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CONSULTING GEOTECHNICAL ENGINEERS

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IN ASSOCIATION WITH
PD-NCB CONSULTANTS LTD.
AND
WRIGHT ENGINEERS LTD.
REPORT NO. 6
HAT CREEK GEOTECHNICAL STUDY
FINAL REPORT
VOLUME 1 - MAIN TEXT

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ABSTRACT

A study was made of the geotechnical implications of mining the No. 1 coal deposit at Hat Creek, B.C. to a depth of 600 ft. The coal is part of a Tertiary formation of very weak rocks, largely siltstone with a high content of active clay minerals. The deposit was investigated by a program of drilling, testing, slope monitoring, air photo interpretation and ground reconnaissance. It is concluded that for feasibility purposes a mean overall pit slope angle of 16° should be adopted, provided that pit slope drainage is installed. Waste dump material will only stand at very flat slope gradients, probably no greater than 1 on 10, and the waste will need to be retained by engineered embankments. Waste dump sites are identified in Houth Meadows and Medicine Creek. Consideration is given to the influence of coal inter-beds on material handling.

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SUMMARY AND CONCLUSIONS

1. PURPOSE OF STUDY

The purpose of the study discussed in this report was to investigate the problems of pit slope and waste dump stability associated with mining the Hat Creek No. 1 coal deposit down to an elevation of 2,400 ft.

The nature of the materials surrounding the coal at Hat Creek is such that some degree of instability would be inevitable and, in recognition of this fact, the PD-NCB Consultants Ltd. pit has been designed to accommodate small scale ongoing failures of operating slopes within the pit. Failures which cannot be tolerated are:

a. Large scale deep-seated failures of the final pit walls which could disrupt the production of the coal to the extent that the supply to the plant could not be maintained or that coal production became too costly.

b. Failure of the slopes adjacent to the access ramp, which would have to remain in operation at all times in order that supply of coal to the powerplant could be guaranteed.

c. Large scale failure of waste dumps which would constitute a safety hazard within the Hat Creek valley.

The design of slopes and waste dumps in which such failures would not occur is the prime objective of this geotechnical study.

2. GEOLOGICAL INVESTIGATIONS

The presence of active clay minerals, principally sodium or magnesium montmorillonites, in the rock surrounding the Hat Creek coal is probably the most significant geological factor in relation to slope stability. These clay minerals have the lowest shear strength of all common geological materials and the presence of relatively small percentages (<10 percent) of montmorillonite can give rise to severe instability problems.

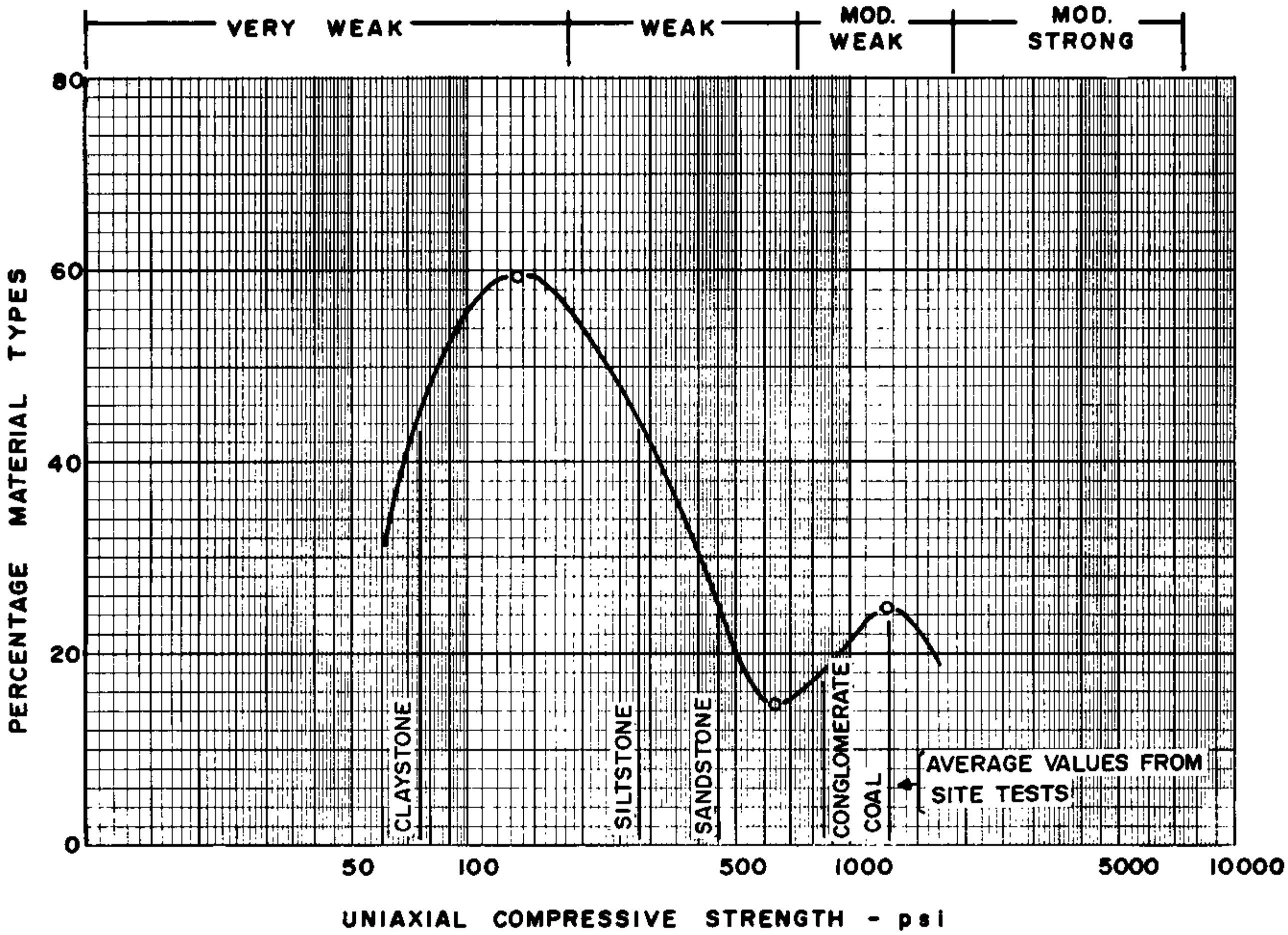
Failure to recognize the seriousness of this problem during early geological exploration studies was due largely to the rapid change in the appearance and physical character of the rocks containing active clays upon desiccation. Optimistic suggestions on pit slope angles were based upon examination of core which had been allowed to dry out in the core shed rather than of fresh core which more accurately represents the in situ character of the material.

Much of the geological work which has been carried out by Golder Associates Ltd (GA) as part of the geotechnical investigation has been related to these clay minerals. Very close supervision of diamond drilling, immediate examination, logging and testing of core and back-up laboratory studies have shown that the materials surrounding the Hat Creek coal are very weak and that the design of slopes in these materials should be based upon soil mechanics principles. While structural features such as bedding planes are present in materials such as the siltstones and claystones, these features are not significantly weaker than the materials themselves and, hence, large scale slope failures in these materials would be controlled by the strength of the mass rather than by particular discontinuities, as would be the case for stronger rocks.

Figure 1 gives an approximate plot of the percentages of materials in different geotechnical categories which are anticipated to occur in the stage 8 pit slopes. This plot shows that a substantial proportion of these slopes will be in materials which can be classified as stiff soils or weak rocks and in which circular type failures can be anticipated. Failures in

ESTIMATED PERCENTAGE OF MATERIAL TYPES APPEARING IN STAGE 8 PIT WALL

Figure 1



Project No. V76349 Drawn I.D.T. Reviewed N.S. Date Feb '77 the stronger materials will be controlled by structural discontinuities but, since these failures will not play a significant role in controlling the overall slopes which are of concern in the design of this open pit, these failures need not be considered in detail in this report.

It must be emphasized that this predominance of weak materials in the pit slopes has only become clear as the geotechnical investigation has proceeded, and that the possibility of structurally controlled failures has been considered and must continue to be considered. There is little doubt that these structurally controlled failures will occur in certain parts of the pit but, on the basis of the information gathered during this program, the opinion of Golder Associates is that such failures will not have a controlling influence upon the pit design.

3. GROUND WATER STUDIES

The importance of ground water in the analysis of pit slope stability has been recognized throughout the evaluation of the Hat Creek deposit and the purpose of the subsurface hydrology studies carried out by GA was to quantify this problem and to investigate the potential for drainage as a means of stabilizing slopes.

These studies have shown that the materials surrounding the coal area are of very low permeability and that drainage would be slow. The critical slopes would require special drainage prior to excavation and details of possible schemes are discussed in this report. Most other slopes in Coldwater rocks would need drainage to improve their stability. An estimate of possible seepage into the pit is also given to enable the mine designers to estimate pumping costs.

4. GEOTECHNICAL CONCLUSIONS

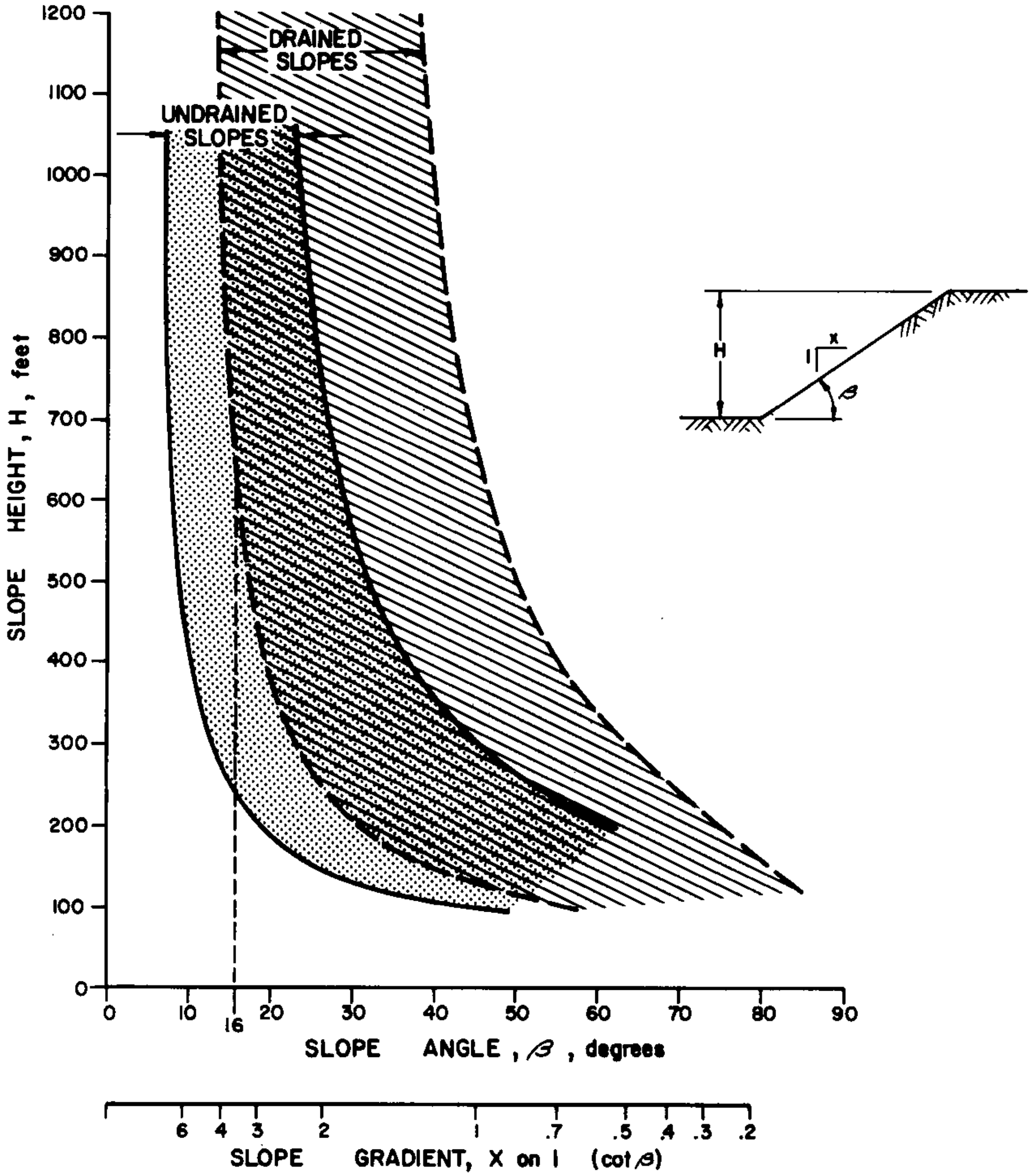
Golder Associates consider that an average slope angle of 16 degrees should continue to be used for overall conceptual pit design purposes. As this project moves into the detailed design and operating phases, consideration will have to be given to variations of this angle, depending upon the distribution of material types in different sectors of the pit. Where massive siltstones and claystones occur and where no gain in shear strength due to the presence of more granular materials can be anticipated, slope angles might have to be reduced below 16 degrees. In other sectors of the pit, it might be possible to steepen slopes by significant amounts. The recommendation to use 16 degree slope angles for conceptual pit design purposes is based upon the opinion that the instantaneous and overall stripping ratios for the actual pit will not differ significantly from those calculated on the basis of the 16 degree overall slopes.

Laboratory testing of the materials in the Hat Creek Basin, back analyses of slope failures on site and a review of literature dealing with slope designs in similar materials has led to a general understanding of the shear strength characteristics of these materials. These characteristics are discussed in this report and the details of the test results are included in appendices to the report.

From the slope design point of view, the most important shear strength characteristics are those associated with the siltstones and claystones. Active clays are dispersed throughout these materials and this results in very low shear strengths. The consequences of this are illustrated in Figure 2 which shows the relationship between slope height and critical slope angle for siltstones, for the range of shear strength values available at the time of writing.

SLOPE HEIGHT VERSUS SLOPE ANGLE FOR SILTSTONE

Figure 2



This plot shows that the critical slope angles for slopes in excess of 600 ft. high lie between 8 degrees and 30 degrees for undrained slopes and between 16 degrees and 48 degrees for drained slopes and that the 16 degree design slopes which have been proposed by PD-NCB would come within this range during excavation of the stage 3 pit. This does not necessarily imply that these slopes would suffer massive failures but it does suggest that serious consideration would have to be given to refining the slope designs in sectors of the pit where slope stability would be controlled by the presence of claystones and siltstones. In the first place, the distribution of these materials in relation to stronger and more stable materials would have to be defined more precisely than could be done on the basis of currently available information. Secondly, the shear strength characteristics of these materials would have to be established by testing a further number of carefully collected and prepared samples and if possible by field observations on trial slopes in these materials. Thirdly, the potential of drainage as a means of stabilizing the higher slopes would have to be evaluated in greater detail than was possible in this program.

As shown in this report, other materials present in the pit slopes, including coals, conglomerates, sandstones and sands and gravels would result in stable slopes in excess of 25 degrees for the slope heights considered in this study.

Provided that stripping ratio calculations and the consequent economic evaluations are realistic, variations in pit slope angles on the basis of field trials and operating experience is a normal procedure in open pit mining. Because of the uncertainty associated with extrapolating the results of small scale laboratory tests to large scale slopes, final slope designs are much more realistic if they are based upon experience gained during the early years of the pit operation. It is recommended that this design approach be applied to the mining of the Hat Creek deposit and that provision be made for ongoing geotechnical studies throughout the life of the project.

While this flexibility in slope design is desirable and acceptable for pit slopes it is completely unacceptable for critical structures such as the access ramp and waste dumps. The stability of these structures must be assured at all times, and hence the slope designs must take the worst possible combination of conditions into account. This has been done for both the access ramps and the waste dumps and recommendations on the construction of these structures are included in this report. It is concluded that the access ramp could be maintained as a stable structure provided that effective drainage of the slopes is provided. During the detailed design stage there might be some merit in considering small changes in the access ramp location in order to take advantage of better quality materials on the eastern flanks of Hat Creek.

In order to improve the stability of the active slide on the west side of the pit, drainage of the lakes in this area is recommended. Consideration should be given to the sequence of removal of the slide material within the pit boundary.

Once the siltstones and claystones have been disturbed, their strength falls to a very low level and stability analyses have shown that failure of the dumped material is likely to occur at relatively flat slope angles and modest dump heights. This means that the containment and sequence of dumping the waste materials would be critical and recommendations on these questions as well as the dump locations are given in the report.

It is with much pleasure that we submit to you the results of this interesting study. We should be glad to answer any questions which might arise from the information contained in the report.

Yours very truly,

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1. INTRODUCTION

1.1 Scope of Study

This report contains the final results of a geotechnical feasibility study of a conceptual 600 ft. open pit mine (down to elevation 2,400 ft.) of the Hat Creek No. 1 Coal Deposit carried out by Golder Associates Ltd. (GA). The location of the project is shown on Drawing 1 (located at the end of the text).

The terms of reference for the study necessitated detailed consideration of the following aspects:

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 the slides identified during the study.
4. The location of suitable waste dump sites.
5. The stability of the waste dumps.
6. Ground water conditions within the surficial deposits, the coal, and other deposits forming the mine and adjacent pit slopes, and an assessment of probable drainability.
7. The nature, and behaviour of the coal inter-beds during mining and subsequent handling.

This work forms part of the Mining Studies being carried out by PD-NCB Consultants Ltd. for British Columbia Hydro and Power Authority (BCH). The main results of the Mining Studies are contained in the PD-NCB Report No. 2 entitled 'Preliminary Report on Hat Creek Open Pit No. 1', dated March, 1976. These conclusions have been updated and presented in PD-NCB Report No. 9, dated March 1977 and entitled 'Revised Report on Hat Creek Open Pit No. 1'.

The interim conclusions of the Geotechnical Study were contained in a report issued by GA in association with PD-NCB and Wright Engineers in October, 1976 and entitled 'PD-NCB Report No. 4, Hat Creek Geotechnical Study, Interim Conclusions'.

Several parallel studies on other aspects of the Hat Creek open pit were carried out at the same time as this study. Where there was an interface, mutual exchange of data and conclusions took place.

Dolmage-Campbell and Associates (DCA) further investigated the geological aspects of the coal deposit. Piezometers were installed by GA in holes drilled under DCA direction and samples were taken from their core for testing.

Integ-Ebasco carried out studies for the Power Plant siting and produced a conceptual design for that plant. Supervision of a short diamond drilling and hydrology testing program for these studies was carried out by GA.

Monenco evaluated various aspects of diverting Hat Creek. A diamond drill hole was sited for this purpose and the cost included in the geotechnical study budget. The supervision of this site work was carried out by GA personnel.

Assistance was given to Acres in their study on the leachate aspects of the waste dumps. Samples were provided from material held by GA and some laboratory work was carried out on their behalf.

Golder Associates were involved in the ground water environmental program as sub-consultants to Beak Consultants; much of the hydrological data acquired during the geotechnical study was also relevant to that study.

Golder Associates were also retained by Sandwell & Company Ltd. for consideration of the geotechnical aspects of the Water Supply Route. The overall review of the geology of the area between Big Bar on the Fraser River and Walhachin on the Thompson River, carried out for the Water Supply study, provided a useful input for this report.

Relationships between the various consultants were good and we should like to acknowledge the help afforded us in our study, particularly by Dolmage-Campbell where the interface was greatest. We also wish to record our thanks to BCH, particularly Mr. R. Woodley and Dr. P.T. McCullough, for their kind assistance during the geotechnical study.

1.2 Methods of Study

The geotechnical study was broadly divided into two parts, a field program of reconnaissance drilling, testing and sampling, and a laboratory/office program of testing and analysis. The following activities were undertaken:

1. Geological and geotechnical reconnaissance of the pit area, Hat Creek valley and neighbouring region.
2. 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.
3. Installation of piezometers to establish the pattern of ground water flow within the coal and the surrounding rocks.
4. In situ permeability testing to assess the permeabilities of representative materials.
5. Execution of a pumping test to assess the drainability of the low permeability materials in the proposed slopes.
6. Installation of slope indicators to assess rates of movement of existing slides and to locate the depth to slide planes.
7. In situ index testing of materials.

8. Laboratory testing to assess the strength and consolidation characteristics of intact and fractured rock, soils from the dump and embankment foundations and waste aggregates.
9. X-ray diffraction analyses to determine the clay mineralogy of the non-coal sedimentary rocks of the proposed open pit.
10. Compilation of geological and geotechnical data from the various sources.
11. Analyses of the stability of ultimate pit slopes, access ramp slopes, waste dump materials and embankment foundations.

The field work was commenced at the beginning of June, 1976 and was completed by the end of September, 1976. A total of 10,070 ft. of diamond core drilling for investigation was completed in 20 holes, 1,059 ft. of rotary drilling in 7 holes for permeability testing, 1,000 ft. of rotary drilling in 5 holes for slope indicator installation, 2,000 ft. of rotary drilling in 5 holes for pump testing, and 63 ft. of rotary drilling in overburden to establish casing for a diamond drill hole. In addition, 2,130 ft. of percussion drilling in 30 holes was carried out to comparatively shallow depths in surficial deposits. Samples were also taken from the BCH large diameter auger program and the DCA exploration holes. The geological logs of these holes are contained in Appendix 1.

In addition, 7 holes (totalling 677 ft.) were drilled for Integ-Ebasco at Medicine Creek and Harry Lake, and a single hole 204 ft. deep for Monenco in the region upstream of the No. 1 Pit.

All the laboratory work was carried out in the GA laboratory in Vancouver except for the X-ray diffraction analyses which were done at the Universities of Western Ontario and British Columbia.

The detailed results of this field and laboratory program are contained in appendices to this report, and analyses of the results are considered in the relevant sections of the Main Report.

1.3 Previous Work

The geology of the Hat Creek area and neighbouring Fraser and Thompson valleys is known primarily from the work of Duffell and McTaggart (1951)* although some earlier work had been carried out. A broad survey of the surficial deposits has recently been carried out by the Geological Survey of Canada (Ryder, 1976). Some specific aspects of the area such as the glacial deposits and alluvial fans have been studied in detail in some publications, (Ryder 1969, Aylsworth 1975). Trettin (1960) has mapped that part of the Fraser Valley between Lillooet and Big Bar Creek, and although this does include part of the mountain range to the west of the Hat Creek valley it does not extend as far as the mine area. A considerable volume of geological facts has been accumulated from the major coal exploration, which has been carried out since 1974. Despite this work, the generally poor rock exposure due to the soil cover, the complex geological structure and the facies variations within the rocks, cause much of the geology of the area to be poorly known, especially on the scale of the engineering structures being considered.

The only previous geotechnical work was carried out by DCA and is contained in their report entitled 'No. 1 Deposit - Rock Mechanics Data' dated August, 1975. This work comprised two reports by Dr. R.B. Peck, laboratory test results from Klohn, Leonoff Consultants Ltd. and X-ray diffraction analyses by Dr. R.M. Quigley of the University of Western Ontario. These results are considered further in Sections 5 and 6.

An initial geotechnical assessment was made by GA in the first PD-NCB report dated November, 1975 and entitled 'Interim Report on Geological and Geotechnical Exploration at Hat Creek'.

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*Details of references are shown in Section 8.

2. PHYSIOGRAPHY*

Hat Creek is located some 120 miles northeast of Vancouver midway between the towns of Lillooet and Ashcroft. It lies in the southern extension of the Interior Plateau physiographic province and it is bounded by the Coast Range Mountains to the west and the North Cascade Mountains to the southeast (see Drawing 1). The physiography of the area is diverse and reflects the marked variations in the geology. A wide range of rock types is present within the geological formations; the rock types vary in age from Permian to Recent. Most of the area is masked by glacial or colluvial deposits.

The upper part of the Hat Creek valley in which the coal is located, lies at an approximate elevation of 3,000 ft. and forms a basin nestling between the northward trending Clear Range to the west and the Cornwall and Trachyte Hills to the east (see Drawing 2, Plate 1). The Marble Range form high ground to the north of Hat Creek. Other than the Trachyte Hills which rise to 4,000 ft., these bounding ranges all rise to over 6,000 ft. The pit itself would lie within the flat slopes of the valley formed by the weak sediments of the Tertiary Coldwater Formation which are present as a faulted block within the older rocks forming the surrounding hills.

All the hills are heavily dissected due to the exploitation of geological weaknesses by drainage and ice; rapid changes in relief are common. On the lower ground the slopes are generally smoother and shallower as the result of glacial deposition, but irregular topography, characteristic of ground instability, may be seen in both the Thompson valley and the Hat Creek valley. Recent rejuvenation of both the Fraser and Thompson River systems has resulted in deep incision of the river courses with consequent effects on the related systems, including the Bonaparte River and Hat Creek.

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*A glossary of geological terms is included as Section 9.

PLATE 1

Panorama of the Hat Creek Valley looking due west.

Extensive erosion surfaces were developed during the Tertiary Period, and, although they have been subsequently dissected, their remnants may be recognized throughout the area. The Fraser and Thompson River systems are now incised into these surfaces.

The predominant trend of the drainage within the area is to the north or to the south, oblique to the main structural grain of the country. Although the overall course of the Fraser is determined by the Fraser River fault system which trends northwest to southeast, the river generally flows southwards between Lillooet and Big Bar Creek. Below Ashcroft the Thompson also flows southwards although upstream its course lies to the west out of Kamloops Lake. Hat Creek runs parallel to the two main water courses (the Thompson and Fraser), but in a contrary direction, i.e. northwards. It drains most of the hills between the Fraser and Thompson divides and eventually flows northeastwards into the Bonaparte River and hence southeastwards into the Thompson River at Ashcroft. The Marble Range and Cornwall Hills, which are formed of limestone, show a general absence of surface drainage.

The drainage of the area has been much affected by the glacial history. Deposition of glacial debris, overdeepening of existing valleys, formation of glacial lakes and the cutting of meltwater channels have all been processes instrumental in modifying the pre-Pleistocene pattern.

3. GEOLOGY

3.1 Regional Structure

The Hat Creek coal deposit lies in a Tertiary sedimentary basin situated within the Cordilleran Mountain Chain of British Columbia (see Drawing 2). The basin is one of three within the province located in a similar tectonic environment, the others being the Merritt and Similkameen Coalfields.

The Canadian Cordillera is formed of two intensely deformed zones, the Eastern and Western Cordillera, separated by a heterogeneous although relatively slightly deformed interior zone (Spencer, 1974). The Hat Creek area lies near the west limit of the interior zone which has also been included with the Eastern Cordillera and considered as the Columbian fold belt (Price and Douglas, 1972). The Fraser Fault zone forms the eastern boundary of the Western Cordillera in the area under consideration.

In the Hat Creek area the strong deformation of the Western Cordillera near the Fraser Fault contrasts markedly with the weaker deformation of the Columbian fold belt. Relatively undisturbed Tertiary and Quaternary volcanic rocks overlie the older folded and faulted rocks. During the period when these materials were extruded the whole area was subjected to block and transcurrent faulting resulting from the northwestward movement of segments of the lithospheric plate to the west of the Cordillera.

The regional trend of the structures within the Cordillera are to the northwest and the Hat Creek area conforms to this pattern, although the Fraser Fault zone at nearby Lillooet has a more northerly trend locally. Some post-Pleistocene activity has been recorded within the Western Cordillera but to date none has been recorded along the Fraser Fault zone or in the Hat Creek area which is generally regarded as being relatively stable.

3.2 Regional Geology

Drawing 2 shows the regional geology of the area within an approximate radius of 14 miles of Hat Creek. The map, compiled from available published sources, reports from BC Hydro files and supplemented by GA and BCH field work, omits the thick cover of surficial materials mantling the area. The reliability of the data is variable, obviously being best within the Hat Creek valley itself where much drilling has been carried out and poor in those areas of thick surficial cover. The geological succession is also shown on the same drawing.

The Hat Creek sedimentary basin was originally larger in extent than it is at the present day; the eastern half of the basin has been faulted out against volcanic rocks and the western margin may be faulted also. Consequently the basin is now seen as a graben within a tract of older rocks. It is possible that the Tertiary basin described by Hoy (1975) to the northeast of Hat Creek is a faulted remnant of the same basin. Folding has also modified the basin. Within the No. 1 pit area the coal is present within two plunging synclinal folds which have been truncated to the south and east (see Drawings 3, 4 and 5). A further coal deposit which is part of the same basin of deposition but structurally separated, is found immediately south of the planned open pit. It has been termed the No. 2 deposit.

The coal is considered to have accumulated within lagoons produced as the mountain chain developed in Tertiary times. Rapid and long continued subsidence permitted the accumulation of great thicknesses of organic material. The distribution of the coal within the basin indicates that the basin probably had an elongate shape suggesting that the subsidence may have occurred along a fault zone, possibly parallel to the Fraser River Fault zone to the west.

The oldest rocks in the area, the Cache Creek Formation of Permian age outcrop in an arc from the north to the southeast of Hat Creek. The formation has been divided into two main parts, the Marble Canyon Formation above, and a low grade metamorphic sequence below, which includes greenstone, chert, phyllite, limestone and quartzite. The limestone forms the Marble Range in the north and the Cornwall Hills in the southeast, with the lower part of the sequence forming the Trachyte Hills between these two areas. Outliers of limestone lie within the proposed waste dump area of Houth Meadows to the north of the pit.

Rocks of the Cretaceous Spences Bridge Formation are present to the southwest of Hat Creek and are poorly exposed, although they produce a strong anomaly on the aerial-magnetic survey.

A Cretaceous intrusive body, the Mount Martley stock, separates the Spences Bridge Volcanics from the Marble Canyon limestone on the western rim of the valley. It is granodioritic in composition and although it has provided a large complement of sediment to both the Coldwater and the glacial deposits in the west, it is poorly exposed.

The Tertiary sequence of the Hat Creek Basin consists of three units:

Miocene Volcanics

$$\left.\begin{array}{l}\text{Coldwater Formation}\\ \text{Kamloops Volcanics}\end{array}\right\}\ \text{Kamloops Group}$$

The Kamloops Volcanics are believed to form the basement of the Hat Creek Basin in the area under consideration, although it is possible that the Marble Canyon Limestone may locally underlie the Coldwater sediments in the northwest. The Kamloops Volcanics are faulted against the overlying Coldwater Formation along the eastern margin of the Hat Creek Basin. The formation includes a diverse group of volcanic rocks including basalt, dacite, rhyolite, agglomerate, breccia and tuff. They may have originated from fissure eruptions along the zones of weakness paralleling the Fraser Fault zone.

The Coldwater Formation in the Hat Creek valley comprises a thick sequence of fine grained clastic rocks, containing a high proportion of the expansive clay mineral montmorillonite and a substantial accumulation of low grade coal up to 1,500 ft. thick. The coal is thickest approximately along the line of Hat Creek itself and it thins rapidly towards the west; the basin is faulted to the east. Although there is much facies variation within the basin, it has been shown that generally sandstones and conglomerates with siltstones predominate below the coal, and siltstones with claystones predominate above. The details of the Coldwater Formation sequence are considered in Section 3.4.

The youngest Tertiary rocks in the area are olivene basalts, which are found in isolated outcrops overlying most of the older rocks. They are also likely to have resulted from fissure eruptions as evidenced by the occasional dolerite dykes which traverse the Coldwater rocks. Highly disturbed deposits composed of coarse basaltic boulders and cobbles set in a fine grained weak detrital matrix may be seen throughout the valley, but particularly towards the south end. Although these have been interpreted as lahar deposits (volcanic mudflows) it is equally possible that they could represent more recent instability of the valley sides, especially where the lava flows overlie bentonitic Coldwater deposits.

3.3 Surficial Deposits of the Hat Creek Basin

There is a thick and almost total cover of surficial deposits over the Hat Creek valley, and thus there are very few natural exposures of the Coldwater Formation. The surficial deposits are varied and have diverse origins. They are described in Table 1, their engineering properties are considered in Section 5 and descriptive logs are found in Appendix I.

The relationships of these various deposits across the Hat Creek valley are poorly known, despite the extent of the exploration program. Other than the recent holes drilled for geotechnical purposes (DDH-76-801 to 76-821, P76-1 to 76-30, and RH 76-5 to 76-21, see Drawing 6) most of the previous holes were triconed down to bedrock and therefore no core was obtained from the surficial deposits. It is considered that the thickness of surficial deposits may have been over-estimated on some occasions as the limit of triconing was taken at the change in drilling characteristics. However, it is felt that the difference in drilling between clayey till or glacial lake sediments and the weathered top of the Coldwater Formation may be very slight in some regions. Some core from surficial deposits drilled during the DCA program was obtained by GA, however it was not possible to put enough supervisory staff on DCA holes to obtain such core on a regular basis. Some drive samples were also obtained, but the time taken and degree of success did not justify the extensive use of this method.

Core recovery has often been poor in the surficial deposits because of their granular nature. Nevertheless the surficial deposits have repeatedly been seen to be highly variable and indicate a complex recent geological history. This is well illustrated by the log of DDH-76-167 which is summarized below and in Drawing 3.

0 - 70 ft.	Triconed
70 - 107 ft.	Slide debris
107 - 217 ft.	Glacio-lacustrine deposits
217 - 295 ft.	Burn zone material
295 - 312 ft.	Bentonite
312 - 329 ft.	Coldwater Formation

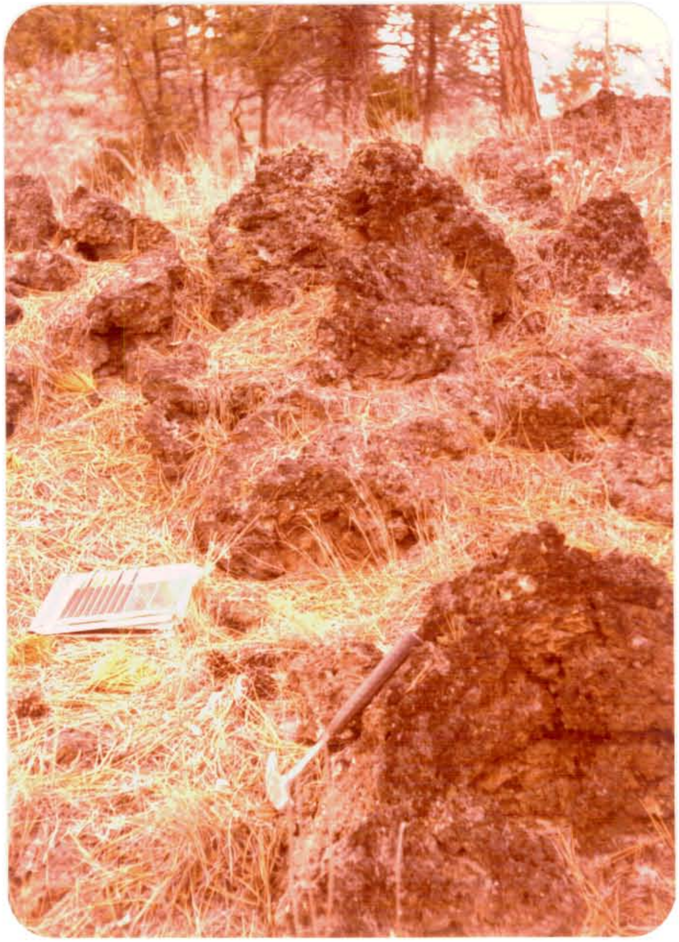
TABLE 1

SURFICIAL DEPOSITS OF THE HAT CREEK NO. 1 DEPOSIT

Type	Origin	Description	Location	Permeability
Till	Glacial Deposit	Cobbles & gravels with occasional boulders up to 36" dia. in a matrix of sand, silt & clay. Locally variable, depending on matrix.	West side of valley	Low
Lacustrine Deposits	Glacial Deposit	Bedded silts with coarse sand & occasional gravel may be also clayey, laminated and/or highly disturbed (as in DDH 76-803).	Locally thru-out glacial deposits.	Low
Glacio-fluvial Deposits	Glacial Deposit	Interbedded sands & sandy gravels with cobbles & boulders up to 24" dia. (approx.). Much variation in grading. Some interbedded tills. (See Plate 2a)	East side of valley	Moderately High
Colluvium	Erosion products of volcanics, limestone & granodiorite	Coarse, angular, roughly bedded perhaps with variable proportion of fines.	Widespread	Gravelly colluvium: moderately high. Clayey colluvium: low.
Slide Debris	Periglacial or Recent instability of till & Coldwater Formation	Composed of variable assortment of till and Coldwater sediments often in a bentonite matrix. (see Plate 2b)	West side of valley especially NW	Very low except along slide planes
Alluvium	Reworking of glacial & Coldwater Formation	Sands and gravels probably with silt inter-beds.	Predominantly in Hat Creek	Variable
Burn Zone	Residue of burning of coal	Generally an irregular mass of red-brown partly-fused claystone & siltstone with some coal. Very hard, maybe with some relic bedding discernible. (see Plate 3a)	Dry Lake area. May be obscured by glacial or slide deposits.	Moderately High
Bentonite	Fines eroded from slide debris	Weak sandy clay high in montmorillonite.	Dry Lake, Houth Meadows	Extremely low
Bentonite Boils	Mobilization of slide deposits by artesian ground water	Liquid bentonite eruptions. (see Plate 6)	West side of valley	Low

a. Glacio-fluvial sands and gravels overlain by silt in cliffs east of Hat Creek (Ref. 82430N, 19790E).

b. Disturbed bentonitic tuffaceous siltstone of the Coldwater Formation showing sheared surface as indicated.



a. Burn-zone debris near Dry Lake.

b. Houth Meadows looking east, showing alluvial deposits. Cliffs in glacio-fluvial material on the east bank of Hat Creek may be seen in background.

Drawing 7 shows the contours on the base of the surficial deposits and Drawing 8 shows the location of the various surficial deposits described above. The depositional history of these deposits cannot be stated with certainty, but it is useful to consider their relationship in order to assist in understanding the character of the materials. The following is considered to be a likely sequence of events during the formation of the surficial deposits:

1. During late Tertiary or perhaps early Pleistocene times burning of the coal at outcrop occurred and produced subsidence zones which subsequently caused ponding into which lacustrine sediments were deposited.
2. The Hat Creek valley was eroded by sheet ice moving in a NW-SE direction. The fault zone approximately along the line of Hat Creek (the Creek fault of this report) was probably exploited by this ice producing a topographic low along the valley.
3. On recession of the ice, a till blanket was deposited over the site.
4. An ice tongue re-advanced over the site from the northwest along Marble Canyon. As this ice receded it left arcuate moraines to the southeast of the area, and cut a meltwater channel to the east of Hat Creek permitting meltwater to flow down the existing Hat Creek valley (see Drawing 7) This channel was backfilled with an assemblage of sands and gravels, silts and some tills, suggesting that there might have been repeated minor re-advances.

5. During periglacial times when the sub-stratum was still frozen and freeze-thaw processes were operative, the surface materials became fully saturated and creep or flow of the upper layers developed. In addition thick mantles of colluvium accumulated on the steeper slopes. Where the materials were particularly weak or expansive, flowslides developed.
6. As the slopes became partially drained the creep and flow processes stabilized. Parts of these old slides have been recently re-activated due to a variety of causes such as changed ground water conditions, progressive weakening of the soils and rock, and topographic changes caused by subsidence or erosion.
7. Downcutting permitted active erosion by Hat Creek and hence reworking of the existing surficial materials to form alluvium.

3.4 Stratigraphy of the Coldwater Formation

The Coldwater Formation, as defined in this report, includes those sedimentary rocks above and below the coal, as well as the coal itself. Because most of the deposits of the Hat Creek Basin exhibit rapidly varying facies within the limited area of the coal development, it is preferable to consider the stratigraphy of the whole basin, including those areas beyond the open pit. The two field programs, carried out during 1976, the one for the coal exploration by DCA and the other for the geotechnics by GA, differed both in location and in approach. The geotechnical investigation concentrated on the areas outside the coal, that is in the area of the final pit slopes, and the coal exploration concentrated on the central part of the pit.

The descriptions of materials given in the GA logs are all made on the basis of the Geological Society of London Engineering Group Working Party Report on "The Logging of Rock Cores for Engineering Purposes" (1970). The descriptions of materials by others has been less precise and not related to standard terminology; for geotechnical purposes it has been necessary to treat some of that data with caution.

This section does not include the detailed stratigraphy or petrology of the coal. At the time of writing this was not available, however brief descriptions are given as accurately as possible. In due course the coal stratigraphy should be incorporated with the descriptions contained in this report to produce a comprehensive description of the Coldwater sequence. The coal zones referred to in subsequent sections are those presented by DCA on their draft sections of November, 1976.

Table 2 shows an outline of the Coldwater Formation using data obtained from the geotechnical drilling at Hat Creek and currently available reports. Appendix 2 contains the petrographic analyses of several rocks from which thin sections were cut.

As will be seen from the geological sections (Drawings 3, 4 and 5) and the stage 8 Pit Wall Geology (Drawing 9) the uppermost beds of the sequence, the claystone-siltstone beds, will be present in an arc of the pit from the northeast round to the south, being downfaulted in that area. They also will be exposed in the centre of the basin in the main synclinal trough. These beds are normally easily recognizable by their uniformity, although to the northwest this is less so where the beds become more carbonaceous. Thin tuff bands often only 1-2 ins. thick are present throughout the sequence and many have been altered to montmorillonite. Clay-ironstone bands (rich in siderite) are interbedded in a similar way to the tuffs. The rocks are weak, poorly lithified and

TABLE 2

STRATIGRAPHY OF COLDWATER FORMATION

Unit	Thickness	Description
Claystone Siltstone	1600'+	Grey to blue-grey uniform bentonitic clayey siltstone-claystone with thin tuff bands which may be highly altered to bentonite. Becomes sandy & conglomeratic towards E. margin (DD-76-815, 816). Limited information from NE indicates increasing carbonaceous content (DD-76-165). Very uniform gamma and density logs. No correlation yet achieved between holes. Colour soon changes to brown on exposure.
Coal - Zone A	560' - 670'	Thick zone showing much variation in coal quality. High proportion of interbeds which are composed of quartz, montmorillonite, kaolinite and occasionally siderite. Geotechnical logs highly variable. Poor conditions.
Coal - Zone B	160' - 270'	Black dull-bright coal with some interbeds. Density and gamma logs reasonably uniform becoming more irregular towards W. Correlation good over much of basin but becomes difficult towards the W.
Coal - Zone C	200' - 400'	Poor quality coal with many interbeds composed of quartz, kaolinite and siderite. Geophysical logs show much variation although less than Zone A. May be gradational into Zone D. Correlation good-poor.
Coal - Zone D	200' - 400'	Black, clean bright coal with very few interbeds. Occasional tuff and ironstone bands, some resin beads. Thickens to E. thins to W. but still recognizable. Very uniform gamma and density logs. Good correlation between holes on overall lithology and on tuff bands.
Sandstone - Conglomerate - Siltstone	1200'+	Variable deposits of green or grey bentonitic sandstone, conglomerate & siltstone. Becomes carbonaceous & silty to N. in upper part of sequence. Some hardened calcareous zones present especially near base of D zone (DD-76-817). Density & gamma logs highly variable but overall trends give good correlation in N. of pit, despite facies changes. Cement in conglomerates weak, either clay (may be bentonite) or calcite.

have a high montmorillonite content (see Appendix 3 - X-ray Diffraction Studies). The mineralogy of the rocks and its influence on their geotechnical behaviour is considered in Section 5. The bedding is indistinct and has been recorded on the logs where recognizable.

A particular study has been made of the sediments interbedded with the coal over the whole range of the four coal zones (see Section 6.4). This preliminary work was concentrated near the centre of the deposit where the coal is thickest and the inter-beds at a minimum (see Drawing 3). Further work will be needed to extend the initial conclusions to the peripheral areas where the proportion of inter-beds is greater.

The inter-beds are predominantly siltstone with claystone and are only poorly developed in the B and D-zones of the coal sequences where the coal quality is at its best. In the A and C-zones inter-beds are more extensively developed. The X-ray diffraction analyses show that in the B, C and D-zones the inter-beds are composed predominantly of quartz and kaolinite with some occasional siderite and felspar. By contrast the A-zone has a high proportion of montmorillonite which usually far exceeds the proportions of quartz and kaolinite; siderite and felspar are also occasionally present. Kaolinite is usually only poorly represented in the A-zone. An analysis of a sample from the C-zone in drill hole DDH 76-124 shows a high montmorillonite content (67 percent) and indicates that the mineralogical pattern typical of the centre of the basin changes laterally.

The beds below the coal are considerably more variable than those above. They were apparently deposited in shallower, more disturbed, water than the later deposits and are more subject to facies change. Overall the sediments are green although they may also be grey. They comprise interbedded sandstones and conglomerates with siltstones becoming more significant at times during the depositional sequence. To the north of Dry Lake, up to 600 ft. of siltstones and sandstones with thin coaly beds are present and appear to lie immediately below the D-zone. Most sandstones and conglomerates are weak; clasts of volcanic debris are not uncommon and tuffaceous material may be present in varying amounts. The uniaxial compressive strength test results show wide variation (see Figure 8 and Appendix 4), but the results are much dependent on the size of the clasts in relation to the size of sample tested. Few index tests have been carried out on these granular beds because of the concentration of the study on the weaker members of the sequence, but it appears that the matrix of many of the beds is bentonitic. The active flowslide (see Drawing 8 and Sections 3.7 and 6.1.3) is largely composed of disturbed or remoulded material from this part of the sequence and its high bentonite content is very apparent in surface exposures. Core composed of gravel-sized clasts with little matrix was obtained in several holes at various levels, and it is uncertain whether this represents washing of the core during drilling or whether it represents open zones in situ.

Attempts to correlate these beds below the coal have not been successful between widely spaced holes but good correlations have been achieved where the density of holes is greater i.e. between DDH 76-808, 809, 811 and 812. Although the grain size and hence density of the sediments differs between the holes, the shapes of the geophysical logs are very characteristic and permit good comparison.

Variable thicknesses of granitic sand/weak sandstone grading into granodiorite breccia appear in the west of the basin tongueing into the finer grained sediments (see Drawing 5). These beds vary in grain size from medium sand to coarse angular bouldery gravel; carbonaceous partings are also found. These deposits have been located in several drill holes and they have been interpreted as coarse colluvial fan deposits although they could equally well have originated from slide activity on the western edge of the basin. They appear to be interbedded with the other Coldwater sediments (see DDH 76-137) but alternative explanations are possible.

3.5 Structure of the Open Pit Area

The structure of the Coldwater Formation in the open pit area is difficult to assess because of the lack of marker beds for correlation between holes. The coal is a facies deposit being dependent on environmental conditions at the time of deposition and therefore accumulating at different times in different parts of the basin. The D-zone of the coal has been found to be a uniform and extensively developed horizon wherever investigated, and it is possible that depositional conditions were comparatively uniform in the early phases of the coal formation, before rapid subsidence of the basin had commenced. Although it is appreciated that the base of the D-zone may not be an exact stratigraphic horizon (i.e. it may be time dependent) it is considered to be the best datum for use in plotting the geological structure of the Coldwater Formation. The data acquired, from measuring bedding dips in drill core and marker bands of limited extent, support the use of the base of the D-zone for structural interpretation.

Drawing 10 shows the stratum contours on the base of the D-zone and illustrates the geological structure. The Hat Creek basin of Coldwater sediments is folded into three parallel folds with the eastward and westward dipping limbs of the structures conforming with the margins of the valley within the area of the No. 1 open pit. The basin is truncated by faulting on the east, and possibly on the west. The main structure is a north-south trending syncline which plunges to the south and closes to the north. A second syncline is developed in the east of the open pit area and has a similar trend and plunge. The tight anticline which has developed between these two synclinal structures has been dislocated by a fault, here termed the Creek Fault. All three structures are truncated in the southeast by a fault termed the Finney Fault. (It should be noted that the position of this fault is somewhat different from the Finney Fault of earlier reports.)

The drawing of the base of D-zone contours has been produced using all available drill hole data. It was initially drawn on the assumption that no faults existed. Subsequently the minimum number of faults were introduced to explain the resultant anomalies in the plot. It will be seen that this drawing differs substantially from the draft drawings at present available from DCA. We do not feel it necessary to use a large number of faults to explain the data and, whilst more faults are undoubtedly present, until they can definitely be proved we have opted for the simplest solution compatible with the data. This approach is considered to be more valid for geotechnical work as it allows consideration of uniformly dipping beds with unfavourable orientations which could have severe implications for slope stability.

The geological structure shown in Drawing 10 seems plausible for a narrow deep basin of weak, poorly consolidated sediments within which is contained a mass of more rigid coal. The fold pattern and conjugate pattern of northeast-southwest and northwest-southeast faulting would be consistent with a major east-west stress field. The Finney Fault has a computed attitude of $80^{\circ}/130^{\circ}$* and the Creek Fault $65^{\circ}/070^{\circ}$. The Creek Fault displaces the Finney Fault suggesting that the anticlinal fold may have been tightened up and faulted in a stage of deformation later than the initial folding and faulting which produced the Finney Fault.

The widespread occurrence of brecciation and shearing within the Coldwater core indicates that other faulting is present within the basin

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*Dip angle and bearing of direction of dip.

although its attitude cannot be determined. It is quite likely that slumping was a major process during the deposition of the sediments, especially during the formation of the coal, and the degree of contortion, within the coal at least, lends credence to this. Shearing parallel to the bedding has been recognized but not in as widespread a fashion as had been anticipated.

The structure outside the coal areas, where the base of the D-zone is not available to use as a marker, is more tentative. To the north of Dry Lake good correlation has been achieved by using the results of the down-hole geophysical logging and the overall structure appears to conform to the same picture as presented by the D-zone further south. To the southeast of the Finney Fault no marker bands have been recognized or geophysical correlations achieved. To the west of the pit area the drill holes are too far separated to be compared. Moreover holes such as DDH 76-805 and 806 were drilled primarily to investigate unstable zones and therefore have yielded only limited data on intact rock at depth. It has been assumed that rocks of the lower part of the Coldwater Formation sequence are present to the west and dip uniformly in towards the basin, but further investigation would be required to substantiate this.

The structure of the core was logged to determine, if possible, the extent and orientation of the jointing. The conventional techniques of core orientation failed to work in the weak Coldwater rocks and thus the spacing and nature of the joints was assessed but not their orientation. Some jointing has been developed within the sequence but is widely spaced. The joints which were logged in core which had dried out, or had not been carefully treated, could be misleading as they may have been produced after drilling. In addition, core breaks induced by drilling are difficult to separate from natural joints or bedding planes in materials of low strength.

Shearing along bedding planes was not a widespread feature in the core of Coldwater sediments although there were zones of significant core loss especially in the more disturbed beds. In contrast, bedding plane shears with highly polished planar surfaces and crushed coal infill were common in the coal itself.

Rock quality designation (R.Q.D.) was measured in all cores and is shown on the geological logs (Appendix 1). However it is now considered that this parameter is not too meaningful in the Coldwater Formation outside the coal. Examination of cores with a measured R.Q.D. of 100 percent has shown extensive shearing and brecciation which has not affected length or percentage of core recovered. It may be found ultimately that this parameter can be correlated with some other property but it has been disregarded in the present analysis.

3.6 Waste Dump Sites

Three areas are recommended for the dumping of waste (see Section 6.2), namely in Houth Meadows, between the mine mouth and the Indian Reservation, and in the Medicine Creek valley. Some investigation has been carried out in each of these areas and the locations of the holes are shown on Drawing 6.

Houth Meadows (see Drawing 8, Plates 3b and 7) is a natural basin bounded to the north by the Marble Canyon Limestone, to the south by a ridge of Coldwater Formation rocks overlain by till, and to the east by a ridge of glacial till. A limestone outcrop within the till ridge suggests that a bedrock spur might underlie the entrance to Houth Meadows. Drainage occurs out of Houth Meadows, through the ridge to Hat Creek. Several percussion holes were drilled on the meadow flats and showed weak silts and sands overlying glacial till. Holes drilled on the ridge between Houth Meadows and the open pit (DDH 76-810, 818) showed slide debris overlying highly weathered Coldwater Formation conglomerates with siltstones. Considerable instability exists on the south side of the basin. A massive flowslide with a scarp near Aleece Lake has brought material northeastwards into Houth Meadows. Although some local bentonite 'boils' may still be seen, it appears that this slide is currently stable. Eastwards along the same slope a tongue of the main active flowslide of the pit area spills over into the meadow area; this slide is currently flowing. A large circular failure has occurred on the hillside between these two slides. Bentonitic fines have been carried into Houth Meadows from all three slides and form unstable masses on the southern edge of the area, as well as contributing to the deposits in the meadows.

The dump area north of the mine mouth will lie entirely on stable glacial deposits and alluvium. To the west coarse glacial tills may be seen in the cliffs above the river, to the east similar cliffs expose glacio-fluvial sands and gravels with interbedded silts and occasional tills.

The dump site at Medicine Creek will lie on a variety of materials. The western embankment will be sited predominantly on volcanic rocks of the Kamloops Group but these may be overlain to the east by Coldwater Formation or glacial deposits. Most of the dumping area and the eastern embankment will lie on glacial deposits or Cache Creek Formation greenstones and phyllites. The glacials are only poorly exposed but the few exposures seen, together with photo-interpretation, indicate that they are predominantly till or glacio-fluvial material. The Coldwater Formation is seen to outcrop further north in Harry Creek, but it has not been seen in Medicine Creek within the area proposed for the waste dump, although it may be covered by the glacials. There is only very limited instability of the present slopes despite their comparative steepness. Further investigation of this area is required during the next phase of the scheme.

3.7 Slide Zones

Areas of instability have long been recognized at Hat Creek (Dawson, 1877, Galloway, 1924), and the present intensive investigation has provided the opportunity to look at these in detail, and particularly to examine their extent. Within the No. 1 pit area all the instability is restricted to the west side of the valley.

Field reconnaissance, drilling and photo-interpretation have enabled the identification of a series of flowslides, which have moved from the west of Finney Lake towards Hat Creek (see Drawing 8). Whilst the main slide (area 1 on the drawing) is old and comparatively stable, lobes of unstable material have sloughed off the toe of the slide and flowed out onto the lower slopes. Movement is still occurring in one of these lobes as demonstrated by slope indicators which have been installed (see slope indicator results in Appendix 9).

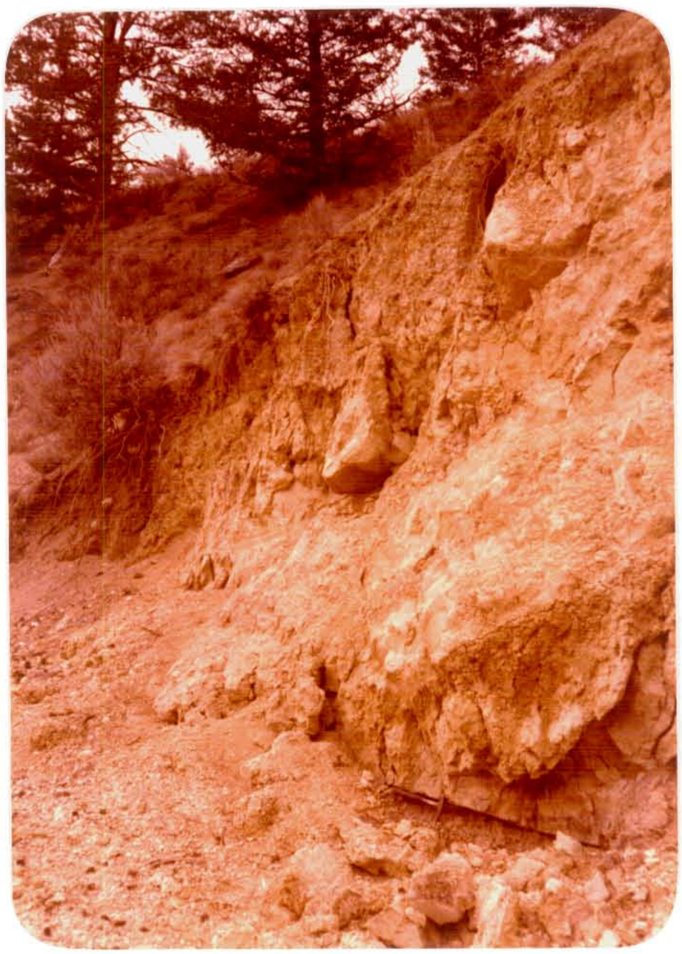
The slide areas have been divided into zones according to their present stability. Active zones are those in which movement is currently occurring, marginally active zones are those in which movement is not demonstratable at present, but which give evidence of being in limiting equilibrium, stable zones are those areas of old slide activity that appear to be stable under present physical conditions. The slides have been numbered on the drawing and are described below.

The main slide area (1) is some 2 square miles in extent and encompasses an area between Aleece and Finney Lakes and the western limit of the Hat Creek valley. The irregular topography (see Drawing 1), poor drainage, arcuate arrangement of hills and lakes together with the many typical slide profiles, is convincing evidence that widespread instability has existed in this area in the past. No active instability is seen although the one slope indicator installed in this area (RH 76-5) indicates possible movement at a similar level to the base of the disturbed zone in the core from the neighbouring hole DDH 76-807. It is likely that the major movement of this slide occurred in periglacial times on recession of the ice. Few rock exposures are seen in this area because of the glacial cover, but the drilling gives reason to believe that most of the movement has occurred within the Coldwater Formation. Volcanic rocks also occur in this neighbourhood, although the relationships are obscure.

Slide 2 is an active flowslide some 6,500 ft. in length which extends from a point north of Aleece Lake northeastwards into the Hat Creek valley (see Plate 4a). A tongue from this slide spills over northwards into Houth Meadows. It comprises predominantly remoulded material of the Coldwater Formation with a variable constituent of glacial till. The slide headwall shows well bedded sandstones and conglomerates, often carbonaceous, micaceous and tuffaceous. Three slope indicators have been installed in this slide, and within the first six months of operation have demonstrated the existence of at least one well-defined shear plane on which the slide is moving. Detailed consideration of this is given in Section 6.1.3. Although the drill core has shown highly disturbed material within the upper 40 - 60 ft. of many holes (see drill holes DDH 76-805, 809, 811 and 812), the slope indicator casings have sheared off along planes below this zone in material logged as intact Coldwater Formation. Well defined shear planes along the margins of this slide can be followed throughout its length. The slide has obviously been moving for some considerable time as it has deflected Hat Creek and produced erosion of the surficial soil in cliffs on the east side of the creek.

Slide 3 is marginally stable or stable. As Slide 2 lies within this area, it is probable that the active Slide 2 merely represents the reactivation of an pre-existing slide. The northern part of the slide appears stable, and

a. Aerial view of toe of active flowslide - Slide 2 in text (Ref. 83240N, 18830E).



b. Highly disturbed Coldwater Formation siltstone and claystone. Hammer lies along slide plane (Ref. 82250N, 18830E).

the southern part shows some evidence of movement especially close to Slide 2 (see Plate 4b).

Slide 4, which has flowed northwards into Houth Meadows, does not appear to be recent. Although some local areas of instability may be seen, it is stable under present conditions.

Slide 5 represents the active toe of the main slide (Slide 1). It consists of lobes of highly disturbed Coldwater sediments also including glacial deposits, which have flowed out over the surficial deposits and Coldwater rocks of the lower slopes (see Plates 5a and 5b). Large voids have been observed and erosion has occurred along the basal slide planes. Gypsum crystals have been seen along some joint surfaces. A slope indicator installed in this slide zone (RH 76-9) is not, as yet, showing any definite trend of movement.

The unstable area designated 6 in Drawing 8 is a circular failure in Coldwater rocks. Although the main slide area appears to be stable, a mass of weak remoulded Coldwater material is present at the foot of the slope and is highly unstable. The age of the slide is unknown.

Upwellings of liquefied bentonite, referred to elsewhere as bentonite 'boils', have been found at some locations on or near the No. 1 open pit area (see Plate 6). They are usually lobate structures with liquid bentonite cores, which at times during the year may flow. They are believed to be associated with slide zones in Coldwater material and the presence of artesian ground water pressures.

a. Lobate flowslides in Coldwater Formation materials (Ref. 79350N, 17010E).

b. Margin of one of active flowslides depicted in 5a. Note erosion along slide plane.

Liquid bentonite 'boil' (Ref. 73580N, 15980E).

4. SUBSURFACE HYDROLOGY

4.1 Purpose and Scope

As part of the geotechnical program carried out by GA a subsurface hydrological investigation was undertaken to assess ground water conditions in the area of the proposed open pit. This study was necessary in order to examine the following:

1. The depth to the water table in the proposed pit area.
2. The distribution of piezometric heads in each geological unit.
3. The drainability of each geological unit.
4. The influence of Hat Creek on local ground water flows.
5. The origin of the ground water.
6. The influence of precipitation on the local ground water regime.
7. The effect that the pit will have on the local ground water regime.
8. The effect that proposed dumps and hydraulic structures may have on the local ground water.
9. The estimated quantity of seepage that will flow into the pit.
10. The effects that geological features, such as faults, bedrock fractures and slide planes, will have on the ground water flow regime.

In order to obtain this hydrogeologic data the following program of field testing and instrumentation was carried out:

1. Installation of piezometers in cored (mud-flush) holes drilled for GA and DCA.
2. Falling head permeability tests in standpipe piezometers set in seven air-flush rotary holes.
3. A 23-day pump test in one screened pumping well with three associated observation wells.
4. The installation of automatic water level recorders in two observations wells to monitor long-term fluctuations in piezometric water levels.

The details of the results and methods of obtaining data are included as Appendix 5 - Geohydrologic Data and Appendix 6 - Pumping Test Report.

4.2 Field Testing Program

This program was carried out during the summer of 1976 and was designed to fit in with the geologic exploration and geotechnical programs being carried out at the same time.

Two types of piezometers were used, and were set in either cored mud-flush diamond-drill holes (3 to 4-inch diameter), or in air-flush rotary holes (6-inch diameter). A total of 74 standpipe piezometers and 19 pneumatic piezometers were installed. Details of the installations including typical designs are included on the hydrologic logs in Appendix 5.

All piezometer installations were designed as permanent installations to provide long-term monitoring of piezometric heads resulting from seasonal changes and pit excavation.

The piezometers were installed preferably in air-flush rotary holes so that problems arising from the mudded walls of the holes were obviated. However advantage was also taken of the large number of mud-flush holes being drilled to install instruments wherever practicable. In the deeper holes, where the hole walls were difficult to stabilize, piezometer installations had to be completed through the drill rods after geophysical logging had been carried out. Piezometers were set in nests of one, two and occasionally three per hole and only one hole had four piezometers (RH 76-15). The upper piezometers were usually set quite easily in the open hole after removal of the drill rods and before collapse of the hole.

A total of twelve 6-inch diameter air-flush rotary holes were drilled specifically for hydrogeological purposes. The locations of these holes are shown in Drawing 6, and they are numbered RH 76-10 to 20 inclusive (one hole had to be redrilled). Four of the holes were drilled around the pumped well RH 76-19 to monitor the pumping test. It was considered essential that all permeability testing be carried out in air-flush holes which were uncontaminated by drilling mud. The holes were drilled near existing geotechnical holes to ensure that details of the local geology were adequately known.

Falling head permeability tests were performed in each of the three piezometers installed in five of the air-flush drill holes. In some cases long periods of time were required for the water in the standpipes to reach a static level before the tests could begin. Some details and results of these tests are summarized in Appendix 5.

A single pump test was carried out in the low permeability siltstones/ claystones above the coal in the south part of the pit area. The pumping well (RH 76-19) was installed with an 8-inch slotted steel casing with an annular gravel pack. Only the Coldwater Formation was screened, the surficial materials being cased off. Three 6-inch observation wells were specifically drilled to monitor the test, and existing piezometers were monitored also. The 23-day test was carried out with the use of a submersible pump, and the initial pumping rate of 1 gpm was reduced to 0.10 gpm after the first day. Recovery levels were monitored on the cessation of pumping. Automatic level recorders were installed in the piezometers in RH 76-16A and 76-149-1 to monitor changes during the recovery period following the pump test. The recorder on RH 76-16A was subsequently removed and the recorder in 76-149-1 left to monitor ground water changes during the spring of 1977.

4.3 Evaluation of Piezometric Data

4.3.1 Piezometric Time Responses

Once installed, all piezometers were read intermittently. To date there are no data available on long term hydrographs of piezometric heads in properly installed piezometers in the Hat Creek valley. A regular monthly monitoring program for all piezometers has been recommended by GA, and it is being carried out by DCA for BCH. This program should be continued. Some water level measurements have been made by others over the last five years in open mud-flush holes. Unfortunately these data are of limited value due to both the formation squeezing in the holes and the presence of a mud cake on the walls of the holes.

The piezometers installed during the 1976 drilling program have been useful in providing initial piezometric head values. Many of the piezometers installed during July and August are still dropping slightly, and appear to be slowly stabilizing. The slow response in some of the standpipe piezometers is not surprising considering the low permeability of the siltstone and claystone (approx. 10^{-8} cm/sec.). Figure A5-1 in Appendix 5 shows hydrographs of piezometers in two holes, (DDH 76-801 and 76-805), which illustrate the response curves experienced in different areas with different piezometer types. The standpipe piezometer in DDH 76-801 is located in siltstone in the southeastern pit perimeter, and the hydrograph shows a gradual decline of the water level in the standpipe. The two pneumatic piezometers in DDH 76-805 showed significant changes during the same period, thus demonstrating the sensitivity of these piezometers in the low permeability sediments. The decline in piezometric heads is also due partly to the unusually dry fall, as normally some evidence of a response to ground water recharge would be expected by early winter. When a full year's data becomes available it will be possible to assess the response of the local ground water flow system to seasonal changes.

4.3.2 Piezometric Head Distribution for the Coldwater Sediments

Drawing 11 shows contours of the piezometric surface in the Coldwater sediments as of November 1, 1976. The plan shows a regular shape, which generally follows the shape of the topography, and no major inconsistencies are apparent. The only anomalous region is around Dry Lake, where the piezometric surface sinks to about 200 ft. below the Hat Creek valley floor in DDH 76-150. On present knowledge it is impossible to give a reliable geological explanation for this anomaly. The shape of the piezometric surface suggests that there is a local ground water sink where the water flows downwards and into a more permeable zone. Further drilling and hydrogeologic investigation in this area will be necessary.

The distribution of the piezometric heads with depth is not well defined, due partly to lack of data and to the variability of measured piezometric heads. Piezometric heads have been plotted on geologic cross-sections. These data generally show a downward movement of the ground water (i.e. from overburden down into the bedrock sediments) along the upper portions of the east and west benches. This effect is clearly shown in the vicinity of the pump test well (see Appendix 6). In the valley bottom the trend is generally reversed, suggesting that Hat Creek is in a ground water discharge area. This trend is supported by the presence of a number of small seeps observed in the western sides of the creek valley. The whole of the hillside, southwest of a line connecting holes DDH 76-807, 76-134 and 76-801, has the characteristics of a major zone of recharge, with much more luxuriant vegetation (balsam fir) than lower down, where high water pressures in piezometers prevail (DDH 76-802 and 76-134). The Kamloops Volcanics and Mount Martley Stock (granodiorite) appear to be zones of rather more permeable rocks. These geologic formations probably underlie the Coldwater Formation (see Drawing 2) and would appear to be a major recharge zone.

The piezometric surface in the Coldwater sediments just east of Hat Creek within the pit area is much higher than the piezometric surface in the overlying surficial deposits. The surficial deposits in the pit area are gravelly tills and glacio-fluvial deposits. These sediments appear to be well drained, particularly in the northeast section of the pit near the proposed ramp. As can be seen in Drawing 11 the piezometric heads in the siltstone of this northeast sector are not anomalously high (i.e. they follow regional trends), and the overlying free-draining tills seem to have had little effect on lowering the piezometric pressures in the siltstone. Further drilling and testing will be needed to determine more accurately the piezometric head distribution and permeabilities in this area, particularly since it is the location of the access ramp.

The surficial deposits on the western bench are less well drained and springs and seeps are common particularly below the 3,000 ft. contour. These seeps are a consequence of a relatively permeable glacio-fluvial aquifer within the surficial till deposits, from which the seeps occur. An extension of this glacio-fluvial aquifer was encountered in RH 76-16 and RH 76-18, where up to 50 gpm of water was blown from the hole during drilling at a depth of about 80 ft.

The ground water conditions in the active slide area (Slide 2, Drawing 8) are either partly the cause, or the result, of the slide movement. Field exposures indicate that permeabilities may have been increased along the slide plane itself following movement. Piezometric heads are generally at or close to ground surface in the area above the slide scarp near Aleece Lake, and are generally low in the area of the toe of the slide.

4.3.3 Permeability of Geologic Units

The results of all falling head permeability tests are shown in Appendix 5. Typical values for the coefficient of permeability are as follows:

Clastic Coldwater Sediments (both basal and upper units)	10^{-8} cm/sec.
Coal	10^{-4} cm/sec.
Basaltic Rock (Tertiary Volcanics)	10^{-4} cm/sec.

The permeability value for the Coldwater sediments agrees with permeabilities determined from the analysis of the pump test. This test showed that it would be possible to depressurize the siltstones, but because of the low permeability and presence of vertical leakage from the overburden aquifers, the process would be very slow (see Section 6.3).

4.4 Chemistry of the Ground Water

Some samples of ground water and surface water were submitted to laboratories for inorganic chemical and isotopic analysis. A copy of the Can Test Ltd. report on the inorganic chemical analysis is included in Appendix 5. The oxygen -18 isotope analysis was carried out at the University of Waterloo, Ontario. A summary of the results is given in Table 3.

Some preliminary comments on the origins and types of ground water can be made:

TABLE 3

SUMMARY OF CHEMICAL ANALYSES OF LOCAL WATERS

Sample No.	Sample Date	Sample Site	Notes	$\delta^{18}O$ (‰)	Inorganic Ions (ppm) Na^+	Ca^{+2}	Mg^{+2}	K^+	HCO_3^-	SO_4^{-2}	Cl^-	pH	EC
76-1	Sept 9/76	Aleece Creek	2,000 ft. from lake outlet	-14.0		44.8	21.7	9.0	-	-	-	7.85	508
76-2	Sept 9/76	Spring	On south shore of Aleece Lake	-14.3	33.0	-	-	-	-	-	-	-	-
76-3	Sept 9/76	Aleece Lake	At outlet from 2' depth	-8.8	38.0	33.9	25.2	11.5	265	52.2	<.5	7.6	508
76-4	Sept 9/76	Well RH76-19	During development	-18.0	110.0	19.0	9.4	18.0	260	47.7	<.5	7.6	677
76-5	Sept 9/76	Hat Creek	Near Hole RH 76-20	-18.1	21.3	58.0	17.4	4.0	-	-	-	8.0	462
76-6	Oct 14/76	Well RH76-19	At end of pump test	-20.1	330.0	47.7	21.6	34.0	1150	17.3	<.5	7.6	1834

Notes:

1) $\delta^{18}O$ is the oxygen isotope concentration in the water given in units relative to Standard Mean Ocean Water (SMOW).

2) EC is the electrical conductivity of the water in micro mhos/cm.

1. The water pumped from the well RH 76-19 was a water of local meteoric origin (i.e. from the atmosphere) and not interstitial water that was sealed in with the sediments at the time of deposition.
2. The near surface ground water can be distinguished by an oxygen -18 isotope concentration of around -14 per mil. ($^{o}/oo$), and deeper ground waters by a concentration of around -20 per mil.
3. The sodium-ion concentration is higher for the ground water of a deeper origin. The presence of high sodium is not surprising in view of the results of mineralogical and physio-chemical analyses carried out on the Coldwater sediments (see Appendix 3).

These preliminary results show that natural isotopes are a useful indicator of the origins of ground water in the area, and that additional sampling can be justified in order to establish the relationship between surface and ground water. For example in the west bench area, the relationship between the lakes and ponds and the ground water flowing towards the proposed open pit will be an important factor in the design of a system for the control of surface and ground water in the area.

5. GEOTECHNICS

5.1 General

In general the geotechnical investigations were carried out in materials of the Coldwater Formation, since these would form the greater part of the pit slopes. Despite the results from the early reports ('No. 1 Deposit, Rock Mechanics Data', DCA, 1975) and the 1974-75 drill logs, it was suspected that the Coldwater Formation would be much weaker than indicated. This was subsequently borne out by the geotechnical drilling which showed most of the materials to be weak and highly susceptible to desiccation or disturbance.

The materials of the Coldwater Formation fall into the range of compressive strengths between stiff soils and weak rocks. Table 4 shows the strength ranges and descriptions commonly accepted and used in this report in comparison with those used previously. Although the materials were usually sufficiently strong and cohesive to be cored, they required careful handling. The core had to be extruded from the barrel and logged immediately, if the true character of the rock/soil was to be assessed. Full-time supervision of the drilling by a geotechnical engineer was therefore required on each rig on each shift worked. Index testing and uniaxial compressive strength tests were carried out at the rig site as soon as possible after each core run. For this purpose portable laboratory trailers were set up on site. Most of the remainder of the geotechnical testing was carried out in the Vancouver laboratory of GA.

5.2 Material Types

It will be appreciated from the stratigraphic descriptions of the Coldwater sequence (Section 3.4) that considerable lithologic variation exists, both in depth through the pit and laterally along any stratigraphic horizon. Therefore in order to reduce the testing program to manageable proportions and to facilitate subsequent analysis, it was necessary to group the materials

TABLE 4

ROCK CORE STRENGTH DESCRIPTION

Golder Assoc. Hardness Code	Geological Society of London Term	Dolmage Campbell Assoc. Term	Approx. Uniaxial Compressive Strength psi [1]	tsf [2]	Field Estimation of Hardness [3]
R5	Extremely strong		>29,200	>2,100	Requires many blows of geological hammer to break.
R4	Very strong		14,600-29,200	1,050-2,100	Requires a few blows of geological hammer to break.
R3	Strong		7,300-14,600	525-1,050	Breaks under single blow of geological hammer.
R2	Moderately strong		1,825- 7,300	131- 525	1/4" indentations with sharp end of geological pick.
R1	Moderately weak	Very hard	730- 1,825	52.5- 131	Too hard to cut by hand into triaxial specimen.
	Weak		182- 730	13.1- 52.5	Crumbles under firm blows of geological pick.
S5	Very weak (rock)	Hard	85- 182	6.1- 13.1	May be broken in the hand with difficulty.
S4	Very stiff (soil)	Moderately hard	42- 85	3.0- 6.1	Indented by finger nail.
S3	Stiff	Soft	21- 42	1.4- 3.0	Cannot be moulded in fingers.
S2	Firm		10.5- 21	.76- 1.4	Moulded with strong pressure of fingers.
S1	Soft	Very soft	5.25- 10.5	.38- .76	Easily moulded with fingers.

Notes:
1) psi = pounds per square inch
2) tsf = tons per square foot
3) All field estimates based on a hand held specimen of rock core.

into categories. Although these may seem to be artificial from a geological standpoint, the subsequent testing showed these divisions to be valid. Petrographic descriptions of some rock types are included as Appendix 2 and the X-ray diffraction studies by Dr. Quigley, referred to later, are in Appendix 3.

5.2.1 Conglomerates

Conglomerates form much of the sequence below the coal, and will be exposed in the upper levels of the ultimate pit walls from the southwest around to the northwest (see Drawing 9). The core recovery of these materials was sometimes very poor, e.g. DDH 76-810, and considerable doubt therefore exists concerning the properties of those lost materials. The conglomerate generally comprises fine to coarse gravel sized material with occasional cobbles set in a sandy or silty matrix (see log of DDH 76-806 from 541 ft.-721 ft.). It is interbedded with both sandstone and siltstone, and is usually grey-green in colour. Some conglomerates are tuffaceous, and probably represent the reworking of coarse tuffs and agglomerates on the margins of the basin. The fines in the matrix are believed to be often bentonitic, especially where the tuffaceous content is high. The compressive strength of the conglomerates is highly variable (see Section 5.4.2), and much dependent on the grading of the samples and particularly on the proportion and mineralogy of the matrix.

5.2.2 Sandstones

The sandstones are normally green or grey, and grade into the conglomerates at one end of the scale and into the siltstones at the other. Mineralogically they comprise quartz, felspar, cristobalite, and siderite and clay minerals resulting from the alteration of minerals of volcanic origin. Rock fragments may be present, and some material may also be carbonaceous. The granitic sandstones and breccias of the western area are high in quartz, muscovite mica and felspar. The sandstones are comparatively strong materials, but they too display a wide variation in compressive strength.

5.2.3 Siltstones and Claystones

Siltstone is the most widespread rock type within the sequence. It is the main constituent of the beds above the coal, it appears as inter-beds within the coal, it is common immediately below the coal in the northern sector of the pit, and it is interbedded with the sandstones and conglomerates in the lowest parts of the sequence observed. The siltstone has a variable proportion of clay and grades into claystone. Few of the rocks seem to have a sufficiently high proportion of clay (>50 percent) to be termed claystones, but most are clayey siltstones. When fresh the rocks are predominantly grey in colour but they rapidly change to shades of brown or olive green on exposure; similar features have been described in the bentonite deposits of Alberta (Scafe, 1973). The change in colour on exposure is the result of the oxidation from ferrous to ferric iron. The compressive strengths of both the siltstone and the claystone are low, with the claystones forming the lower part of the range close to true bentonites. Most siltstones are highly bentonitic, and others are carbonaceous. Disturbance by shearing or brecciation often characterizes these rocks, although it may only be recognizable on freshly broken surfaces of core.

Discrete tuff bands are common within the upper siltstone sequence. They are often highly bentonitic, although not invariably so. Due to their thinness (1-2 ins.) they are rarely discernible on the geophysical logs, and it has not been possible to use them for correlation purposes between drill holes. Nevertheless it is likely that they are continuous over long distances.

Clay ironstones rich in siderite occur in a similar way, but they are also thin, and cannot be used for correlation.

5.2.4 Coal

Like the conglomerates, the coal shows a wide range of strengths. However, in this case the variation is caused by the presence of inter-beds and sheared surfaces aligned unfavourably to the major principal stress direction during testing. Where intact samples of coal have been tested they have been shown to have strengths characteristic of moderately strong rocks.

The coal exhibits a wide range of other properties much dependent on the percentage of non-carbonaceous detrital matrix contained within the mass.

Cleating is only poorly developed in the coal but resin beads, ironstone nodules and tuff bands may also be found.

5.2.5 Other Material Types

Volcanic rocks of the Kamloops Group are extremely variable. They would not be intersected in the stage 8 pit as laid out at present, but some changes in slope could result in these appearing in the excavations. The only rock tested, an andesite, showed a strength significantly higher than the overlying rocks.

Seams of bentonite have been located in several drill holes, usually in association with slide zones. Bentonite-rich soils are often exposed within the slide zones. 'Boils' of liquefied bentonite are present in the southwest of the pit area, near DDH 76-802 and elsewhere in slide zones. These materials apparently result from remoulding Coldwater Formation sediments, or from glacial sediments rich in Coldwater material. Their moisture content and 'erupted' state is a reflection of the ground water conditions. These surficial bentonites have a very characteristic hackly texture and soapy feel.

5.3 Mineralogy

Because it was suspected that montmorillonite would be a constituent of some of the rocks of the Coldwater Formation, a program of mineral identification by X-ray diffraction was undertaken. The results of the studies carried out are included as Appendix 3. The conclusions by Dr. Quigley of the University of Western Ontario, who did much of the laboratory work, are contained in the same appendix.

5.3.1 Earlier Work

During 1975 a series of samples was chosen at random from the core of drill holes DDH 75-49 and DDH 75-50, and from a trench dug near Hat Creek. These were sent to Dr. Quigley for analysis, and he concluded that all the samples were high in bentonite and had a significant sodium content. Some samples also contained cristobalite, felspar, quartz and possibly tridymite. Of these sample locations, DDH 75-49 was in sediments below the coal, DDH 75-50 was probably in sediments above the coal and the trench sample was not identified.

5.3.2 1976 Work

During the early part of the geotechnical study it was suspected that tuff beds interbedded with the Coldwater sediments were bentonitic, and a particular effort was made to sample these for X-ray diffraction analysis. The choice of sample was made on physical appearance. At the same time the samples were selected routinely for carrying out Atterberg Limits and a selection of those that showed high liquid limits were also sent for X-ray diffraction. Samples from outcrop locations showing obvious bentonitic material (bentonite 'boils' and the head of the flowslide) were similarly sent for analysis at the University of Western Ontario. Later in the program samples were chosen on a random basis.

A special study was made of the sediments interbedded with the coal to assess their handling characteristics during coal processing. Samples were taken from the four coal zones for Atterberg Limits and X-ray diffraction; analyses were carried out at UBC on some of these samples.

Samples were also taken of the waste residue from the coal sampled in the auger holes BAH 2, 3, 4 and 5 for Birtley Engineering Ltd. X-ray diffraction analyses were carried out by Core Laboratories - Canada Ltd.

The results from the various studies as shown in Appendix 3 indicate that, whilst there were distinct tuff bands which had subsequently been altered to montmorillonite, the bulk of the Coldwater Formation sequence outside the coal had a high montmorillonite content. Moreover, within the coal sequence, the A-zone which is the highest zone, also had an appreciable montmorillonite constituent, and the lower B-, C- and D-zones showed only traces, the clay mineral in those zones being mostly kaolinite.

The analyses carried out by Dr. Quigley on the sediments above and below the coal indicated that there appear to be four typical mineral assemblages:

1. Essentially pure montmorillonite with trace amounts of quartz and felspar (<10 percent).
2. Montmorillonite with moderate amounts of quart, felspar and possibly cristobalite (10-30 percent).

3. Montmorillonite with up to 10 percent of siderite ($FeCo_3$).

4. Siderite with subsidiary montmorillonite, quartz or felspar.

The dominant cation in the montmorillonites tested is sodium (Na), but sufficient magnesium (Mg), calcium (Ca) and iron (Fe) also exists to ensure that a predominantly divalent regime exists in the double layer crystal lattice. This is consistent with the results of the Atterberg Limits and soil activities obtained by GA. Both of these measured parameters, whilst being characteristic of highly plastic clays, are much lower than would be expected from a pure Na-montmorillonite, yet higher than would be expected from a pure Ca-montmorillonite.

Some zones sampled in the beds above the coal have been high in siderite, with the other constituents being present in minor amounts. They were sampled because of their resemblance to tuffs in colour and texture. They are light green to light grey, very fine-grained dense deposits with a lower than average moisture content. They are sedimentary in origin and could equally well be considered as clay-ironstone. They are widespread in the upper beds, locally present within the coal, but apparently absent in the lower beds.

The mineralogy carried out on the coal inter-bed samples (see Section 6.4) indicates that the beds of the lower three zones comprise predominantly quartz and kaolinite with a trace of montmorillonite and occasional siderite. In the A-zone, not only is the kaolinite and quartz content much reduced, but montmorillonite and felspar become much more common.

It is apparent from the results that the mineralogy of the Coldwater Formation is much dependent on the supply of volcanic detritus, either directly deposited as ash, which was subsequently lithified to tuff, or from reworking of the detritus on the margins of, or in proximity to, the basin of deposition. The montmorillonite/cristobalite suite is characteristic of in situ alteration of silicate minerals, which, according to Grim (1968), can only occur in water and not under conditions of terrestrial deposition. The fact that kaolinite and not montmorillonite is present in the lower three zones of the coal, suggests that at the time of deposition the prevailing conditions were not right for the crystallization or alteration of pre-existing minerals to montmorillonite.

5.4 Testing

5.4.1 Identification Tests on Coldwater Sediments

Index testing was carried out in the field and in the Vancouver laboratory of GA to determine plasticity indices, clay contents and natural moisture contents of the siltstones and claystones encountered. This testing was carried out to help identify material types and possibly to correlate with physical properties, such as shear strengths. The detailed results are included as Appendix 7. The procedures that were used required a great deal of time and care to ensure reliable results. The materials were tested without drying from their natural moisture contents. The ranges and mean values for the siltstones, claystones and bentonitic inclusions are as follows:

	Range	Mean
Liquid Limit, percent	35 - 320	118
Plastic Limit, percent	20 - 62	32
Plasticity Index, percent	10 - 280	81
Natural Moisture Content, percent	10 - 83	30
Activity, $\frac{\text{Plasticity Index}}{\text{Clay Fraction}}$	0.8 - 3.0	1.8

Figure 3 shows the liquid limits plotted against the plasticity indices, and illustrates the very large range of values measured. This figure clearly shows that the fine grained materials encountered during the investigation were highly plastic. Figure 4 shows a histogram of the natural moisture

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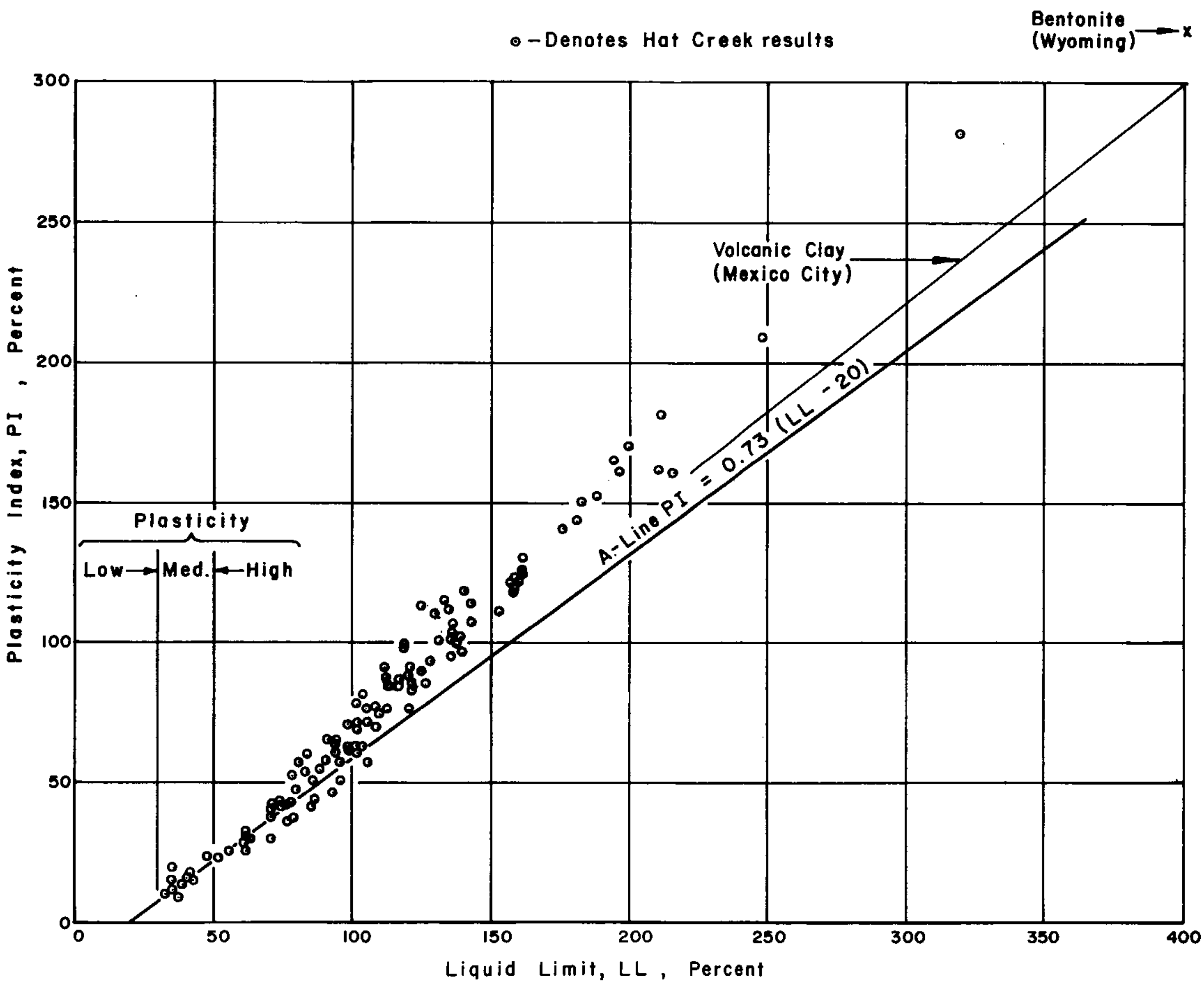

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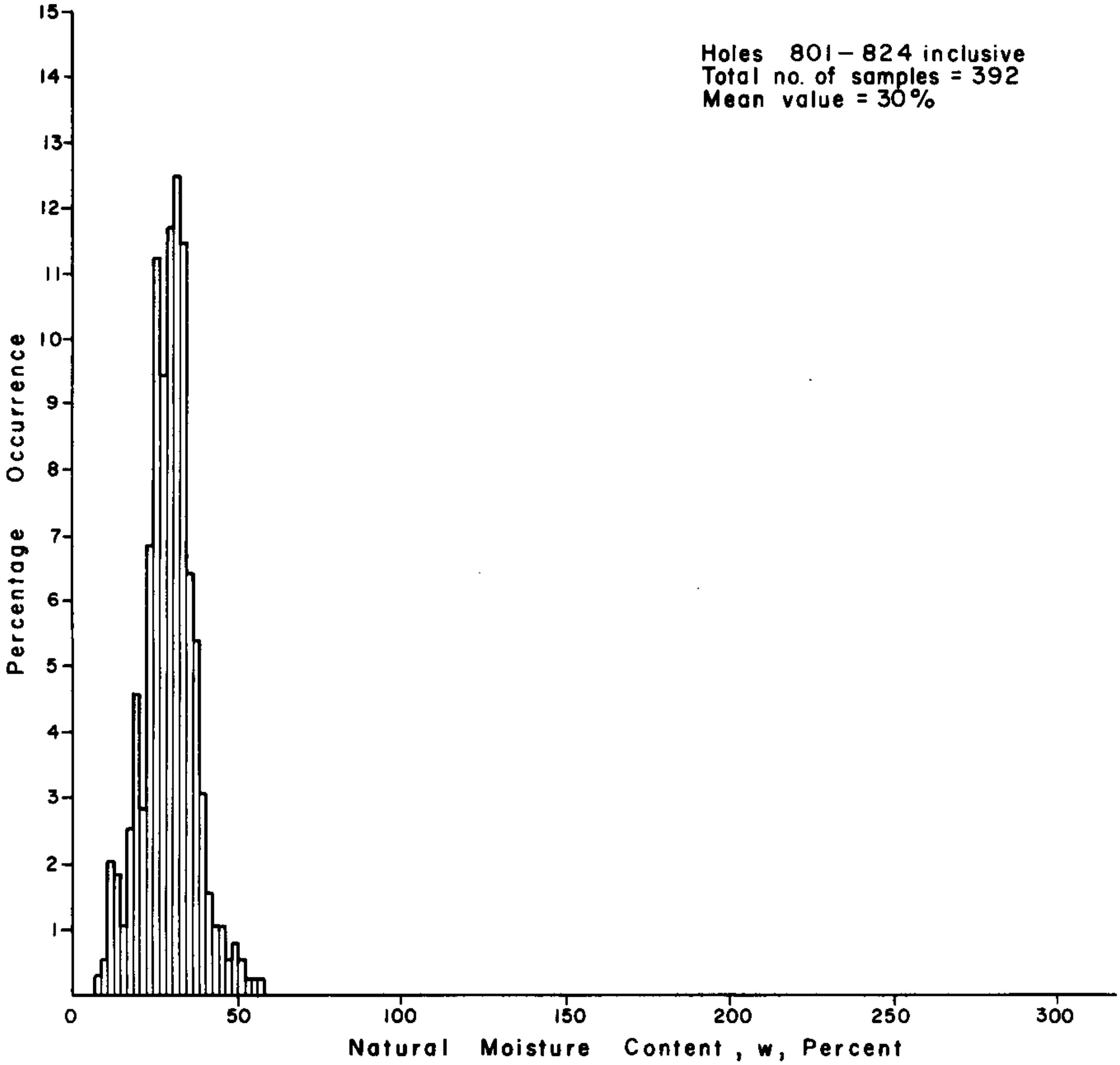
PLASTICITY CHART

Figure 3

HISTOGRAM OF NATURAL MOISTURE CONTENTS Figure 4



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contents, indicating that the mean moisture content measured is around 30 percent. Generally in situ moisture contents were very close to the corresponding plastic limits. Figures 5 and 6 respectively show histograms of the liquid limits and plasticity indices.

Very high values for liquid limits, as found in these materials, are often associated with a very active clay mineral such as montmorillonite.

Grain size distributions were obtained on 25 samples to obtain the clay fraction, i.e. the percentage less than 2 microns (μm), and this information was used to calculate the activities. Activity, defined by Skempton (1953) is the ratio of the plasticity index to the percentage clay fraction. Figure 7 shows the activities measured for the Hat Creek materials plotted on the graph for the pure clay minerals developed by Skempton. The mean activity for the Coldwater siltstones, claystones and bentonites is 1.8. Clearly this plot indicates the presence of montmorillonite minerals.

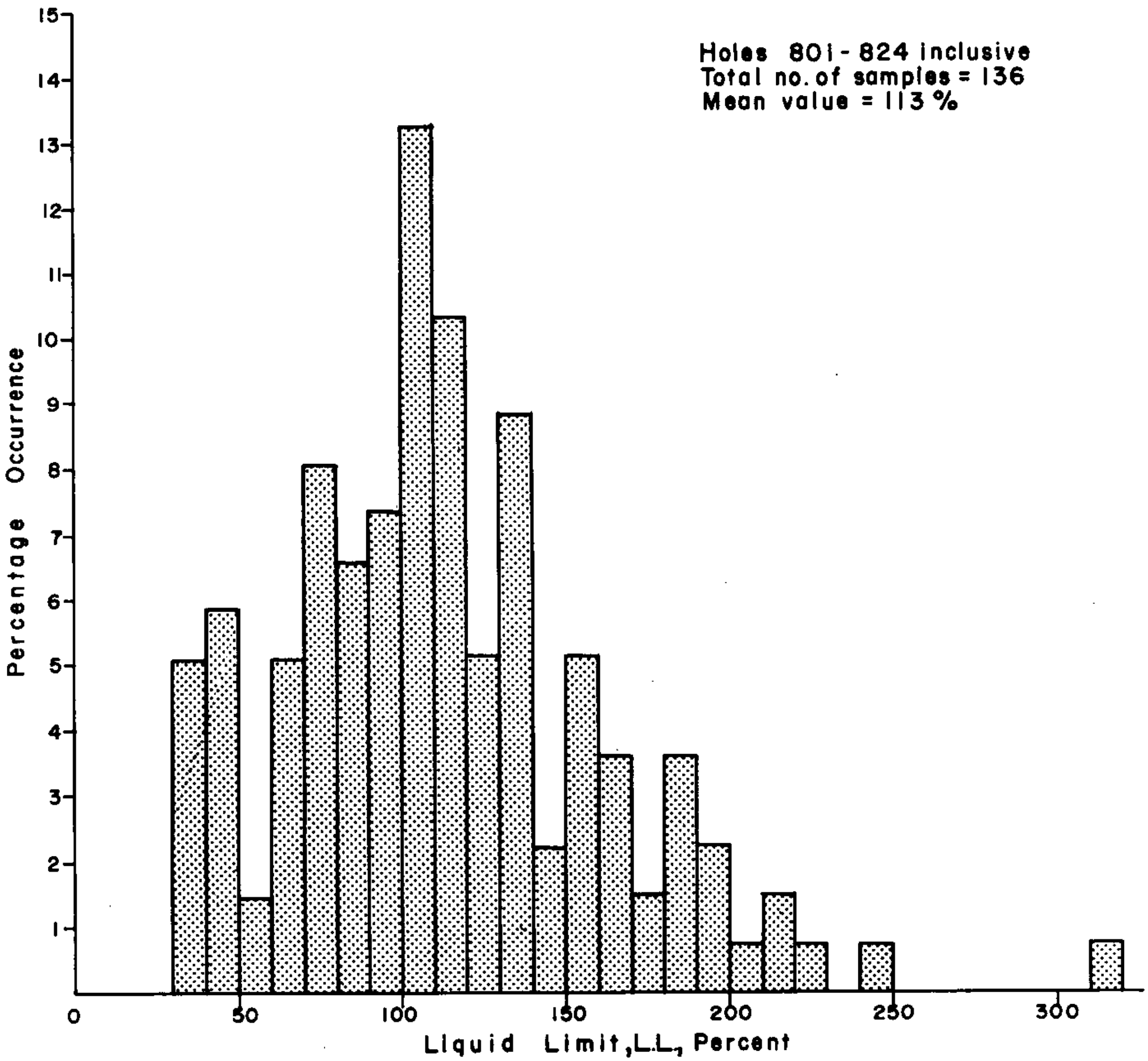
Further investigation of clay mineralogy was carried out by Dr. R.M Quigley at the University of Western Ontario using X-ray diffraction techniques on a total of 43 samples, (see Section 5.3.1). The tests by Dr. Quigley confirm the presence of active clay minerals, predominantly sodium, magnesium and calcium montmorillonite. Dr. Quigley suggested that materials with permeabilities as low as 10^{-9} to 10^{-10} cm/sec. and very low residual angles of friction in the range 5 to 10 degrees can be expected to occur.

5.4.2 Uniaxial Compression Tests

Uniaxial compressive strength testing of rock core samples was carried out in the field, in conjunction with triaxial compression and direct shear strength testing of materials in the laboratory in Vancouver. The uniaxial compressive strengths were measured in order toio assess the variations in strength

HISTOGRAM OF LIQUID LIMITS

Figure 5



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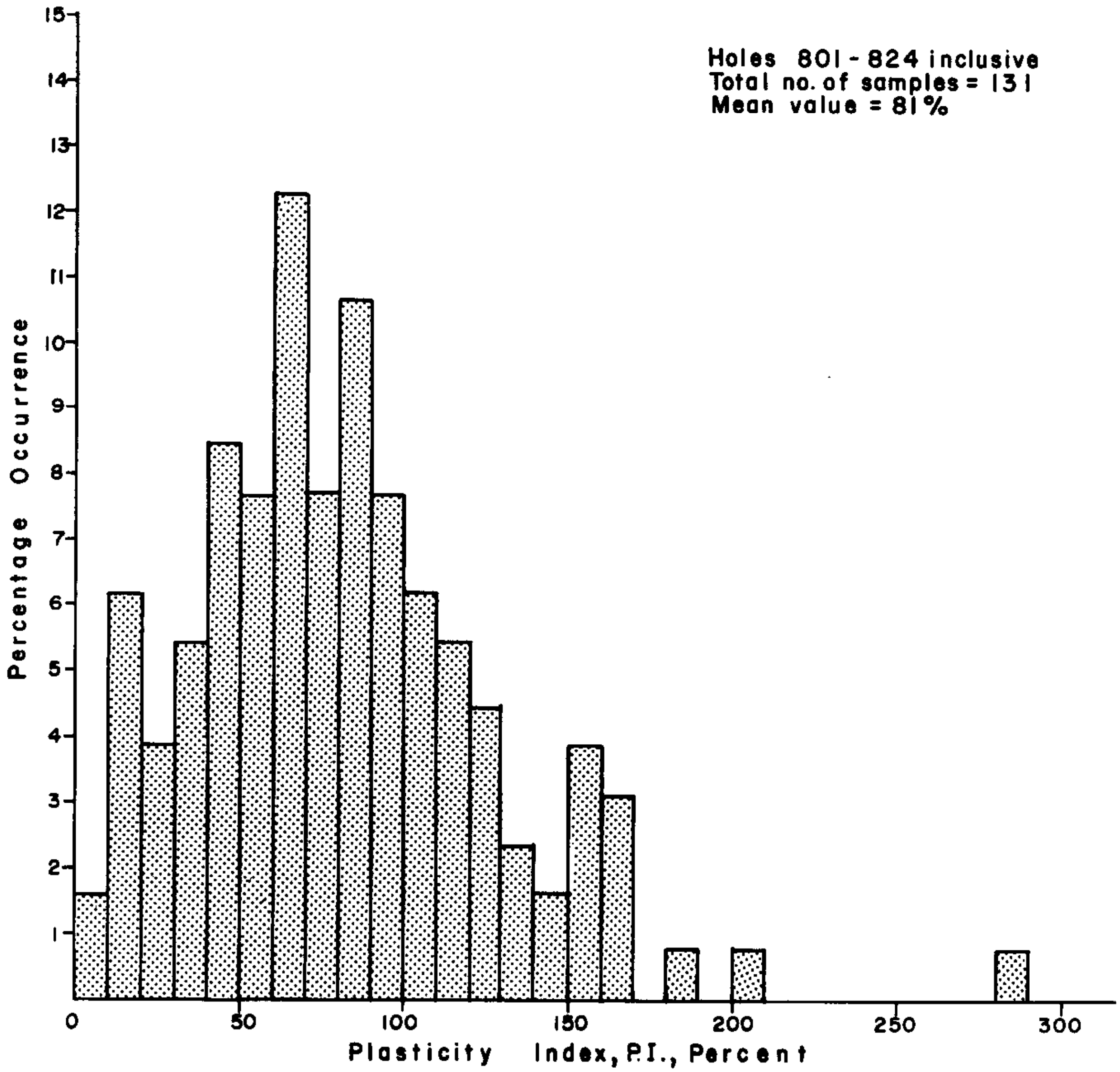
HISTOGRAM OF PLASTICITY INDICES Figure 6



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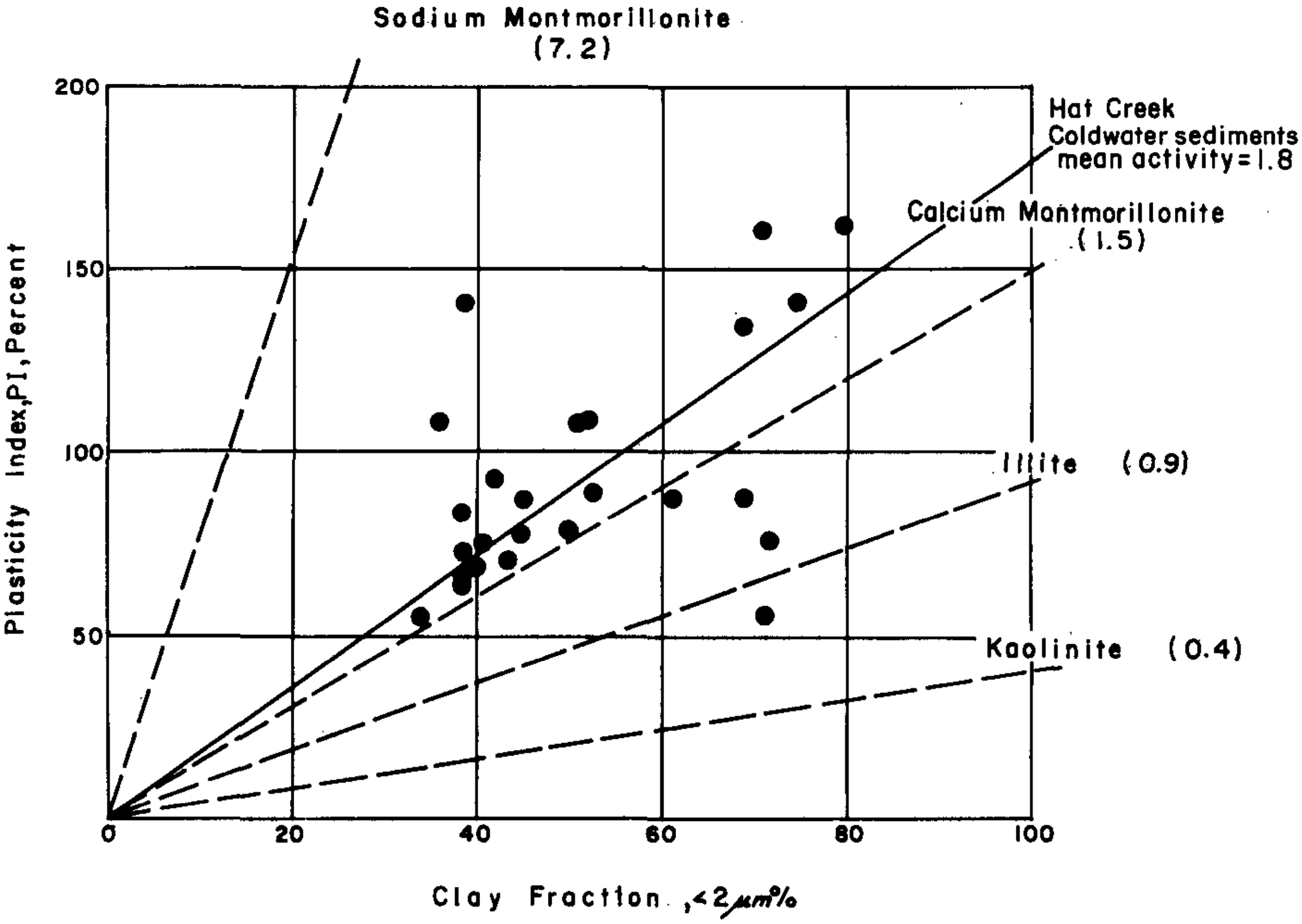
ACTIVITY

Figure 7

Chart after Skempton (1953)

● - Denotes Hat Creek results

$$\text{Activity} = \frac{\text{Plasticity Index}}{\text{\% Clay fraction}}$$



of the rock types encountered, and to provide a semi-quantitative rock grade classification.

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

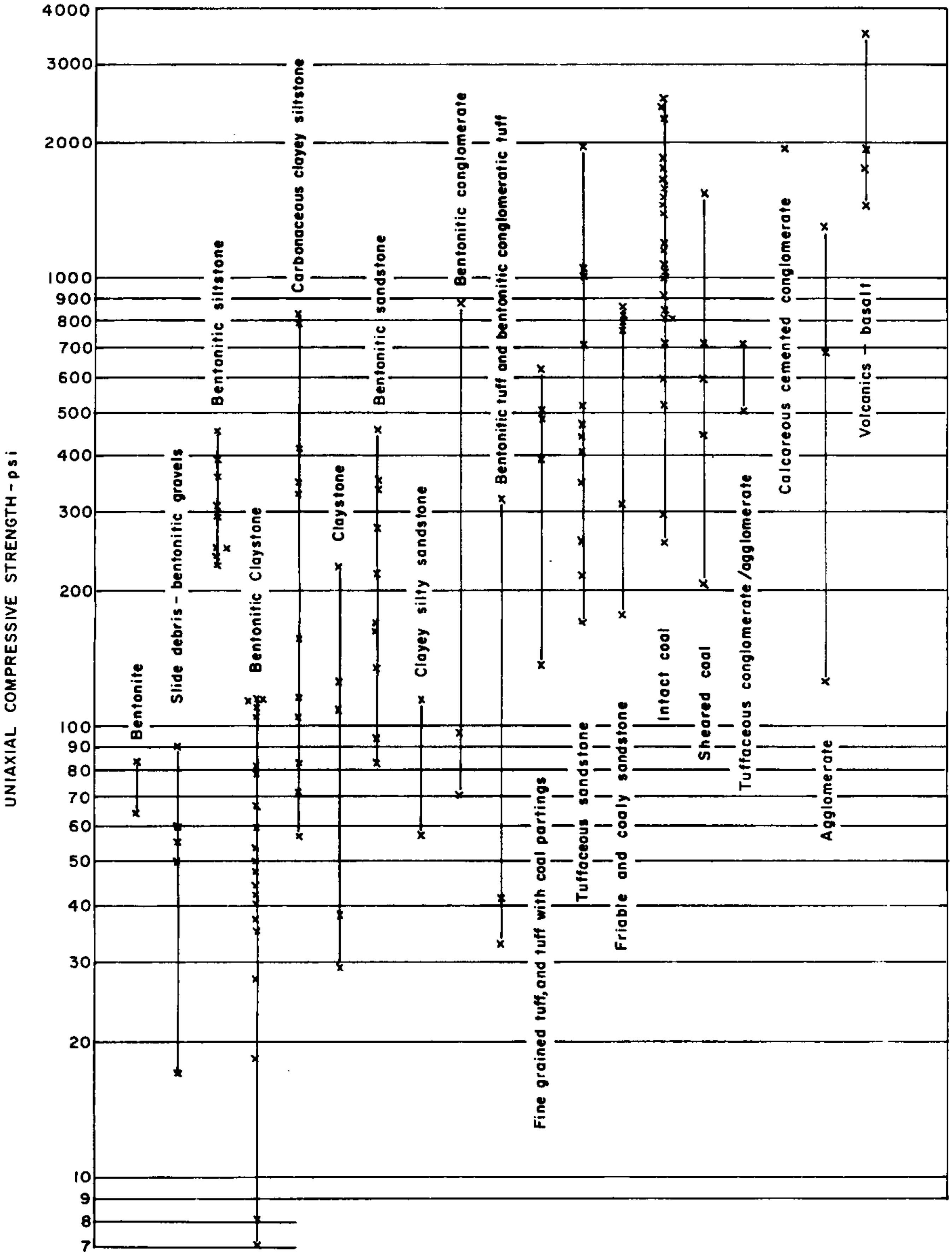
Material	Average Uniaxial Compressive Strength, Psi
Andesite	>3000
Coal	1250
Conglomerate	850
Sandstone	450
Siltstone	280
Claystone	75

Figure 8 shows the results of the uniaxial compressive strength tests plotted against rock types, illustrating the wide range of strengths encountered. The word 'rock' should be applied with caution to the siltstones and claystones, since their strengths place them into the range of stiff soils, (see Section 5.1). Details of the uniaxial compressive strength testing are included in Appendix 4.

It should be noted that the uniaxial test is essentially a rapid undrained test. In general, and in particular with siltstones or claystones, immediately after coring, the material has high negative pore pressures within the sample. These pressures tend to hold the sample together, with the result that the apparent undrained shear strength is much greater than the cohesion measured in terms of effective stresses. This difference, which is apparent from an inspection of Figure 8 and Figure 9, is a function of rate of testing.

UNIAXIAL COMPRESSIVE STRENGTHS

Figure 8



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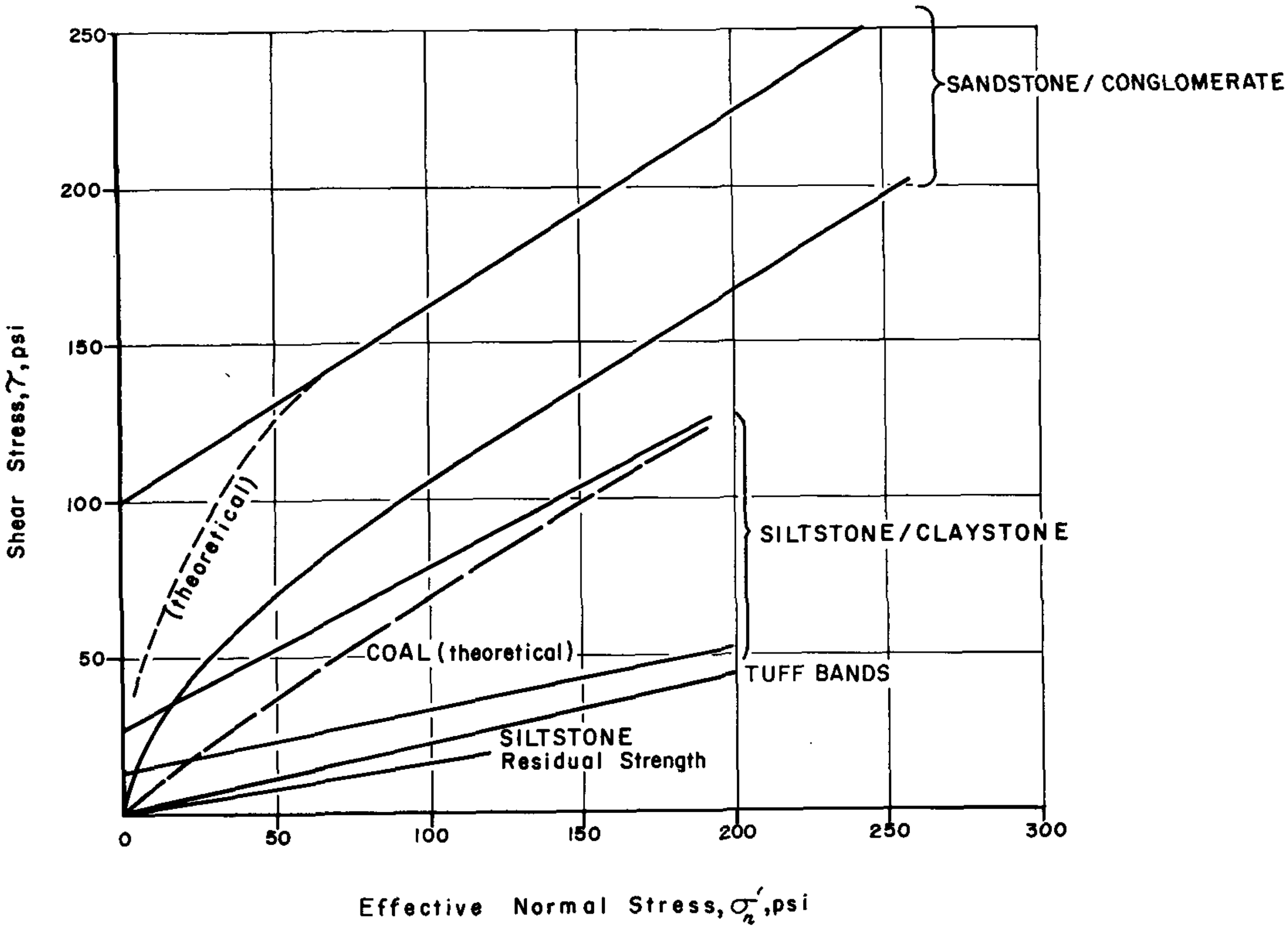

MOHR ENVELOPES OF EFFECTIVE STRESS
COLDWATER SEDIMENTS

Figure 9

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The uniaxial compressive strength has been used, therefore, primarily to assist in the rock classification.

5.4.3 Shear Strengths of Coldwater Sediments

Shear strength testing was carried out in the laboratory, measuring parameters in terms of effective stresses. These tests included consolidated undrained triaxial compression tests with pore pressure measurements, consolidated drained triaxial compression tests with volume change measurements, and direct shear box tests. Because of the extremely low permeabilities of the materials, the shear strength testing was carried out at very low strain rates with many tests lasting 60 hrs. The testing program was therefore very time consuming. The materials required very careful handling during sampling, transportation and preparation, but because of the weak nature of most of the specimens, some sample disturbance was inevitable.

The majority of the tests were drained triaxial compression tests on the weaker materials such as the siltstones, claystones and bentonites. The maximum particle size of the conglomerates was large in comparison with the core size, and they were therefore unsuitable for use in the normal size of test cell. Since the conglomerates are strong, stability is controlled by the weaker siltstones and claystones and the strength of the conglomerate is not a critical factor.

The criterion for failure was taken as the point of maximum principal effective stress ratio, σ_1'/σ_3', with the shear strength parameters, apparent cohesion c', and angle of internal friction ϕ', expressed in terms of effective stresses. Stress-strain curves and details of the tests are included in Appendix 8. A summary of the effective shear strength parameters for the different material types is given below.

Material Type	Angle of Internal Friction ϕ', degrees	Cohesion, c', psi
Sandstone, upper bound (measured)	32	100
Coal, (measured and theoretical)	40 to 30	0
Siltstone, upper bound	27	20
lower bound	11	13
residual	9	0
Bentonitic tuff bands, shear box (cut & polished surface)	12	0

These results are shown graphically in Figure 9. The theoretical curves shown for the coal and sandstone were calculated from an equation by Ladanyi and Archambault (1970) using the uniaxial compressive strengths. Details are given in Appendix 8.

The strengths of the siltstone appear to lie within a broad range bounded at the upper limit by a strength envelope that is associated with intact siltstone, and at the lower limit by an envelope that appears to be associated with shearing or brecciation. The bentonitic tuff bands were sheared in a direct shear box along pre-cut and polished surfaces, and again these tests were performed at very slow rates of strain.

Residual shear strength testing was carried out in the Civil Engineering laboratories at the University of British Columbia in a reversible direct shear box at very slow rates of strain. This testing was carried out on two samples of siltstone and required a great length of time for the residual condition to be reached, each test lasting almost 2 months. Even so, because of the impermeable nature of these materials, uncertainty exists as to whether the lower limit of the residual shear strength was actually reached.

The tests do indicate however, that extremely low shear strength are possible. Details of these tests are included in Appendix 8.

The behaviour of these materials during shear was typical of heavily over-consolidated bonded clay shale, in that the test specimens initially compressed and then dilated.

Where high swelling minerals such as montmorillonite are present, even in modest proportions, excavations can cause lateral yielding to such an extent that shear strengths along potential failure surfaces are eventually reduced to residual values. Initially the swelling due to lateral stress relief induces negative pore water pressures within the materials, but with time these pressures dissipate. This means that slopes are stable initially, but with time stability decreases, and progressive failure ensues.

5.4.4 Shear Strengths of Surficial Soils

Triaxial tests were performed on the surficial glacial, alluvial and colluvial soils, which overlie the Coldwater sediments. A summary of the effective shear strength parameters are shown below and in Figure 10.

	Angle of Internal Friction ϕ', degrees	Cohesion, c', psi
Alluvial Sands and Gravels, Hat Creek	42	0
Glacial Till, Medicine Creek	30	2
Colluvial Clayey Silt, Houth Meadows	19	4

These results are from a limited number of tests, but they represent reasonable values for the shear strengths of the surficial soils encountered in the Hat Creek valley. Details of the tests are included in Appendix 8.

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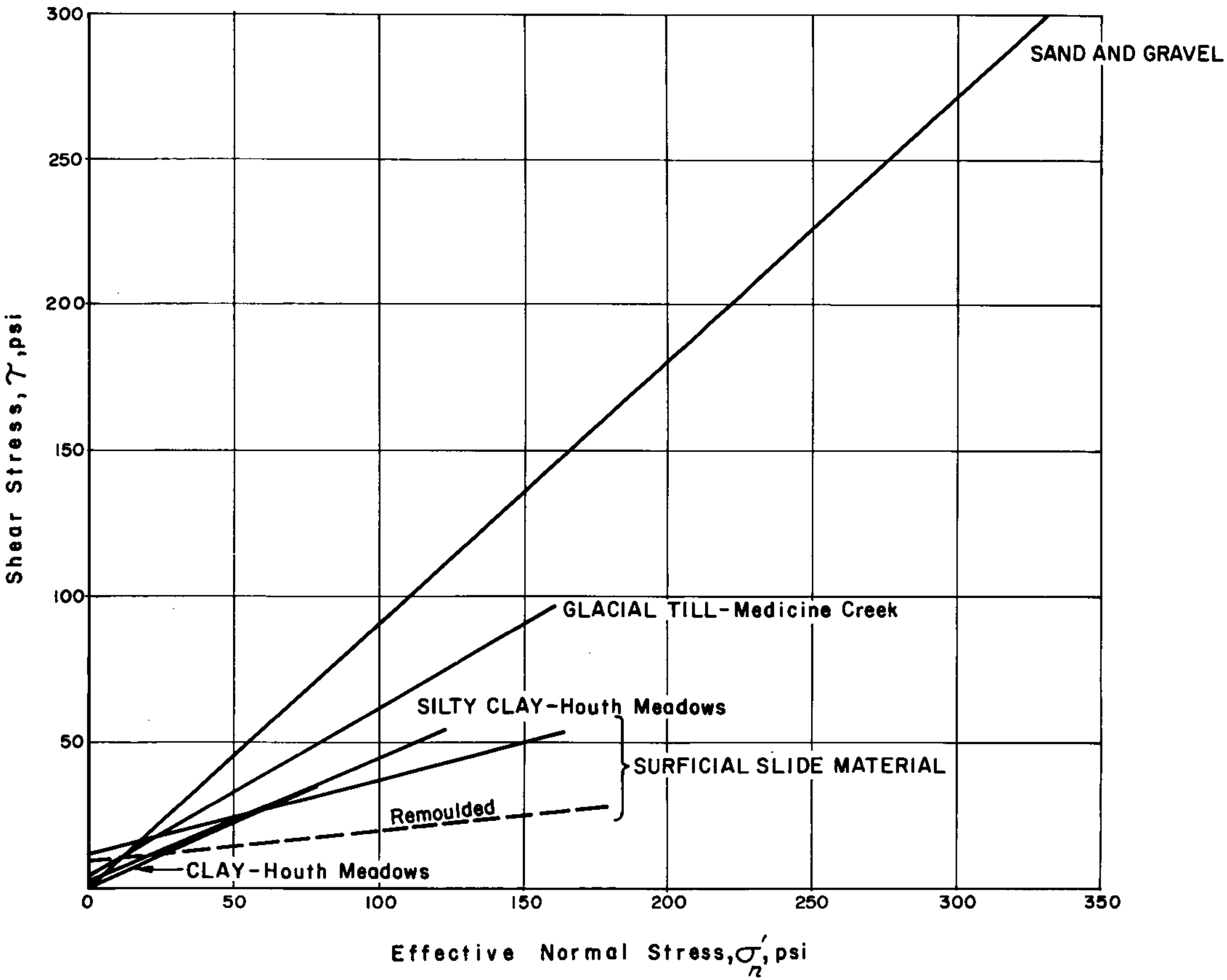

MOHR ENVELOPES OF EFFECTIVE STRESS
SURFICIAL SOILS

Figure 10

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5.4.5 Waste Aggregate Strength

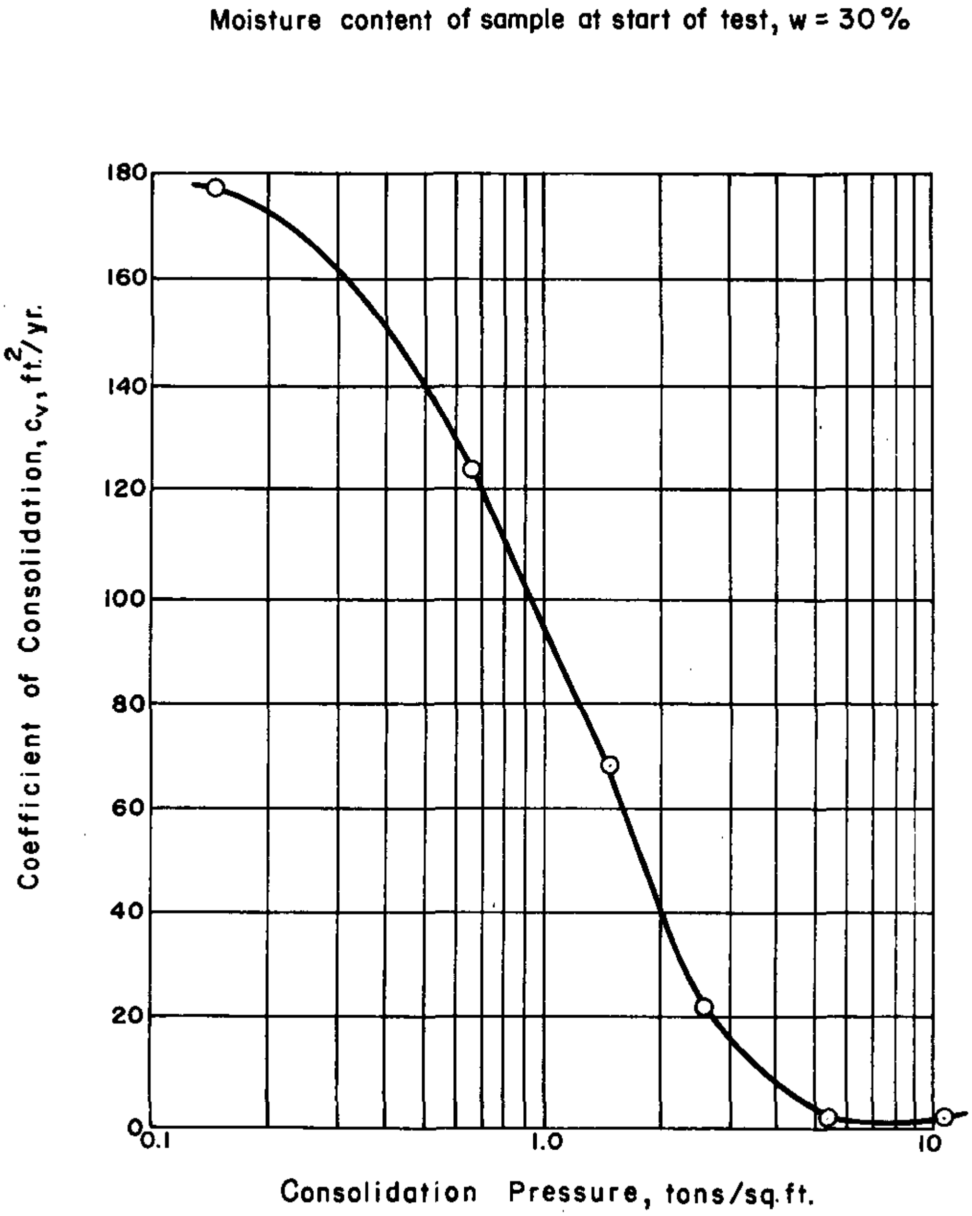
An attempt has been made to produce representative samples of the waste dump aggregate and to measure its shear strength and consolidation parameters. Representative sections of siltstone and claystone core were broken down to a maximum size of 1-1/2 inches and mixed with water to obtain moisture contents close to the mean natural moisture content of 30 percent.

Consolidation testing on loose samples of the aggregate in an oedometer showed that the coefficient of consolidation, c_v, was in the range of 0.2 to 180 ft^2/year ($1x10^{-4}$ to $1x10^{-1}$ sq.in/min.), depending on the stress level. The variation is shown on Figure 11, and details of the test are given in Appendix 8. These results indicate that the waste dumps would behave in essentially an undrained condition. The only consolidation that would occur would be on initial rapid consolidation due to expulsion of air from the voids of the material.

Partially consolidated undrained triaxial tests were therefore performed, and the results are shown on Figure 12. The envelope is non-linear until the stress is reached at which the voids in the material become saturated at a confining pressure of about 150 psi. This would be equivalent to a height of approximately 400 ft. of waste aggregate. Because of the high swelling characteristics of the Coldwater sediments, these results are felt to be a reasonable representation of the waste material as they would behave in the dumps. Details of the tests are included in Appendix 8.

Additional undrained triaxial compression tests were carried out on samples of the waste dump aggregate in a completely unconsolidated condition at moisture contents wet and dry of the mean natural value. These stress envelopes are shown on Figure 12, and indicate maximum strengths of 4 and 25 psi for the material wet and dry of the mean moisture content respectively.

CONSOLIDATION TEST ON WASTE DUMP AGGREGATE   Figure 11



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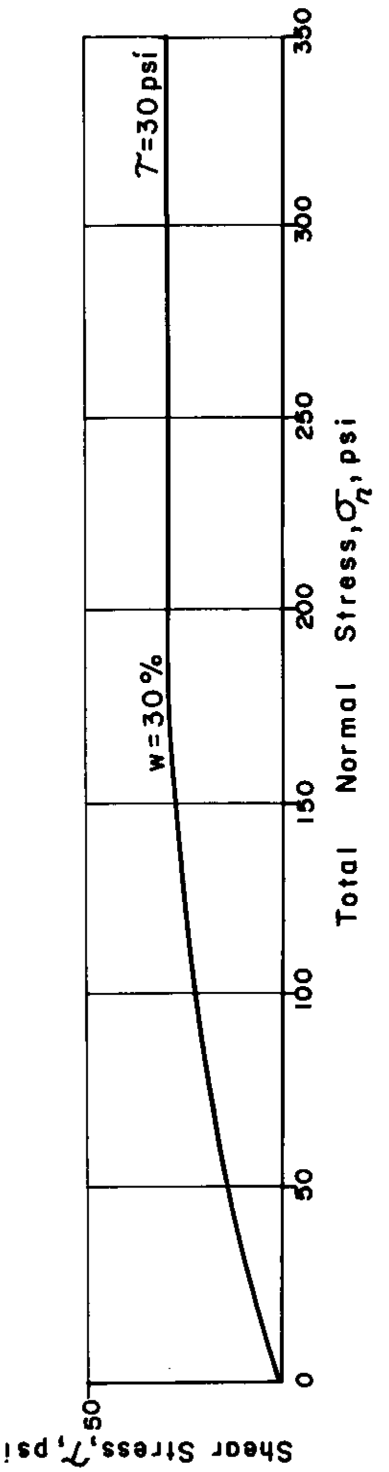
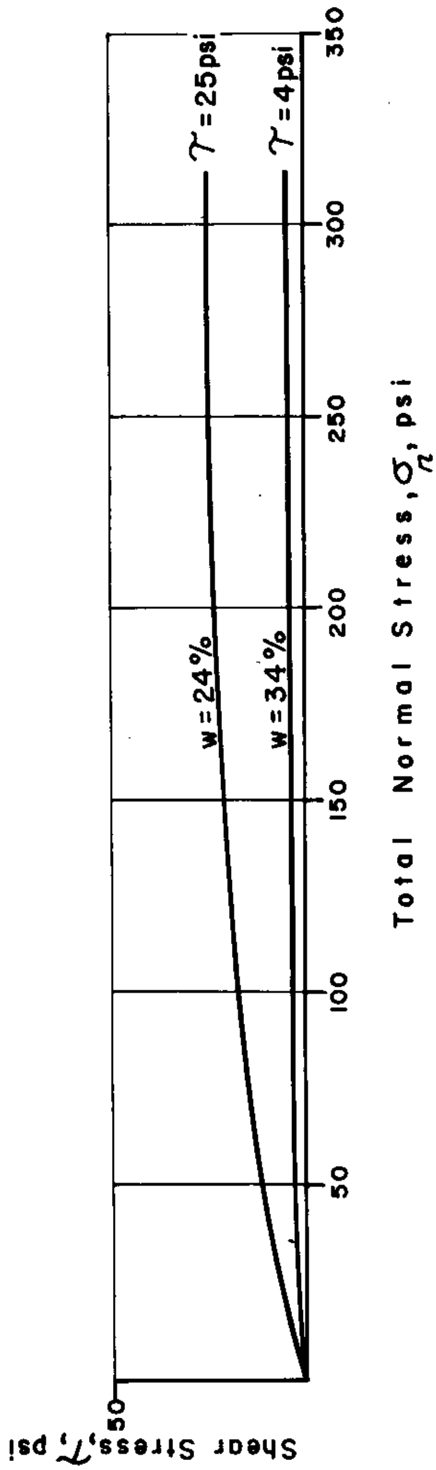
MOHR ENVELOPES OF TOTAL STRESS
WASTE DUMP AGGREGATE

Figure 12

PARTIALLY CONSOLIDATED
UNDRAINED TEST



CONSOLIDATED
UNDRAINED TESTS



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Clearly, initial rapid consolidation due to expulsion of air, in the partially saturated material, results in a substantial improvement in strength. This strength increase could be depended upon at shallow thicknesses of dumping, but at greater depths the voids of the material would close and the air would be sealed within the mass.

6. ENGINEERING ANALYSIS

6.1 Stability of Pit Slopes

6.1.1 General

In the engineering of this pit the basic approach should be to maintain a flexible design that can handle a certain volume of intermittent slope failure. To design all slopes to satisfy the conditions of long-term stability normally associated with large dam construction, would be wasteful and uneconomic. Such slopes, as evidenced by existing conditions in the valley, would be about 1 on 10, or about 6 degrees.

Nevertheless, while local bench failures of the slopes should be assumed during the operation of the pit, certain critical issues have to be examined. These are as follows:

a) the possibility of the occurrence of massive pit slope failures that would severely disrupt the supply of coal; and

b) failure of sections of cut on the vital access ramp that could lead to ramp closure.

6.1.2 Stability of Slopes in Over-consolidated Clays and Claystones

Clays and clay shales that have been heavily over-consolidated tend to exhibit a significant decrease in shear strength after failure. Ultimately, after sufficient strain has occurred the shear strength reaches a lower limiting or residual value. In clays the necessary strain may be very large, but it tends to be concentrated in a thin slip zone, and the displacement involved may not be large relative to the size of the slope mass. Such behaviour is sometimes referred to as work-softening, and it can be described in terms of two strength values, a) the peak or failure stress τ_f, and b) the residual stress τ_r.

Observations on slopes in fissured over-consolidated clays indicate that first-time slides take place at some value of the shearing resistance intermediate between the peak and the residual states. This depends on a brittleness index, defined by Bishop (1971), as

$$I_B = \frac{\tau_f - \tau_r}{\tau_f}$$

According to Bishop some evidence suggests that, if I_B is less than 30 percent, stability analyses based on the peak shear strength are little in error. However, if I_B is around 70 percent or more, as is common with heavily over-consolidated fissured clays, the average shear strength on a slide surface at failure lies closer to the residual than to the peak value.

In a similar manner, Skempton (1970) argues that it is reasonable to design against failure using the fully softened shear strength, which is a value intermediate between the peak and residual strengths, and which is equivalent to the peak strength parameters of the clay normally consolidated. Because of the inevitable sample disturbance, which occurs during drilling and testing, laboratory measured shear strength parameters of 'undisturbed' samples may approach the fully softened state, which Skempton regards as being operative under failure conditions.

In an over-consolidated clay, the necessary strain to mobilize the operative shear strength can occur as a result of swelling of the material following excavation. This requires initial creep straining of the mass. Creep is a function of time and the level of load application, and the shear strength and the stability of slopes in such materials is therefore time-dependent. By excavating slopes to moderate angles in the first place, mobilizing shear stresses can be lessened, the rate of creep strain reduced, and therefore the deterioration of friction to residual states can be retarded. Casagrande (1949) in a discussion of the failures in the Panama Canal slopes concluded that the shear strength of the clay-shale was time-dependent. Because of reductions in normal stresses and increases in shear stresses following excavation, the material had substantially decreased in strength over many years.

Most workers agree that the process of failure is progressive, but that ultimately, after a continuous slip surface has developed, requiring movements of the order of several feet, the residual state is reached. High swelling clays with a tendency to expand following excavation and stress release, as are present in Hat Creek valley, may suffer a large drop in strength from peak conditions. However, drained rather than undrained strength parameters represent the lower limit in strength of over-consolidated clays. The drained strength values particularly in clays of very low permeability, may take a considerable number of years to be realized.

6.1.3 Analysis of Active Slide in Hat Creek

Slides on the west side of Hat Creek valley are described in Section 3.7, and Slide 2, which is active, has been monitored by slope movement measuring devices (see Appendix 9).

Within a few months of installation, slope indicators installed in RH 76-5, 76-6, 76-7 and 76-8 in Slide 2 indicated shear movements at depths of around 100 ft. Movements in holes RH 76-7 and 76-8 were sufficiently large by November, 1976, that the inclinometer could not be lowered past the shear zone. A plan and profile of the slide is shown on Drawing 12 with the slope indicator holes that sheared projected onto the plane of the section. A near straight line can be drawn between the four shear zones, indicating that the base of the shear surface is inclined at 4 degrees to the horizontal. Piezometric elevations are shown for RH 76-5, 6 and 8. The mean slope of the ground surface is about 5 degrees.

Analysis of the slide, using the method of infinite slope stability for steady seepage conditions by Skempton (1957), indicates that the average shear strength mobilized on the slip surface is represented by a friction angle of 6.8 degrees and zero cohesion. This is very close to measured residual friction angles for the bentonitic clayey siltstone on which the slide is moving.

The cause of the initial mobilization of the slide is speculative, but clearly the undisturbed Coldwater beds are at shallow depths at the toe of the slide, and mobilization is being continually reactivated by Hat Creek eroding the toe of the moving mass. The minimum volume of the proven active portion of the slide, assuming that on average it is 100 ft. thick and that it terminates near to Aleece Lake, is about 17 million cu.yds. Slope indicators installed further uphill might prove that the extent of the movement is still further back; this should be investigated. Movements on more than one shear plane at greater depths might also be occurring, but once the slope indicator casing shears, the measuring device obviously cannot pass beyond this point.

The reason that the slide movement tends to be in a northeasterly direction, rather than more nearly due east, may be because the Coldwater deposits are buttressed by greater thicknesses of glacial deposits south of 78,000 N.

From the above analysis it can be concluded that, while such sliding could eventually take place in ultimate pit slopes, it would be necessary for friction angles to be reduced to residual values. However, residual values can be ascribed only to shear planes that are pre-existing, either as a result of tectonic shearing or old landsliding, or planes that are formed ultimately by large strains resulting from pit excavation. We are of the opinion that, apart from the surficial slides, pre-existent uniform shear planes on a large scale sloping continuously towards the pit are unlikely to be present.

Further definition of the extent and rate of movement of the active and potentially active slides is clearly necessary. However, prior to mining, an improvement in the stability of the area would be achieved by draining the numerous lakes that exist on the west side of the proposed pit. It is recommended that such measures be undertaken. A further improvement in stability could be achieved by partial removal of the active slide within the bounds of the ultimate pit, preferably at an early stage in the mining activity. This would have the effect of reducing the driving forces in the active slide, while drainage would tend to increase effective stresses, andd hence the strength that could be mobilized within the slide mass.

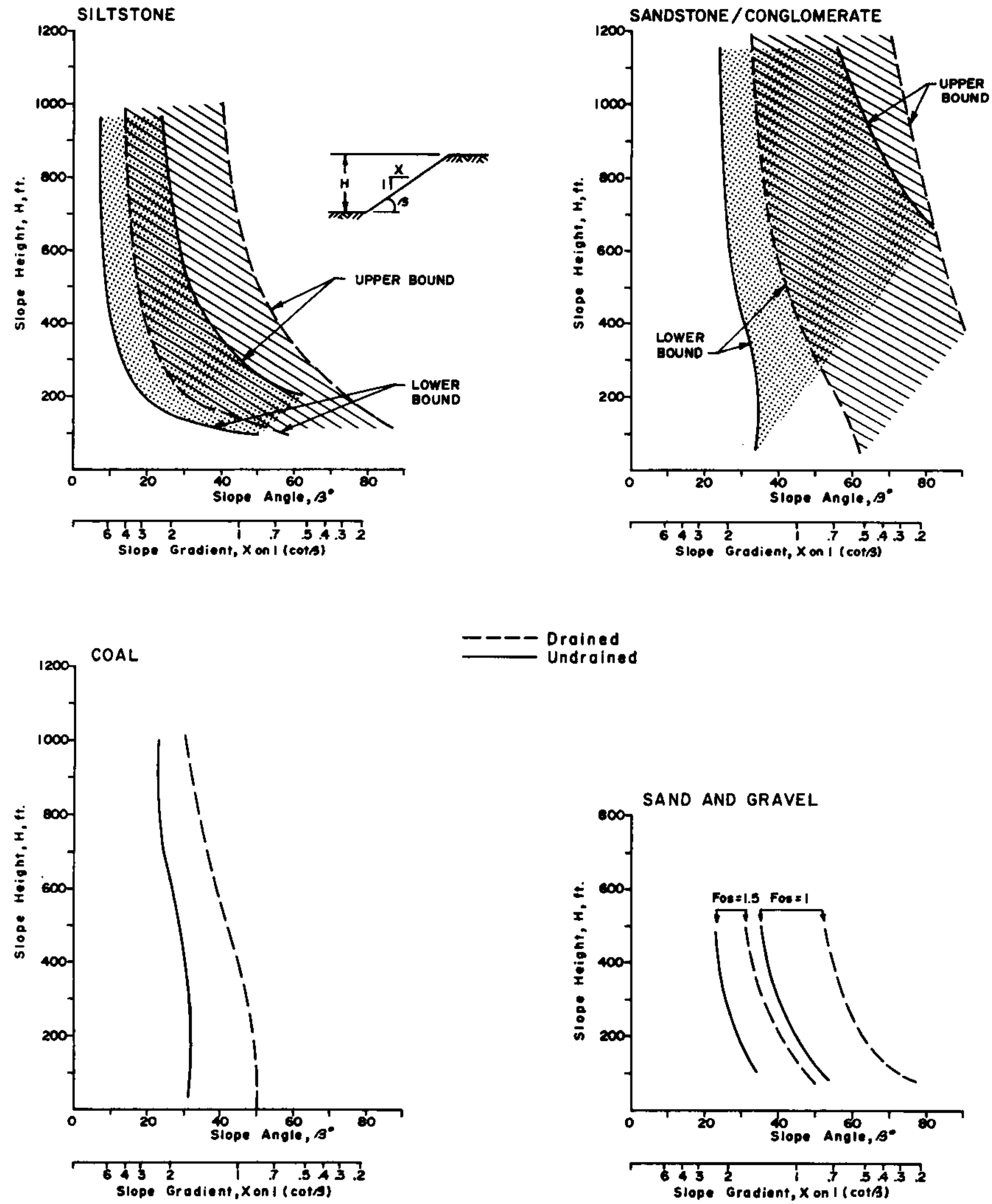
6.1.4 Stability Analyses of Pit Slopes

Geological information on the Hat Creek materials gathered so far indicates that discontinuous small-scale planes of weakness would exist in actual slopes and that these would lead to local bench failures. However, preferred planes of weakness or persistence of uniform geological structures that would be conducive to massive slope failure are not apparent.

Where a material exists which has no joint system especially favourable for sliding, such as in a closely fractured rock, rock mechanics engineers have formed it useful to analyse slopes initially using the methods of soil mechanics (see Jaeger 1971). It is reasonable, therefore, to analyse the stability of ultimate and intermediate pit slopes on the assumption that failure in the slope would be through homogeneous material of uniform strength, the failure surface being a circular arc. Furthermore, for the purposes of feasibility, as dealt with in this report, where no first-hand experience of mining in the material is available, the only measurements of material strengths that can be used for stability analyses are laboratory tests. Such testing of the Hat Creek materials indicates that, while a fair degree of scattering exists in the strengths of the samples of core that were subject to triaxial shearing, the clayey siltstone, which is the predominant rock type, is relatively uniform in strength with respect to depth and areal location. Therefore, for the purpose of stability analyses of first-time slides in intact siltstone and claystone, the lower bound strength parameters shown on Figure 9 would provide a conservative estimate of the shearing resistance of these materials.

Using the Bishop simplified stability analysis, programmed for computer, and stability charts prepared by Hoek and Bray (1974), slope height/slope angle relationships have been developed, and these are presented as charts on Figure 13. The charts show slope angles for limiting equilibrium, i.e. a factor of safety of unity. Although the predominant material type is the weak clayey siltstone, additional charts have been prepared assuming uniform slopes composed of the other materials. These curves indicate the improvement in stability that might be expected where such stronger materials occur in the slopes, even in minor amounts. Each chart shows curves representing drained and undrained conditions in the slopes. The charts for the siltstone, the predominant material type, and that for the sandstone/conglomerate show two sets of curves representing the upper and lower bounds of the measured material strengths. For clarity the chart for the siltstone has been redrawn on Figure 14 for the range of slope angles 5 to 30 degrees by plotting slope height against cotangent of the slope angle, i.e. the slope gradient, and so covers the range of slope angles under discussion. Also shown on this chart, is the line representing the lower of the two residual shear strengths measured in the siltstones. This line, however, would be applicable only for a slope failure along a pre-existing

SLOPE HEIGHT VERSUS SLOPE ANGLE   Figure 13



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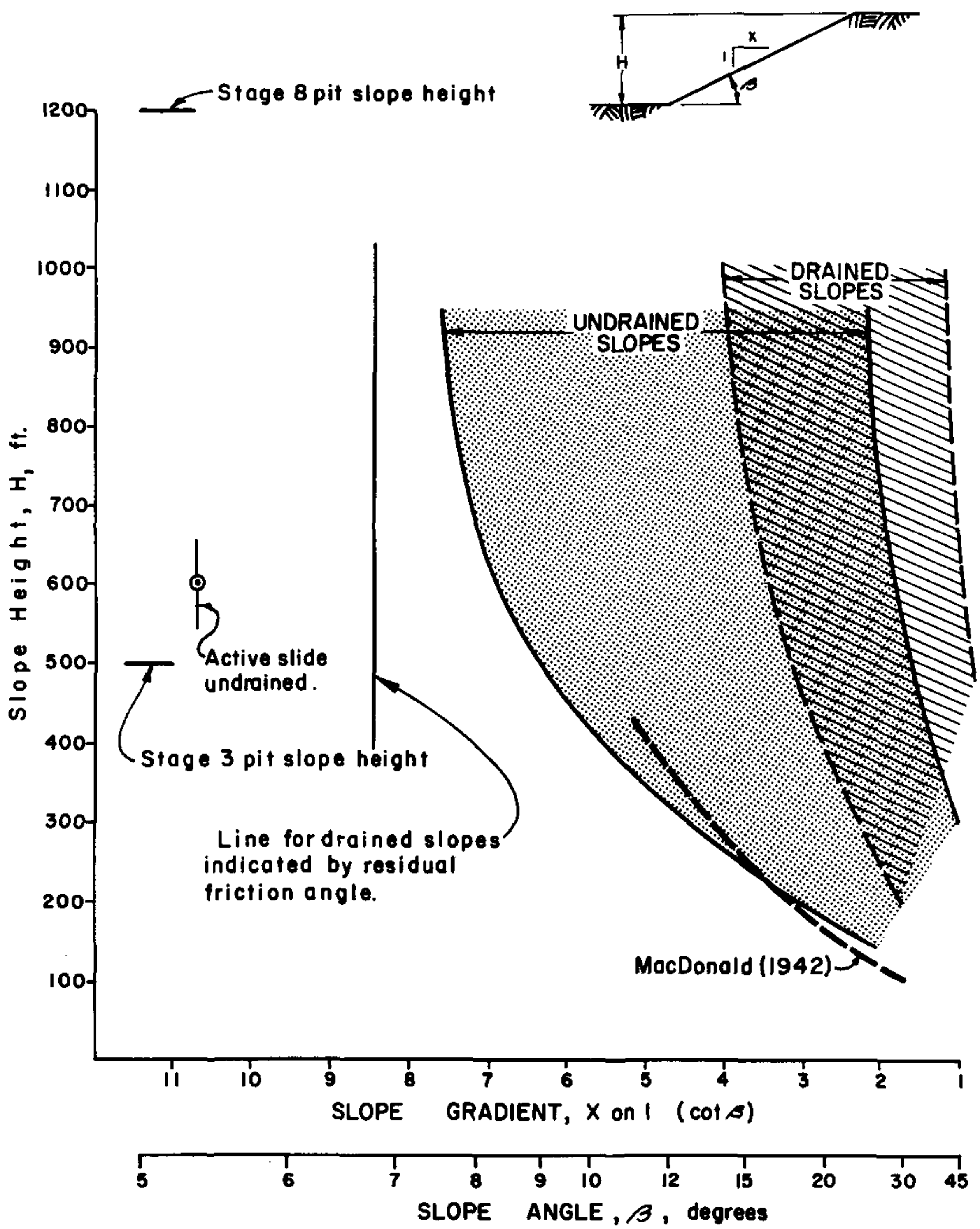
SLOPE CHART OF HAT CREEK SILTSTONE

Figure 14



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shear plane, resulting either from early tectonic movements, or gradual creep movements developing as a result of pit excavation. Such a slip plane is located beneath the slide on the west side of the valley, as discussed above. We do not consider that these conditions will apply in the open pit slopes once the surficial slides have been removed.

Figure 14 also shows the curve prepared by Macdonald (1942) for slopes of the Panama Canal Culebra cut excavated in very weak clay shales. This curve was found by experience to give a realistic estimate of slope stability not only in the Panama cut, but also in excavations in the bentonitic clay shales at the Oahe Dam on the Missouri River, see for example Knight (1963). The material at Oahe was described by Crandell (1952) as a Cretaceous mudstone and moderately siliceous claystone containing more than 25 bentonite beds between a fraction of an inch and 10 inches thick. In general, at the Oahe project slopes of 1 on 6 to 1 on 7 that are 200 - 300 ft. high have long-term marginal stability. A cut 100 ft. high might stand at 1 on 3 for a few months. Such failures however are structurally controlled by the bentonite beds, and caution should be exercised in any attempt to extrapolate this experience to likely behaviour in the Hat Creek materials.

The charts on Figures 13 and 14 show that for the Hat Creek materials slope angles decrease with increase in slope heights, tending towards limiting values, which depend on the strength of the materials. They also show that drainage yields a substantial improvement in stability. For a mean strength between the upper and lower bounds of the siltstone, the weakest material, ultimate pit slope angles of 16 degrees would have acceptable margins of safety, providing that slope drainage measures were undertaken. In some areas of the pit walls where inclusions of stronger material are present the slopes could be steepened beyond 16 degrees. In other areas where the lower strength bound of the siltstone is operative, pit slope angles would have to be flattened to less than 16 degrees. Until a further knowledge of the geology of pit walls is obtained the degree of flattening or steepening cannot be estimated.

6.1.5 Access Ramp

Transportation to and from the pit must be maintained at all times, and the access ramp is therefore a vital line, the stability of which must be asssured. Since the stability of the ramp is more certain in sand and gravel or coal, rather than siltstones, it would be preferable to align the ramp such as to secure maximum advantage from the location of the infilled bedrock channel. Bedrock information available to date indicates that it might be preferable to swing the line of the access ramp eastwards possibly up to about 15 degrees, see Drawing 4. This should be carefully investigated by a future program of drilling. Although greater depths of excavation would be involved, the side slopes could be steepened, and the net increase in volume of excavation of the ramp would be worthwhile in terms of increased ramp stability. Moving the ramp as suggested would have the added geotechnical advantage of somewhat increasing the toe support to the critical ridge of weak Coldwater rocks alongside the southeast corner of the proposed waste dump in Houth Meadows. Also by moving the ramp, a small waste dump could be located in the bottom of the valley further increasing the support to the Houth Meadows dump.

For ramp excavations in the glacial sand and gravel infilling the bedrock channel, the side slopes could be excavated to 1 on 1.5 (33-1/2 degrees) provided that the following two conditions prevail:

1. The gravel underlies the base of the excavation for a depth of at least 0.3 times the depth of the cut.

2. The piezometric elevation in the siltstone is not above the level of the base of the excavation.

These criteria would ensure a factor of safety of not less than 1.5.

Where coal underlies the gravel the same side slope angles as for the sand and gravel could be maintained, provided that the coal is drained and intact, and does not include weak clayey layers.

Where clayey siltstone or coal with significant clayey inter-beds is encountered at the base of the gravel it would be necessary to flatten the lower levels of the side slopes of the ramp. The extent of such slope flattening could be determined by further exploratory drilling along the line of the ramp, but in order to design the excavation it would be necessary to secure this information in advance.

For the present feasibility purposes it should be assumed that the lower side slopes of the ramp, where the base of the excavation encounters the siltstone, would need to be flattened to 1 on 2.5 (22 degrees) and maintained at this angle. This is designed to ensure a factor of safety of at least 1.5, provided that the piezometric levels are not higher than the base of the gravel.

Because of the high pore water pressures currently existing in the underlying clayey siltstone, it would be necessary to install a permanent dewatering system alongside the deeper sections of the excavation. It is estimated that an outside line of wells would extend for a maximum distance of 2,500 ft. on each side of the cut, and that these wells would be installed in advance of the ramp excavation in order to obtain prior depressurization. Immediately after excavation these would be supplemented by shallow sump wells installed at the base of the excavation, possibly together with horizontal drain holes installed in the side slopes at selected locations. The estimated costs of the installation of dewatering facilities are included in Table 5 discussed in Section 6.3.

6.1.6 Seismicity

Although the Hat Creek mine site is located within a major fold belt along which intensive faulting and volcanic activity has existed in comparatively recent geological time, it is not subject to a high level of seismic activity at the present time. The fault zones in the northwestern United States along which such intensive movement is still occurring, extend out to sea beyond Vancouver Island, and have limited influence on the Coastal ranges of British Columbia. A profile of reducing seismic activity runs eastwards from the British Columbia coast through to the Rocky Mountains, and although some of the faults to the west of the Coast Range are active, those to the east are considered to be stable. Some isolated seismic activity is recorded throughout this eastern area, and it is probably related to deep-seated block adjustment rather than continuous activity along particular structures. An exception to this seems to be the Yalakom Fault zone, a branch of the Fraser fault system extending northwestward from Lillooet. A post-Pleistocene displacement has been recorded within this zone at Seton Dam, near Lillooet, and a Richter Magnitude 5.0 seismic event was recorded near Relay Mountain in 1926. The main Fraser fault is considered to have been inactive since Tertiary times.

An analysis of the seismic risk at Hat Creek has been produced by the Victoria Geophysical Observatory and is included as Appendix 10.

The record of data compiled over the period 1899-1974 shows that only 10 events of Modified Mercalli Intensity II or more would have been felt at the site, although a total of 1169 earthquakes were recorded. The largest acceleration known at the site, 0.02 g, was produced by the 1946 earthquake of magnitude 7.3, for which the epicentre lay in the Strait of Georgia near Powell River.

Although it is realized that the time over which the above data has been collected is too short for accurate estimation of seismic risk, it is concluded by the Observatory that the maximum acceleration of the earthquake that would probably occur at Hat Creek with a return period of 100 years is 0.017 g. Similarly they conclude that the maximum acceleration of the seismic event that would probably occur during the life of the mine (say 30 years) would be less than 0.01 g.

Based on this and similar data, the interior of B.C. is generally regarded as a minor seismic risk. Hat Creek lies close to the boundary of Zones 1 and 2 as shown on the Seismic Zoning Map for Canada (1970). This indication of risk, however, refers to frequency of occurrence rather than the magnitude and consequent maximum acceleration of the earthquake.

Consideration should be given to the maximum likely event occurring along the Yalakom Fault zone at its closest point to Hat Creek and the effect that it would have upon the slopes of engineered structures at Hat Creek. The distance from Seton Dam to the centre of the Hat Creek pit would be approximately 18 miles. Based on attenuation curves presented by Schnabel and Seed (1973) for earthquakes in the Western United States, the maximum acceleration in rock can be estimated at varying distances from the causative fault. Thus for surface earthquakes at a distance of 18 miles, the average maximum accelerations for earthquakes of magnitude 5.2, 5.6, 6.6 and 7.6 would be 0.03 g, 0.10 g, 0.20 g and 0.30 g respectively. However, the attenuation is inversely proportional to the distance from the nearest point on the fault where the earthquake originates. Thus for deep-seated earthquakes, which appear to be the seismic pattern on the Yalakom Fault, the predicted ground accelerations on reaching the surface would be significantly reduced. If for example a magnitude 7.6 earthquake occurred at a depth of 30 miles, the surface ground acceleration would be reduced by half to about 0.15 g.

It is, therefore, reasonable to assume that the maximum probable acceleration that could be experienced at Hat Creek would not exceed 0.1 g. This is not a large acceleration, and it means that earth slopes in the mine would not have to withstand large relative differences between sustained and cyclic stresses. The response of pit and waste dump slopes to an earthquake can be postulated by considering the materials in both cases as insensitive cohesive soils. In general, such materials exhibit marked increases in strength with increase in strain rate, and at the same time decreases in strength caused by alternating or cyclic loading. For insensitive clays under moderate levels and duration of cyclic loadings, there is a net increase in strength. This would be particularly true for the stiff over-consolidated materials in the pit slopes, and assuming that the material in the waste dumps is unsaturated it would likely apply also. Slides in clay deposits during earthquakes usually result either from liquefaction of sand or silt lenses with the clay, or by slumping and collapse of fills due to liquefaction of silt or sand foundations. While the former condition is unlikely to arise in the waste dumps at Hat Creek, the latter condition could arise with poorly designed dumps, particularly in Houth Meadows, see Section 6.2 below. Here the saturated loose silt foundations could readily liquefy if lateral spreading of the foundations were possible. It is important, therefore, to ensure that retaining embankments are founded on firm foundations, thereby containing the potentially hazardous loose silt.

The foundations for the waste dump retaining embankments should therefore be given detailed investigation during the design phases of the project. The waste dumps have a greater seismic risk than the pit slopes, since the former must stand for all time. Beyond this, the seismic risk to the mine development is not considered to be a serious problem.

6.2 Waste Dumps

6.2.1 Location

A number of alternative solutions for disposal of waste have been studied. However, since the majority of the waste is likely to be in a very weak condition, remaining so for many years, it is recommended that dumping be carried out behind compacted retaining embankments in Houth Meadows, Medicine Creek, and the area north of the pit referred to by PD-NCB as No. 1 dump. In this report 3 types of waste are considered:

1. Surficial glacial deposits of sand, gravel and till. This material would be used for compacted retaining embankments.
2. Pit waste consisting of weak rock ranging from clayey siltstone, sandstone, conglomerate, and segregated waste from coal inter-beds. Also included is any thin till deposits and mixed slide debris, and till on the west side of Hat Creek.
3. Ash from the power plant.

6.2.2 Volume of Waste

At stage 8 of No. 1 pit it is estimated by PD-NCB in their report March, 1976, Table XI, that storage would be needed for 121 million loose cubic yards of ash, and a total of 885 million bank cubic yards of surficials and pit waste. Our estimate indicates that this is equivalent to a total of approximately 1,210 million loose cubic yards of storage. This figure is based on the bank yardage given above and on the following assumptions:

1. About 130 million cu.yds. of surficial gravel and till would be used in compacted retaining embankments, for which the swell factor would be zero.
2. The remaining surficial till and slide debris would be dumped and would have a swell factor of 15 percent, while the weak qock would swell by up to 35 percent. Our estimate of swelling is based on density measurements made on the materials in the laboratory.

The split in volume between the surficials and the rock has been estimated on the basis of drill hole information.

6.2.3 Dumped Waste

Apart from selected sand, gravel and till used in compacted retaining embankments, it is our opinion that the remainder of the waste, including all the pit waste defined above, would be very weak material. This would be because of the mineralogy and poor cementation of the rock, its remoulded condition after handling and the method of disposal by unselective dumping. Our laboratory studies indicate that consolidation of the waste would be insignificant during the life of the mine, and even for many years thereafter. The consolidation data presented in Section 5.4.4 indicates that the waste would behave as a partially saturated material. Initially, a rapid consolidation resulting from displacement of air out of the voids of the material would occur. Subsequently, however, and for the major portion of the consolidation, the settlement and reduction in pore water pressure would be slow comparable to that of a clay of very low permeability. Furthermore, the material displays marked decrease in the rate of consolidation with increase in stress. This means that the more deeply buried material would consolidate very much more slowly than the looser surface material. Acceleration of drainage by the incorporation of gravel blankets within the fill is not considered feasible. Unless very carefully constructed graded filters were provided above and below the gravel blankets, and this is far from a routine operation, the clay in the waste would quickly form a sealing layer on the gravel drain. It is assumed, therefore, that the waste would behave essentially in an undrained and undrainable condition during the life of the mine.

Undrained triaxial shear testing of remoulded samples of selected core as described in Section 5.4.4 clearly showed that the material would be very sensitive to changes in moisture content. Assuming that the average moisture content of the material in the pit as mined would be about 30 percent, see Figure 4, upper and lower strength limits of the waste have been chosen at 5 percent dry and 5 percent wet of the in situ moisture content respectively. Climatic conditions could lead to drying of the waste. On the other hand water ponded behind the dumps would tend to be soaked up by the dumped waste.

Stability analyses indicate that for the proposed high dumps the critical mode of failure would be within the slope of the dumped waste such that the material would tend to slough over the retaining embankments. For feasibility purposes, therefore, allowing for static and seismic loading conditions, it is recommended that slopes of the dumped waste should be selected according to the following criteria:

1. For slope heights up to 250 ft. slope gradients not to be steeper than 1 on 10.
2. For slope heights greater than 250 ft. slope gradients not to be steeper than 1 on 20.

These gradients are not unduly conservative, but actual dumping experience, coupled with testing in the dumped state of the actually mined material and observation of slope movement, might indicate that steeper slope gradients could be accommodated. It is important, therefore, that the location and design of retaining embankments should enable such changes to be incorporated. Flexible designs would accommodate more or less material in each area.

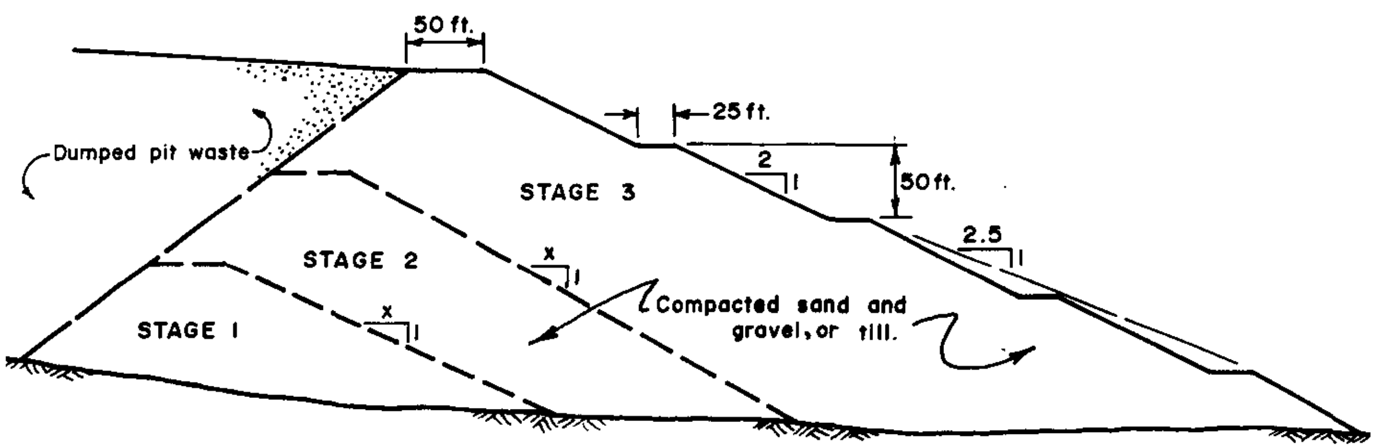
6.2.4 Retaining Embankments and Construction Materials

These structures would utilize the stronger glacial sand and gravel, and glacial till, and would be carefully engineered to contain the very weak dumped pit waste.

The likely requirements for embankment material would dictate the use of both the sand and gravel, and the till, and for this purpose we have shown a preliminary section on Figure 15. The glacial till would require compaction to reach acceptable strength. For feasibility purposes, it should be assumed that the sand and gravel would be treated likewise, although when studying specific designs at a later date, it might be possible to use dumped and spread sand and gravel in conjunction with compacted till. The till could be used in embankments in Medicine Creek, while the sand and gravel could be used in Houth Meadows and north of the pit. The lower levels of the dumps at the bottom of the valleys would be provided with an underdrain of gravel, cobbles and boulders to provide drainage for the streamlets behind the dump, but in addition it might be necessary to pump flood water from behind the dumps to prevent ponding. The mean outside slope gradient of 1 on 2.5 is dictated by requirements for rehabilitation of the slopes of waste dumps. Stability considerations alone would very likely show that steeper slopes would be acceptable.

Although the use of the powerplant ash as a structural material has not been considered in this study, it could be used in conjunction with the sand and gravel to boost available quantities of stronger materials. Its use as a filter material for drainage blankets within the dumped pit waste is possible, but as mentioned above this would need careful construction and field

TYPICAL WASTE DUMP RETAINING EMBANKMENT Figure 15



Slope x of initial stages would vary to suit stability requirements and availability of construction materials from pit excavation.

Project No. V76349 Drawn C.G. Reviewed N.S. Date Jan '77 control. Moreover, the demands on available sand and gravel might well dictate that the ash should be used to supplement the gravel.

6.2.5 Layout of Dumps

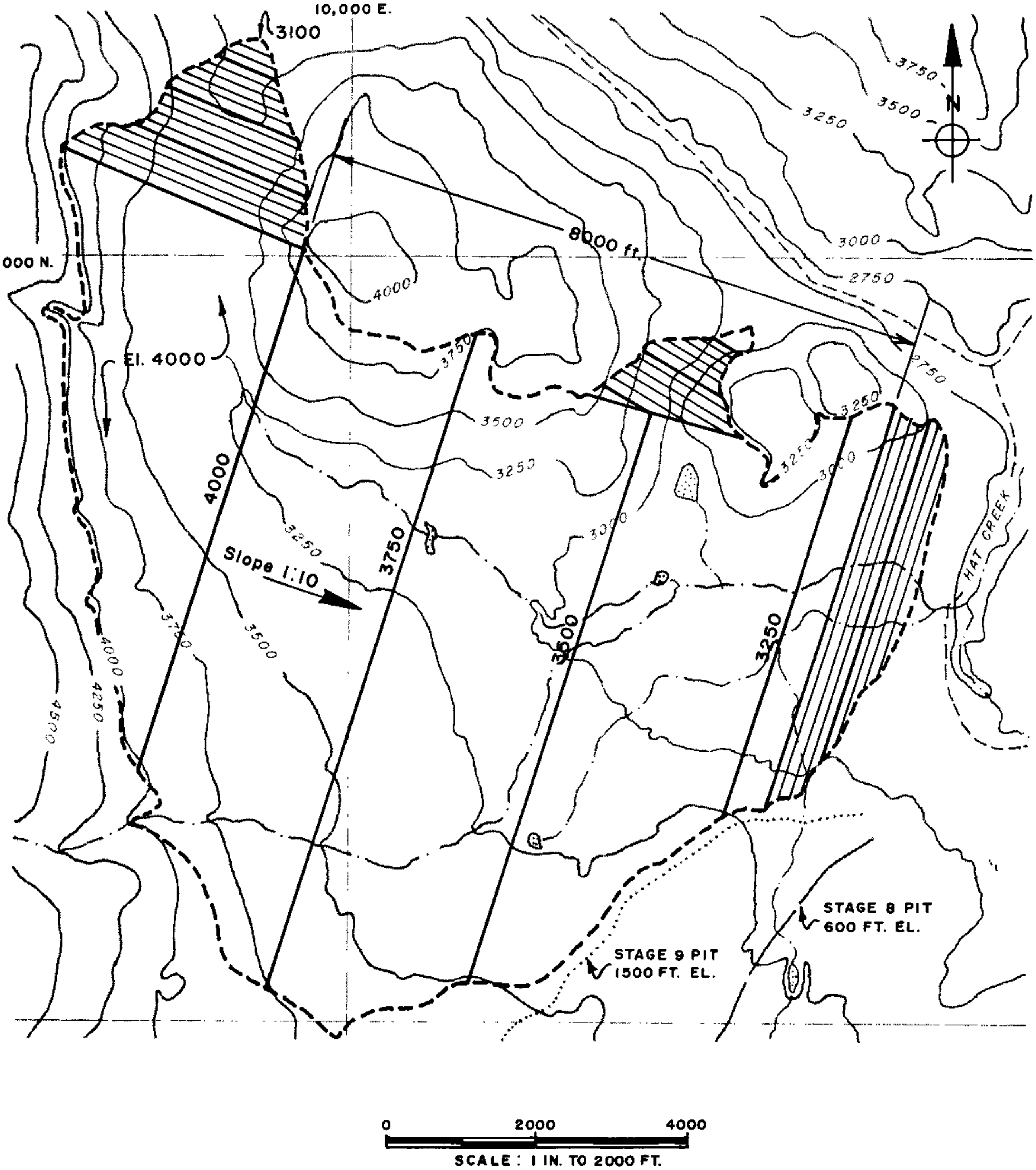
Basins large enough to receive the above volumes of waste would be Houth Meadows and Medicine Creek, and up to about 20 percent of the volume could be dumped north of the pit in No. 1 dump. Houth Meadows is a preferable location because of its close proximity to the point of exit of the waste from the mine. Possible layouts of waste dumps yielding the same total volume of storage are discussed below.

<u>Alternative A</u>

It might be possible to store up to about 1.0×10^9 cu.yds. of waste in Houth Meadows by constructing a retaining embankment to El 3200 ft. at the lower end of the meadow, and a high embankment to El 4000 ft. across the upper saddle overlooking Marble Canyon. The waste would then slope at 1 on 10 towards the valley, as shown on Figure 16. This scheme, however, should not be used for feasibility purposes, because as discussed above there is a strong possibility that the waste would not stand at a slope height of 750 ft. at this gradient. Actual experience of the behaviour of the waste during mining might show that such a scheme is possible, but it should not be relied upon for planning purposes. Nevertheless, the most favourable layout discussed in Alternative B below could be engineered at the early stage of dumping to take advantage of the above scheme at a future date.

ALTERNATIVE A
HOUTH MEADOWS WASTE DUMP

Figure 16



NOTE:
Alternative A involves dumping virtually all the material in Houth Meadows, with a smaller dump north of the mine in PD-NCB's dump No. 1.

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For Alternative A the surplus 200 million cu.yds. of waste could be disposed of in dumps north of the pit similar to those discussed below. It would not be necessary to use Medicine Creek for waste storage.

Alternative B

For feasibility purposes it would be preferable to flatten the angle of the dumped waste slope in Houth Meadows to 1 on 20 as shown in Figure 17. The lower retaining embankment would be constructed to El 3250 ft., and the waste would rise to El 3800 ft., with a less massive embankment needed on the upper saddle at the top of the dump.

This scheme in effect shifts the centre of gravity of the dump eastwards and reduces the weight of the dump by about one half, with the result that less thrust would be placed on the northwest corner of the ultimate pit slopes.

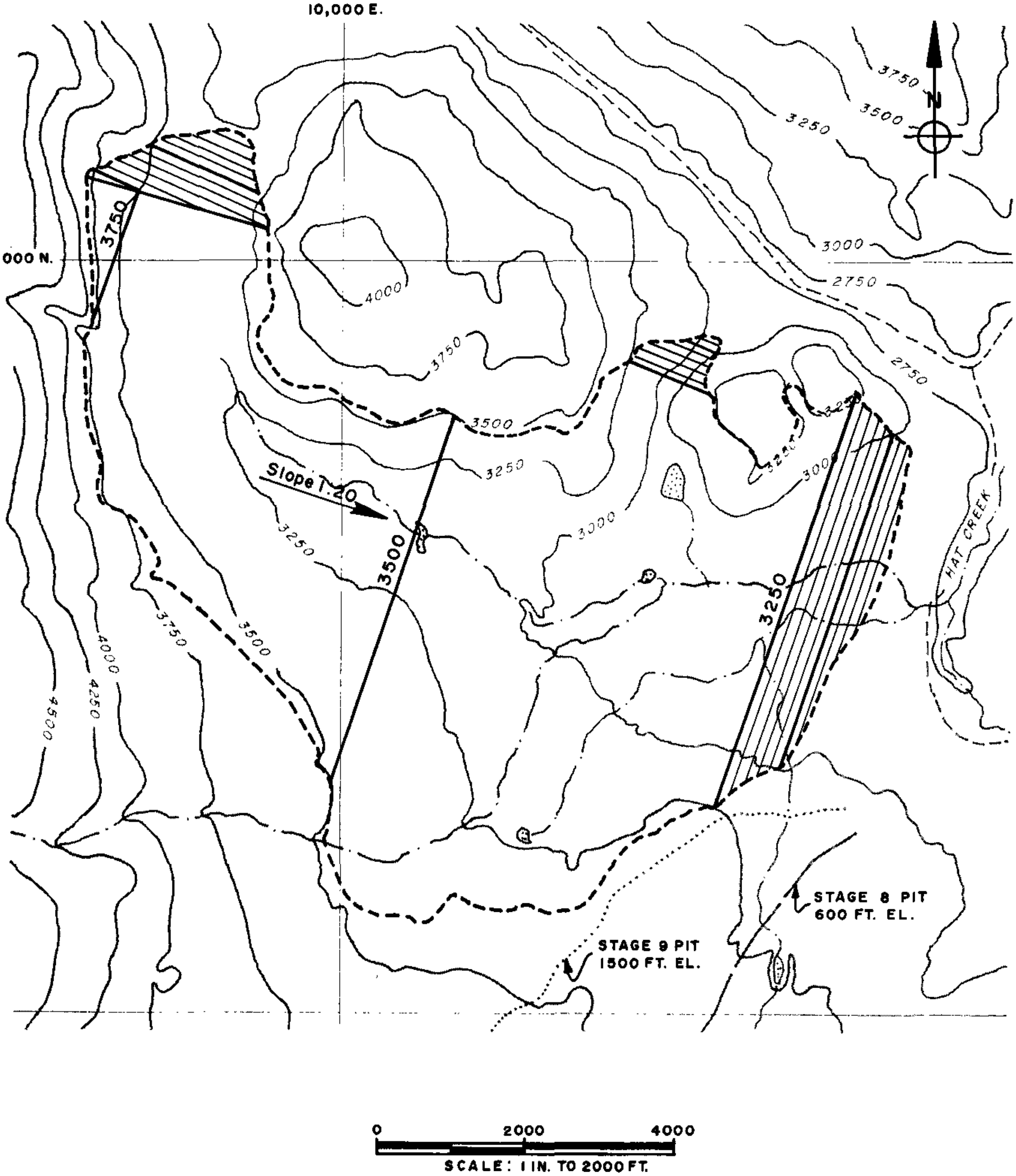
The volume of waste stored in Houth Meadows using this layout would be about 550 million cu.yds.

A large portion of the balance of the waste would be stored in Medicine Creek in a dump up to El 4000 ft., as shown on Figure 18. It would be retained by two embankments, one constructed to El 3750 ft. on the west, and another smaller structure to El 4000 ft. on the east. The slope of the dumped waste would be 1 on 10, but the height of the slope would not exceed 250 ft.

The dump would contain about 480 million cu.yds. The remaining 180 million cu.yds. of waste could bedisposed of in

ALTERNATIVE B
HOUTH MEADOWS WASTE DUMP

Figure 17

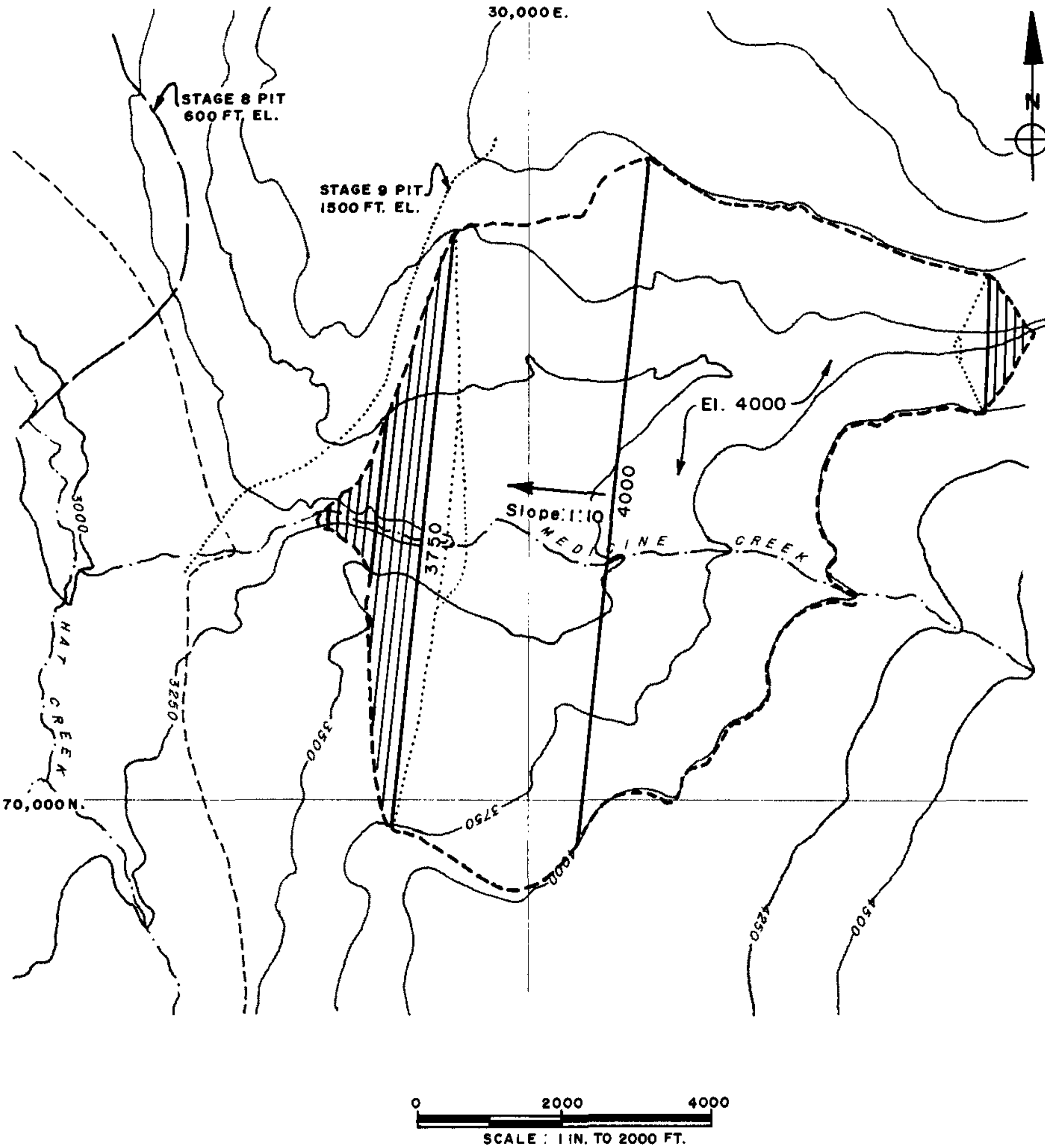


NOTE:
Alternative B includes dumping in Medicine Creek - see Fig. 18

Project No. V76349 Drawn rd.t. Reviewed N.A.S. Date Jan.'77

ALTERNATIVE A
MEDICINE CREEK WASTE DUMP

Figure **18**



NOTE:
Alternative B includes dumping in Houth Meadows - see Fig.17

Project No. V76349 Drawn L.d.T. Reviewed N.A.S. Date Jan '77 comparatively shallow dumps north of the pit.

The volumes of the compacted retaining embankments using this scheme would be about 77 million cu.yds. in Houth Meadow, 38 million cu.yds. in Medicine Creek, and about 12 million cu.yds. in No. 1 dump north of the pit and in Hat Creek valley infill. Drill hole information indicates that approximately 75 million cu.yds. of sand and gravel, and about 90 million cu.yds. of till would be available at stage 8 on the east side of the pit, assuming that pit slopes were excavated to an average angle of 15 to 16 degrees. Steepening of pit slope angles on this side of the pit would substantially reduce such quantities. However, as noted above, about 120 million cu.yds. of ash would be available to supplement the gravel. Up to about half of the ash could possibly be mixed with the gravel, and if further quantities were needed, the ash could be used in zoned embankments. However, studies of the ash have not been carried out as yet, because no samples are available.

It would be necessary to construct the embankments in stages, using whatever material was available at each particular stage of the pit excavation. In the detailed planning of the pit it would be necessary at each stage to determine whether available quantities of gravel and till would be sufficient to construct embankments to the height required to meet storage volumes needed.

If the pit is excavated as proposed from the north, the sand and gravel would be available first, and they would be used to construct retaining embankments for the dump in Houth Meadows. The high level saddle embankments would be constructed of till, primarily to ensure that leachate did not seep over the saddles into the Marble Canyon drainage basin, and secondly to conserve sand and gravel for other uses. As the pit excavation progressed deeper and extended south, surficial excavations would be mainly till, which would be used to construct retaining embankments for the dump in Medicine Creek.

Alternative B would involve transporting material a considerable distance to Medicine Creek with the ramp designs envisaged at present. However, such a scheme would be feasible with regard to waste dump stability. No similar assurance could be given regarding the stability of the waste in Alternative A at this time. Differences in dumping costs between the two schemes, however, might justify very detailed future study of scheme A, particularly the in situ strength of the dumped waste.

6.2.6 Foundations

Geological consideration of the waste dump and embankment foundations appears in Section 3.6. In general, foundations appear to be adequate at the locations shown.

In Houth Meadows the north abutment would be the limestone bluffs, and the base of the embankment would probably be underlain by glacial till over sand and gravel (Plate 7). The south abutment of the embankment would be Coldwater rocks and the load carrying capacity of this abutment would need

Houth Meadows looking east towards proposed embankment locations.

PLATE 7

further investigation to ensure that the stability of ultimate pit slopes was not endangered. The smaller retaining embankments on the saddles at the north side of Houth Meadows would very likely be underlain by till over bedrock at shallow depths. The interior of Houth Meadows contains very soft clayey silts that may have originated as outwash from the slide on the south-west of the meadows. This material would underlie the dumped waste, but not the retaining embankments as proposed. With the flat dumped waste slopes as proposed, such soft underlying material would not impair the stability of the waste.

North of the pit in No. 1 dump, drilling indicates that the foundations of the waste dumps would be thin till overlying sand and gravel, and such strata would be adequate for the retaining embankments.

Medicine Creek appears to contain till, possibly overlying Coldwater rocks locally, although the main embankment would probably lie on Kamloops Volcanics. For the present feasibility purposes it can be assumed that the retaining embankments would be adequately founded.

Detailed design work should be preceded by thorough investigation involving drilling, testing and analysis of all sites selected for waste dump retaining embankments.

6.2.7 Construction

Construction of the waste dumps should be in the following sequence:

1. Construct an initial stage of the compacted retaining embankment across the downhill end of the waste dump valley.

2. Deposit waste immediately behind the embankments by dumping in an uphill direction. Dumping at the higher end of the valley and allowing the material to to slough down would not be acceptable. Uncontrolled flowslides in these materials would have the potential of travelling large distances, probably at high speed, and could overtop the retaining embankments. Dumping in layers in an uphill direction would achieve a moderate degree of surface compaction of the dump, and would help to improve the overall stability.
3. Repeat 1 and 2 by raising the retaining embankment a further stage, and continue dumping behind in an uphill direction.

Dumping from the advancing face of the waste would require construction of gravel pads 5-10 ft. thick to distribute the load of the spreader on the surface of the waste.

6.3 Mine Dewatering for Slope Stability

6.3.1 General

Dewatering or depressurizing of the mine slopes would be essential in critical parts of the pit such as the access ramp area. It would also be necessary in other slopes, especially where weak, low permeability materials are present. The data collected as part of the hydrogeologic program have been used to study the feasibility of depressurization and to produce an estimate for the cost of depressurization on the scale anticipated.

The study must be regarded as preliminary, as more data on the feasibility of depressurization in the bedrock sediments would be required in order to make a more refined assessment.

The following assumptions have been made:

1. A collection system would be installed to collect and divert surface water from around the pit and to discharge this water well away from the pit.
2. The existing system of lakes would be drained.
3. The effects of seepage from the waste dumps and from the Hat Creek diversion channel or pipe would be negligible.
4. The dewatering system for each stage of pit excavation could be installed and operated for at least one year in advance of the time that the excavation is expected to commence.
5. The siltstones and claystones of the Coldwater Formation are of a relatively low uniform permeability of about 10^{-8} cm/sec., and the coal formation has a permeability of about 10^{-4} cm/sec.
6. A storage coefficient of 10^{-7}, as determined in the pumping test, is a representative value for both the coal and the siltstone sediments.
7. The bedrock aquifers have relatively uniform hydrogeologic characteristics, and given sufficient time, at least one year, the water would be released from aquifer storage.

6.3.2 Methods of Dewatering

A number of methods were considered. These include:

1. Drilling and construction of vertical wells.
2. Drilling slightly inclined horizontal holes.
3. Construction of adits as drainage galleries.

The preferred method is the use of vertical wells, because of their lower cost and greater flexibility; extra wells can be added or superfluous wells removed as the excavation of the pit proceeds. In contrast, the location of an adit would have to be carefully planned, and its location and rate of construction would be determined by the sequence of pit excavation.

Slightly inclined horizontal holes could be used in combination with the use of vertical wells. Because of the high water tables and unstable sediments, it would not be feasible to use this method alone.

6.3.3 Proposed Dewatering Scheme

In order to get an approximate idea of the feasibility and possible costs of a vertical well dewatering system, a preliminary design has been made. This design is based on the assumptions listed above.

The sequence of typical well construction proposed would be as follows:

1. Drill an 8-inch hole.
2. Install a 4-inch plastic slotted pipe to the bottom of the hole.
3. Install a gravel pack into the annular space.
4. Develop the well with an air surge.
5. Install an electric submersible type pump (generally ranging from 2 to 5 horse power).

The depth of the wells would generally vary between 400 to 1,200 ft., and they would be installed at spacings ranging from 300 to 600 ft. centres. Two well types would be required: a) shallow wells of moderate capacity to dewater the relatively pervious surficial materials; and b) deep wells of low capacity to depressurize the bedrock. As an alternative to the installation of a pump, some of the low production holes could be bailed out, or blown with air at regular intervals.

The estimated number of wells required is shown in Table 5. Well depths of 600 ft. and 1,000 ft. deep were assumed as typical values, and the estimated total installed costs of these wells, including the pumps are \$17,500 and \$30,000 (1976 dollars) per well respectively. The 150 ft. deep well is assumed to be a typical well depth in the surficial sediments (cost \$10,000).

The pumping rates assume that the initial flows from the wells in the surficials would average 10 gpm per well and that this rate would decline uniformly with time. The expected pumping rates from the 600 and 1,000 ft. holes are expected to range between 0.1 and 0.6 gpm for the siltstones and claystones and 0.8-5.0 gpm for the coal units. Because of the comparatively low well yields, the cost of pumping is expected to be relatively small as compared to the capital cost of the dewatering system.

The estimated total cost of the dewatering system as shown in Table 5 is approximately \$9 million.

6.4 Coal and Inter-beds

6.4.1 Geotechnics of the Coal

The coal is one of the stronger members of the Coldwater sequence, and clean intact coal provided the highest uniaxial compressive strength (2,496 psi) measured in the field, other than the basement rocks. However, the coal is traversed by joint systems and bedding planes; partings of siltstone, claystone or volcanic tuff are not uncommon. Whereas aspects such as the failure modes and diggability in the Coldwater sequence outside the coal will be determined

TABLE 5

ESTIMATED NUMBERS OF WELLS, COSTS AND PUMPAGE RATES

Critical Installation Date (Year) (1)	To Be Used For Stage No.	Wells to be Installed				Wells to be Removed				Net Total Wells Installed (4)				Estimated Total Pumpage (gpm) (5)	Estimated Incremental Cost of Well Install'n $1000 (1976) (6)
		150' (2)	600'	1,000'	Obs. (3)	150' (2)	600'	1,000'	Obs. (3)	150' (2)	600'	1,000'	Obs. (3)		
1981	1	10	4	4	4	0	0	0	0	10	4	4	4	103	348
1982	2	5	21	4	5	0	0	0	0	15	25	8	9	183	609.5
1984	3	5	10	25	5	4	10	0	0	16	25	33	14	202	1,057.5
1987	4	2	12	10	2	0	8	5	2	18	29	38	14	220	563.0
1990	4	2	12	10	2	0	8	5	2	20	33	43	14	250	563.0
1993	5	2	15	11	3	2	13	6	1	20	35	48	16	200	660.0
1996	5	2	15	11	3	2	13	4	1	20	37	55	18	180	660.0
1999	6	2	3	20	3	4	2	12	1	18	38	63	20	150	724.5
2002	6	2	3	20	3	4	1	12	2	16	40	71	21	130	724.5
2007	7	2	5	30	2	4	3	26	2	14	42	75	21	120	1,050.5
2008	7	0	10	30	1	2	8	25	0	12	44	80	22	110	1,104.0
2010	8	0	10	20	1	2	8	20	0	10	46	80	23	100	799.0
Totals		34	120	195	34	24	74	115	11						8,863.5

Notes:
1) Wells must be installed at least 1 year before required drawdown is to be achieved.
2) 150' well is estimated average depth of overburden well, (i.e. in surficial sediments).
3) Obs. = observation hole with nest of piezometers.
4) The depth of some wells will be reduced by cutting casing as the pit is excavated.
5) These figures should be taken as a very approximate guide to the expected pumpage rates. The probable accuracy is ± 30 percent.
6) These figures are based on 1976 ($) and are intended to be a guide to costs based on the use of present day drilling equipment and materials. These costs include the cost of pumps and a water collection and disposal system. No allowance has been made for collection and disposal of surface water run-off.

by the inherent strength of the material, in the coal they will be determined by the presence of these discontinuities or partings. No systematic study of the fracture patterns within the coal has been carried out, but it is apparent that the bedding is a major persistent feature, and it is seen to be highly contorted and sheared in many places. Cleating within the coal is only poorly developed. Zones of broken or crushed coal have also been found during the drilling, and it is likely that these zones may be more extensive and possibly represented by the occasional lengths of high core loss. There are some harder bands within the coal sequence, such as ironstone, and a zone of calcification regularly occurs immediately below the D-zone in the vicinity of Dry Lake (see geological and geophysical logs of DDH 76-817 for example).

6.4.2 Geotechnics of the Coal Inter-beds

Particular consideration has been given to the sediments interbedded with the coal due to the need to control the ash content of the fuel delivered to the power-plant. It is of importance to know what proportion of the inter-beds can be separated from the coal in the pit, and what proportion will need to be separated subsequently by processing.

Consequently, it was decided to examine a complete sequence through the coal bearing strata, as exemplified by a series of holes drilled near the centre of the basin. The stratigraphy of the four holes selected is shown on Drawing 13. DDH 76-817 gave complete coverage of the D-zone, DDH 76-191 gave complete coverage of the B-, C- and D-zones and incomplete coverage of the A-zone, DDH 76-135 completed the coverage of the A-zone.

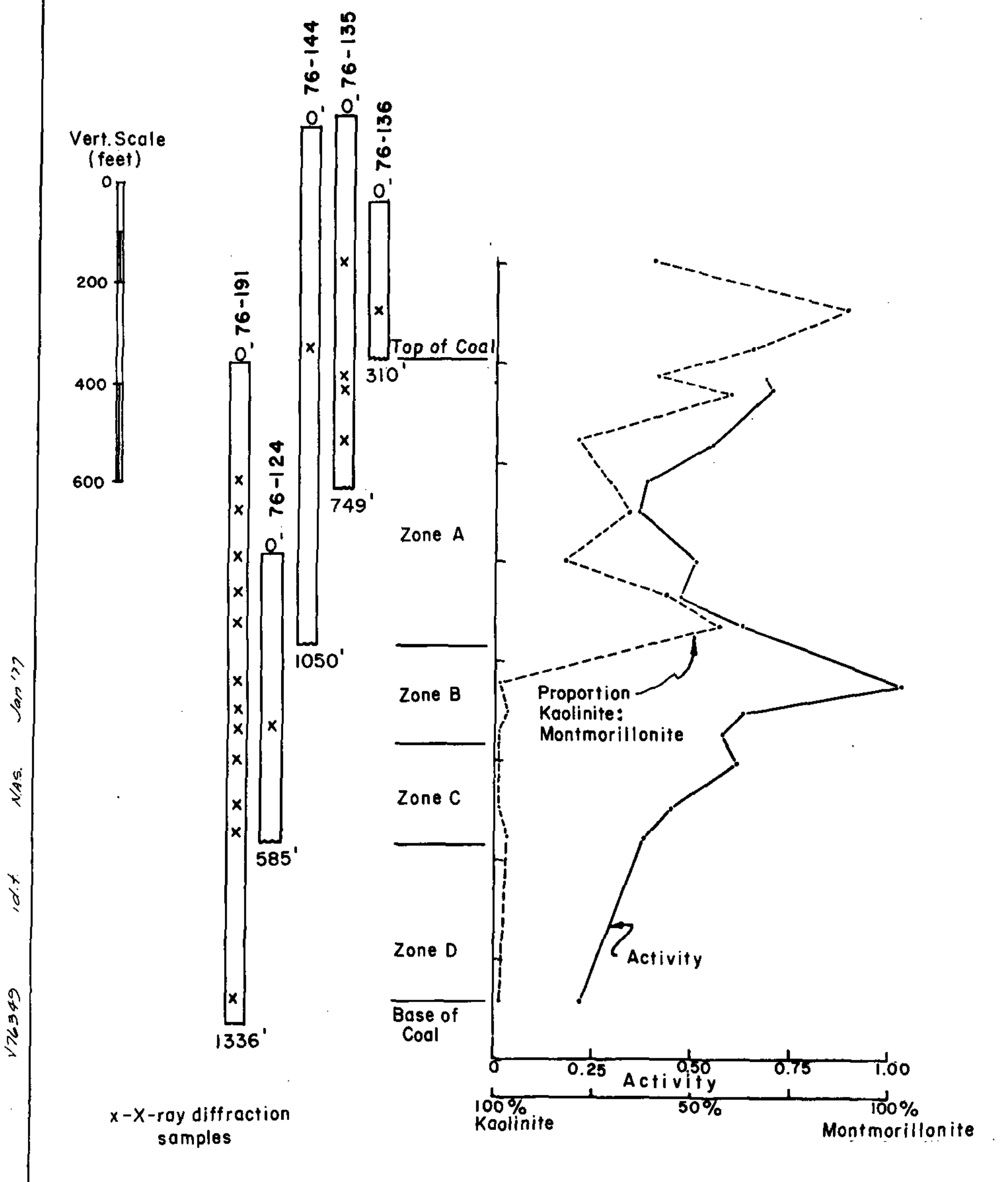
It will be seen from the drawing that inter-beds are largely absent from the B and D-zones. They form a substantial proportion of the C-zone, which is only thin in DDH 76-191, but the A-zone consistently shows a high proportion of interbedded sediments. X-ray diffraction studies carried out at the Univ-sity of British Columbia (see Section 5.3) showed that kaolinite is the dom-inant clay mineral in the lower three zones, and that it is replaced to a large extent by montmorillonite as the main mineral in Zone A (see Figure 19). A sample was analysed from the clayey fraction of the coal sample obtained in BAH 76-2, 3, 4 and 5 in a zone which possibly lies at the base of the A-zone or at the top of the B-zone. It showed kaolinite as the main constituent, with subsidiary montmorillonite, quartz, felspar, siderite and pyrite.

The inter-beds are predominantly siltstone, often clayey or carbon-aceous and silty, and with a variable quartz content. They fall into the zone of inorganic clays of medium plasticity and compressibility on the plasticity chart. They normally range from very stiff soils to very weak rocks, although they may occasionally be weaker. Despite the montmorillonite content in the A-zone beds, their measured plasticity is lower than would be expected. This may be due to the quartz content, the presence of illite or the fact that they are Ca-montmorillonites. There is considerable evidence of movement within the inter-beds shown by shearing and slickensides (see logs of DDH 76-191). Because of the weakness of the inter-beds in comparison with the coal, it is likely that local bench instability within the coal sequence will be caused by failure along the inter-beds.

It must be emphasized that the above comments are valid only to the area of the coal deposit examined. In view of the extreme facies variation to the west, it is probable that the proportion of inter-beds will increase in that direction in most zones. It is at present unknown whether montmoril-lonite content becomes a feature of the lower coal zones outside the centre of the basin.

MINERALOGY OF COAL INTER-BEDS

Figure 19



6.4.3 Experience with Plastic Clays on Other Projects

Because of the possible difficulties in excavation and subsequent handling of clay inter-beds of high plasticity, a search was made of the published literature to gain the benefit of mining experience elsewhere. In fact, the search was only poorly productive and the success was possibly a reflection on the few mining schemes in which the problem of expansive materials has been encountered or that authorities have been reluctant to write on their problems. However, problems relating to bentonites in civil engineering projects and landslides are common and the experience gained particularly from canal and dam site excavations is valuable. The references cited below are detailed in Section 8.

The project with most relevance to Hat Creek in this connection is the Centralia Coal Mine in Washington State (Douglas, 1975). Data from this mine were obtained from GA personnel employed there, from published information and from a site visit (see Section 6.4.4). The Centralia coal is found in rocks of Tertiary age. It is interbedded with sandstones, siltstones and claystones and thin Ca-montmorillonite tuffs are interspersed throughout the coal sequence. Not only have these bentonitic materials caused slope failures but they initially proved difficult to remove during washing. They also accumulated on conveyors and trucks and other flat surfaces. Methods have now been found to minimize the problem in the washing plant, and by keeping a film of water on all working surfaces no clay adherence occurs. However, it has been found that due to the thin coating of clay on some coal fragments, the coal stockpile at the power plant becomes difficult to dig after it has been standing for any appreciable length of time.

Yancey and Geer (1961) carried out cleaning trials on a pilot scale of coal from the Big Dirty Seam near Centralia. They found that the presence of the expansive clay 'caused difficulty at every step in the investigation because of the amount, low density and stickiness.' However, they concluded that cleaning could significantly reduce the ash content of the coal but that any washing plant would have to be carefully designed to overcome the difficulties. This has been substantiated by the experience at the Centralia mine.

The Yallourn and Morwell Open Pit Mines in Victoria, Australia have been well described by Stewart (1960) and Gloe (1960). Clays are not common within the thick coal seams (up to 543 ft.) in those pits and there is no record of any problems occurring in clay working or handling. However, thicker and plastic clays of 160 ft. maximum thickness are found within the burned subsided zones above the coal. Problems developed with the use of the bucket-wheel dredgers in these clays at both pits (A. Brown, personal communication), and Rodgers (1960) has described the difficulty of discharging 'mildly sticky overburden' from the buckets at Morwell due to the build-up of a coating several inches thick on the bucket-surfaces. Moreover movement of the excavators across the burn-zones was often difficult. The mineralogy of the clay has not been ascertained, but plasticity indices indicate a clay of medium to high plasticity. Re-design of the buckets alleviated the problem. It is likely that the materials producing the problems were weak normally-consolidated clays with a high moisture content. Comparable materials at Hat Creek might be found within the slide-zones.

Phosphate mining in the Bone Valley Formation, Florida has encountered significant problems in the disposal of the phosphatic clay wastes (Hoppe, 1976). The problem was also well described in a USBM publication in 1975 concerning the disposal of slimes. The waste is primarily a suspension of clay particles in water. Because the clay minerals present are primarily montmorillonite (20 to 25 percent) and attapulgite (5 to 10 percent), both of which are highly plastic and exhibit colloid-like behaviour, the slimes are extremely difficult to drain and very slow to settle. The fine grain size of the materials is an added difficulty. A similar problem was found in the disposal of liquid wastes at Centralia. Much research is being carried out to solve this problem. The clay minerals are dispersed throughout the granular phosphate deposit and reach a maximum concentration of 30 to 40 percent; slope stability problems do not apparently occur in the open pits. There is no record of the clay minerals proving to be a problem in the beneficiation process where the -14 mesh fraction is separated after the ore has been crushed to +3/4 inch size.

Bentonite is mined in open pits in Wyoming for commercial purposes, the Black Hills Bentonite Company being one of the major producers. However, because of the low rainfall in that part of the central U.S.A., few problems seem to be experienced. There is generally no need for beneficiation of the material and the mined product is stored under cover for protection against the infrequent rain.

Bentonitic shales underlie the uranium-bearing rocks mined by Highland Uranium Ltd. for the Exxon Corporation in Wyoming. Grade control is very tight and the close spacing of the exploratory holes permits the uranium bearing sandstone to be selectively worked without inclusion of the expansive materials. No handling or transport problems therefore ensue. By contrast, an underground development in the same formation ran into significant problems. As underdrainage of the sandstone was necessary, haulages were driven in the bentonitic shale and trafficking difficulties were experienced.

The highly bentonitic nature of the Pierre Shale at the Oahe Dam site in S. Dakota caused design problems in the cut slope, the dam foundations and the power and outlet works tunnels (Underwood, 1961; Knight, 1963). There is no record of difficulties of working with these materials although they were not used compacted in the dam core but only slightly compacted in upstream and downstream berms. The area is semi-arid with an annual rainfall of 16 inches.

The Panama Canal stands as the best practical example of excavations in bentonitic materials. The long history of excavation, sliding, investigation, monitoring and remedial work has yielded much valuable data. That part of the canal that is unstable lies within the Tertiary Cucaracha and Culebra Formations. These rocks are composed largely of tuffaceous shale in which Ca-montmorillonite is generally abundant. The Culebra Formation also contains siltstone and sandstone (Banks, 1972; Beene, 1971).

In the lengthy account on the excavation of the canal (Goethals, 1915) much space is given to the difficulties of excavating the materials and to stabilizing the slopes, but very little mention is given to difficulties of handling or transporting the materials. Indeed, many of the slides were removed by water monitoring using high pressure pumps which would not be possible for material of a highly plastic nature. However, although part of the 1913 Cucaracha slide was removed by sluicing, when the canal cut was flooded in that year the remainder of the slide proved very difficult to excavate. From Geothals' account, there seem to have been few problems in dumping the materials which could be related particularly to their mineral composition.

Analogies between deposits in far separated localities can be misleading. It is known thatthe Cucaracha and Culebra deposits have certain characteristics not possessed by the Coldwater Formation: the bedding is well developed, uniform and dips at a shallow angle locally unfavourable to the comparatively steep cuts of the canal banks; the rocks are block faulted, overlain by stronger volcanic rocks, and heavily slickensided in places. It is likely that only the residual shear strength would be developed along the bedding plane surfaces. Many of these conditions seem not to apply at Hat Creek.

6.4.4 Transport, Handling and Processing of Materials

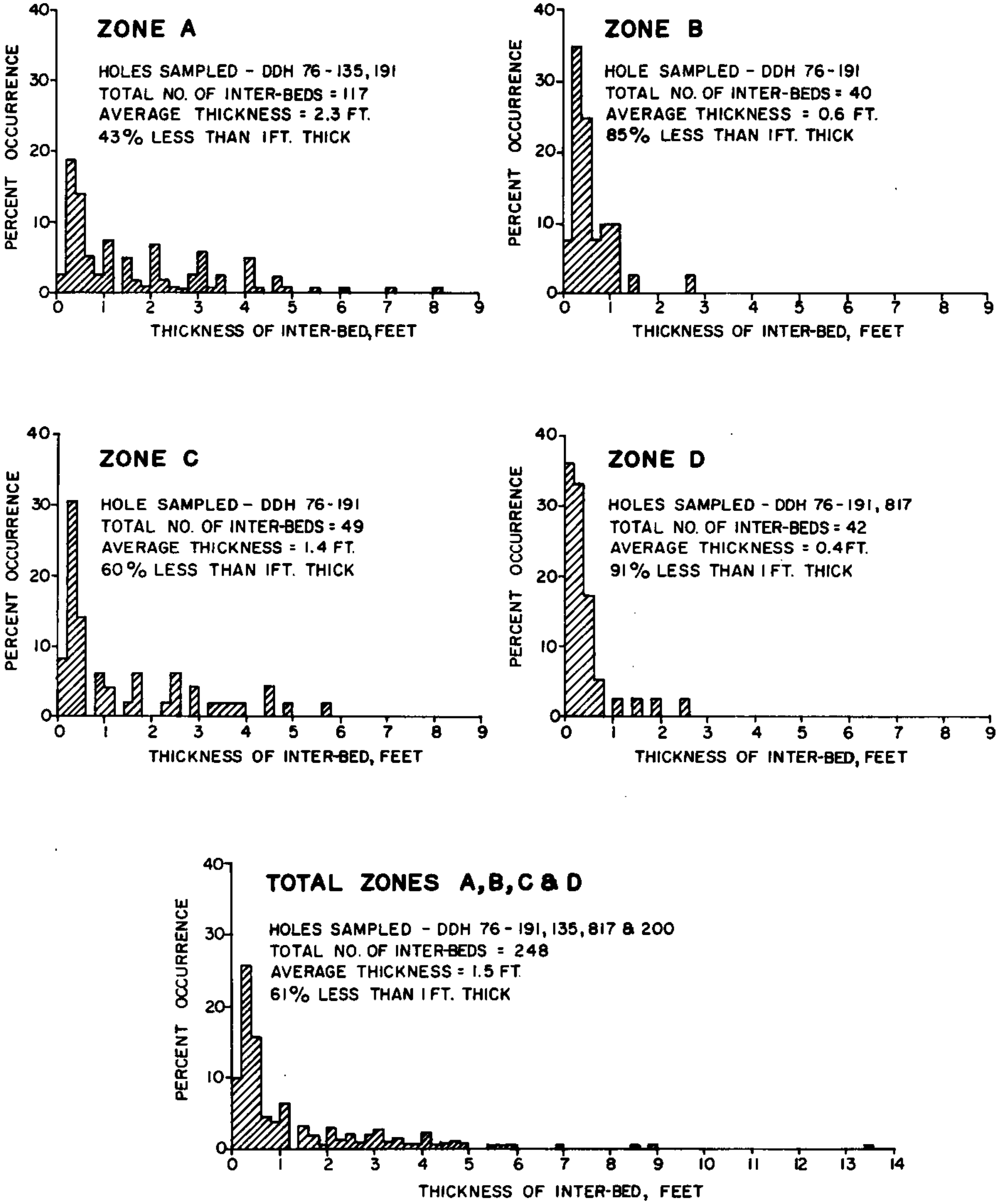
The presence of significant quantities of montmorillonite in the Coldwater rocks has given rise to concern about the transportation, handling and processing of the materials to be mined. In order to gain first hand experience of the potential problems, a visit was made to Centralia Mine in Washington State where bentonitic inter-beds occur within the coal. The serious problems which can arise in handling and processing materials with a high bentonite content were examined, and the methods of overcoming them discussed with mine officials.

Information gathered to date at Hat Creek suggests that the problems of handling and processing the coal should be significantly less severe than at Centralia. Figure 20 shows histograms of the thicknesses of individual inter-beds in any one coal zone. It will readily be seen from these results and the drill logs of the relevant holes that in the B- and D-zones the beds are thin and only poorly developed. In the A- and C-zones by contrast the inter-beds are thicker and more frequent. These plots also underrate the importance of the beds in these zones because of the significant areas of core loss during drilling of the weaker beds. However since the inter-beds are thicker they ought to be easier to remove in the pit, minimizing the proportion of waste that has to be separated later. Some thin beds of bentonitic material will therefore remain in the A-zone, and they will be impossible to separate from the coal during mining. They are considerably less plastic than the comparable beds in the sequence at Centralia, where the problems with bentonitic materials have largely been overcome.

Considering the distribution of bentonitic materials within the coal as seen in the center of the basin, it is our opinion that transportation, handling and processing of the Hat Creek coal should not present serious problems. However it will also be necessary to examine the plasticity of the inter-beds towards the margin of the basin.

HISTOGRAMS OF COAL INTER-BED THICKNESSES

Figure 20



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However, most of the Coldwater rocks which surround the coal have montmorillonite dispersed throughout them, and are likely to prove difficult to transport and to handle. The characteristics of the material in the active slide in the northwest of the valley are typical of those which can be expected when the material has been disturbed and remoulded and when the moisture content is relatively high. No firm guidelines on the handling of this type of material can be offered at this stage, but it is recommended that maximum use should be made of experience which exists in mines such as Centralia and the uranium mines in Wyoming, where successful techniques for handling such materials have been developed. It is recommended that specific studies of the materials handling techniques used by these mines should be included in the next phase of the Hat Creek mining study. Moreover full use should be made of any excavations for sampling purposes on the site to examine and handle the material in bulk.

6.4.5 Diggability

There has been some discussion on the use of bucket wheel excavators for mining some of the materials at Hat Creek. A full discussion on the functioning and effectiveness of bucket wheel excavators exceeds the scope of this report; reference may be made to the comprehensive text entitled 'The Bucket Wheel Excavator' by Rasper, 1975.

Rasper suggests that the digging power for a bucket wheel excavator can be calculated as follows:

$$N_{dig} = 0.00584 \frac{k}{\eta} \sqrt{\frac{Q_{th.S.}\eta_{f.R}}{f}}$$

where N_{dig} is the minimum digging power in kilowatts

k is the specific digging resistance per centimetre width of knife

η	is the overall efficiency referred to the bucket wheel shaft
Q_{th}	is the theoretical output (m^3/h of loose material)
η_f	is the percentage of bucket filled
f	is the amount of swell ($1.3<f<1.65$)
S	is the number of bucket discharges per minute
R	is the radius of the cutting circle of the bucket wheel (m).

This equation predicts a parabolic relationship between digging power and output.

An important component of this equation is k, the specific digging resistance, which depends entirely upon the properties of the material being excavated. Rasper quotes the following values:

Sand and gravel	k = 20 kg/cm
Clay	k = 29 kg/cm
Sandy loam	k = 33 kg/cm
Hard and saturated clay	k = 56 kg/cm
Clay consolidated by hard intermediate layers	k = 150 kg/cm
Sandy frozen gravel	k = 170 kg/cm

Experience with the Coldwater sediments at Hat Creek suggests that the value of k may lie between 25 and 35 kg/cm, but that occasional hard bands (such as calcareous zones and ironstone beds) will be encountered which could cause the value to increase by a factor of three or four locally. GA believe that bucket wheel excavators could be used in the Coldwater materials provided that the mine plan can be designed to accommodate them. It may also be necessary to make special provision for cleaning the buckets, as the materials will tend to be sticky under certain moisture content conditions. The BWE being used at Centralia was not operating in the bentonitic materials of the coal sequence but in surficial deposits.

On the eastern side of the pit, there are substantial quantities of surficial sands and gravels with interbedded tills which could be excavated by bucket wheel, but these materials are probably more variable. The properties of the till and its distribution would need to be investigated further.

Burn zone materials and hard layers of calcareous siltstone (particularly prevalent at the base of the D-zone) could be encountered, and these could have very high specific digging resistance values. Similarly the coals could contain harder bands (ironstone and tuff) which would make digging by bucket wheel excavator difficult. The maximum size of boulder on the site is approximately 36 inches on the west and rather less on the east side of the pit. Consequently, the performance of bucket wheel excavators in materials other than the Coldwater rocks would require further examination before a decision on their use could be made.

6.4.6 Blasting

Apart from isolated zones of burnt materials, layers of hard calcareous material and random boulders, it is anticipated that blasting will not be required in mining the Hat Creek deposit. Consequently, blasting is reduced from a primary excavation technique to a secondary method for dealing with zones which are not practical or not convenient to excavate by digging.

7. RECOMMENDED FURTHER PROGRAM

It is considered essential that geotechnical investigations, monitoring and analysis should be continued both during the design phase of the project, and during subsequent mine development. Because of the weak nature of the materials in the pit and waste dumps, and their variability, it will be necessary to collect more data for design purposes and to maintain a continuing program to permit existing assumptions to be checked and refined. The monitoring program should be designated to detect departures from assumed design conditions during the various stages of pit and waste dump development. To carry this out will necessitate further drilling, instrumentation, in situ and laboratory testing, as well as geological mapping of all faces within the pit as they become exposed.

Those aspects which need to be investigated further before the design of the 600 ft. pit and waste dumps can be finalized are as follows:

1. Ground Water

   a) Further definition of the pattern of ground water pressure distribution both in areal extent and depth within the area of the proposed pit slopes.

   b) Further investigation of the extent to which the mine slopes can be depressurized, particularly those materials other than the siltstones already tested.

   c) Further evaluation of the permeability of the surficial materials and the extent to which they can be dewatered.

   d) Examination of the influence that the limestones might have on the regional ground water system.

2. Slope Stability

   a) Detailed examination of the access ramp area in order to optimize the alignment and hence permit detailed design of the stabilization measures.

   b) Investigation of slide areas beyond the west side of the proposed pit to determine the extent of the instability. More extensive monitoring of movement will be required.

3. Waste Dump Embankments

   a) Further investigation of embankment locations and foundations.

   b) Examination of material availabilities and sequences of construction vis-a-vis dumping.

4. Material Testing

   a) Continuation of the program of material testing, con centrating on the weak low permeability siltstone and waste dump aggregates.

5. Excavations Produced for Exploration

   a) Full geotechnical use should be made of any excavation (open cut, adit, tunnel or shaft) for obtaining bulk coal samples. These rock exposures should be fully logged and extended where practicable to view representative materials for geotechnical purposes. Use should be made of the bulk materials so obtained for testing and observation of their behaviour in the field. The opportunity should be taken for monitoring ground water movement resulting from the excavation.

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9. GLOSSARY OF GEOLOGICAL TERMS

Agglomerate - A volcanic rock formed predominantly of cemented non-angular fragments greater than 2 cm in diameter.

Alluvium - A term for all detrital deposits resulting from the operation of present rivers, thus including sediments deposited on river beds, flood plains, lakes, fans and estuaries.

Andesite - A dark coloured, fine grained extrusive rock composed primarily of sodium and calcium silicate minerals.

Anticline - A fold, the core of which contains stratigraphically older rocks than the limbs, and whose form is concave downwards.

Aquifer - A formation, group of formations, or part of a formation that is water bearing.

Artesian (pressure) - Ground water pressure which induces the water level to rise above the aquifer, whether or not the water flows at the surface.

Ash (volcanic) - Uncemented volcanic debris consisting of fragments generally less than 4 mm (see tuff).

Basalt - A dark coloured lava rich in calcium, magnesium and iron silicate minerals but containing little or no free silica.

Bentonite - A clay formed from the decomposition of volcanic ash, mainly montmorillonite. Bentonite boil - an upwelling of liquid bentonite.

Breccia (volcanic) - A rock formed by the cementation of angular fragments of volcanic rock during an eruption.

Brecciation - The production of a fragmental rock (breccia) by faulting or sliding.

Clast - The coarser portion, usually consisting of rock pebbles, of a conglomerate set in a fine detrital matrix.

Clastic - A textural term applied to rocks composed of fragments derived from pre-existing rocks.

Claystone - A fine grained rock made up predominantly of clay sized particles, i.e. more than 50 percent smaller than .002 mm diameter.

Cleating - Sets of close joints in coal, perpendicular to each other and to bedding; tight cross jointing.

Colluvium - A deposit formed by the accumulation of soil and rock fragments as the result of weathering processes and transport by gravity (synonym of talus and scree).

Conglomerate - A cemented sedimentary rock formed mainly of rounded water worn fragments corresponding in their sizes to gravel or pebbles.

Creep - A slow, continuous downward and outward movement of slope-forming soil or rock.

Cristobalite - A crystalline form of silica occurring as minute octohedra or cubes in certain lavas, stable above $1470^{\circ}C$ (see tridymite).

Dacite - An extrusive igneous rock predominantly composed of plagioclase felspar, quartz, pyroxene and/or hornblende with minor biotite and sanidine felspar.

Desiccation - A drying out process, usually in connection with the loss of water from sediments.

Detrital - Pertaining to loose rock and mineral that has been derived from the disintegration of older rocks and transported from its place of origin.

Diorite - A coarse grained igneous rock composed essentially of sodic plagioclase felspar together with silicate minerals rich in iron and magnesium such as biotite, hornblende and pyroxene. Small amounts of quartz (free silica as SiO_2) may be present.

Dolerite - A rock of basaltic composition, consisting essentially of labradorite, and pyroxene with a characteristic ophitic texture.

Dyke - A tabular igneous intrusion that cuts across the planar structures of the surrounding rock.

Erosion Surface - A land surface shaped by the disintegrating, dissolving and wearing action of streams, ice, rain, winds and other agencies.

Felspar - A group of the most important rock forming minerals comprised of aluminous silicates of potassium, sodium, calcium or barium.

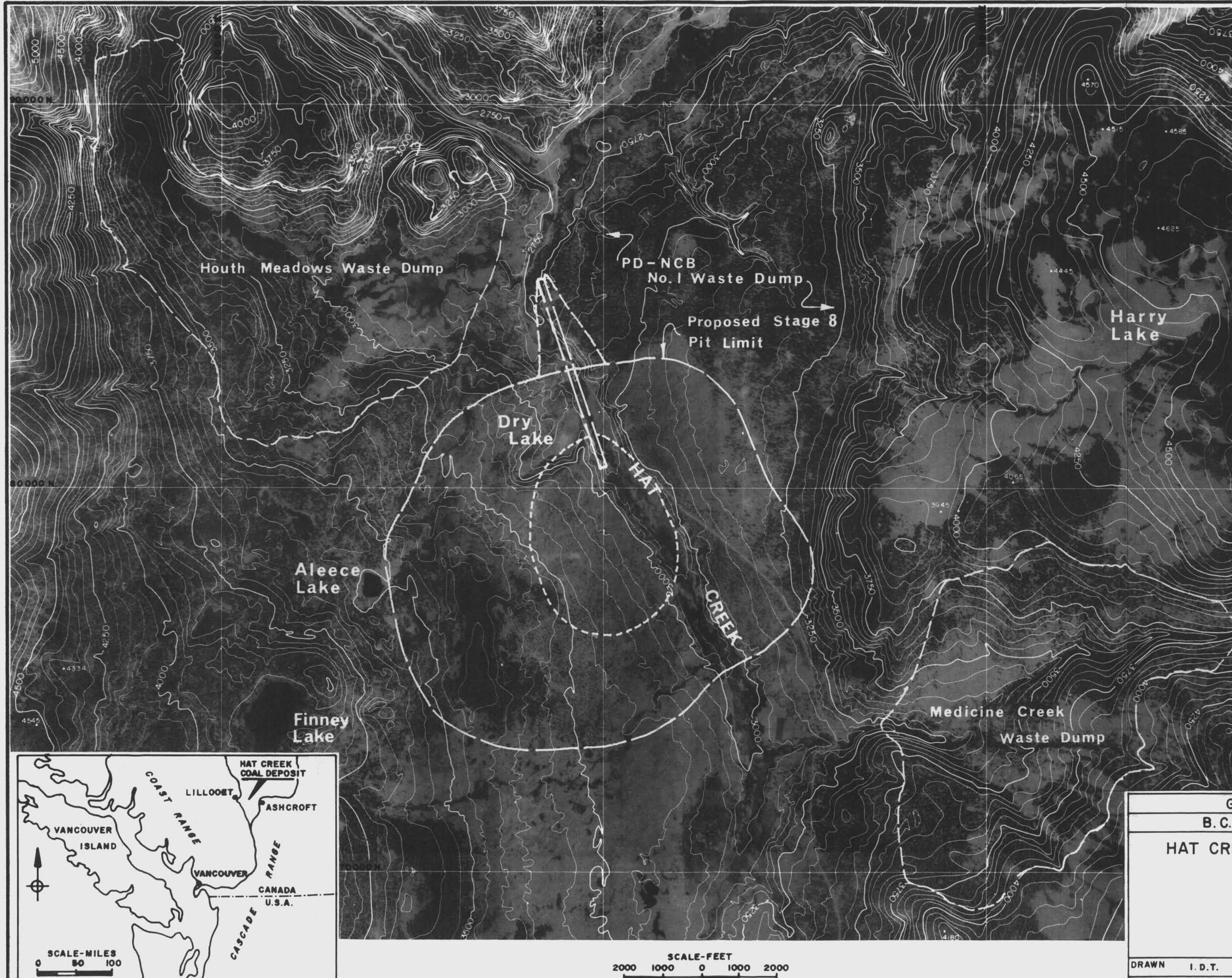
Fissure Eruption - The emission or eruption of volcanic materials at the earth's surface from a fissure.

Flowslide	-	Soil or rock failure characterized by a considerable distance of travel and much internal readjustment; the movement may not be confined to a discrete plane of sliding. Velocity of failure may vary from a slow creep to extreme mobility.
Glacial Drift	-	A general term applied to all sediment transported by a glacier and deposited directly by or from the ice, by running water emanating from a glacier, in glacial lakes or in the sea.
Glacio-fluvial	-	Pertaining to streams flowing from glaciers, or to the deposits made by such streams.
Glacio-lacustrine	-	Pertaining to glacial-lake conditions or to the sediments deposited in lakes marginal to a glacier by glacial melt water streams.
Graben	-	A block that has been downthrown along faults relative to the rocks on either side.
Granodiorite	-	A coarse grained igneous rock composed predominantly of quartz, plagioclase and orthoclase felspar and silicate minerals rich in iron and magnesium such as biotite and hornblende. It contains less quartz and orthoclase felspar than granite.
Gravel	-	Generally used to describe an aggregate with a high proportion of particles larger than 2 mm; more specifically the grain size range is 2-60 mm.
Greenstone	-	A field term applied to altered basic igneous rocks which owe their colour to the presence of chlorite, hornblende and epidote.
Hackly (texture)	-	Showing jagged points in fracture.
Hydrograph	-	A graph showing stage, flow, velocity or other variation of the quantity of water with time.
Illite	-	A clay mineral formed by the decay of muscovite or felspar, either by weathering or hydrothermal processes; an hydrous potassium aluminous silicate.
Kaolinite	-	A clay mineral formed by the weathering of felspars followed by the action of gases; an hydrous aluminous silicate.
Lacustrine	-	Pertaining to lakes, or sediments deposited in a lake environment.

Lahar	-	A deposit derived from a flow of water-saturated volcanic debris - a type of mud flow.
Leachate	-	The liquid that has percolated through the soil or other medium.
Lithify	-	To turn to rock; to crystalize from a magma or to consolidate, such as the process of induration of a loose sediment.
Metamorphism		Any change in the texture or composition of a rock produced by exterior agencies, especially by deformation or rise of temperature.
Micaceous	-	Having an obvious mica content.
Montmorillonite	-	A clay mineral, which swells greatly on absorbing water, formed by the alteration of aluminous silicates in the decomposition of volcanic ash. Commonly called bentonite.
Moraine	-	A mount, ridge or other distinct accumulation of unsorted, unstratified glacial drift deposited chiefly by direct action of glacier ice in a variety of topographic landforms.
Muscovite	-	A tabular or platy silicate mineral, which splits easily into thin elastic plates, occurring as an original constituent of acid igneous rocks.
Nodule	-	Small more or less rounded body generally somewhat harder than the enclosing sediment or rock matrix.
Olivene	-	A magnesium iron silicate mineral occurring in basic igneous rocks such as basalts and dolerites.
Periglacial	-	Processes, conditions, areas, climates, and topographic features at the immediate margins of former or existing glaciers and ice sheets, and influenced by the cold temperature of the ice.
Petrography	-	The branch of geology treating the systematic description and classification of rocks.
Phyllite	-	A fine grained rock formed from shale, mudstone or siltstone by metamorphism, but intermediate in grain size and cleavage development between a slate and a schist.
Physiography	-	A term used to describe existing nature as displayed in the substance form and arrangement of the surface of the lithosphere.
Quartz	-	A crystalline form of silica, occurring as an essential mineral in the more acid igneous rocks, granites, rhyolites, etc.

Rejuvenation	-	An elevation of the base level of a stream, changing the gradient and thus initiating a new cycle of erosion.
Rhyolite	-	An extrusive fine grained igneous rock, generally with coarse grained crystals set in a fine grained groundmass and showing flow textures.
R.Q.D.	-	Rock Quality Designation - an index expressing the percentage of total drill core greater than 4" length present in any one drill-run.
Sandstone	-	That fraction of a grain size distribution between .06 and 2.0 mm; a cemented rock consisting of predominantly sand size sediment derived from the weathering and erosion of pre-existing rocks.
Scarp	-	A regular relatively steep slope produced by faulting, erosion, or instability.
Siderite	-	Iron carbonate, occurring in sedimentary deposits as beds and nodules in coal measures.
Siliceous	-	Having an obvious silica content.
Siltstone	-	A sedimentary rock composed predominantly of at least two-thirds silt-sized minerals and intermediate between a sandstone and claystone.
Specific Storage	-	The volume of water released from or taken into storage, per unit volume of the porous medium, per unit change in head.
Storage Coefficient	-	The volume of water an aquifer releases from or takes into storage, per unit surface area of the aquifer, per unit change in head.
Stratigraphy	-	The part of descriptive geology that pertains to the description, character, thickness, sequence, age and correlation of rocks. Stratigraphic column - a chronological listing of stratigraphy. Stratigraphic horizon - a discrete member of stratigraphy; a marker.
Succession	-	A chronological listing of that part of descriptive geology pertaining to the description, character, thickness, sequence, age and correlation of rocks.
Surficial	-	Unconsolidated residual, alluvial or glacial deposits overlying the bedrock.

Syncline	-	A fold, the core of which contains stratigraphically younger rock than the limbs, and whose form is concave upwards. Synclinal - a descriptive term for a fold in rocks in which the strata dip inward from both sides towards the axis.
Tectonic	-	Pertaining to the rock structure and external forms resulting from the deformation of the earth's crust.
Till	-	Unsorted and unstratified drift deposited directly by and underneath a glacier, or by flow off a glacier, without subsequent reworking by water from the glacier and consisting of a heterogeneous mixture of clay, sand, gravel, cobbles and boulders varying widely in size and shape.
Transmissivity	-	The rate of horizontal water flow through a unit width of a vertical section of the saturated aquifer, under a unit hydraulic gradient, at the prevailing water temperature.
Tridymite	-	A crystalline form of silica occurring in acid igneous rocks, stable between 870^{o} and 1,470^{o}C (see cristobalite).
Tuff	-	A rock formed of compacted volcanic fragments, generally smaller than 4 mm in diameter (see ash).
X-ray Diffraction	-	A method of quantitative mineralogical examination in which a powdered specimen of material selectively diffracts X-rays.



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B.C. HYDRO & POWER AUTHORITY		
HAT CREEK GEOTECHNICAL STUDY		
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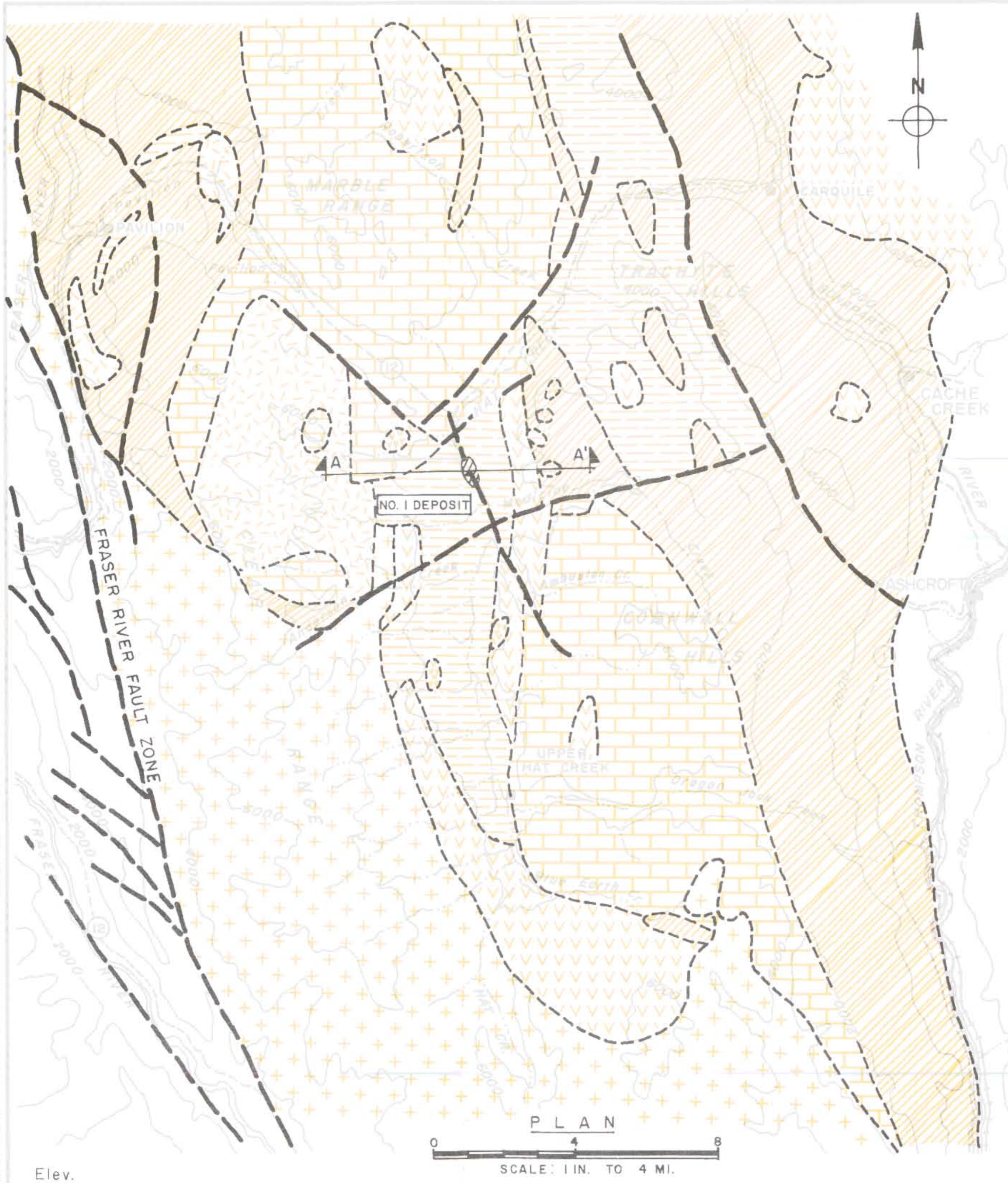
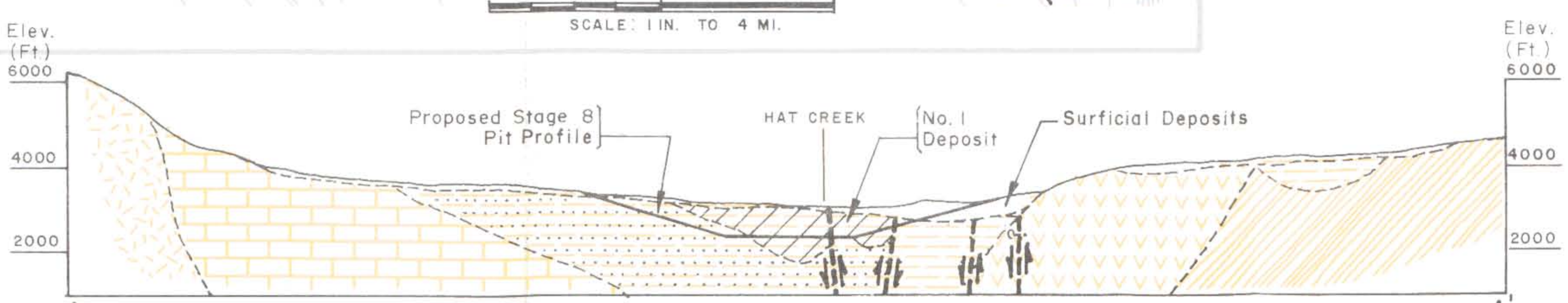
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 1





SCHEMATIC GEOLOGICAL SECTION A-A'

NATURAL SCALE: I IN. TO 4000 FT.

GEOLOGICAL SUCCESSION

Cenozoic	Quaternary	Recent	alluvium, colluvium, landslide debris, peat, volcanic ash.
		Pleistocene	glacial till, glacio-lacustrine silt, glacio-fluvial sand and gravel, landslide debris, colluvium, volcanic ash.
	Tertiary		Olivene basalt and lahar (Miocene)
		Kamloops Group	Coldwater Formation; conglomerate, sandstone, siltstone, claystone and coal, often bentonitic or tuffaceous (Eocene)
			Kamloops Volcanics; basalt, andesite, dacite, rhyolite with associated tuffs, agglomerates and breccias (Eocene).
Mesozoic	Early Tertiary to Late Cretaceous	Spences Bridge Group	volcanic and minor sedimentary rocks.
Palaeozoic	Permian	Cache Creek Group	Marble Canyon Formation; limestone
			Greenstone, chert, argillite, quartzite, limestone and phyllite.
	Intrusive Rocks		
Mesozoic	Early Cretaceous to Late Jurassic	Mount Lytton Batholith (Mount Martley Stock).	granodiorite, quartz diorite and diorite

LEGEND:

- - - - Inferred Geological Contact

— — — Inferred Fault

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G.S.C. Ashcroft Sheet - Map 1010A.
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B.N. Church - Geology of the Hat Creek Basin - B.C. Dept. of Mines - Summary of Field Work, 1975.
Dolmage Campbell & Assoc. - Outline Map 1" = 2000', 1976.
Golder Assoc., B.C. Hydro & Power Authority - Field Work, 1976.

NOTES:

Glacial cover omitted from Plan.
Coldwater Formation subdivided by rock types on section as follows:

Siltstone and claystone

Coal

Sandstone, conglomerate siltstone.

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HAT CREEK GEOTECHNICAL STUDY

REGIONAL GEOLOGY

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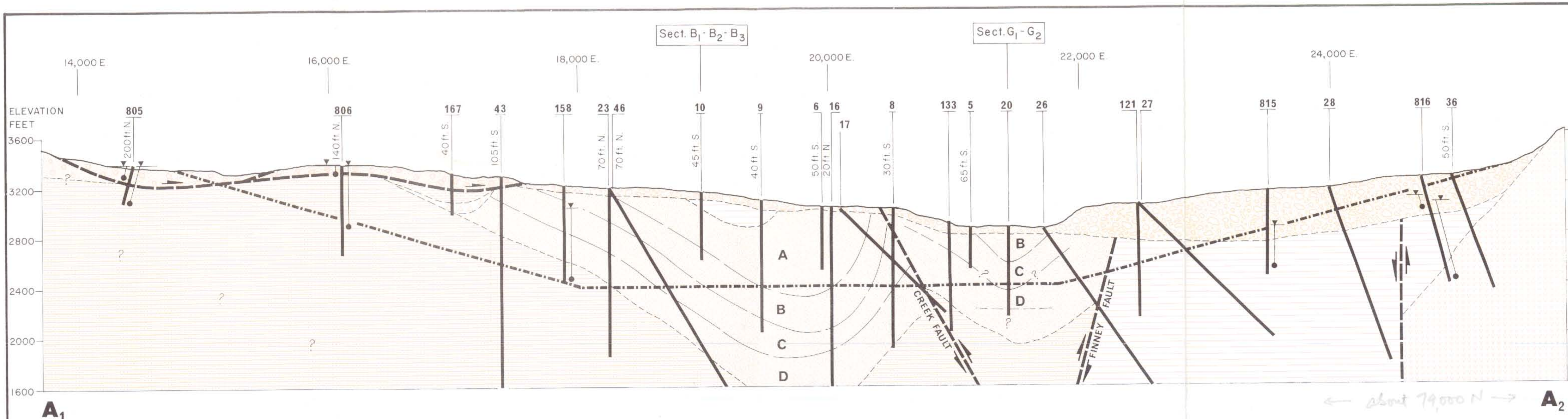
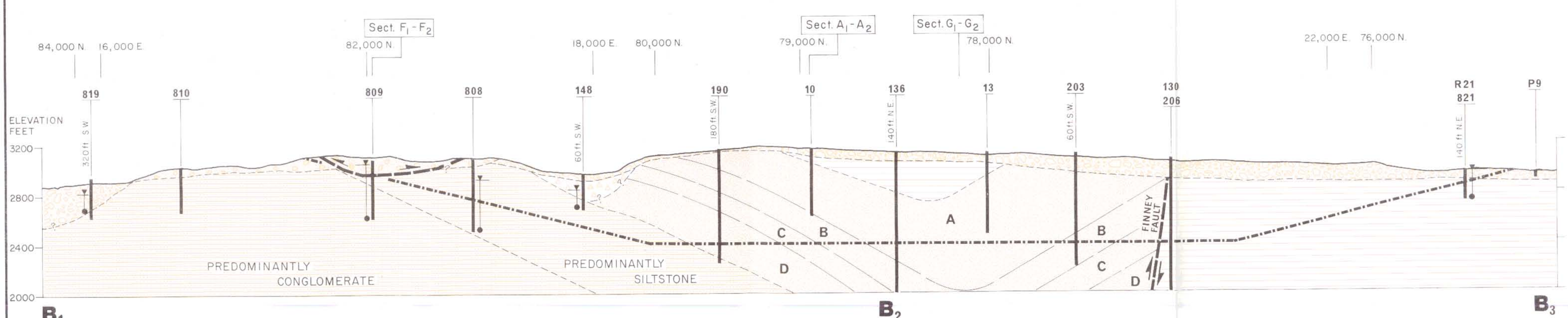




LEGEND

Quaternary
- Glacial, alluvial and colluvial deposits
- Glacial lake deposit
- Granodiorite colluvium
- Burn zone
- Slide zone

Tertiary
- Coldwater Formation
  - Claystone and siltstone
  - Coal (Zones A, B, C and D)
  - Sandstone, conglomerate and siltstone
- Kamloops Volcanics

Geological boundary (approximate)

Inferred geological boundary -?-?-

Shear zone or base of active slide

Fault

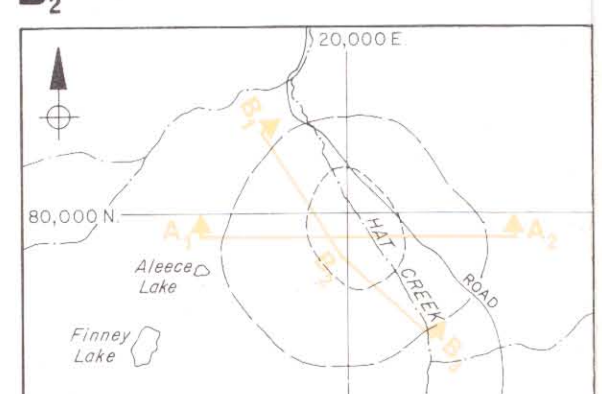
Base of Stage 8 pit and/or Access Ramp

819 Drillhole number

320 ft. S.W. Distance hole is offset from section line

Piezometric elevation as of November 1, 1976.

Piezometer location in drillhole



LOCATION PLAN

Scale - Miles

0 2

NATURAL SCALE - FEET

800 400 0 400 800

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HAT CREEK GEOTECHNICAL STUDY

GEOLOGICAL SECTIONS SHEET I

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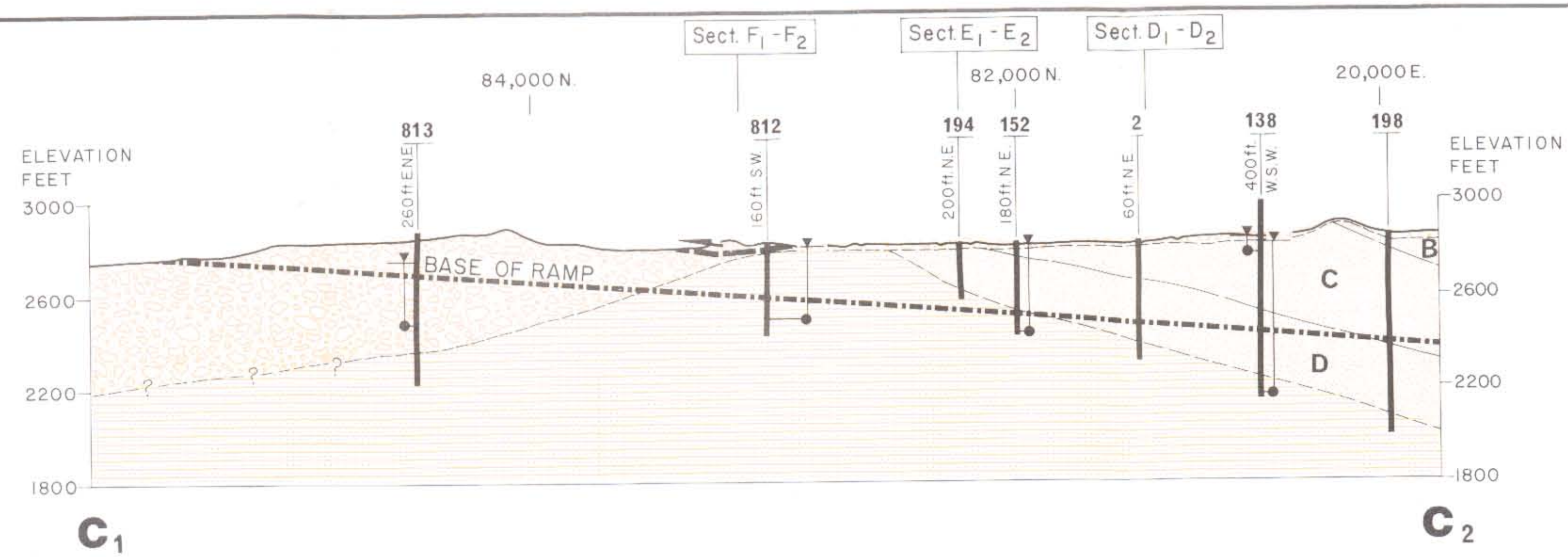
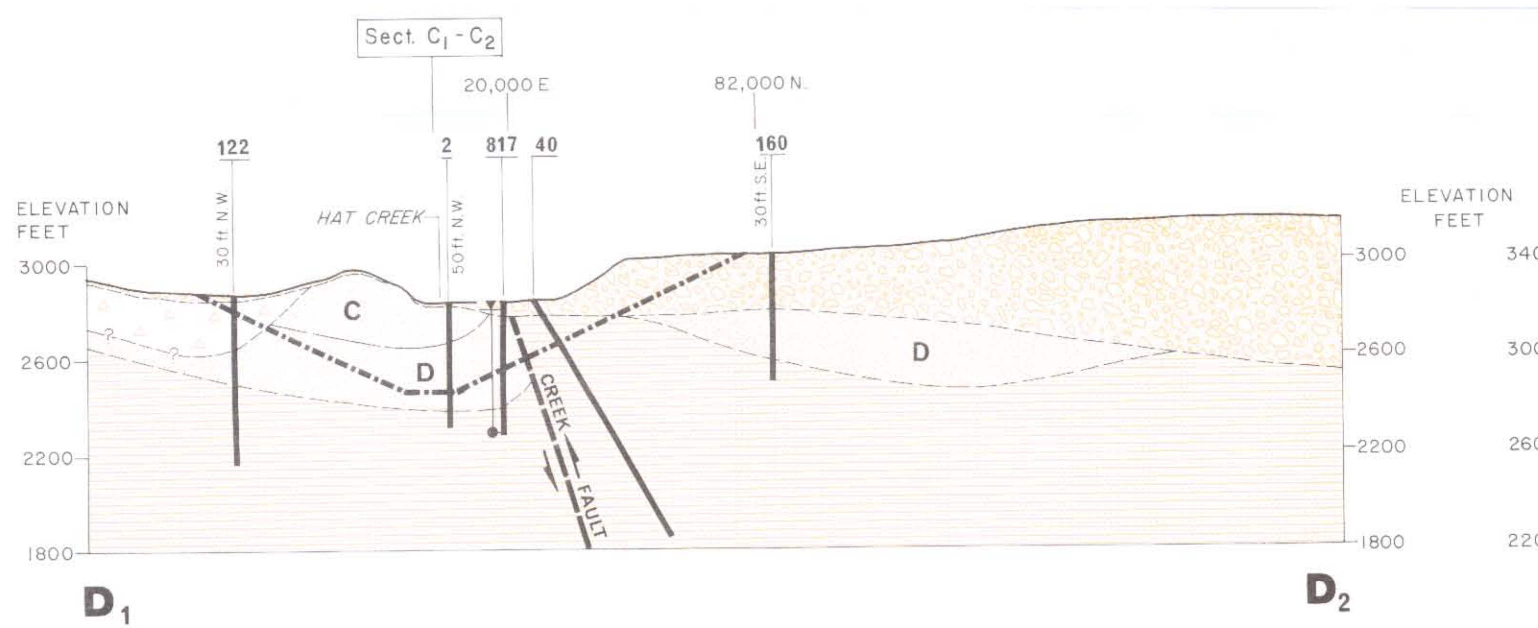
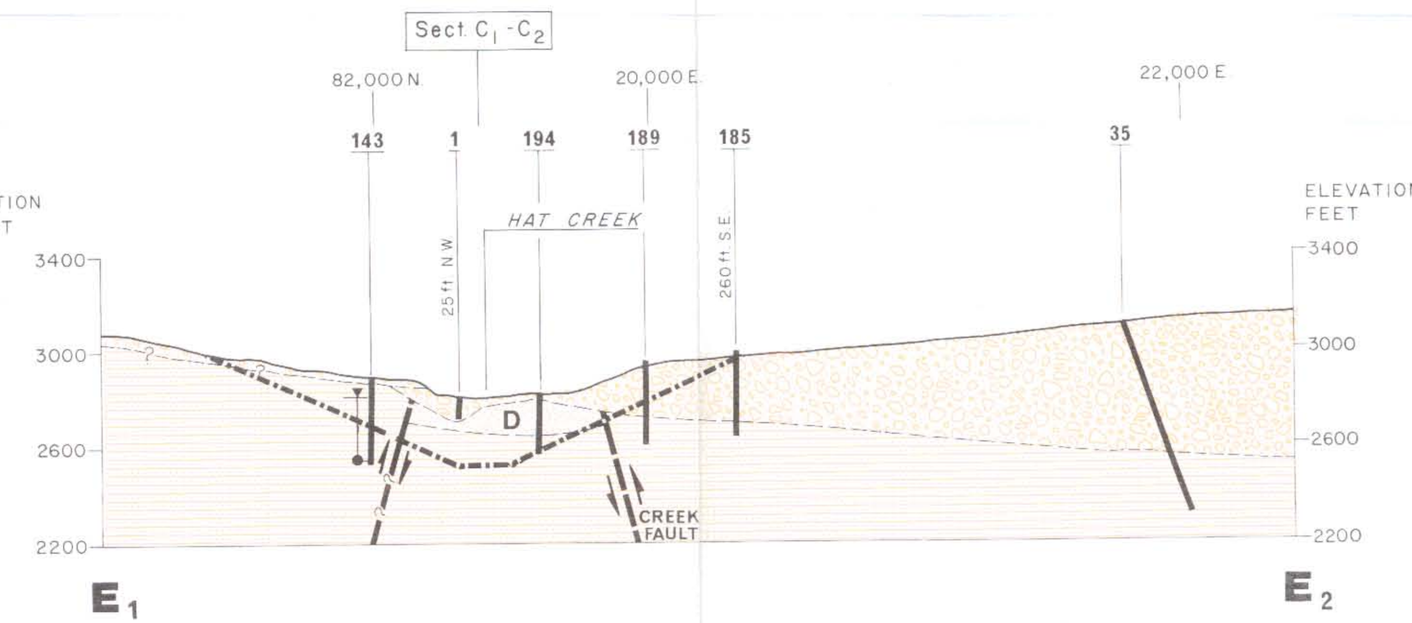
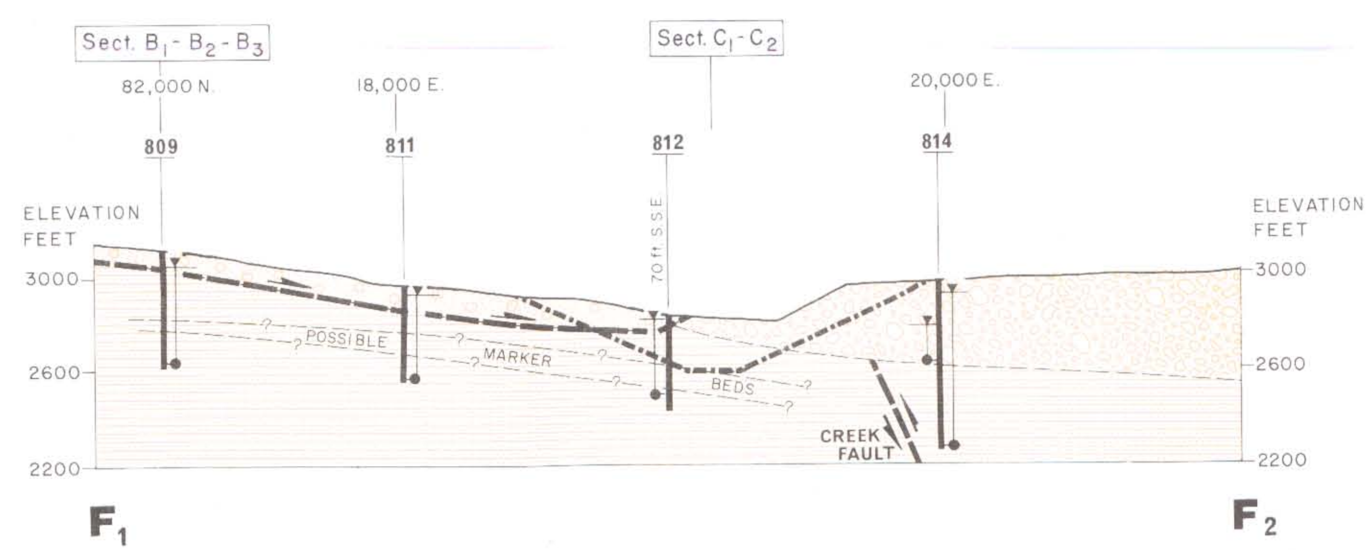
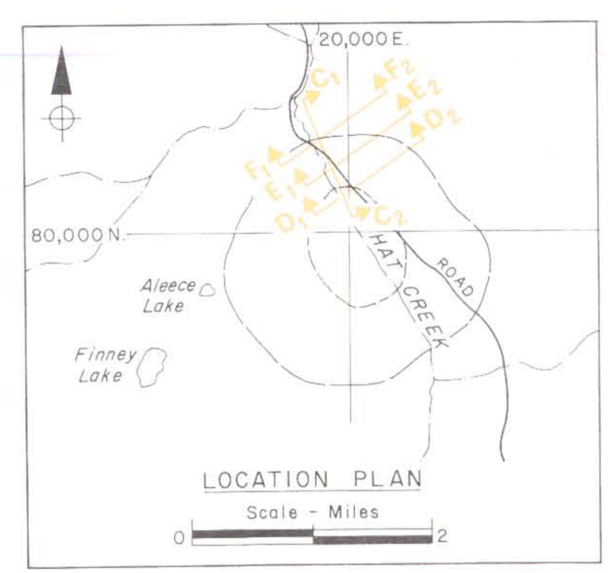
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 3











NATURAL SCALE - FEET

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B.C. HYDRO & POWER AUTHORITY

HAT CREEK GEOTECHNICAL STUDY

GEOLOGICAL SECTIONS SHEET 2

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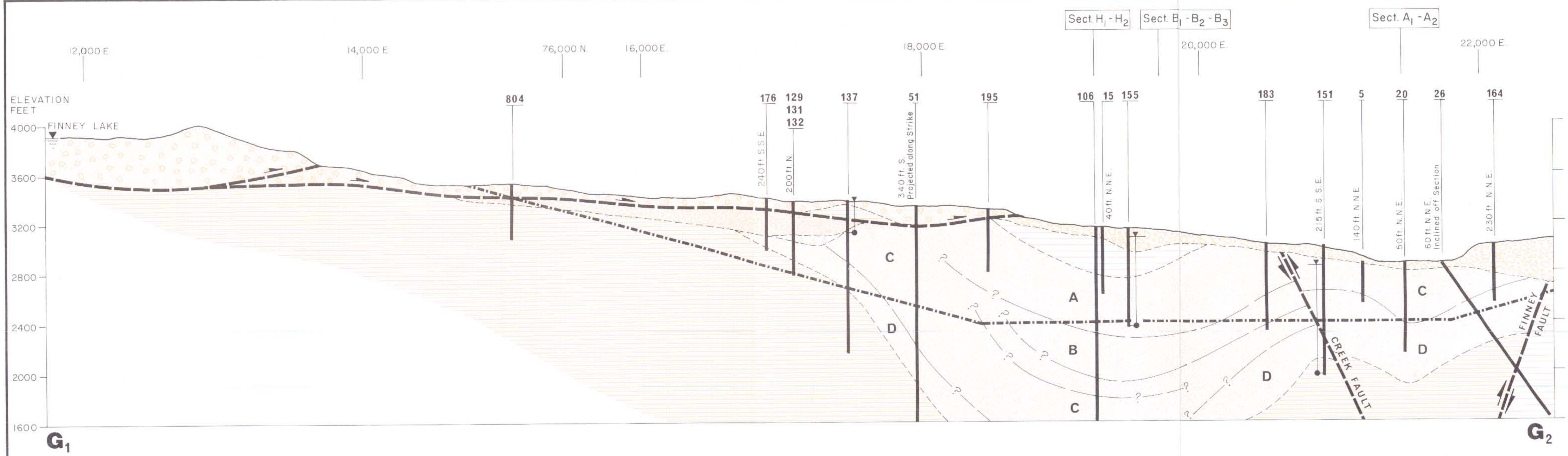

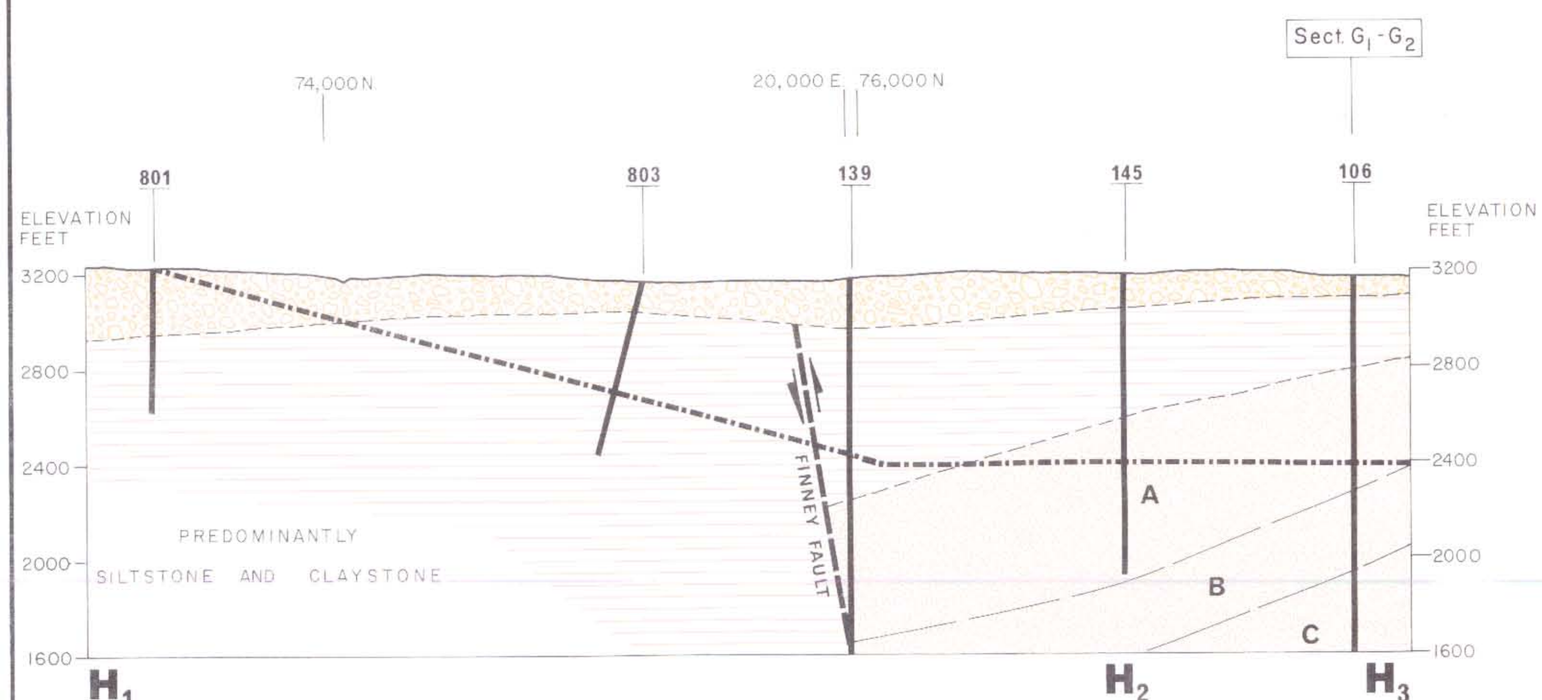

LEGEND

Quaternary
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Inferred geological boundary

Shear zone or base of active slide

Fault

Base of Stage 8 pit and/or Access Ramp

819 Drillhole number

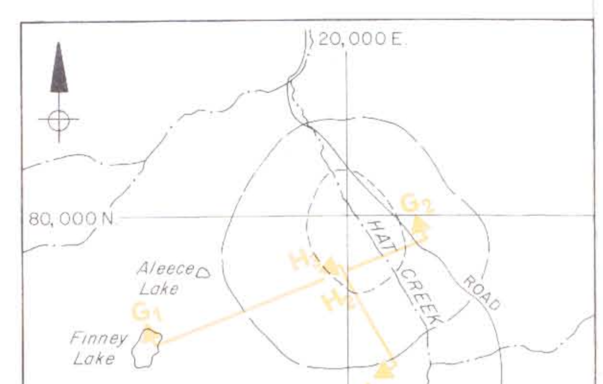
320 ft. S.W. Distance hole is offset from section line

Piezometric elevation as of November 1, 1976.

Piezometer location in drillhole

NATURAL SCALE - FEET

800 400 0 400 800



LOCATION PLAN

Scale - Miles

0 2

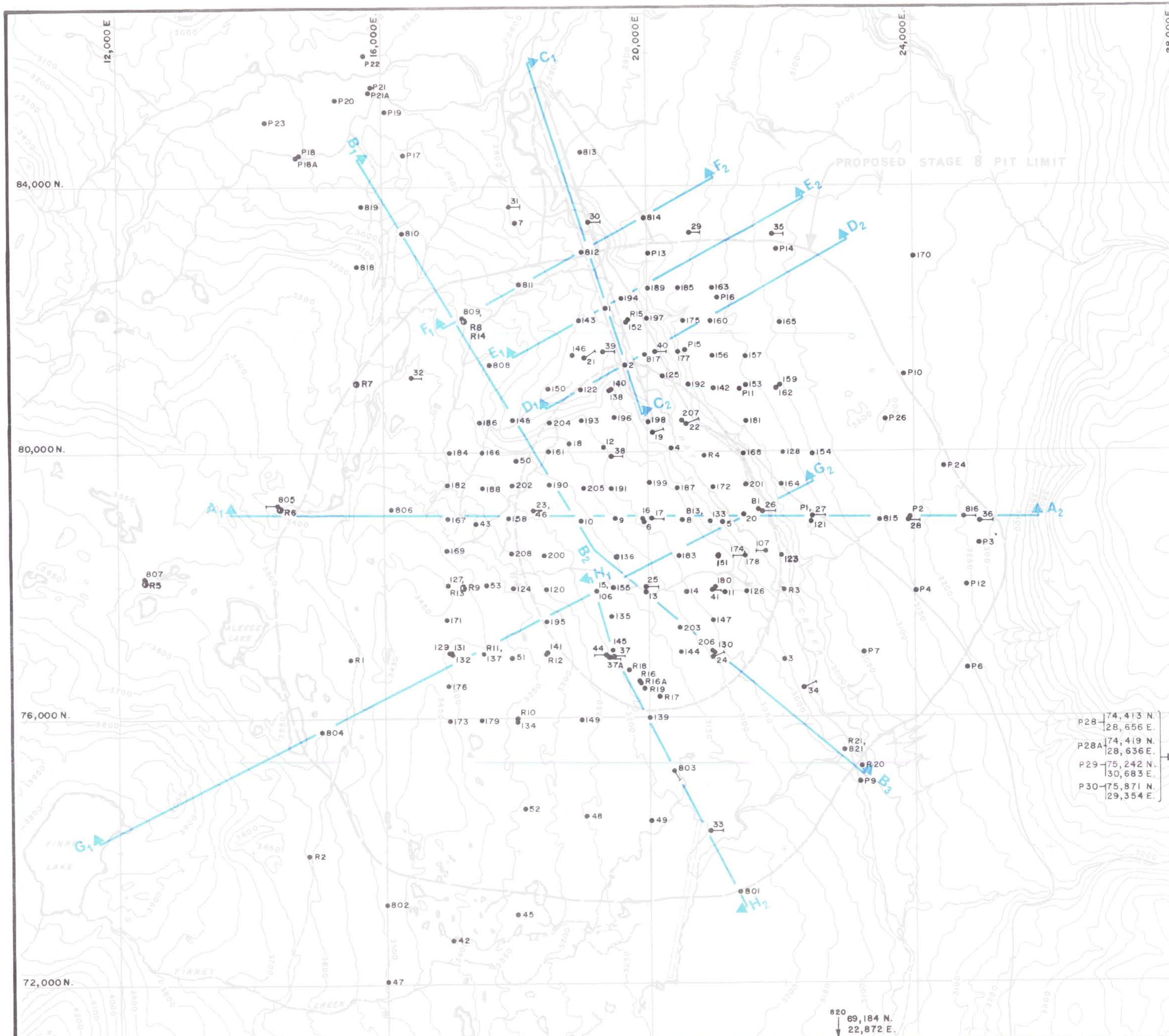
Golder Associates

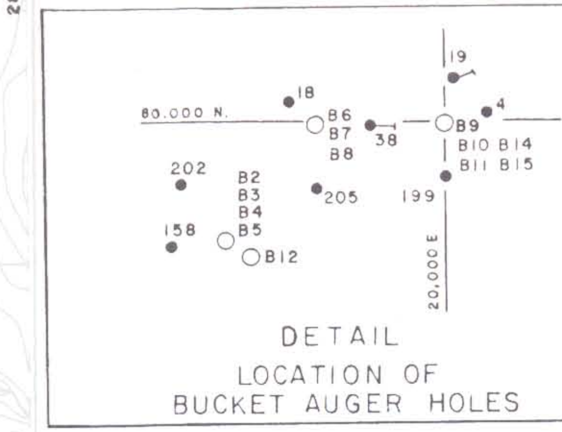
B.C. HYDRO & POWER AUTHORITY

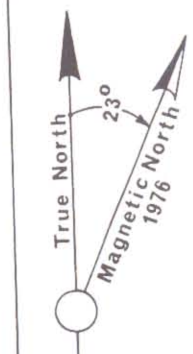
HAT CREEK GEOTECHNICAL STUDY

GEOLOGICAL SECTIONS SHEET 3

DRAWN I.D.T.	CHK'D	APP'D
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 5







LEGEND

○ Vertical exploration hole
○⁄ Inclined exploration hole

Subdivided as shown below.

Prefix	Hole Type
● None	Diamond Drill Hole (DDH)
● R	Rotary Hole (permeability test)
◑ R	Rotary Hole (slope indicator)
● P	Percussive (Becker) Hole
● B	Bucket Auger Hole

Drilling Periods:

1925	DDH 1 to 7
1957	DDH 8 to 15
1959	DDH 16 to 22
1974	DDH 23 to 48, RH 1 and 2
1975	DDH 49 to 53, 106, 107, RH 3 and 4
1976	DDH 120 to 208, 801 to 828, RH 5 to 21, P 1 to 30, BAH 1 to 15

NOTE: For brevity on plan, year prefix omitted and letter prefix shortened.

SCALE - FEET
2000 1000 0 1000 2000

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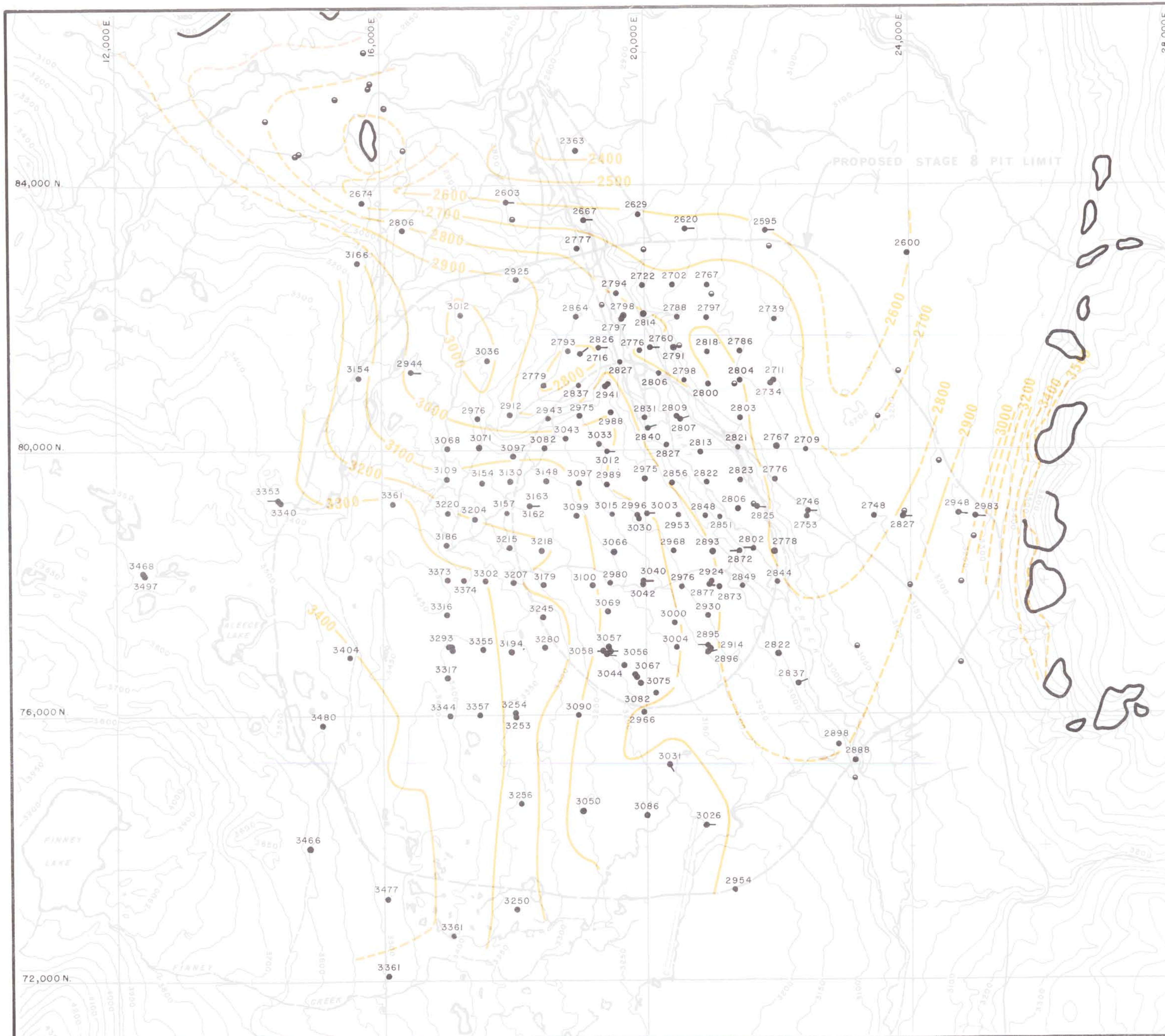
HAT CREEK GEOTECHNICAL STUDY

SITE INVESTIGATION

DRAWN I.D.T.	CHKD.	APPD.
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 6



LEGEND

- Outcrop boundary
- Contours, 100' interval, elevations in feet
- Inferred contours
- Exploration hole
- Inclined exploration hole
- Drill hole too shallow for interpretation
- 3113 Data point } elevation in feet
- 1400 Data point, inclined drill hole } elevation in feet

True North
Magnetic North 1976
23°

SCALE - FEET
2000 1000 0 1000 2000

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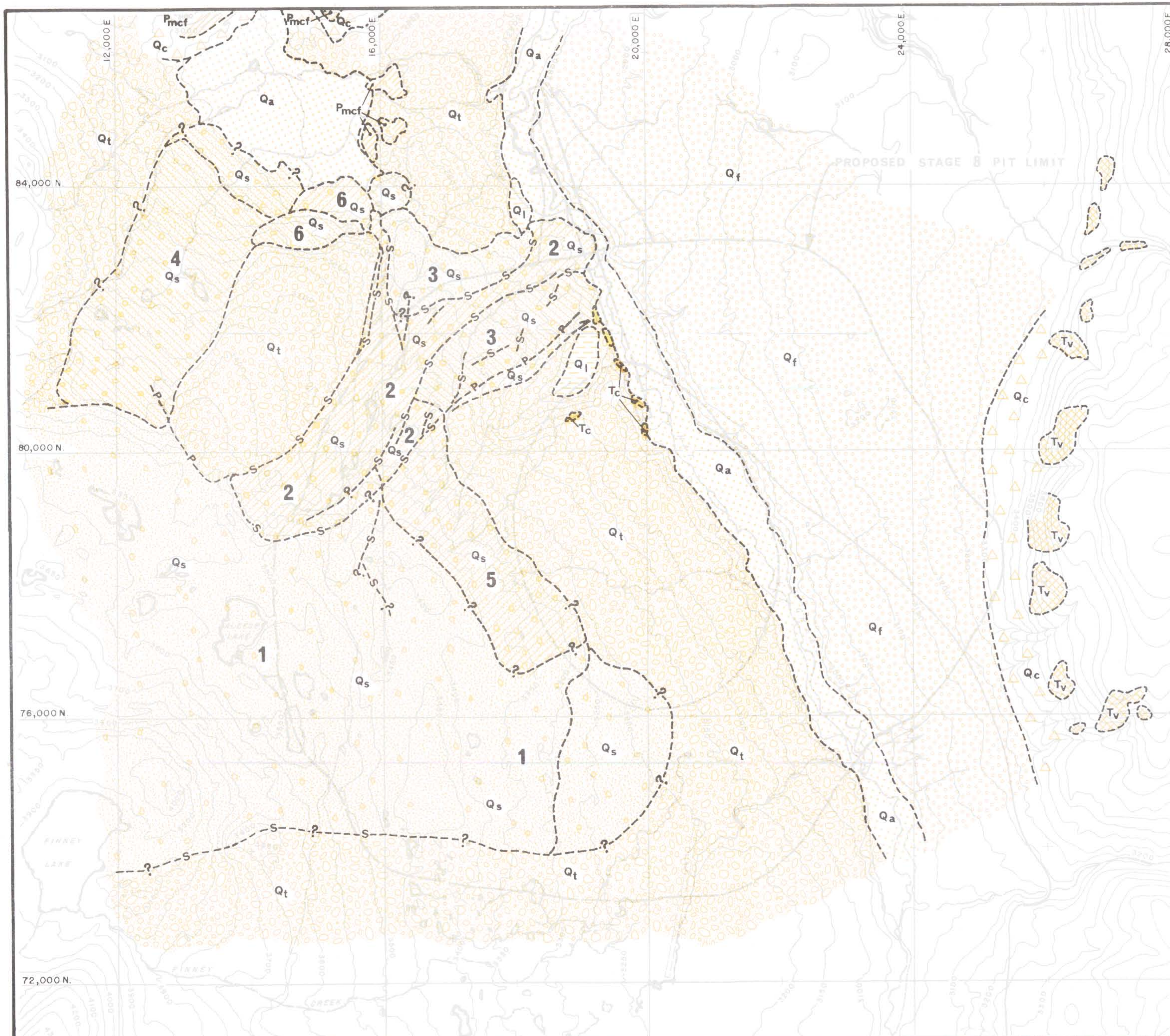
HAT CREEK GEOTECHNICAL STUDY

STRATUM CONTOURS ON THE BASE OF SURFICIALS

DRAWN C.G. & I.D.T.	CHKD.	APPD.
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 7



GEOLOGICAL SUCCESSION

Quaternary	Recent	Alluvium	Q_a
		Colluvium	Q_c
		Lacustrine deposits	Q_l
	Pleistocene – Recent	Slide Deposits: Active zone	Q_s
		Slide Deposits: Marginally active zone	Q_s
		Slide Deposits: Stable zone	Q_s
	Pleistocene	Till	Q_t
		Glacio-fluvial sands and gravels with till	Q_f
Tertiary		Kamloops Volcanics	T_v
		Coldwater Formation	T_c
Permian		Marble Canyon Formation	P_{mcf}

LEGEND

- – – – – – – Geological boundary
- – – – ? – – – Doubtful boundary
- – – – S – – – Active shear plane
- – – – P – – – Photo-lineament
- **4** Slide area (See main report, section 3.7)

SCALE - FEET

2000 1000 0 1000 2000

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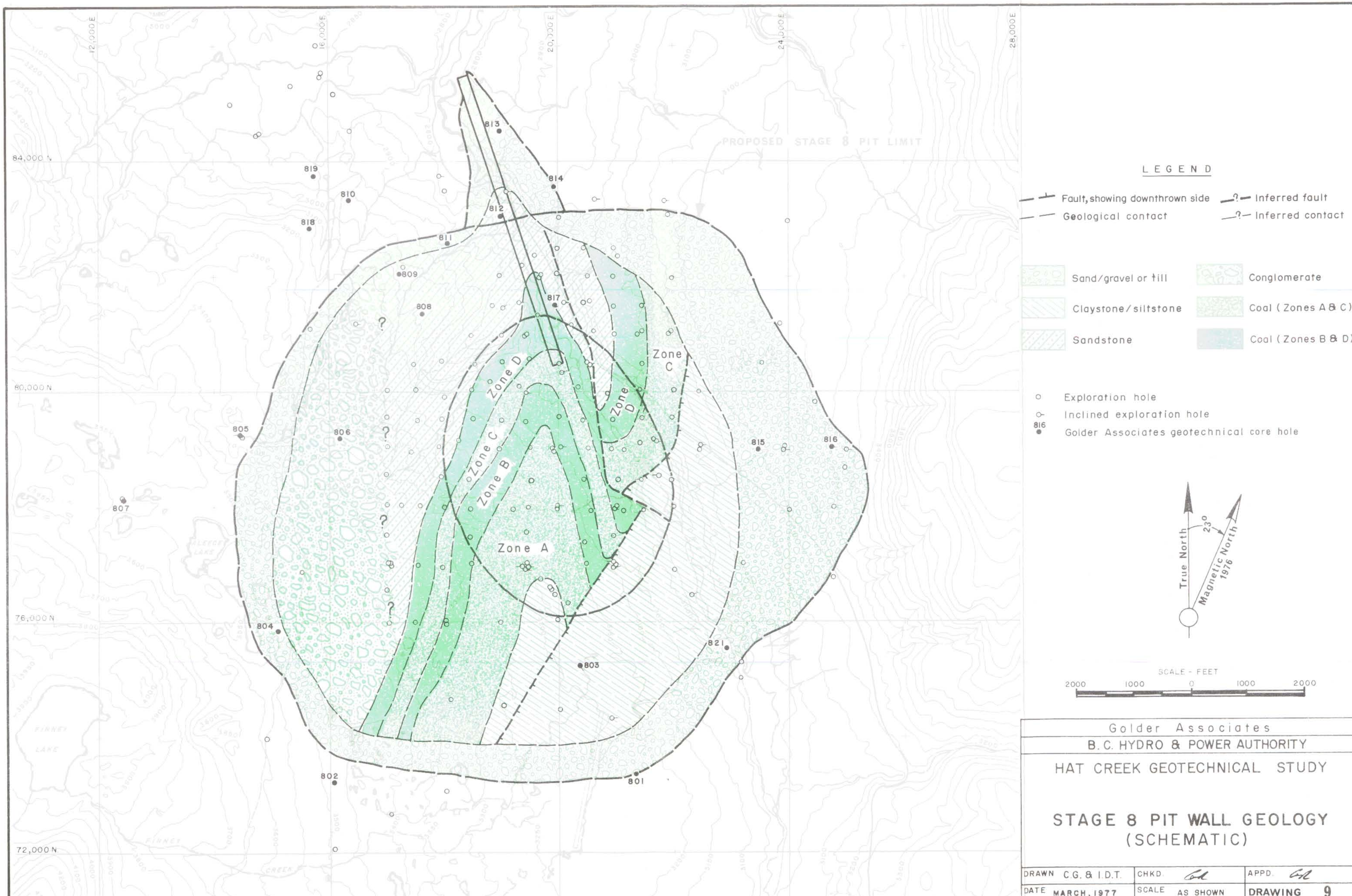
HAT CREEK GEOTECHNICAL STUDY

DISTRIBUTION OF SURFICIAL DEPOSITS

DRAWN	I.D.T.	CHKD.	[signature]	APPD.	[signature]
DATE	MARCH, 1977	SCALE	AS SHOWN	DRAWING	8



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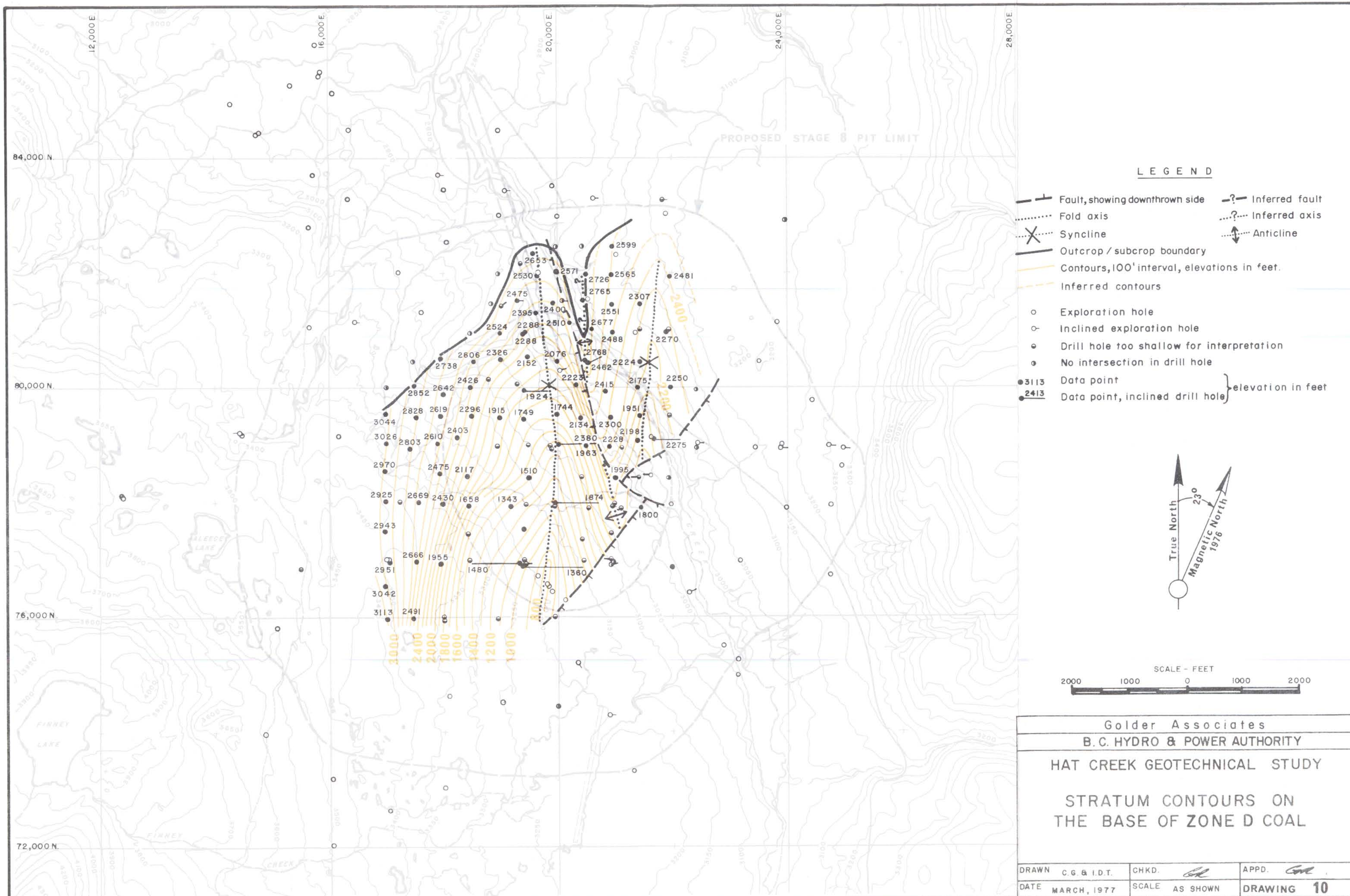
HAT CREEK GEOTECHNICAL STUDY

STAGE 8 PIT WALL GEOLOGY (SCHEMATIC)

DRAWN C.G. & I.D.T.	CHKD.	APPD.
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 9


LEGEND
Fault, showing downthrown side
Inferred fault
Fold axis
Inferred axis
Syncline
Anticline
Outcrop / subcrop boundary
Contours, 100' interval, elevations in feet.
Inferred contours
Exploration hole
Inclined exploration hole
Drill hole too shallow for interpretation
No intersection in drill hole
3113 Data point
2413 Data point, inclined drill hole
elevation in feet
True North
Magnetic North 1976
23°
SCALE - FEET
2000 1000 0 1000 2000
PROPOSED STAGE 8 PIT LIMIT
12,000 E
16,000 E
20,000 E
24,000 E
28,000 E
84,000 N.
80,000 N.
76,000 N.
72,000 N.
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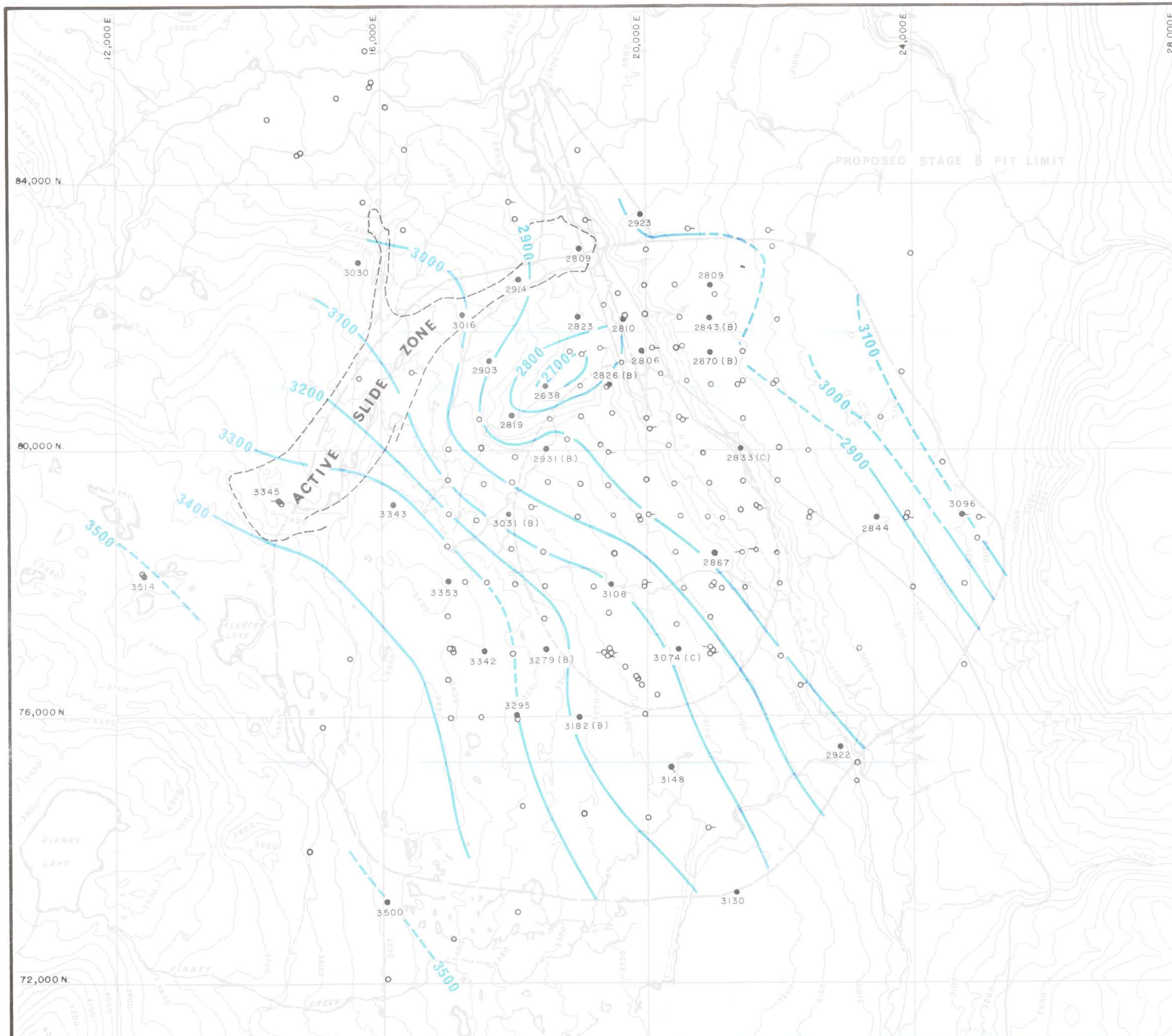
HAT CREEK GEOTECHNICAL STUDY
STRATUM CONTOURS ON THE BASE OF ZONE D COAL
DRAWN C.G. & I.D.T.
CHKD.
APPD.
DATE MARCH, 1977
SCALE AS SHOWN
DRAWING 10



True North

Magnetic North 1976

23°

LEGEND

Piezometric contours, 100ft. intervals, elevations in feet.

Inferred piezometric contours.

o Exploration hole

o- Inclined exploration hole

o3113 Data point, piezometric elevation in feet, Coldwater Formation

o3113(B) Data point, (below coal)

o3113(C) Data point, (in coal)

SCALE - FEET

2000 1000 0 1000 2000

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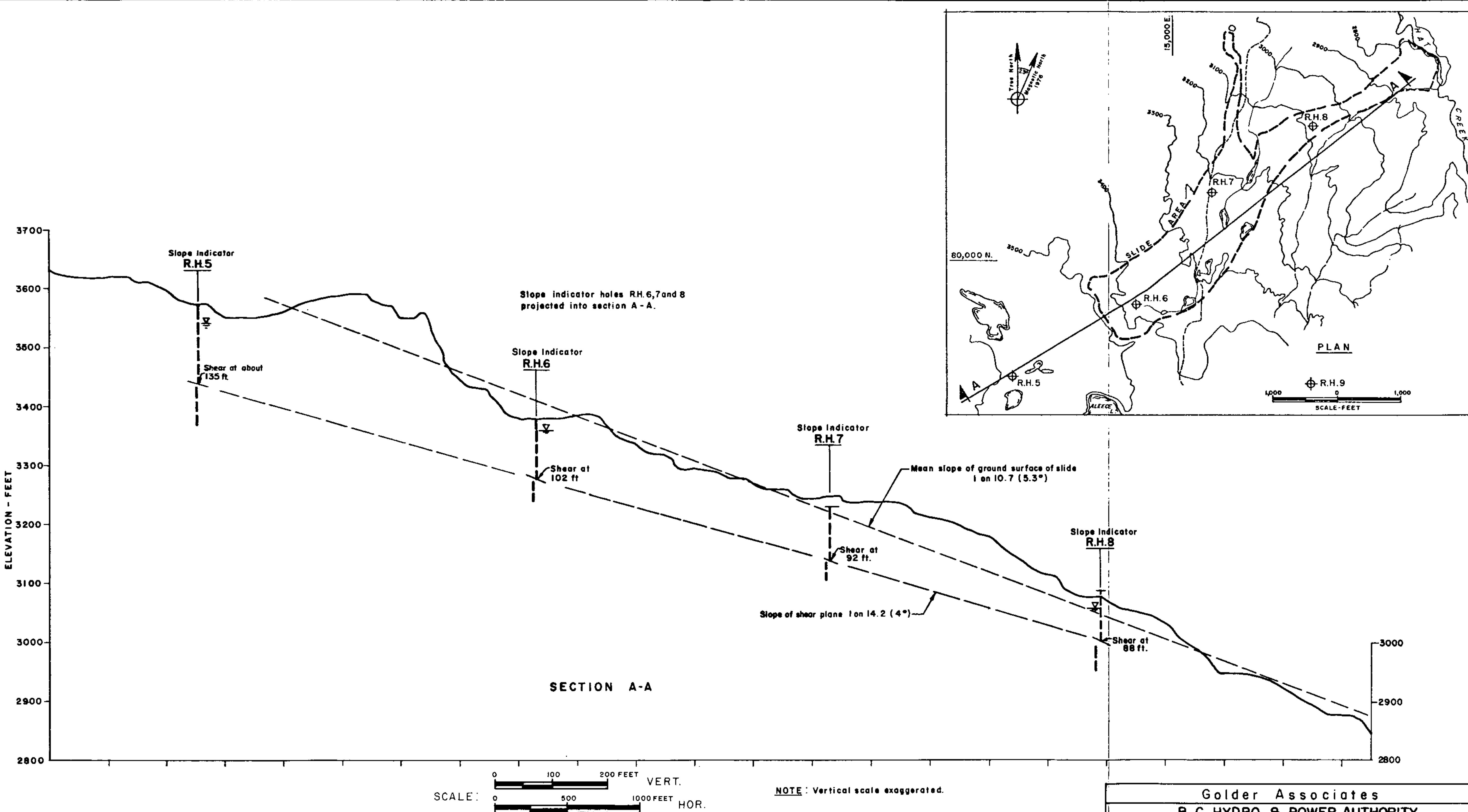
HAT CREEK GEOTECHNICAL STUDY

PIEZOMETRIC SURFACE OF COLDWATER FORMATION NOV. 1st., 1976.

DRAWN I.D.T.	CHKD. G.E.R.	APPD. G.E.R.
DATE MARCH, 1977	SCALE AS SHOWN	DRAWING 11



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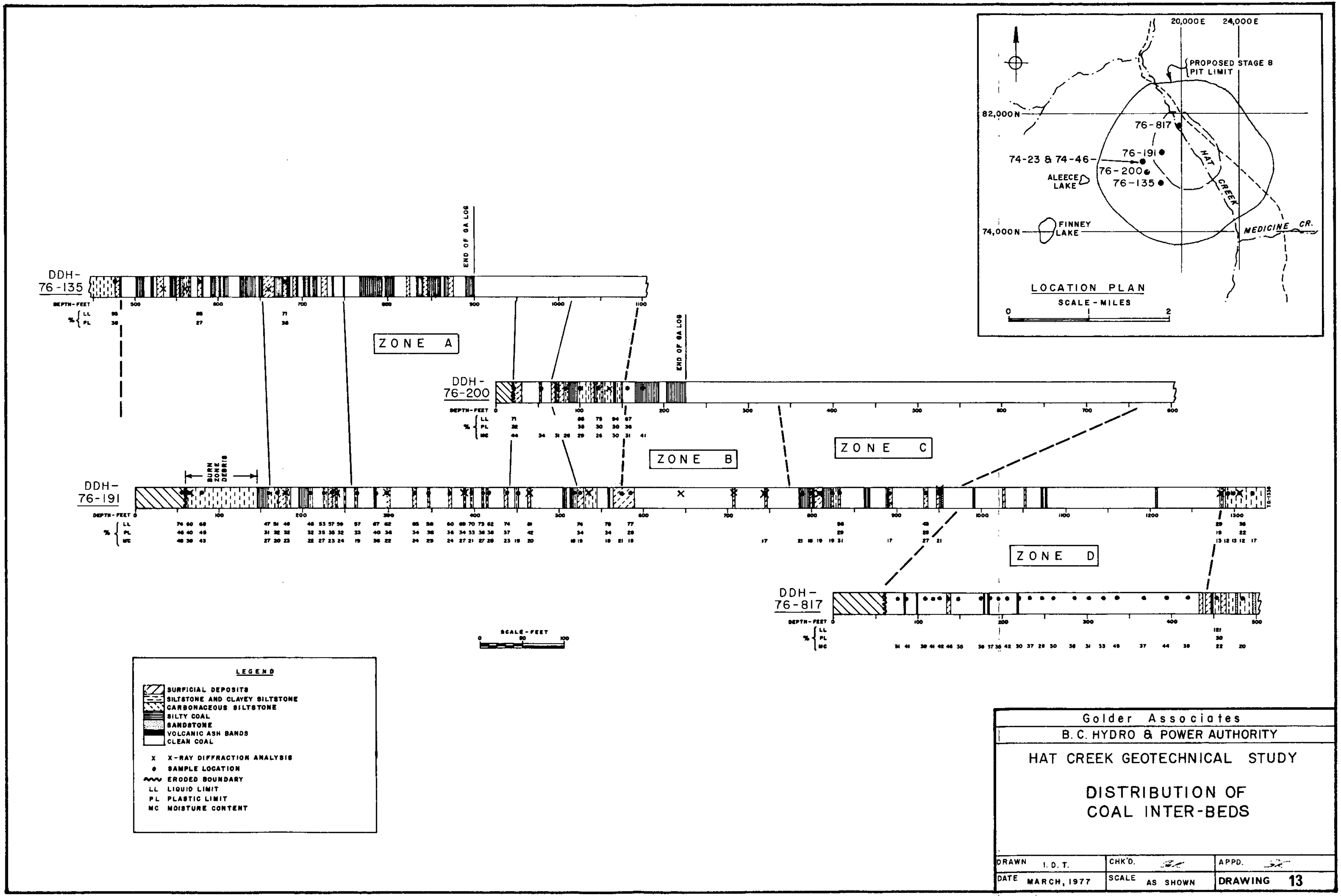
HAT CREEK GEOTECHNICAL STUDY

ACTIVE SLIDE
PROFILE

DRAWN IDT	CHKD.	APPD.
DATE MAR. 1977	SCALE AS SHOWN	DRAWING 12



20,000 E
24,000 E
PROPOSED STAGE 8 PIT LIMIT
82,000 N
74,000 N
76-817
76-191
74-23 & 74-46
76-200
76-135
ALEECE LAKE
FINNEY LAKE
HAT CREEK
MEDICINE CR.
LOCATION PLAN
SCALE - MILES
0
2
DDH-76-135
DDH-76-200
DDH-76-191
DDH-76-817
END OF GA LOG
BURN ZONE DEBRIS
ZONE A
ZONE B
ZONE C
ZONE D
DEPTH - FEET
LL
PL
MC
SCALE - FEET
0
50
100
LEGEND
SURFICIAL DEPOSITS
SILTSTONE AND CLAYEY SILTSTONE
CARBONACEOUS SILTSTONE
SILTY COAL
SANDSTONE
VOLCANIC ASH BANDS
CLEAN COAL
X X-RAY DIFFRACTION ANALYSIS
• SAMPLE LOCATION
ERODED BOUNDARY
LL LIQUID LIMIT
PL PLASTIC LIMIT
MC MOISTURE CONTENT
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HAT CREEK GEOTECHNICAL STUDY
DISTRIBUTION OF COAL INTER-BEDS
DRAWN I. D. T.
CHK'D.
APPD.
DATE MARCH, 1977
SCALE AS SHOWN
DRAWING 13