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Preliminary Lithologic, Geotechnical, and Geophysical Data from Drill Hole CW-81-2, Chuitna West Coal Field, Cook Inlet Region, Alaska

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

Prepared in cooperation with the Alaska Department of Natural Resources, Division of Geologic and Geophysical Surveys.

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[In pocket]

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INTRODUCTION

The drilling and logging activity described in this report was undertaken in July 1981, as part of the Energy Lands program of the U.S. Geological Survey. The general objectives of the project of which this work is a part are to provide an understanding of the nature, location, and extent of the engineering geology and environmental geology concerns in areas of potential coal development in the Cook Inlet region, Alaska. The lithologic, geotechnical, and geophysical data presented in this report include some of the data needed to evaluate geologic hazards, and to predict the response of geologic materials to large-scale coal mining and related development in the Chuitna West coal field of the Beluga coal resource area. Specifically, the information may be used in evaluation of natural- and cut-slope stability, spoil-pile stability, ground response to seismic activity, blasting effects, excavatability, ground-water conditions, and erosion potential.

The drill site (fig. 1, point C), located on the edge of a small, gently sloping basin draining northwestward into the Chuitna River, is approximately 90 km, (55 mi) west of Anchorage, Alaska, and 29 km (18 mi) northwest of Tyonek, a native village on the northwest side of Cook Inlet.

The drilling and core sampling involved strata of the Tyonek Formation of lower Oligocene to middle Miocene age (Wolfe and others, 1966; Wolfe and Tanai, 1980), and overlying surficial deposits of Quaternary age. A generalized log showing lithologies found in the drill hole is presented in figure 2. Barnes (1966) described and mapped the regional geology and coal resources of the Beluga-Yentna region, which includes the Capps and Chuitna West coal fields. Preliminary geotechnical data from two drill holes in the Capps coal field have been compiled by Chleborad and others, (1980; 1982). Brief descriptions of environmental geologic concerns in this vicinity have been presented by Schmoll and others (1981) and Schmoll, Gardner, and Yehle (1981). From outcrops along the Chuitna River, in the Chuitna West area, Barnes (1966) identified one principal coal bed, the Chuitna, and several minor coal beds in the vicinity of the drill site. At present, stratigraphic correlation of the three principal coal beds in drill hole CW-81-2 has not been made with the beds identified by Barnes. Instead, the coal beds in the drill hole are referred to as the upper bed, the middle sequence, and the lower bed, based on their relative positions.

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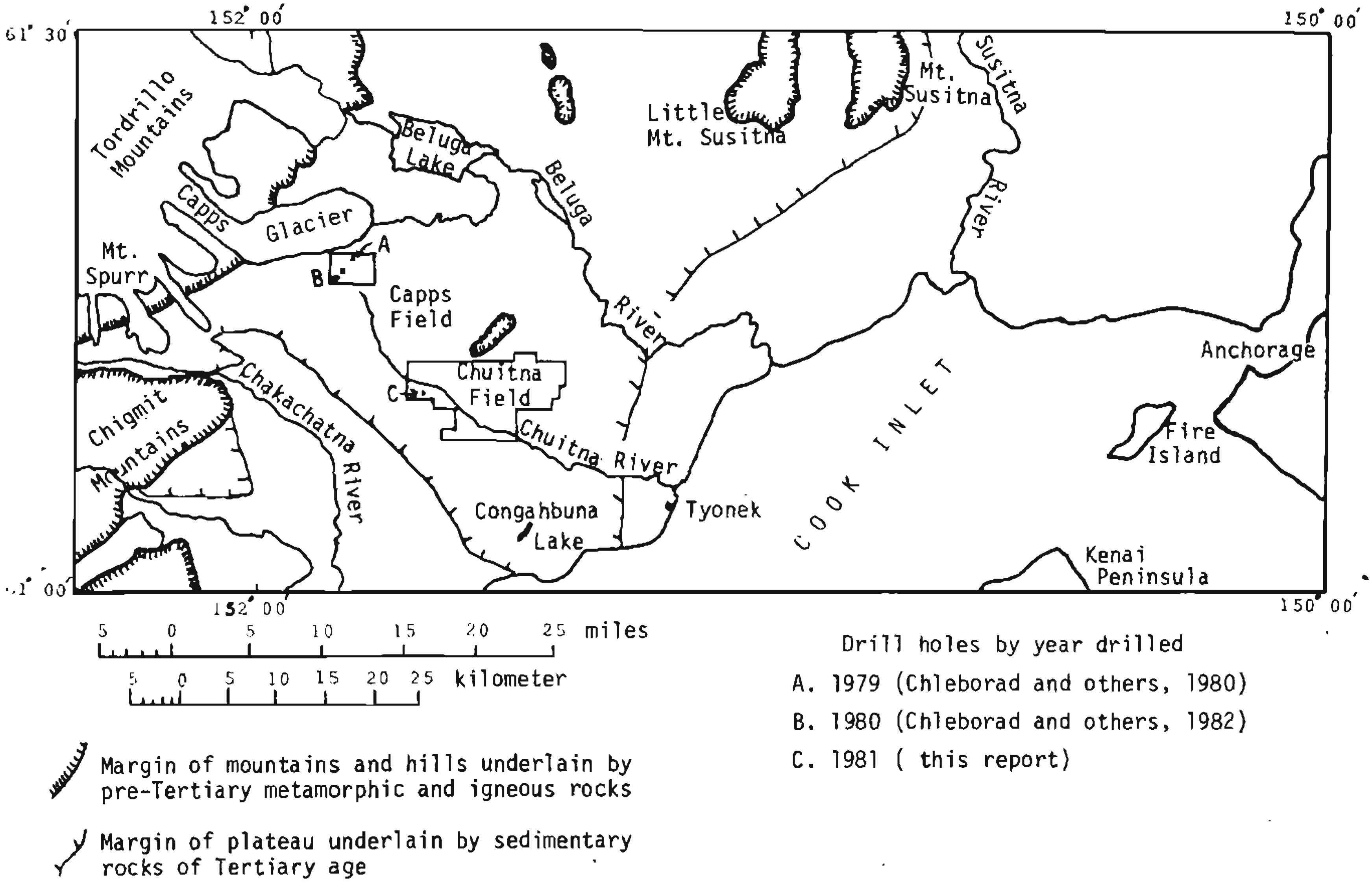

Figure 1. Index map showing some of the major Beluga coal fields and vicinity.

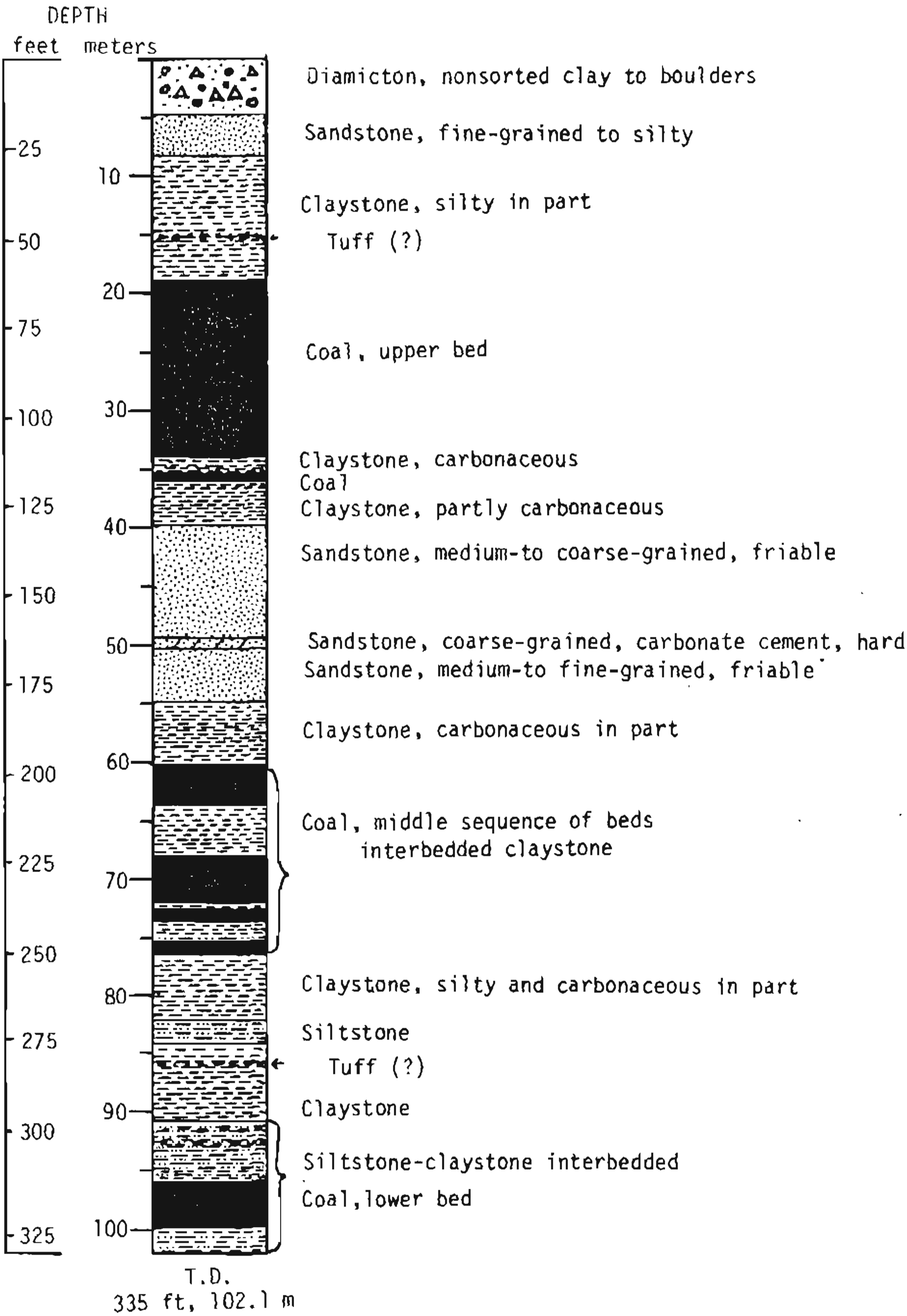

Figure 2. Generalized lithologic column showing stratigraphy in drill hole USGS CW-81-2, Chuitna West coal field, Cook Inlet region, Alaska.

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DRILLING AND RELATED OPERATIONS

The objective of the drilling program was to obtain continuous core of geologic materials suitable for lithologic studies, physical property tests and strength determinations.

The inaccessibility of the drilling location necessitated the use of tracked vehicles and fixed-wing aircraft to transport equipment, personnel, and supplies. A track-mounted Acker MB III coring drill was contracted for this study. Drilling commenced on July 21, 1981, using an HQ rotary-wireline core system (6.4-cm- (2.5-in.-) diameter core size), a conventional diamond bit, and unmuddied water. Drill hole CW-81-1 (NE1/4 SW1/4 sec. 33, T. 13 N., R. 13 W.) was cored and then cased to 7.3 m (24 ft). To that depth weakly consolidated materials were found and core recovery was poor. With further coring some highly fractured coal was encountered at 11.1 m (36 ft) and core recovery continued to be poor. Because small coal fragments continually became lodged between the drill stem and the sampling split barrel, causing malfunction of the wireline system, the hole was abandoned at a depth of 13.4 m (44 ft).

The drill was then moved to another site, approximately 244 m (800 ft) downslope to the northwest, and on July 24, 1981, drilling of hole CW-81-2 (SE1/4 NW1/4 sec. 33, T. 13 N., R. 13 W.) began. The hole was cored and then cased to 7.6 m (25 ft). Artesian water flowing at a rate of 15-19 L/min (4-5 gal/min) was observed on the morning of July 27, 1981. It was thought that the flow originated at the base of the upper coal bed at a depth of 36 m (118 ft). Quik-gel bentonite mud had to be added to the drilling water at a depth of 47.3 m (155 ft) because of poor core recovery and caving of sand. After passing through the zone of caving sand, some of which was recovered, there was good core recovery for the remainder of the hole. Drilling ceased on August 1, 1981, after penetrating a short distance below the lower coal bed.

Geophysical measurements were conducted in the hole immediately after the completion of the drilling and continued on the following day. Measurements indicate that a total of 3.7 m (12 ft) of caved material accumulated in the bottom of the hole by the time logging was completed.

Field Geotechnical Logging Operation

The retrieval, logging, testing, and packaging of the core were accomplished in three steps.

First, the core in the split-tube sampler was transferred at the drill rig to the logging team. Drilling information was recorded, including time of recovery, depth of the cored interval, nature of the drilling fluid, and hydrologic conditions. The core was photographed on color film using both an instantaneous-development camera and a 35-mm single-lens reflex camera. Included in each photograph was a card identifying the core tube number and the depth of the core in meters and feet, and an appropriate page from a rock color chart (Goddard and others, 1948).

Second, information regarding lithology, discontinuities, color, laminations, hardness, and degree of weathering was recorded. Strength index and moisture content tests were performed on selected samples to provide a base of field data to compare with subsequent laboratory tests. To test samples having unconfined compressive strengths of less than 0.5 MPa (72.5 lbf/in^2) a pocket-penetrometer strength tester (Soiltest, Inc., 1978) was used. For material of greater strength the point-load test of Brock and Franklin (1972) was used. The presence of carbonate was determined by application of dilute hydrochloric acid to small areas of the core at selected intervals. The lithology and geotechnical properties determined in the field are given in the geotechnical log (pl. 1, in pocket).

Third, untested core was wrapped in cheesecloth, labeled, coated with polycrystalline wax, and placed in boxes with split styrene inserts to protect the core and to minimize disturbance during transport to U.S. Geological Survey laboratories in Colorado. To avoid contamination, coal samples were not waxed; instead they were sealed in plastic sleeves. Only a limited number of tests were performed in the field because most of the sample was needed for additional tests to be conducted in the laboratory, including grain-size distributions, Atterberg limits, bulk densities, clay mineralogy, slake durability, unconfined compressive strength, geochemistry, and coal quality analysis.

GEOTECHNICAL PROPERTIES

Lithology

Geologic materials observed consist of five principal types. In order of abundance these are: claystone, coal, sandstone, siltstone, and diamicton.

Claystone, including carbonaceous claystone, makes up approximately 40 percent of the core. The thickest homogeneous unit of claystone exists between a 7.6- and 18.8-m (24.9- and 61.7-ft) depth, which is above the upper coal bed. Between the upper coal bed and the middle sequence of coal beds, there occurs a 3- to 5-m- (9.8- to 16.4-ft-) thick sequence of claystone which becomes more carbonaceous at depth as it grades into the coal. An alternating sequence of claystone and siltstone exists between the middle sequence and the lower coal. Silty claystone occurs beneath the lower coal.

Coal, thought to be lignitic to subbituminous, makes up approximately 29 percent of the material cored and is the second most abundant lithology found in the drill hole. Three coal zones were identified from the core: (1) the upper coal, a massive highly fractured bed, 15.5 m (50.0 ft) thick, (2) a middle coal sequence consisting of six seams from 0.5 to 1.8 m (1.5 to 5.8 ft) in thickness interbedded with claystone beds, and (3) the lower bed, 4 m (12.5 ft) in thickness. The letters M, O, and Q have been assigned, respectively, to the above three beds by local workers (B. J. G. Patsch, written commun., 1981). Only a few minor claystone partings were observed in the upper and lower coal beds.

Sandstone comprises approximately 19 percent of the total core. It ranges in texture from very fine to very coarse grained and from silty to well sorted. Except for interbedded lenses less than 0.5 m (1.6 ft) thick, most of the sandstone is contained in two thick units. The uppermost unit, from 4.9 to 7.2 m (16.1 to 23.6 ft) in depth, is very fine grained and in places silty. The lower unit, from 40.1 to 55.5 m (131.6 to 182.0 ft) in depth, ranges in grain size from fine sand to pea gravel and is very friable. The lower unit had poor core recovery because of its highly friable nature. However, within this lower unit a 1-m (3.3-ft) interval of very hard, carbonate cemented, coarse-grained sandstone was found from 50.0 to 51.1 m (164.0 to 167.5 ft). Lithologic characteristics above and below this cemented zone appear to be the same. Extensive caving, confirmed by the caliper log, took place above and below the carbonate cemented zone.

Siltstone makes up approximately 7 percent of the cored material and occurs primarily in units 0.5-1.5 m (1.6-4.9 ft) thick. These units are interbedded with claystone, and primarily lie beneath the middle coal sequence. The siltstone is fairly clayey and commonly grades vertically into claystone units. Less commonly the siltstone contains scattered, fine-grained sandstone stringers.

Diamicton, which represents about 5 percent of the cored material, is presumably of glacial origin. It extends from beneath the surface organic mat and volcanic ash layers to a depth of 4.9 m (16.1 ft). The diamicton is poorly sorted and particles range in size from clay to boulders.

Discontinuities

The types of discontinuities identified in drill hole CW-81-2 were high-angle to vertical joints and noncylindrical fractures. Dips between 25° and 30° were measured along bedding planes throughout the core. However, evidence of discontinuities and movement along the bedding planes themselves was not found. Those discontinuities observed immediately after core recovery are plotted on plate 1 (in pocket) using a system modified from Rankilor (1974). The letter "B" under the joints column identifies the core as being highly broken in noncylindrical pieces. These broken zones contain both natural and induced fractures and in some cases, it is difficult to distinguish between the two. Noncylindrical fracturing occurred in all coal beds in drill hole CW-81-2 as well as the upper coal bed in the abandoned hole. Coal recovered from previous drill holes was much more competent.

High-angle to near-vertical fractures were found predominantly in the coal beds, but a few were observed in the other lithologies. Most fractures appeared to be fresh with no clear evidence of secondary mineralization. The freshness of the fractures in the coal suggests that its highly fractured nature may result from expansion of the core after it was removed from the confinement of the in situ stresses. A few slickensides were observed in the clay-rich lithologies, suggesting the possibility that some minor faulting may have occurred.

Strength Properties

Strength indices were determined in the field by pocket penetrometer or by point-load. Compressive tests were conducted in the naturally humid environment of the field area usually within a half hour of core extraction. Thus samples are believed to have been at or near natural moisture contents at the time of testing. Materials with strength values beyond the limit of the pocket penetrometer (0.5 MPa, 72.5 lbf/in^2) were tested using the point-load method developed by Broch and Franklin (1972). It should be noted here that the pocket penetrometer values are correlative to the approximate uniaxial compressive-strength values, $I_s(50)$x24, derived from the point-load tests and not to the strength index, $I_s(50)$. The method describes testing the core sampled both axially (load applied parallel to the bedding plane) and diametrically (load applied perpendicular to the bedding plane). Test results are "corrected" to a reference diameter ($I_s(50)$) of 50 mm (1.97 in.) and the approximate unconfined compressive strength was calculated by multiplying the reference-diameter ($I_s(50)$) value by an empirically determined coefficient of 24. The method described above was developed for essentially horizontal strata. However, bedding planes in the drill hole dip 25°-30°, thus it was difficult to apply the load as stated in the testing procedures. Therefore, load was generally applied parallel and perpendicular to the long axis of the core. Test results obtained were compared to results obtained on similar lithologies, from previous test holes, in the Tyonek Formation, where the dip was 3°-5° (Chleborad and others, 1980; 1982). The comparison showed little difference in calculated strengths, therefore, the authors believe the results obtained this year are probably valid as indices.

Approximate uniaxial compressive strength indices ranged from 0.72 to 6.92 MPa (104 to 1004 lbf/in^2) for the diametral tests and 0.72-7.70 MPa (104-1117 lbf/in^2) for the axial tests. Pocket penetrometer values are not presented in the strength analysis. Mean approximate uniaxial strength indices determined from diametral tests were:

Siltstone-------------------	5.83 MPa	(846 lbf/in^2)
Carbonaceous claystone------	4.03 MPa	(585 lbf/in^2)
Claystone-------------------	3.18 MPa	(461 lbf/in^2)
Sandstone-------------------	2.76 MPa	(400 lbf/in^2)

There were too few axial samples tested to derive valid mean values. Strength values for the claystone beneath the middle coal sequence appear slightly greater than values for the claystones above the sequence, perhaps due to the greater overburden stress. Not included in the above range of strength values are values for the carbonate cemented sandstone unit, as its strength exceeded the limits of the field testing equipment, 55 MPa (8000 lbf/in^2). The two units of unconsolidated friable sandstone that comprise the major zones of no recovery are also not represented as these units essentially had no intact strength once removed from their surroundings.

The approximate unconfined-compressive-strength values of the core derived from the point-load tests, ranged from about 0.8 to 8.0 MPa (116 to 1160 lbf/in^2). These values are compared to a relative scale of rock and soil hardness devised by Jennings and Robertson (1969) and shown in figure 3. The scale classifies the tested materials as ranging from stiff soil to very stiff soil or soft rock. The prevalence of low-strength values indicates that the material can be easily excavated. However it also indicates a potential for erosion and cut-slope stability problems if not adequately evaluated in development plans.

Moisture Content

Moisture content samples were taken at intervals of approximately 0.5 m (1.6 ft) or at changes in lithology. Samples between 10-20 g were weighed, dried for about 4 hours in an oven at 105°C (221°F) then weighed again to determine the moisture content in percent dry weight. Mean and median moisture-content values in percent dry weight for the various lithologies are listed below:

	Percent	
Lithology	Mean	Median
Claystone-------------------	15.5	14.9
Carbonaceous claystone------	16.9	16.1
Siltstone-------------------	17.7	18.8
Sandstone-------------------	18.0	18.5

Due to the large number of carbonaceous claystone and claystone samples, the median values probably reflect the moisture content of these units more accurately, whereas the moisture content for the sandstone and siltstone unit are probably best represented by the mean values because fewer samples were tested. Several coal samples were tested and yielded moisture contents of approximately 30 percent each.

GEOPHYSICAL LOGGING WITH HYDROLOGIC INTERPRETATIONS

A suite of seven geophysical logs was run soon after coring reached the final depth of 102.1 m (335.0 ft). These logs included continuous recordings of neutron porosity, gamma-gamma density, natural gamma, single point resistance, spontaneous potential (SP), fluid temperature, and hole diameter. The geophysical logs are reproduced as a refined composited version on plate 2 (in pocket). A Well Reconnaissance Geologger was used to obtain the logs as was done for similar work in 1979 and 1980 (Chleborad and others 1980; 1982). Instrument settings identical to those used in the 1980 logging were used whenever possible.

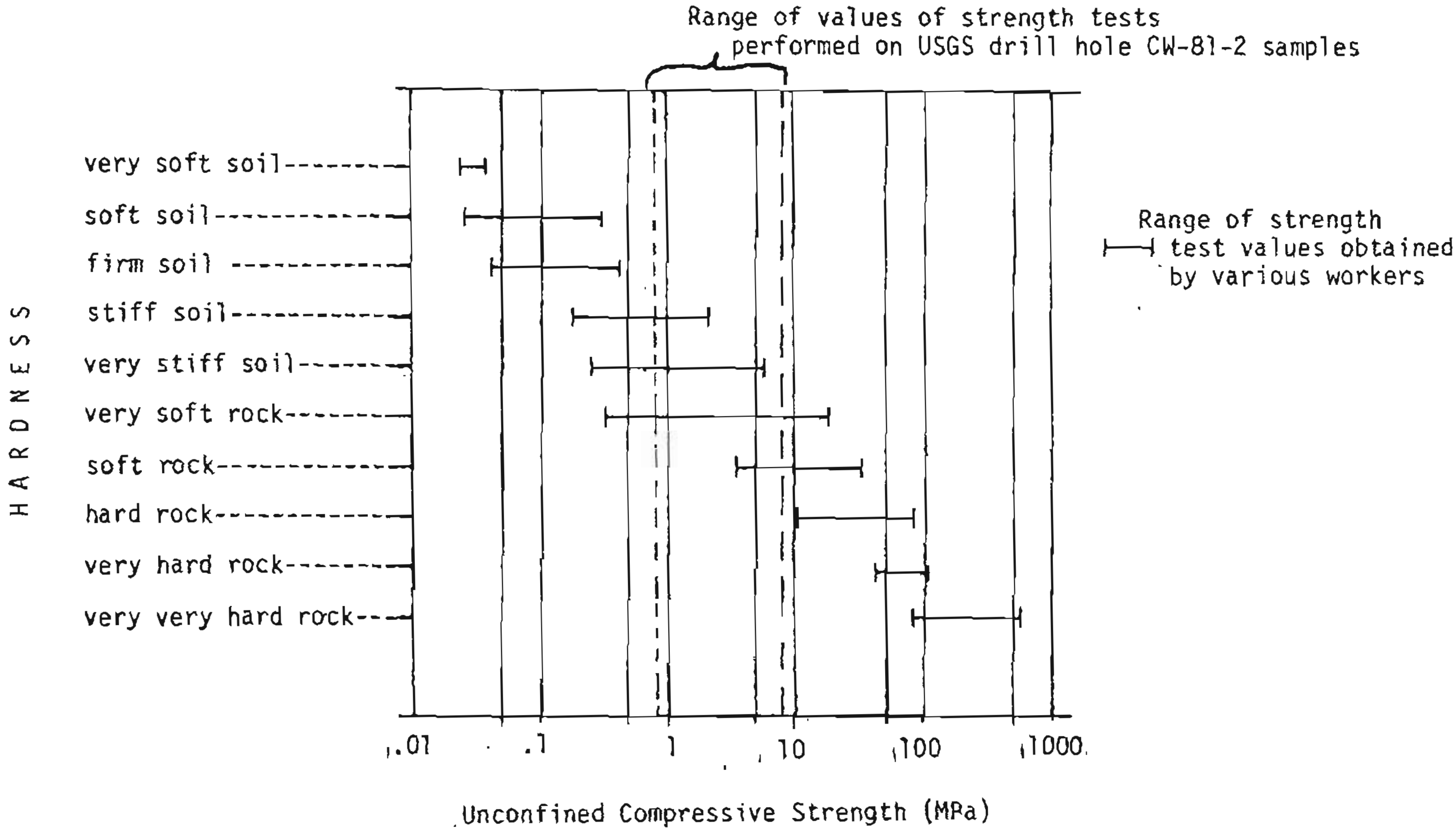

Figure 3. Relationship between qualitative hardness terms and unconfined compressive strength (Jennings and Robertson, 1969).

All geophysical logs were run under flowing artesian conditions of (15-19 L/min (4-5 gal/min)) and the only casing in the hole was an 11-cm (3.6-in.) inside-diameter steel casing that extended to 7.6 m (25 ft) below ground surface. The initial depth of geophysical logging, 98.5 m (323 ft), was about 2 m (6.9 ft) less than the final depth of drilling due to accumulations of caved material. The hole continued to fill slowly with debris from the walls during geophysical logging. All logs were made at an uphole speed of 3 m/min (10 ft/min), except for the temperature log which was run at a downhole speed of 1.8 m/min (6 ft/min). Temperature logging followed all other logging by about 12 hours, during which time the natural artesian flow of the hole was undisturbed.

The composite of smoothed geophysical logs on plate 2 shows generally excellent correlation between lithologic units identified through detailed examination of the core and the radiation and electric logs. The caliper log proved to be a good diagnostic tool for identifying beds having high or low competence. Although the high-resolution temperature log is difficult to interpret with respect to lithology, it reflects hydrologic conditions better than the other logs of this hole.

Two conspicious lithologic units are evident on the log suite: a very competent, dense, low porosity, carbonate cemented sandstone bed from 50.0 to 51.1 m (164.0 to 167.5 ft); and a hard tuffaceous(?) bed from 85.9 to 86.1 m (282.0 to 282.4 ft).

The dense nature of the carbonate cemented bed was strongly reflected on all logs except the SP and temperature logs. The fact that this bed withstood significant hole caving, both above and below itself as shown by the caliper log, is evidence of its competence. Although cemented sandstones are not commonly thought of as aquicludes (confining beds), this bed, if it has much lateral continuity, may severely restrict vertical ground-water movement.

The tuffaceous(?) bed caused significant responses on three logs as follows: (1) a low natural-gamma spike, (2) a high electrical-resistance spike, and (3) a high density gamma-gamma. The lack of diagnostic character on the neutron log is probably due to the relatively large sphere of radiation influence with respect to the thinness of the bed, whereas the smaller sphere of influence of the other radiation logs allowed detection of this bed. If the tuffaceous(?) bed was a meter or more thick, deflections on the radiation logs presumably would be more pronounced. Because of these distinctive responses, this bed could serve as a marker horizon recognizable on geophysical logs in other holes in the area.

The two thickest intervals for which no core was recovered, 43.1-50.0 m (141.5-164.0 ft) and 51.1-55.5 m (167.5-182.0 ft), have a similarity in geophysical log responses which suggests that they are very similar in composition. These responses strongly suggest that these two intervals are composed of moderately well sorted, friable sandstone of a uniform character. The caliper log clearly shows that the material is highly susceptible to caving. It seems logical to conclude that the porosity, and probably the permeability, of these beds is substantially greater than that of the recovered calcareous sandstone bed at 50 m (164.1 ft).

Above the two thick nonrecovery intervals are two thinner nonrecovery intervals between 38.4 and 42.7 m (126 and 140 ft). It is particularly interesting that the two thinner nonrecovery intervals have different log responses from the thicker zones below. In these upper thin intervals the logs deflect in directions that imply greater silt and (or) clay content and generally shows more resistance to caving than do the thicker intervals below.

The drill-hole-fluid temperature log is the most valuable log of the suite for interpretation of the ground-water system. Ground water moving through porous or fractured rocks within 100 m (328.0 ft) or so of the surface may be expected to keep those beds which serve as aquifers cooler than other beds behaving as aquicludes. This phenomenon occurs because in general the temperature of recharge water, which is believed to enter the system from the surface, remains cooler than that of subsurface materials that are not subjected to ground-water circulation but instead are warmed by normal geothermal heat from below. Therefore, the interface between relatively permeable and relatively nonpermeable beds is commonly a zone of significant temperature change. This change takes the form of an increase of temperature as the probe's sensor is lowered past the bottom of a water-yielding bed, and is a consequence of the above-mentioned effect of permeability contrast and of uphole artesian flow. The magnitude of deflection on the temperature log is commonly directly proportional to the volume of water entering the hole at that point and its temperature contrast directly proportional to the amount of upflowing water it joins.

The temperature log shows three depths where temperatures in the drill hole rise significantly. A 0.4°C (1.3°F) increase occurs within the top half of the upper coal bed at approximately 19.8 m (65 ft), a similar though more abrupt rise shows within the same coal bed at about 26 m (85.3 ft) and a rise of 1.3°C (4.3°F) occurs at 73.6 m (241.5 ft), at the bottom of the middle coal sequence. In accordance with the explanation given above, ground water is presumed to be entering the drill hole at these depths where the temperature gradient is steep. Narrow cold troughs of temperature change occur on the log at 26 m (85.3 ft) and 73.6 m (242.8 ft). It is thought that water inflow is considerably greater from those parts of the coals opposite these troughs than elsewhere. It follows, then, that since the volumetric rate of water moving upward in the hole increases as each successive inflow interval contributes water, a smaller temperature log deflection opposite the topmost coal does not necessarily signify that less ground water is entering the hole there than elsewhere.

In summary, the suite of geophysical logs from drill hole CW-81-2 shows good correlation with the lithologic description of the core, and strongly reflects the presence of the carbonate cemented sandstone bed and tuffaceous(?) bed. The latter unit may be a potential marker horizon on other geophysical logs in the area. The geophysical logs indicate that the major nonrecovery zone is comprised of clean, friable sandstone of uniform character and suggests lithologic differences between it and other no recovery zones. Although interpretation of ground-water movement from these logs is complicated by flowing artesian conditions, the temperature log in particular indicates that parts of some coal beds are conducting ground water. The logs further suggest that ground-water flow is significant only in several thin zones. Some siltstone and claystone beds and one thin cemented sandstone bed exhibit relatively high density and low saturated porosity, and appear to act as the major confining beds for pressuring the ground-water system.

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