearing, the influence of these deposits on the valley hydrology is at present unknown.

3.3.2 Pit Stabilization Aspects

Based on the above piezometric regime and material permeabilities, it seems likely that a significant inflow of water will occur from the surficials, volcanics, and the coal, especially early in the pit life. However, the Coldwater sediments other than the coal, which will form much of the final pit walls, do not appear to be easily drainable within the time available for mine development. An extensive network of wells, adits or other depressurization installations could offer some prospect of stabilization by reduction of pore water pressures, but further investigation will be necessary to determine how effective they would be. The pump test currently in progress will clarify the drainability of the materials when it is complete in late October.

4.0 GEOTECHNICS

4.1 General

The Golder Associates diamond drilling program was carried out almost entirely in the Coldwater Formation sediments which will be present in the final pit walls. Almost without exception these rocks were found to be inherently weak and highly susceptible to desiccation or expansion. In consequence, so that the true material properties could be assessed, all the core from the Golder Associates geotechnical program was logged immediately as it was extruded from the barrel and index testing was carried out on site wherever possible.

4.2 Rock Types

Due to their mode of deposition as facies deposits in a local basin, a complete spectrum of materials exists from claystone-siltstone-sandstone-conglomerate, with the coal being characteristic of a very particular environment within that basin. Uniform conditions were operative during some periods of deposition however, and the upper part of the Coldwater sequence shows very little variation in comparison with the lower two units. Despite this variation the test results show that the geotechnical properties fall into several quite separate categories which have been used in subsequent analysis.

The materials present in the Coldwater sequence fall within the strength range of very stiff to hard soils and weak to moderately weak rocks. They mostly represent heavily overconsolidated soils in which fissuring has developed. Some degree of cementation may be present, but lithification is poor. Alteration is common, however, and in the tuffaceous rocks especially, many of the silicate minerals have been changed to montmorillonite. Weathering is difficult to assess because of the low strengths involved and discolouration and softening are the only marked expressions discernible.

4.2.1 Conglomerates

Conglomerates form much of the sequence below the coal and will outcrop in the west, northwest and north walls of the pit. They generally comprise fine to coarse gravel-size material, with occasional cobbles, set in a sandy or silty matrix. Their strength is much dependent on the matrix and the extent to which the gravel particles are in close contact. They are generally interbedded with sandstones and occasionally with siltstones, and are grey-green in colour. They grade into tuffs as the proportion of volcanic material in the matrix increases.

4.2.2 Sandstones

The sandstones cored are usually green or grey, medium to fine grained and grade into siltstones. They may be completely structureless or alternatively closely interbedded with siltstones. The constituent minerals are rarely quartz but more generally weak feldspar and clay minerals. In the west of the area highly micaceous sandstones derived from the granodiorite are common.

4.2.3 Siltstones

The siltstones are grey or brown in colour and contain varying admixtures of clay or sand. They may be montmorillonitic and are susceptible to shearing and brecciation. Although some siltstones are structureless, many show some bedding and may even be shaley. Claystones have been described from the sequence but generally these rocks would be more aptly described as clayey siltstones.

4.2.4 Coal

The coal appears to be the strongest member of the Coldwater Formation. It varies from the clean pure variety to dirty material more correctly called carbonaceous siltstone. It is closely cleated and may contain interbeds of siltstone or tuff.

4.2.5 Other Material Types

Volcanic tuffs, or ashes as they may be called if poorly cemented, are particularly characteristic of the upper part of the sequence, although they are present to a lesser extent elsewhere. They are frequently highly bentonitic, and although at present difficult to follow between drillholes, they may be continuous over significant distances.

A suite of volcanic rocks has been shown to underlie the Coldwater Formation in the east at least. The only rock tested, an andesite, shows a strength significantly higher than the overlying rocks.

Sandy bentonites often underlie the surficial materials and may be partially responsible for their instability. They are cream to light green in colour and show the typical hackly texture and soapy feel of highly expansive minerals.

4.3 Index Tests

Index testing was carried out in the field and in our Vancouver laboratory to determine Atterberg limits and natural moisture contents of the fine grained materials encountered. The range of values measured are as follows:

Liquid limit	35 - 320%
Plastic limit	20 - 62%
Plasticity Index	10 - 280%
Natural moisture content	10 - 83%

Generally the natural moisture contents of the materials encountered were very close to the plastic limit with the liquid limits rising to very high values. High values for liquid limits are often associated with materials containing a very active, i.e. swelling, clay mineral such as montmorillonite. Because of these very high index values, samples were sent to Dr. R.M. Quigley at the University of Western Ontario, London, Ontario for analysis by X-ray diffraction to determine the clay mineralogy. The results to date indicate that almost all the samples tested show the presence of montmorillonite. The presence of an active clay mineral, such as montmorillonite, suggests that the minerals could have very low permeabilities, low residual shear strengths and high swelling characteristics.

4.4 Rock Strength

Strength testing has been carried out in two ways, unconfined compressive strength testing in the field and detailed shear strength testing in the laboratory. The unconfined compressive strength testing was performed to assess the variation in strengths of the rock types encountered and to provide semi-quantitative rock grade indices.

The average unconfined compressive strengths of the main rock types are as follows:

Andesite	>3000 lb/in^2
Coal	1250 lb/in^2
Conglomerate	850 lb/in^2
Sandstone	450 lb/in^2
Siltstone	280 lb/in^2
Clayey Siltstone	75 lb/in^2

The shear strength testing is continuing in the laboratory to establish shear strength parameters in terms of effective stresses. These tests include consolidated undrained triaxial tests with pore pressure measurements, and consolidated drained triaxial tests with volume change measurements. Because of the very low permeability of the materials involved, the shear strength testing has been carried out at very low strain rates to allow full dissipation of pore water pressures.

The materials tested to date in the shear strength program are the weaker materials as indicated by the unconfined compressive strength results. The grain size of the conglomerates makes them unsuitable for small diameter testing. The criteria for failure has been taken as the point of maximum effective principal stress ratio σ_1'/σ_3', with the shear strength parameters, c', the apparent cohesion and $\emptyset'$ the angle of internal friction, expressed in terms of effective stresses. The shear strength parameters determined to date are as follows;

Sandstone	$\phi' = 32°$,	$c' = 14{,}500\ lb/ft^2$
Siltstone	$\phi' = 27°$,	$c' = 3{,}000\ lb/ft^2$
Clayey Siltstone	$\phi' = 10°$,	$c' = 1{,}500\ lb/ft^2$

The result for the clayey siltstone probably represents a value close to the residual shear strength for that material, as the samples tested were strongly disturbed and contained many discontinuous sheared surfaces. Great care has been taken in the handling and preparation of test samples, but because of the friable nature of most of the material, sample disturbance and weakening is inevitable. The measured strengths probably represent a lower limit for the material as it would exist in the pit slopes sometimes after excavation when softening of the rock has had time to occur. Where high swelling minerals are present, excavation may cause lateral yielding to such an extent that shear strengths along potential failure surfaces are reduced to residual values. Work is continuing on the measurement of residual shear strength parameters, and on stability analyses taking account of these results.

The behaviour of the materials during shearing is typical of many heavily overconsolidated soils in that the test specimens initially compress and then dilate to produce a single failure surface in the drained triaxial condition.

Testing to establish the residual shear strength is presently being undertaken at the University of British Columbia in a reversible direct shear machine. Results from the first test show a residual angle of friction, ϕ_r', of 8.5° on the slickensided surfaces of a clayey siltstone sample.

4.5 Permeability

Field permeabilities have been measured by falling head tests at shallow depth in the Coldwater Formation sediments, and in the volcanics. A pumping test is currently in progress. Permeabilities in the volcanics and coal appear relatively high (approximately 10^{-4} cm/sec.) while the other Coldwater sediments appear to have relatively low values of approximately 10^{-8} cm/sec.

4.6 Rock Mass Properties

Examination of the rock as revealed in the drill cores shows that the rock materials are intersected by joints, faults and shear zones; similar features are seen in the small outcrops on the site. However, none of these discontinuities is sufficiently prominent to be traced from one drillhole to the next on the present drillhole spacing. It is considered that because of their small dimensions in relation to the failure surfaces being considered these rock mass discontinuities should be discounted as a major factor in the failure mechanism.

Rock structure may also be produced by the interlayering of material types. The interbedding of sandstones and claystones for example could permit structurally controlled failures where the beds are uniformly folded or tilted. However the range of dips encountered in any drillhole suggests that local folding is superimposed on the overall basin structure.

The presence within the rock masses of continuous very weak thin layers of bentonites, derived from weathered volcanic ashes cannot be discounted at this stage. Studies are underway to examine orientation of the bedding of such materials that could prove critical to the pit slope stability.

5.0 ENGINEERING ANALYSIS

5.1 Stability of Pit Slopes

5.1.1 Critical Areas

At the outset the assumption has been made that local bench failures of the pit slopes will be a reoccurring feature and can be handled as a part of the system of mining.

The critical issues are:

a. the probability of overall pit slope failures,

b. the failure of sections of the cut along the access ramp, which could lead to ramp closure.

5.1.2 Failure Mechanisms

For the purposes of stability analysis, it has been assumed that an ideal condition exists in which the material on any section in the slope is homogeneneous and of uniform strength. This implies that within the slope there are no preferred planes of weakness of sufficient extent to bring about a massive slope failure in such zones. Undoubtedly preferred planes of weakness would exist in the actual slopes, but it is assumed that these would not cause more than small block or bench failures. The evidence on which these assumptions are based is inconclusive, but the general lack of correlation between boreholes drilled to date indicates that any preferred planes of weakness that do exist are likely to be local in extent. Slope indicators installed in slide areas on the west side of the deposit will be monitored over the winter, and the results may throw some light on this problem. Furthermore the material strengths from visual examination and laboratory tests seem confined to a narrow range for material classified as either very weak rock or stiff soil. In general terms, therefore, it is our opinion that structural features such as joints and bedding planes will not control the mode of failure as is usually the case for stronger rock masses. The material will in contrast fail as a fissured or brecciated overconsolidated clay. In practice the shear strength of such material is time dependent. Hence, while such material may stand for a time at comparatively steep slopes, in the very long term, slopes will fail and flatten. This is the condition of natural slopes seen in Hat Creek today. An open pit excavation in Hat Creek materials would obviously stand at steeper angles immediately after excavation, and fail some time in the future, the time to failure depending on the rate of softening due to water and hence on the permeability of the material. The lower the permeability the lower the rate of softening and strength loss.

5.1.3 Long Term Slopes

Analysis of existing slopes in Hat Creek particularly along the south side of Houth Meadows indicates that a slope 300 ft. high has failed at an angle of about 20° possibly in weak conglomerates. This indicates ultimate shear strength parameters of $\phi' = 30°$ along that particular section, assuming that in the long term, the cohesion decreases to zero.

Results of preliminary triaxial compression tests carried out under drained conditions, which represent long term strengths, indicate that shear strengths can be as low as $c' = 1{,}500$ lb/ft^2 and $\phi' = 10°$ for highly plastic slickensided clayey siltstones, and as high as $c' = 14{,}500$ lb/ft^2 and $\phi' = 32°$ for sandstones and conglomerates. Middle of the range siltstones indicate $c' = 3{,}000$ lb/ft^2 and $\phi' = 27°$.

Mining studies carried out by PD-NCB Consultants have shown that with the constraints of final slope angles, bench failure and operating conditions the overall slope angle would be between 15 and 16°. Stability analyses for a slope of this angle at the deepest section, namely along the west slope where the final pit wall would be 950 ft. high, and assuming a phreatic surface below the potential failure surface, indicate a factor of safety of 1.3 for average shear strength parameters within the range $c' = 1{,}000\ lb/ft^2$, $\phi' = 27°$ to $c' = 4{,}000\ lb/ft^2$, $\phi' = 19°$. These conditions would in general be met by the siltstone and obviously by the sandstone or conglomerate, but slickensided claystone/clayey siltstones would be inadequate. Thus, providing the slope is in material at least as good as moderately intact siltstone, or perhaps even claystone/clayey siltstone that has not suffered previous shearing, the ultimate slope should have an acceptable margin of safety for the time interval envisaged at the end of the mining operations. This assumes that no excess hydrostatic pressures exist above the potential failure surfaces. To achieve this condition, pressure reduction by means of drainage may be required in certain locations.

Clearly the above discussion implies uniform materials over the pit, and since conditions will vary, it follows that in some areas where materials are stronger, the slopes could be steepened, while in other areas where weaker rocks predominate the slope angles might need to be flattened. Since the clayey siltstones predominate in the upper end of the geological succession and would appear in the southeast wall of the pit, these slopes might need to be flattened. The degree of flattening or steepening elsewhere cannot be estimated until the testing program is complete and the geology is better defined. It is considered, however, that on the average the mean slope angle of 15 to 16° will be feasible in the ultimate pit. It is recommended that this slope angle be used in evaluating the overall feasibility of the project.

5.1.4 Short Term Slopes

Because of the limited height of operating slopes and because of the relatively short time for which such slopes would have to remain stable, bench face angles of 60° to 70° are considered to be feasible. Golder Associates have always maintained that some failures on unfavourable structural features will occur in those operating slopes and the overall pit development was designed to accommodate such failures.

5.1.5 Removal of Surficial Soils

The east and south sides of the pit are overlain by hard tills and dense sands and gravel, and these materials would not be subject to sliding at the slope angles of 15° to 16° envisaged for the pit. Slopes could be steepened in these deposits but as a result the underlying weaker rocks would be unnecessarily overloaded, and hence it is not recommended.

On the west side of the pit extensive slide movements are evident in the surficial deposits; old currently stable slides also exist and could be reactivated by mining activity. The active slides are composed of a mixture of glacial deposits and Coldwater sediments and are in a semi-fluid condition. They are unstable at slopes greater than 7 degrees. By draining the numerous lakes on the west side of the pit, movement of the active slide should be arrested to the extent that it would not flow into the pit as excavation proceeds. Alternatively the active slide material could be removed entirely prior to pit excavation.

5.1.6 Access Ramp

Cuts over much of the access ramp would be excavated in coal and testing of this material is not yet complete. However, indications are that cuts up to 300 ft. deep at slope angle not exceeding 25° would be permanently stable, providing good drainage is maintained. Fortunately drainage of the coal ought to be relatively easy to accomplish.

5.2 Waste Dumps

It is estimated by PD-NCB that about 1,150 million cu.yds. of waste rock and surficial soils would need to be banked outside the pit. Between about 10 and 20 per cent of this material, predominantly surficial mudslide debris, would be in a very soft or semi-fluid condition. As such the mud-slide debris could not be expected to stand in dumps at slope angles greater than about 1 in 10. It is proposed that this material would be dumped behind specially engineered retaining embankments in Houth Meadows. Embankments constructed of compacted sands and gravels up to about 100 ft. high between the limestone bluffs and outcrops as shown on Figure 2, would form the retaining embankments. The soft surficial materials could be dumped behind these embankments and the waste would slope up to about El. 3750. The volume of material thus contained would be about 350 million cu.yds.

Although examination of the topography shows that greater volumes of waste material could be contained in this area, the stability of the material would be questionable, either because of overtopping of the retaining embankments, or by failure of the south side of the dump walls into the pit itself.

The larger part of the balance of the waste rock material could be disposed of in Medicine Creek, where again engineered retaining embankments of sand and gravel or the sounder rock would be built, but to greater heights. A dump to El. 4100 as shown on Figure 2 would contain about 850 million cu.yds., bringing the total dump volume to 1,200 million cu.yds. Alternatively the height of the dump in Medicine Creek could be reduced to about El. 4000 and about 150 million cu.yds. of the waste material dumped to the north of the pit as planned in the PD-NCB Report No. 2.

6.0 CONCLUSIONS

At this stage in the Hat Creek Geotechnical Study with the 1976 field work complete and the laboratory testing program approximately half finished the following broad conclusions have been reached:

1. The final mine slopes of 15-16° as recommended in the PD-NCB mine feasibility studies will be possible provided that some drainage is employed. The cost of drainage of the low permeability materials is likely to be high.
2. The range of rock shear strengths, the distribution of materials in the slopes and the variation in slope heights indicate that some slopes will be considerably more sensitive to failure than others. It will be necessary therefore to concentrate drainage measures in certain areas of the pit.
3. Local steepening of the slopes will be possible where it can be shown reliably that materials with higher than average strengths will be present.
4. Removal of surficial materials on the west bank and the subsequent excavation of the pit could re-activate old slides. A continuous program of drainage and monitoring of movement will probably be necessary from the commencement of work on the pit.

5. Due to the presence of old flow slide debris, waste dumps formed only of weak surficial materials should be dumped in Houth Meadows.

6. An adequate site for the dumping of the major portion of the waste materials exists in Medicine Creek; the proposed small dump to the north of the pit is satisfactory.

7. Many of the waste materials will be bentonitic and will deterioriate rapidly on exposure. Handling problems may result and special measures may have to be employed to alleviate the difficulties.

8. It will be essential that special drainage measures be undertaken to ensure the stability of the 25° access ramp slopes.

9. Drainage of many of the small lakes on the western side of the proposed pit will be necessary in order to improve the stability of the flow slide materials adjacent to the pit perimeter.

Until our studies are complete we are unable to comment on the problems that might be encountered with bentonite in a coal preparation plant.

Our laboratory testing is continuing and will permit us to refine our ideas on rock strengths in due course. This data is unlikely to affect our main conclusions.

7.0 FURTHER PROGRAM

To complete the present geotechnical study program the following work has still be to carried out:

1. further triaxial testing of claystone, siltstone and coal;
2. index testing to complete the coverage from drillholes in various parts of the pit;
3. further geotechnical mapping using the 1:8000 aerial photographs;
4. semi-quantitative X-ray diffraction analysis by Prof. Quigley to determine proportions of swelling minerals present;
5. completion of the study of the coal interbeds to determine the nature of the fine grained beds;
6. detailed analysis of waste dump stability;
7. estimates of the availability of embankment construction materials.

Yours very truly,

GOLDER ASSOCIATES

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D.B. Campbell, P.Eng, Principal

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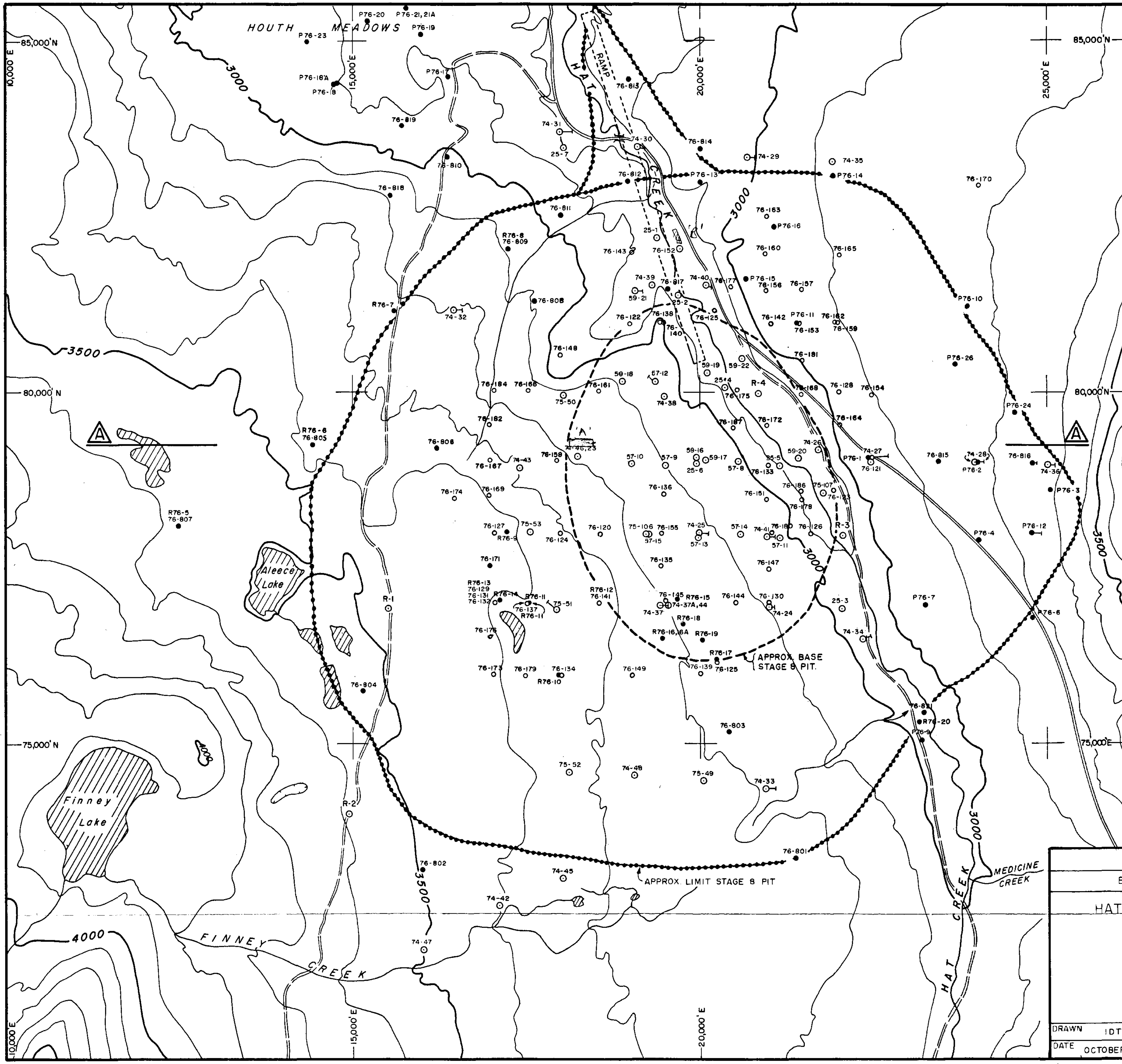
V76349



(M1)

LEGEND:

- ● GOLDER ASSOC. PROGRAM
- O DOLMAGE CAMPBELL PROGRAM

PREFIX:

'R' ROTARY HOLE

'P' PERCUSSIVE HOLE

ALL OTHER HOLES DIAMOND DRILLED

NOTE:

SECTION A-A SHOWN ON FIG. V76345-3.

DRILLING PERIODS :-

1925	-	HOLES 1 to 7
1957	-	" 8 to 15
1959	-	" 16 to 22
1974	-	" 23 to 48, R.1 & R.2
1975	-	" 49 to 110, R.3 & R.4
1976	-	" 111 onwards

SCALE - FEET

1000 0 0 1000 2000

Golder Associates

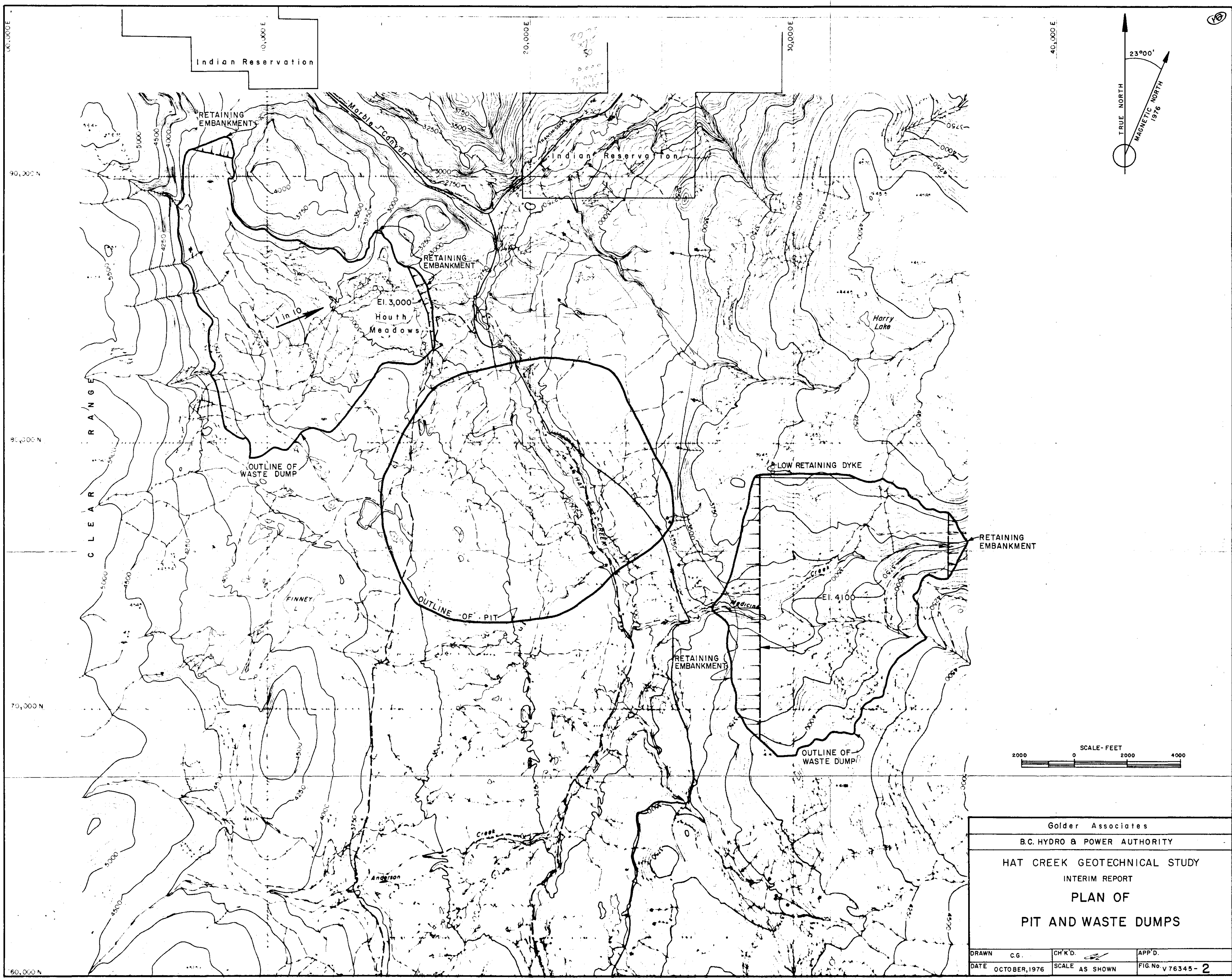
B.C. HYDRO & POWER AUTHORITY

HAT CREEK GEOTECHNICAL STUDY

INTERIM REPORT

LOCATION PLAN

DRAWN IDT	CH'K'D.	APP'D.
DATE OCTOBER, 1976.	SCALE AS SHOWN	FIG No V76345 - 1



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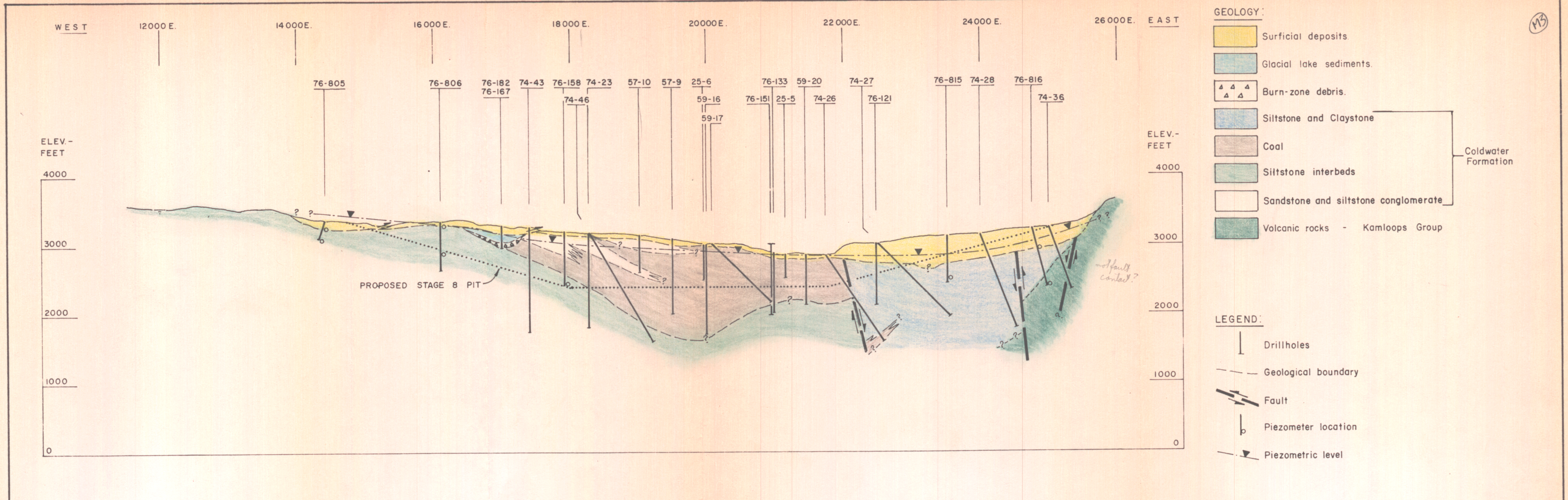
HAT CREEK GEOTECHNICAL STUDY

INTERIM REPORT

PLAN OF PIT AND WASTE DUMPS

DRAWN C.G.	CH'K'D.	APP'D.
DATE OCTOBER, 1976	SCALE AS SHOWN	FIG. No. V76345-2



SECTION A-A

FOR LOCATION OF SECTION, SEE FIG. 76345-1.

NATURAL SCALE - FEET

1000 0 1000 2000

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HAT CREEK GEOTECHNICAL STUDY

INTERIM REPORT

GEOLOGICAL SECTION THROUGH PROPOSED PIT

DRAWN IDT	CH'K'D.	APP'D.
DATE OCTOBER, 1976	SCALE AS SHOWN	FIG. No. V76345 - 3