FOUNDATION SOIL CHARACTERIZATION FOR THE DALTON HIGHWAY

This report serves to gather together all known test hole information for foundation soils on the Dalton Highway. In addition, it analyzes this data by statistical methods and characterizes foundation soils to be expected all along the route. It identifies thermal state and frost classification for the soil types, and calculates thaw strain and settlement potential due to permafrost degradation.

This report shows that nearly all of the foundation soils along the route are in permafrost zones, most of it ice rich, with a potentially high settlement if thawed. Only a few short sections of river bottom and the hill top alignment at miles 95-100 and 105-112 lack permafrost or have any extent of non-frost susceptible soils.

Data from this report could be applied toward answering questions on paving of the Dalton Highway. The cold continuous permafrost of the Arctic Foothills and Arctic Coastal Plain Subprovinces should allow paving with no subsequent degradation of the permafrost foundation soils provided the thickness of gravel embankment is sufficient to prevent thawing below the existing permafrost surface. The remainder of the route to the south will require careful analysis and possible strengthening or replacement of foundation soils. Sections of the road having weak base and subbase layers would need rebuilding to obtain thick enough layers of free draining non-frost susceptible material under a pavement. In all cases, route alignment and grades should be improved where needed before any paving is done.

This Dalton Highway materials investigation will be implemented by a seminar with R&M presenting soils characterization methods to DOT&PF personnel and highway design consultants. That will allow its use in design of new road alignments and performance predictions for the Dalton Highway.

The cover photo shows massive ice along the Dalton Highway.

Al Brawner
Research Engineer
Department of Transportation
and Public Facilities
Research Section

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

FINAL REPORT

BY

C.L. Vita, J.W. Rooney, C.H. Riddle
and L.J. Acomb

R&M CONSULTANTS, INC.
5024 Cordova Street
Anchorage, Alaska 99503

September 1984
for
STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
Division of Planning and Programming
Research Section
2301 Peger Road
Fairbanks, Alaska 99701

DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

TABLE OF CONTENTS

APPENDICIES

LIST OF FIGURES

LIST OF TABLES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

1.0 INTRODUCTION

In this report we present the results of our geotechnical characterization of natural foundation soils along the Dalton Highway from Livengood to Prudhoe Bay. The scope of this work was identified in the R&M letter proposal of May 15, 1984 to Mr. David Esch, ADOT/PF under DOT/PF Research Term Agreement 82IP342.

The purpose of the route geotechnical characterization is to help provide DOT/PF a basis for assessing potential foundation soil conditions. Particular emphasis has been given to assessment of foundation soil thaw settlement performance of the Dalton Highway and provision of a means for prioritizing anticipated field studies on planned upgrading of the highway system and for programming possible maintenance requirements related to thaw settlement. The general scope of our effort to fulfill this study purpose is:

(1) At a horizontal scale of 1:63,360, identify and map landform profiles/terrain units along the route centerline foundation soils (from the bottom of the road embankment to a depth of 10 feet north of Atigun Pass and 15 feet south of the Pass); and,

(2) Characterize the landforms in the profiles for:

- Landform Genetic Type
- Landform Depths (to 10 feet or 15 feet)
- Thermal State (frozen or not frozen)
- Soil Type (soil texture - USC System)
- Frost Classification (USACE System)
- Thaw Strain Potential

Identification or characterization of the road embankment and structure is not included as part of this study. Foundation soil frost heave potential is only considered in terms of the implications/limitations of landform frost classification by the USACE system. In addition to the above, we have:

- Presented mathematical techniques for updating the characterization presented here with available, subsequent segment-specific data;

- Used practical state-of-the-art statistical techniques to account for geotechnical variability and uncertainty;

- Outlined a technically rigorous strategy for using thaw strain potentials in thermal analysis of thaw settlement and its practical application in planning and design;

- Identified certain route conditions, features and concerns that may be of interest to planning and design.

2.0 ROUTE CHARACTERIZATION METHODOLOGY

A landform-based approach is used here for route characterization. Landforms are elements of the landscape that can be correlated to varying degrees with geotechnical behavior and subsurface conditions.

Landforms are formed by a single geologic process or a combination of associated processes which have both characteristic surface features (such as topography, drainage patterns and gully morphology) and typical, recurrent ranges of geotechnical properties, including characteristic distributions of soil properties, such as density, moisture and grain sizes. Sand dunes, moraines, floodplains, alluvial fans, and glaciofluvial outwash are all examples of landforms. Each have characteristic surface forms that can be identified by field observation and airphoto or other remote sensing interpretation techniques.

The basic premise of landform-based characterization is that a practical, efficient way to use geotechnical data needed in analysis and design of a transportation system is achieved by organizing and statistically characterizing exploration data by landform and geologic region or physiographic province (Refs. 7, 9, 10, 15,22-31).

Once the landforms at a site are identified, the characteristic distributions of landform soil properties (as well as some understanding of stratigraphy, soil structure, drainage characteristics, and groundwater conditions) can be inferred. The sharper the distributions the more precisely can geotechnical properties and behavior be predicted.

Sharp distributions are associated with uniform or "homogeneous" properties and broad distributions with variable or "heterogeneous" properties. A given landform can have either homogeneous or heterogeneous properties, or both. For example, sand dunes are relatively homogeneous in most properties, and landforms composed of wind blown silts may have a homogeneous grain size distribution but heterogeneous moisture content.

Distributions of geotechnical properties are variable with landform location because of differences in climate, weathering rates and processes, and predominant bedrock type. Landform property distributions are also sample volume (site size) dependent; uniformity or homogeneity between samples or "sites" tends to increase with sample volume (site size) depending on the degree of spatial autocorrelation of the property.

Because geotechnical conditions in the arctic and subarctic are complex and highly variable, it is impractical to characterize soil conditions with certainty along an entire alignment. Therefore, geotechnical evaluations must be done with limited field data. Landform-based procedures provide a rational approach for making meaningful predictions where site-specific subsurface data are sparse or nonexistent. These procedures involve the following actions:

(1) The landforms occurring along a route are identified using terrain analysis techniques (Refs. 7, 8, 9, 10, 15, 31).

(2) All available subsurface data are statistically characterized by landform and region to give landform/region statistics of available pertinent geotechnical parameters.

(3) Site/segment-specific profiles are developed as needed for analysis and design.

In the third phase, prior information from the landform/region statistics are used to augment available site/segment-specific data to create an expanded data base from which updated landform/site data estimates of site-specific soil property parameters can be made. An updating model for making estimates of any site-specific soil property parameter is presented in Refs. 22, 24, 27 and summarized below as well as in Appendix F.

2.1 LANDFORM PROFILE MAPPING OF THE ROUTE

The first step of landform-based route characterization is to map (using terrain analysis techniques) observed and inferred landforms and associated terrain features in plan and, where possible, in profile along the route. In profile, the route centerline can be represented by a "landform profile" showing the landforms occurring from the ground surface to a limiting depth (beyond which there is generally little affect of soil or rock conditions on facility performance); in plan, "terrain units" can be used to map landform transitions and interpreted profiles along the route.

2.2 LANDFORM STATISTICAL CHARACTERIZATION

2.2.1 Geographic Scales

In general, landform data can be utilized at three (or more) geographic scales. In order of decreasing size and data availability but increasing geographic specificity, these are:

(1) for all known occurrences of a landform or landform group (of similar landforms),

(2) for all regional occurrences of a landform or landform group within a particular local geologic region, unit or physiographic province and

(3) for site-specific occurrences of the landform in the given region.

In general, landform property distributions are scale and location dependent. It is assumed that the forms of the probability density functions (PDF) or basic shapes of the property distributions are constant, whereas the statistical parameters of the PDF's generally are location and scale dependent (Refs. 22, 27). Landform property parameters that are not strongly location dependent for a given site size (volume) are "statistically homogeneous"; parameters that are relatively location dependent are "statistically heterogeneous". Statistical homogeneity implies site-to-site uniformity; conversely, statistical heterogeneity implies site-to-site variability.

The working principal for predicting landform soil properties wherever the landform occurs is to utilize all available representative data obtained for the given landform. Combining landform data from different geographic scales and locations is termed "geographical updating". Incorporating additional, new information at a given geographic scale or location is termed "information updating". Both forms of updating utilize Bayesian techniques (Refs. 22, 27).

2.2.2 Geographic Updating

Geographical updating proceeds down the level of scale in the direction of increasing site specificity. In this study, data for each landform have been:

(1) combined to form a set of landform statistics, and

(2) where appropriate, separated by geologic region to form a set of landform/regional statistics.

The landform or landform/regional statistics can be used as prior data for site-specific occurrences of the landform. This prior data can be used with site-specific sample data to calculate posterior, updated estimates of the parameters of the property distributions for each stratum comprising a segment/site soil profile.

Geographical updating can be accomplished at any scale of site-specificity, as data availability and needs warrant it; the principals of updating apply in the same way. With time, as more data becomes available, each scale can itself be informationally updated to reflect the new data.

2.3 SEGMENT-BY-SEGMENT SOIL PROFILE DEVELOPMENT

2.3.1 Soil Profile Segmenting

Soil profiles are used to idealize soil stratigraphy and associated material properties within a specific site area or segment length for engineering analysis and design purposes. A segment is defined as a reach of alignment which can be adequately characterized for a given (set or single) engineering purpose by a single soil profile.

Note that each point of a route can belong to more than one soil profile (and associated segment) where significantly different characterizations are required for the various specific analysis and design purposes--e.g., within the limits of available data, segment-by-segment soil profiles characterized for thaw stability may be different than soil profiles characterized for frost heave or erosion. The primary objective of soil profile development is to adequately represent--as simply as possible--the pertinent geological and geotechnical details that could potentially affect the conditions or structures of concern.

Segment-specific soil profile development starts with identification of the landform profile (geologic cross sections of the landforms) at the site, which is then refined as needed using available site-specific data. Differences between landform profiles (representing spatial relationships of soils having similar geological genesis) and soil profiles are dependent on anticipated engineering behavior. Landform changes affect soil profiles where the changes potentially affect geotechnical response. Contiguous landforms may have sufficiently similar engineering characteristics that they can be treated as a single stratum or soil profile. Or, a single landform may be characterized by more than one stratum because of significant spatial differences in soil property parameters within the occurrence of the landform at that site. Thus, soil profiles can be simplifications or elaborations of landform profiles.

2.3.2 Updating of Soil Profiles

Soil property parameters for each stratum in the soil profile are estimated using available site-specific (sample) data and statistically characterized landform (prior) information. Formal, mathematical techniques for updating are given in Appendix F.

2.3.3 Limitations on Interpretations

Without site-specific subsurface data, soil profiles are limited to that which can be inferred from landform profiles and a prior knowledge of characteristic landform stratigraphy and associated material properties. Interpretation of the geotechnical response of the profile could statistically consider the potential effects of the characteristic stratigraphy and properties.

Development of the site soil profile is dependent on site geology and limited by available site data. Erratic soil profiles are the most difficult to characterize; they require greater geologic insight into the processes involved in the sites depositional environment. Depending on the design phase, adequate consideration must be given to the impact of very localized geological and climatological inhomogeneities which can dominate engineering behavior--e.g., massive ground ice in permafrost. The potential effect of unanticipated negative conditions should be considered since, regardless of specific technique, subsurface conditions are never completely defined in exploration or analysis such that critical geotechnical details may go undetected or be inadequately interpreted and eventually results in unsatisfactory performance. Careful engineering and geological interpretations and assumptions based on sound judgement remains fundamental to the site characterization process (Ref. 4).

2.4 METHOD APPLICATION TO DALTON HIGHWAY

Application of the route characterization methodology to the Dalton Highway consists of:

(1) Mapping the landform profile (terrain units) along the route, as described in Section 3.3;

(2) Developing a landform characterization for:

(A) thaw strain potential (based on frozen and thawed dry density), as discussed in Appendicies C and D;

(B) soil type (texture); and

(C) USACE frost classification (based on landform and texture); and,

(3) Matching landform thaw strain potential estimates, soil type and frost class to the landforms identified in the landform profiles shown on the route sheets.

No site-specific subsurface data were used to update the landform characterizations given in Section C.1 of Appendix C. Subsequent updating of the landform thaw strain potentials (and soil texture and frost heave class, as appropriate) presented here with segment-by-segment subsurface (borehole) data can be done using the updating techniques presented in Appendix F.

3.0 ROUTE SHEET DEVELOPMENT

Geotechnical characterization parameters for the Dalton Highway route are shown on the "Characterization of Foundation Soils" route sheets, found in Appendix A. These route sheets, numbered 1 through 26, provide coverage of the entire Dalton Highway route. Sheet 1 begins near Livengood at the start of the highway and Sheet 26 is located in the vicinity of Deadhorse Airport near Prudhoe Bay. An index of these sheets has been prepared at a scale of 1 inch = 16 miles (1:1,000,000). Included on the 26 route sheets are a topographic map base and data bands with explanations of information shown in the data bands. A full explanation of terrain unit definitions is provided on the first page of the appendix.

3.1 MAP BASE

Base maps, shown at the top of each route sheet, were taken from U.S. Geological Survey (USGS) topographic quadrangle maps at a scale of 1 inch = 1 mile (1:63,360). Information on the base maps include topography, water, and cultural features; also, the Trans-Alaska Pipeline System (TAPS) is shown, as was mapped by the USGS. Each sheet presents a portion of highway route approximately 6 miles wide by 16 miles long.

At the relatively large scale of the base maps, R&M's plotted location of the TAPS Fuel Gas Line (shown on sheets 17 through 25) was approximated by using existing information. Additionally, we have plotted important features such as DOT/PF camps, CRREL Field Test Sites and other features along the highway.

3.2 DALTON HIGHWAY LOCATION

We have plotted the Dalton Highway as originally shown on the 1975 photo-revised USGS topographic maps. Exceptions to this are several areas in which road construction was not complete at the time that the aerial photography was taken. Sources for completing the highway location were Brown and Kreig (Ref. 5) and as-built drawings provided by ADOT/PF. The highway route has been shown as a solid line for ease in identification.

Mileposts for the Dalton Highway, as shown in 5-mile increments on the route sheets, were provided by ADOT/PF.

3.3 DATA BANDS

As explained below, the data bands are representations of certain selected geotechnical information and can be found directly below the strip maps. Boundaries between adjacent classifications in the data band were projected vertically downward from the strip maps in all cases. Because of this, it is important to note that lengths along the individual data bands are not true horizontal scale distances. To arrive at an accurate lineal summary of data it is necessary to project the data band boundary marks to the strip map and measure actual horizontal distances on the map.

3.3.1 Segment Number Band

Segments of the Dalton Highway route are given by route sheet number and individual analysis/design segment within the route sheet. Individual segment boundaries were generally based on a change in terrain unit type. Segments are numbered south to north (right to left) on the drawings.

3.3.2 Terrain Unit Band

This band contains a lineal representation of the terrain units (landform profiles) present on centerline. Each terrain unit crossed by the route is noted, as are all terrain unit boundaries.

Representations are shown depicting terrain units to 10 feet in depth north of Atigun Pass and to 15 feet south of Atigun Pass, as requested by ADOT/PF. Average depths of individual landforms along with the standard deviations (Appendix C) were developed for the route. Abbreviated terrain unit symbols can be found on the explanation portion of the route sheet. A full explanation with landform - terrain unit definitions is provided on the first sheet of Appendix A.

3.3.3 Soil Type Band

The soil type band contains a lineal representation of the soil types present to a depth of about 15 feet both by name and by Unified Soil Classification (USC). It can be used to identify segments of similar soil type along the highway alignment. Generally, surficial organic material (12 inches or less) is not included in the description. Soils are classified using the Unified System (USCS) and are indicated by USC symbol such as "GW", for well graded gravel. An individual entry may consist of a single soil type, a range of soil types, or several different soil types, depending on the variation of soils within the unit both laterally and with depth.

The method of separating soil types is important; a horizontal bar indicates vertically distinct soils while a comma (,) indicates soils mixed together or interlayered with the first listed soil expected to be dominant. For example, a segment might contain cover deposits of windblown silt with scattered small sand dunes overlying coarse floodplain deposits of gravel with sand lenses. The classification for this deposit might be

SILT (ML) & SAND (SP, SP-SM)
―――――――――――――――――――
GRAVEL (GP, GP-GM) & SAND (SM, SW-SM)

No attempt is made in this classification to specify the thickness of the cover deposits. Generally, the lateral boundaries of soil types coincide with terrain unit and landform boundaries. However, several terrain units may be classified under the same soil type, or a single terrain unit may have several soil types within it.

Classification of the upper 15 feet of soils is dependent on interpretation of available data using geologic judgement. Data used to classify soils include: the occurrence of terrain units and landforms; statistical analysis of laboratory test results with regard to occurrence within a given landform, aerial photographs; and published maps and literature.

A dash mark is used for bedrock segments where soil classifications have not been made.

3.3.4 Thermal State Band

The thermal state band contains the estimated area-wide permafrost description. Data used for assessing permafrost classification for this band include occurrence of permafrost as noted in any available boreholes and their relationship within terrain units, aerial photographs, slope aspect, topography and surface disturbance.

The permafrost classification system consists of four categories:

GA - Generally Absent: estimate 0-10 percent of the map area represented by the segment shown in the band is underlain by near-surface permafrost.

S - Sporadic: estimate 11-50 percent of the map area represented by the segment shown in the band is underlain by near-surface permafrost.

D - Discontinuous: estimate 51-90 percent of the map area represented by the segment shown in the band is underlain by near-surface permafrost.

GF - Generally Frozen: estimate 91 to 100 percent of the map area represented by the segment shown in the band is underlain by near-surface permafrost.

This system is used to describe only the aerial distribution of permafrost beneath the mapped area. It does not apply to and is not used to describe the vertical distribution of permafrost.

3.3.5 Frost Classification Band

This band displays the frost classification for alignment soils using the classification of the U.S. Army Corps of Engineers (USACE). Criteria for frost classification is grain size distribution with the percentage finer than 0.02mm being the primary factor. The following table gives each frost group with the corresponding soil types.

Frost group Number	Soil Type	Percentage finer than 0.02mm, by weight	Typical soil types under Unified Soil Classification System
	Non-frost suseptible (NFS)	‹3	GW,GP,SW,SP
F1	Gravelly soils	3 to 10	GW,GP,GW-GM,GP-GM
F2	(a) Gravelly soils	10 to 20	GM,GW-GM,GP-GM
	(b) Sands	3 to 15	SW,SP,SM,SW-SM,SP-SM
F3	(a) Gravelly soils	›20	GM,GC
	(b) Sands, except very fine silty sands	›15	SM,SC
	(c) Clays, PI ›12	-	CL,CH
F4	(a) All silts	-	ML,MH
	(b) Very fine silty sands	›15	SM
	(c) Clays, PI ‹12	-	CL,CL-ML
	(d) Varved clays and fine-grained banded sediments	-	CL and ML CL,ML, and SM; CL,CH, and ML; CL,CH,ML, and SM

Soil type (texture) data was used to derive the frost group classification.

3.3.6 Thaw Strain Potential Band

This band contains a three level classification of thaw strain potentals (an estimate of vertical strain if a frozen soil thaws) for each landform within a segment of alignment. The classification consist of the following calculated thaw strain potentials:

THAW STRAIN POTENTIAL CLASSIFICATION	STRAIN VALUES
LOW	<10%
MODERATE	10-25%
HIGH	>25%

Landform values are taken from Table C-1, as estimated using thaw strain relationships presented in Appendix D of this report.

A dash mark is used for bedrock to represent a lack of data for this material.

3.3.7 Comments Band

Included here are physiographic subprovince divisions and locations of major stream crossing and any other items that may be of interest in an overall assessment of route foundation soil conditions.

4.0 DALTON HIGHWAY ROUTE DESCRIPTION

The Dalton Highway route has been divided (as shown in Figure 4-1) into physoiographic provinces and subprovinces based on Wahrhafting (Ref. 30). The physiographic province and subprovince division boundaries for the route are shown by corresponding route sheet and milepost in Table 4-1. Physiographic subprovince boundaries are also shown in the Route Sheets Comments data band and on the Index of Route Sheets.

4.1 GENERAL GEOLOGY AND SOILS

4.1.1 Interior Province (MP. 0.0 to 156.3)

The Interior Province include the Kokrines-Hodzana Highlands on the north and the Livengood Upland on the south. These two upland areas are divided near Hess Creek by the narrow Rampart Trough. Topography is rolling, characterized by rounded even topped ridges.

The entire area is within the Yukon drainage basin with the Koyukuk and Tanana Rivers bounding it, north and south, respectively.

Vegetal cover consists of muskeg grasses and stunted black spruce and tamarack in the frozen lowlands and on north-facing slopes. Mixed birch, aspen, spruce and cottonwood thrive on the well drained southern slopes and along major river valleys. Little to no silt cover is present on some of the higher bedrock hills north of the Yukon River.

Permafrost is present throughout the uplands, occuring continuously in low lying areas and on north-facing slopes. Solifluction features are locally well developed. Segregated ice is common. On south facing slopes and along major drainages, permafrost is generally discontinous.

Schist and gneiss, with a general northeast-trending structural grain, are present in the northern portion of the uplands. Highly deformed sedimentary and volcanic rocks containing conspicuous limestone units are present elsewhere. Small granitic intrusions are scattered throughout but are particularly evident between Prospect Creek and the Yukon River. In the sourthern part, a thick mantle of windblown silt lies on the lower slopes of hills and thick accumulations of organic rich silt (muck) overlies deep stream gravels in the valleys.

4.1.2 Arctic Mountains Province (MP 156.3 to 359.6)

The Arctic Mountains Province is subdivided into the Chandalar Ridge and Lowland, Central Brooks Range and the Arctic Foothills (Southern and Northern).

The Chandalar Ridge and Lowland Section consists of east-trending lines of lowlands and upland passes ranging from 3-10 miles in width. This section is underlain by continuous permafrost. The ridges are, in part, composed of resistant massive greenstone. The lowlands are underlain largely by cretaceous sedimentary rocks.

The Brooks Range is a series of rugged, east trending ridges rising as high as 8,000 feet. Steep slopes, cirques and other features typical of glacial erosion are predominant, although active glaciers are few and very small. Rock glaciers, solifluction and other periglacial phenomenon are common.

The Atigun, Chandalar, Dietrich and Middle Fork Koyukuk River Valleys form a natural access channel across this rugged area. The pass between the Atigun and Chandalar headwaters, at an elevation of about 4750 feet, is the highest point along the Dalton Highway route. Drainage into the main river is by short, steep, intermittent streams which often have formed coarse fans. In steeper areas near Atigun Pass, intermittent streams flow through blocky talus cones.

Alpine tundra vegetation is present in the valleys of the Atigun and Chandalar Rivers. In the Dietrich and Koyukuk Valleys mixed interior forests of spruce, aspen and birch occur near the active floodplains. Except for a limited thaw bulb under the larger active streams, permafrost is continuous.

The highway route is, for the most part, confined to the lower river valleys where alluvial, colluvial and glacial deposits mask the bedrock. In several areas, especially in the upper Atigun Valley, bedrock should be expected at shallow depths below natural ground surface. Limestone, shale, conglomerate and quartzite are rock types that may be encountered.

The Arctic Foothills consist of rolling plateaus and low linear mountains; they are divided into two sections. The Northern section rises from an altitude of 600 feet on the north to 1,200 feet on the south. The Southern section is 1,200 feet to 3,500 feet in altitude and has local relief of as much as 2,500 feet.

The main drainage feature is the Sagavanirktok River which flows just to the east of the Dalton Highway route. Numerous small streams, often with beaded drainage patterns feed the "Sag" River. Scattered thaw lakes are present. Vegetation is limited to dry tundra on the hills and muskeg in the small valley bottoms and upper terraces of the Sag River.

Shallow thaw ponds are scattered throughout the area, especially in drainage divides. To the south, morainal lakes like Island Lake are present. Permafrost is continuous and "cold". Even under the active floodplain of the Sag River, only a shallow thaw bulb is present. Extensive aufeis accumulation is common on the river. Ice wedges, polygonal ground, and other permafrost features are present throughout.

The Arctic Foothills are composed of relatively soft sedimentary rocks, some of which are coal bearing. Under certain conditions segregated ice has been found in these rocks. In the floodplain of the Sag River alluvial gravels cover the bedrock, but on the hills, especially in the northern area, only a shallow veneer of silt and colluvium is present. South of Slope Mountain thick deposits of ice-rich tills cover the bedrock.

4.1.3 Arctic Coastal Plain Province (MP 359.6 to 414.9)

The Arctic Coastal Plain Province extends from the shoreline of the Arctic Ocean to the vicinity of Sagwon Bluffs (near TAPS Pump Station No. 2). The Arctic Coastal Plain province is divided into the Teshekpuk Lake and White Hills subprovinces. Scattered groups of low hills rise above the plain in the White Hills subprovince; the Teshekpuk Lake section is flat. The ocean has retreated from this portion of Alaska only relatively recently in the geologic past, leaving a uniform, rather featureless plain dotted with ponds and crossed by north-flowing rivers. The Arctic Coastal Plain is poorly drained and very gently sloping, rising to an elevation of 600 feet at the southern margin. It is underlain by continuous permafrost.

Soils consist of unconsolidated marine sediments, mainly sands and gravel. A thin cover, generally less than ten feet thick, of fine-grained, ice-rich, windblown silt lies over the marine sediments except in the active floodplains of rivers. Terrain in this section is characterized by poorly drained bogs and shallow thaw ponds and lakes. In the floodplains, stream-deposited sand and gravel overlies the marine sediments, with thin deposits of silty soil. The environmental concerns associated with shallow lakes has resulted in the attempt to avoid these features during construction of the Dalton Highway.

4.2 ROAD CONDITIONS

4.2.1 Alignment

The history of the Dalton Highway and its development originally as a pipeline and oil field haul road has been well documented in the literature (Refs. 19, 14). The initial 56 mile segment, beginning from the Elliott Highway near Livengood and extending to the Yukon River was designed and constructed in 1969 and 1970. Design criteria was based on Alaska State Highway Department secondary road standards; however, emphasis on access to and priorities for the proposed oil pipeline location made it necessary to modify the design at certain points along the route (Ref. 1). Design of the Yukon River to Prudhoe Bay road segment was begun in 1970 and, after permitting delays, actual construction took place in 1974.

In very general terms, geotechnical related route criteria gave major emphasis to utilizing an embankment overlay concept when ever possible. Avoidance of "sidehill" or "through" cut road sections was considered desirable and necessary in order to minimize potential adverse natural ground thermal degradation or erosion in the primarily frozen ground having variable ice content. Performance of certain roadway cut sections in frozen ground along the Dalton Highway have since been evaluated by various investigators and the success of these sections has ranged from good to poor (Refs. 3, 13, 14, 18).

Terrain and geotechnical conditions highly influenced the location of both the road and oil pipeline. Final roadway alignment was selected after completion of extensive reconnaissance and detailed field studies. Design criteria and final design plans were reviewed by various governmental agencies prior to beginning construction.

Areas presenting more difficult roadway alignment concerns included:

LOCATION	MILEPOSTS	CONCERN
South of Erickson Creek	9.5 - 11	Ice rich soils and sidehill grade
South of Hess Creek	20 - 23.5	Massive ice and sidehill grade
South of Sukakpak Mtn.	197.8 - 204.7	Massive ice, pingos, taliks and cross-drainage
North of Dietrich Airport	211.8 - 221.8	Massive ice (except at granular alluvial fans) and sidehill embankment
Chandalar Shelf	238 - 239	Sidehill, steeper grade in frozen ground
Atigun Pass	245 - 248	Steeper grades, sidehill, some unstable side slopes
North of Galbraith Lake	272.4 - 310.5	Massive ice and some sidehill embankment
North of Pump Station 3	314.9 - 317.5	Massive ice
North of Pump Station 3	319.2 - 321.0	Massive ice
Happy Valley Cut	326.5	Throughcut in ice rich material with massive ice
Happy Valley	326.5 - 340.2	Massive ice
Sagwon	349.3 - 353	Local massive ice

Additional concerns associated with alignment geometry difficulties and special drainage requirements have not been cited here since this is beyond the scope of this report. More conventional concerns associated with embankment thaw subsidence are addressed in Appendix C. Also, as stated previously, frost heave problems have not been addressed since this concern is beyond the scope of this report.

4.2.2 Embankment

The embankment and or structural section represents the more significant portion of the roadway in terms of supporting traffic loadings. This study addresses foundation soil conditions only and specifically excludes consideration of the embankment or structural section as that work is being completed by others. Both the State of Alaska Department of Transportation and Public Facilities (ADOTPF) and the U.S. Army - Cold Regions Research and Engineering Laboratory (CRREL) have conducted on-going studies of the Dalton Highway performance. Shortly after construction ADOTPF and CRREL established a number of test sites along the highway starting just north of the Yukon River. Information on these test sites is presented in various CRREL reports and other references.

With the exception of those areas where unfrozen floodplain gravels were available, most of the embankment material was obtained from bedrock borrow sources. Since the quality of these bedrock sources varied significantly, it is important to recognize that the embankment structural performance is in part, controlled by the specific characteristics of the rock source and type from which it was derived. The ability of the embankment section to respond to non-structural conditions, such as foundation soil deformation, is also influenced by the fill characteristics; admittedly to a somewhat lessor extent.

Embankment instability, deformation and displacement is readily evident along some segments of the route and can be correlated reasonably well to those terrain units having higher thaw strain characteristics. In these areas, the greater amount of ground subsidence has resulted in development of thaw ponds and interrupted drainage along the embankment toe section at many locations and, slope or shoulder failures in more severe cases.

Intermittent maintenance and grading of the road surface tends to partially obscure the embankment deformation characteristics and, therefore, the extent of embankment subsidence that may have occurred cannot normally be ascertained. Also, the amount of thermal degradation and maximum depth of annual thaw is generally unknown. Some limited information has been obtained at isolated embankment locations where test holes were drilled in the roadway during late summer and early fall for the recent natural gas pipeline studies. (As an example, pertinent boreholes located adjacent to CRREL test sites are listed in Appendix B.) In addition, estimates of thaw depths can be made based on suitable thermal modeling techniques.

4.2.3 Significant Erosion

In general, erosion has not been a major concern with the Dalton Highway performance. During the design and construction period considerable attention was given to erosion control and to potential for long term thermal erosion or thaw degradation, particularly in areas having massive ground ice. Special erosion control studies were made by Alyeska Pipeline Service Company on selected soil, drainage and ground ice conditions and design procedures were developed to minimize adverse impacts. The Wiseman Cutoff Trail and Hess Creek Test Site were locations of two special erosion studies (Refs. 2, 18).

Particular attention was given to minimizing and mitigating the effect of thermal degradation and headward erosion induced by concentrated draingages. Significant gulley erosion occurred along certain segments of the road where concentrated drainage at culvert locations induced rapid thaw and carried away large quantities of material. Control measures typically included use of geofabrics, granular backfill, broken rock and various type diversion structures. Examples of major gulley erosion and drainage control applications exist south of Sukakpak Mountain between Mile 198 and 202.

4.2.4 Performance

This study addresses only the characteristics of the natural foundation soils along the Dalton Highway and does not assess conditions relating to the roadway embankment or structure. Roadway surface conditions along the route vary substantially and are, to a large degree, dependent upon the characteristics of the imported embankment material contained in the structural section. Normal deficiencies in roadway surface conditions are evidenced by potholes, rutting, shoving, soft spots and other forms of distress produced by varying traffic and wheel load repetitions. These forms of distress along with road maintenance operations, such as "motor grading", all tend to mask the effect of problems that may be resulting from natural foundation soil deformation. Examples of roadway surface deficiencies produced by foundation soil deformation include local and longitudinal slope failures, usually accompanied by differential movement along open cracks, and undulating roadway surface resulting from thaw subsidence and or frost heave effects.

Due to the number of parameters involved, it is not always possible to directly relate roadway surface deficiencies to the cause of failure. In many cases the time and temperature dependent thermal regime and, more particularly, the freeze/thaw interface tend to control the roadway condition and directly influence performance. During the thawing period, initial near surface wheel load capacity constraints gradually transform to problems normally associated with affects resulting from deeper seated ground thaw subsidence or displacement.

In this study we have attempted to provide a means for correlating interpreted foundation soil characteristics with apparent longer term road performance conditions that have or may still result from subsurface subsidence or deformation. Terrain units having higher thaw strain characteristics combined with deeper thaw penetration obviously represent conditions where large road deformations should have or will continue to occur.

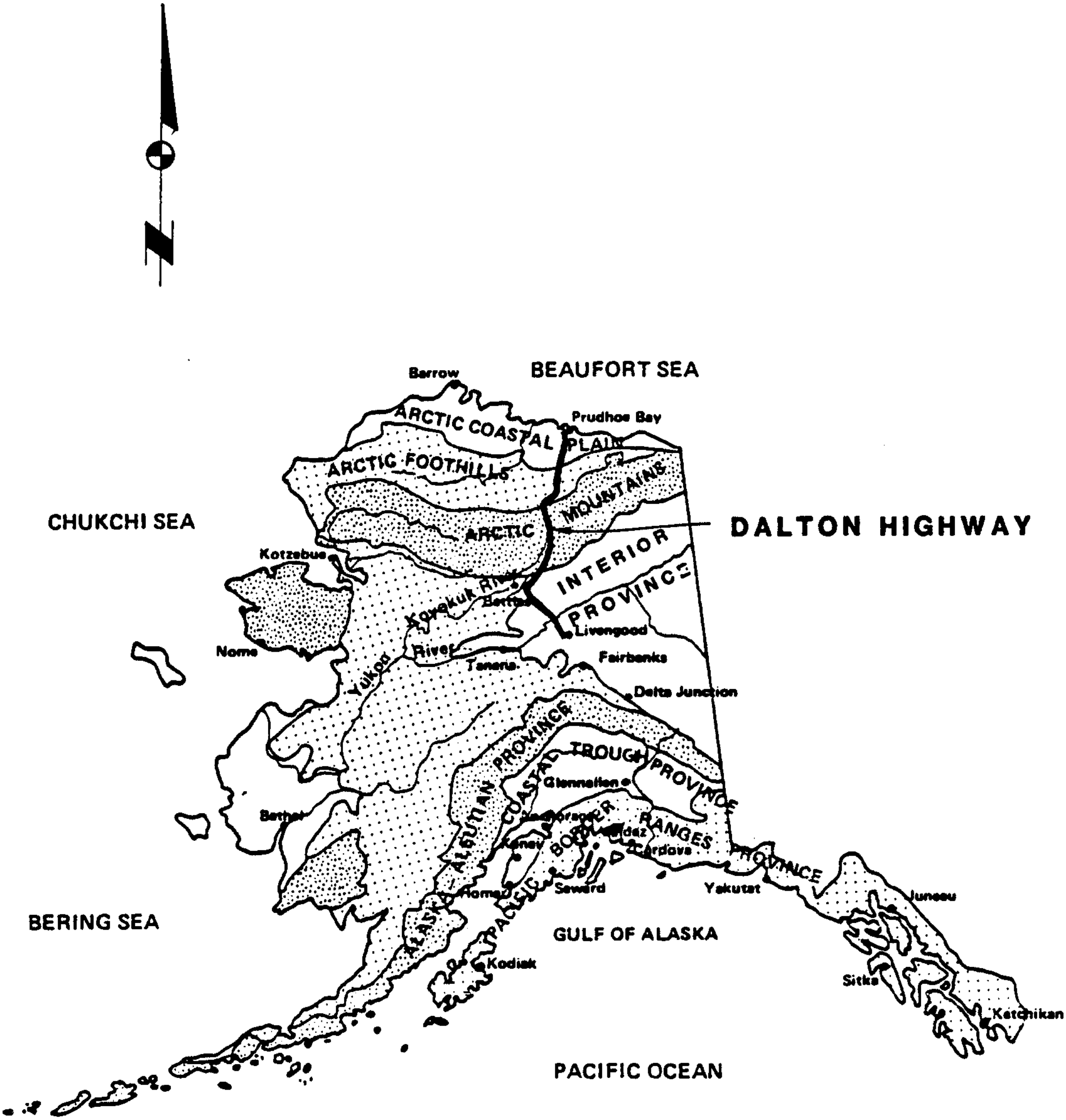


Figure 4-1. PHYSIOGRAPHIC PROVINCES OF ALASKA (from Wahrhaftig, 1965)

DWN /OEP CKD /CHR DATE SEPT 1984 SCALE NTS	R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS PLANNERS SURVEYORS	STATE OF ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS	F.B. GRID PROJ. NO. 451099 DWG. NO.

TABLE 4-1

PHYSIOGRAPHIC PROVINCE AND SUBPROVINCE DIVISIONS

Code	Province & Subprovince	Route Sheets	Estimated Mileposts
3	INTERIOR PROVINCE	01-10	0.0 - 156.3
3C	Livengood Upland	01-02	0.0 - 021.4
3B	Rampart Trough	02-02	21.4 - 026.3
3A	Kokrine-Hodzana Highlands	02-10	26.3 - 156.3
2	ARCTIC MOUNTAINS PROVINCE	10-22	156.3 - 359.6
2D	Chandalar Ridge & Lowland	10-11	156.3 - 174.6
2C	Central Brooks Range	11-17	174.6 - 278.3
2B	Arctic Foothills (Southern)	17-19	278.3 - 312.9
2A	Arctic Foothills (Northern)	19-22	312.9 - 359.6
1	ARCTIC COASTAL PLAIN PROV.	22-26	359.6 - 414.9
1B	White Hills Section	22-25	359.6 - 401.9
1A	Teshekpuk Lake Section	25-26	401.9 - 414.9

5.0 REFERENCES

1 Alyeska Pipeline Service Company, 1971, Project Description of the Trans-Alaska Pipeline System, Vols. 1-3 and Appendix Volumes 1-16.

2 Alyeska Pipeline Service Company, 1974, "Thermal Erosion Control: Wiseman Cut Off", Report No. TE-004, Prepared by R&M Engineering & Geological Consultants, Unpublished.

3 Berg, R.L. and Smith, N., 1976, Observations Along the Pipeline Haul Road Between Livengood and the Yukon River, CRREL Special Report No. 76-11.

4 Baecher, G.B., "Exploration Strategies", Proceedings, Site Characterization and Exploration, ASCE, June, 1978.

5 Brown, J., and Kreig, R.A., eds., 1983, "Guide to Permafrost and Related Features Along the Elliott and Dalton Highways, Fox to Prudhoe Bay, Alaska", Guidebook 4, Fourth International Conference on Permafrost, 1983: Alaska Division of Geological and Geophysical Surveys, 230 p.

6 Harr, M.E., Mechanics of Particulate Media - A Probabilistic Approach, McGraw-Hill, 1977.

7 Hunter, J.M., et.al., "Site and Route Studies," Chapter 5, Permafrost Engineering Design and Construction, G.H. Johnstons, Ed., John Wiley and Sons, New York, 1981.

8 Krieg, R.A., "Terrain Analysis for the Trans-Alaska Pipeline", Civil Engineering, Volume 47, No. 7, 1977, pp. 61-65.

9 Krieg, R.A., and Reger, R.D., 1976, "Preconstruction Terrain Evaluation for the Trans-Alaska Pipeline Project", in Coates, D.R., ed., Geomorphology and Engineering: Stroudsburg, Pa., Dowden, Hutchinson and Ross, pp. 55-76.

10 _____, 1982, "Airphoto Analysis and Summary of Landform Soil Properties Along the Route of the Trans-Alaska Pipeline System", Alaska Division of Geological and Geophysical Surveys Geologic Report 66, 149 p.

11 Lumb, P., "Variability of Natural Soils", Canadian Geotechnical Journal, Vol. 7, No. 3, 1970.

12 _____, "Safety Factors and Probability Distribution of Soil Strength", Canadian Geotechnical Journal, Vol. 7, No. 3, 1970.

13 Mageau, D.W. and Rooney, J.W., 1984, "Thermal Erosion of Cut Slopes in Ice-Rich Soil", Alaska Department of Transportation and Public Facilities, Report No. FHWA-AK-RD-85-02.

14 McPhail, James F., McMullen, W.B. and Murfitt, A.W., 1975, "Design and Construction of Roads on Muskeg in Arctic and Subarctic Regions", Sixteenth Annual Muskeg Research Conference, National Research Council of Canada, Montreal, Canada.

15 Mollard, J.D., Landforms and Surface Materials of Canada, 7th Edition, J.D. Mollard and Associates Ltd., Regina, Saskatchewan, 1982.

16 Nelson, R.A., Luscher, U., Rooney, J.W., Stramler, A.A.; "Thaw Strain Data and Thaw Settlement Predictions for Alaskan Soils", Proceedings Permafrost: Fourth International Conference, National Academy Press, Washington D.C., July 1983.

17 Raiffa, H. and Schlaifer, R., Applied Statistical Decision Theory, Harvard University Press, Cambridge, MA., 1961.

18 Rooney, J.W. and Condo, A.C., 1984, "Hess Creek Thermal Erosion Test Site: Frozen Cut Slope Surface Treatments", Third International Specialty Conference: Cold Regions Engineering, Vol. III. Edmonton, Alberta.

19 Roscow, James P., 1977, 800 Miles to Valdez: The Building of the Alaska Pipeline, Prentice-Hall.

20 Smith, N. and Berg. R.L., 1973, "Encountering Massive Ground Ice During Road Construction In Central Alaska" in Permafrost, the North American Contribution to the Second International Conference Yakutsk, Siberia, U.S.S.R.: Washington, D.C.; National Academy of Sciences, pp. 730-736.

21 Vanmarke, Erik H., "Probabilistic Characterization of Soil Profiles" Proceedings Site Characterization and Exploration, ASCE, June, 1978.

22 Vita, Charles L., "A Landform-Based Probabilistic Methodology for Site Characterization", Proceedings Nineteenth Annual Symposium on Engineering Geology and Soils Engineering, Idaho State University, April, 1982.

23 ______, "Thaw Plug Stability and Thaw Settlement Evaluation for Arctic Transportation Routes; A Probabilistic Approach", Proceedings Permafrost: Fourth International Conference, National Academy Press, Washington D.C., July, 1983.

24 ______, "A Geotechnical Engineering Systems Approach for Arctic Transportation Facility Planning and Design", Civil Engineering Systems, England, Vol. 1, No. 2, Dec. 1983.

25 ______, "Landform-Based Characterization of Soil Properties", Probabilistic Characterization of Soil Properties: Bridge Between Theory and Practice, ASCE, May, 1984.

26 ______, "Probabilistic Thaw Settlement Evaluation for Route Characterization", to be presented at "Arctic '85: Civil Engineering in the Arctic Offshore", ASCE, March, 1985.

27 ______, " Route Geotechnical Characterization and Analysis", Journal of Geotechnical Engineering, ASCE, Vol. 110, No. 12, December 1984.

28 ______, " Statistical Techniques For Route Geotechnical Characterization", in preparation.

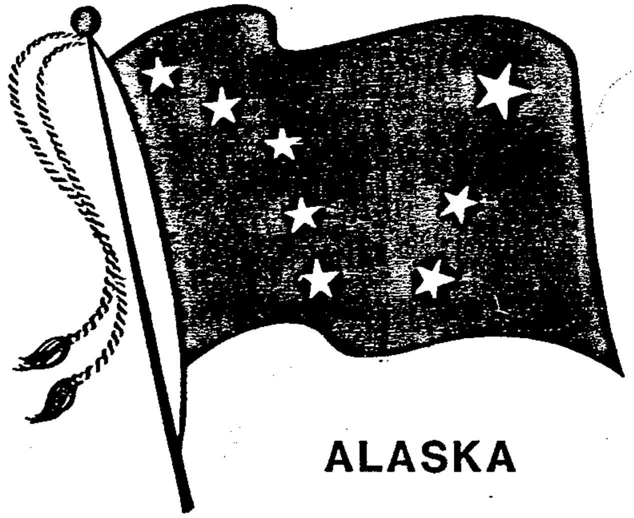
29 Vita, C.L., and Rooney, J.W., " A Unified Geotechnical Engineering Systems Approach Applied to Arctic Pipeline Planning and Design", Proceedings Pipelines in Adverse Environments II, ASCE, November 1983, pp. 291-299.

30 Wahrhaftig, Clyde, 1965, Physiographic Divisions of Alaska, U.S. Geological Survey Professional Paper 482, U.S. Government Printing Office, Washington, D.C., 52 p.

31 Way, Douglas, Terrain Analysis, 2nd Edition, McGraw-Hill, New York, 1978.

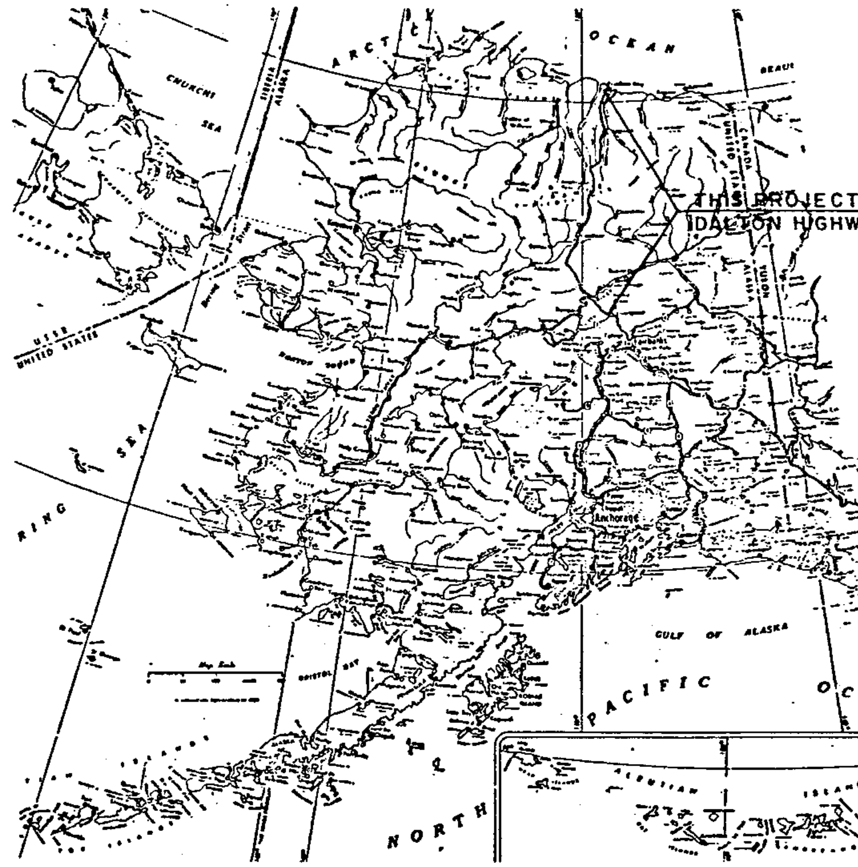
APPENDIX A

ROUTE SHEETS



ALASKA

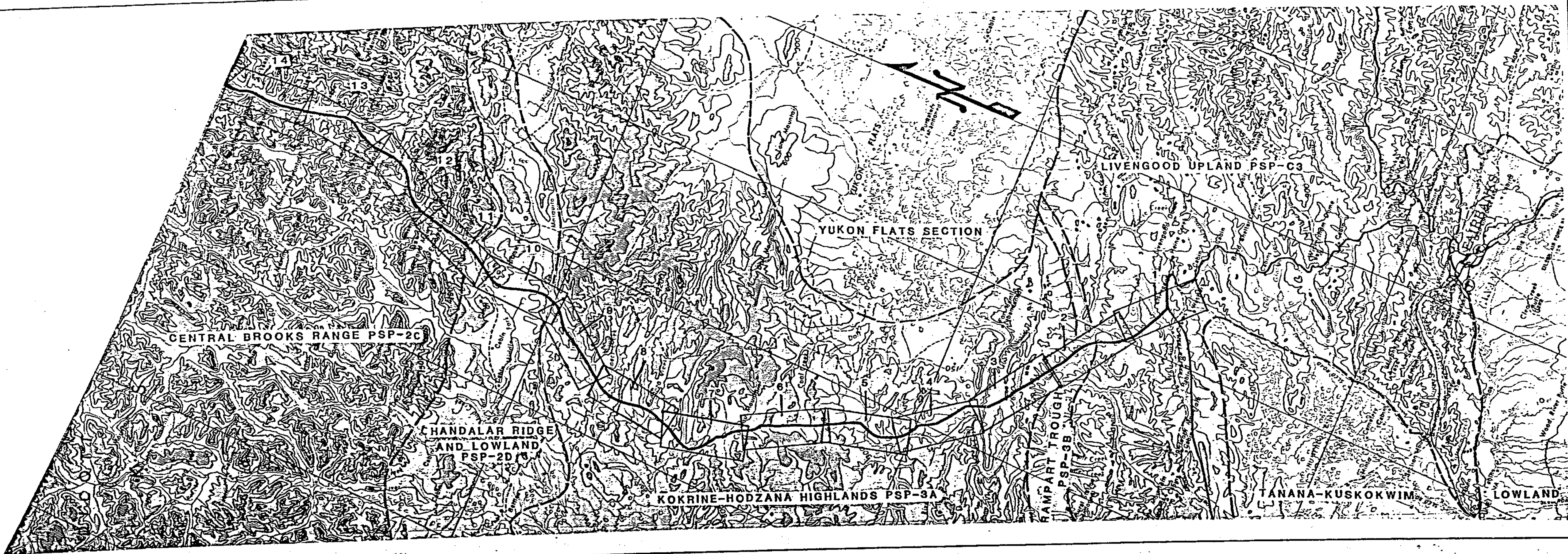
STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES



DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

Prepared by:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS



DALTON HIGHWAY ROUTE

LOCATION AND NUMBER OF GEOUNDATION SOILS ROUTE SHEET

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

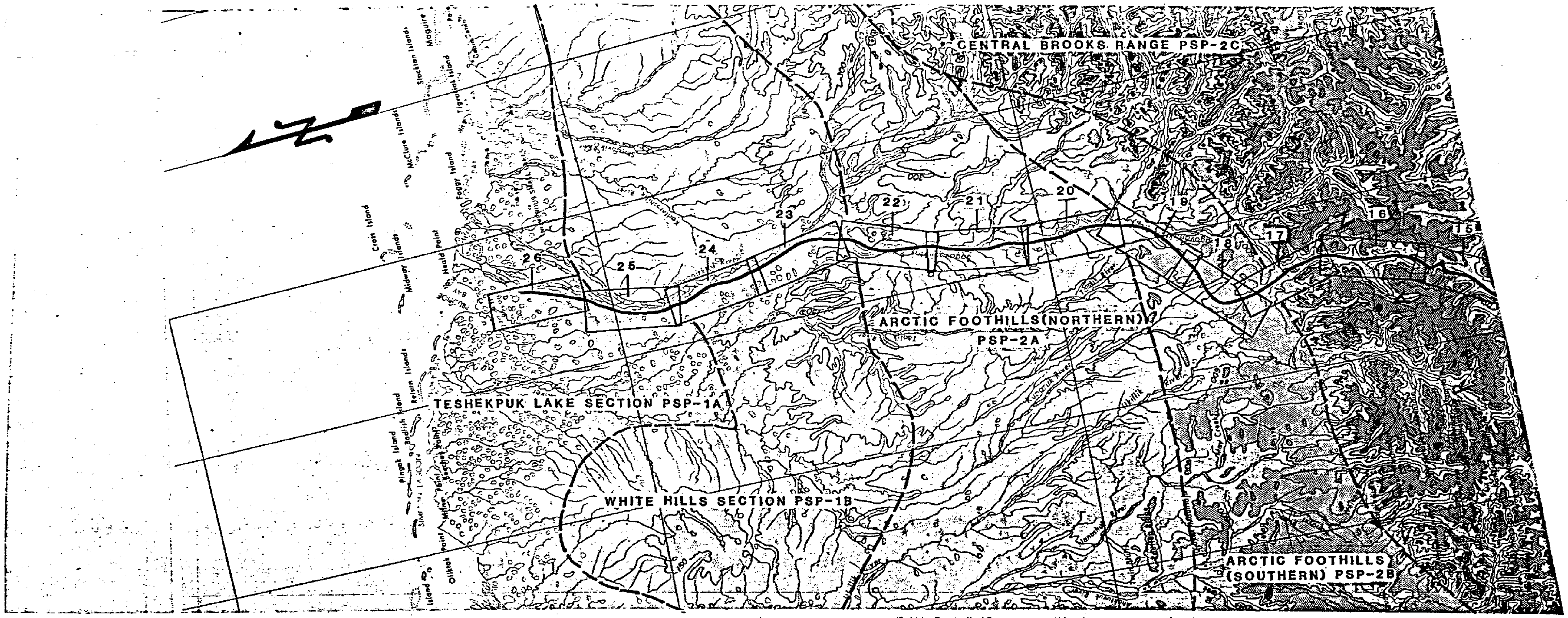
ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES
10 5 0 10 20

INDEX OF ROUTE SHEETS -1



DALTON HIGHWAY ROUTE

LOCATION AND NUMBER OF SUBGRADE FOUNDATION SOILS ROUTE SHEET

PREPARED BY :

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES
10 5 0 10 20

INDEX OF ROUTE SHEETS -2

LANDFORM CLASSIFICATION UNITS

BEDROCK, Bx

In place rock that is overlain by unconsolidated material or exposed at the surface. The following three modifiers are used for all bedrock landform units (including igneous bedrock, metamorphic bedrock and sedimentary bedrock). Weathered, highly fractured or poorly consolidated bedrock is indicated by the modifier -w (as in Bx-w); unweathered consolidated bedrock is indicated by the modifier -u (as in Bx-u). The modifier -r is used to represent the residual soil weathered from underlying local bedrock (as in Bx-r). This residual soil unit usually includes some intimately intermixed colluvium and fluvial slopewash deposits because it is not generally possible to distinguish residual soils from other transported materials on the basis of borehole data alone. This unit frequently also contains varying amounts of thin interlayered loess. The various weathering zones and colluvial deposits are normally layered in bedrock thus:

Occurrence of zones in nature	C Bx-r Bx-w Bx-u	Bx-r Bx-w Bx-u	Bx-w Bx-u	Bx-u
Terrain units as depicted on maps	C Bx	Bx	Bx-w	Bx-u

COLLUVIAL DEPOSITS, C: Deposits of widely varying composition that have been moved downslope chiefly by gravity. Fluvial slopewash deposits are usually intimately intermixed with colluvial deposits.

- **Ca – Avalanche Deposits:** Rock fragments, plant debris and soil deposited by slush and snow avalanches. Deposits are generally fan- or cone-shaped and covered with scattered large blocks.
- **Cg Rock Glacier:** A tongue shaped mass of angular rock fragments formed by movement of an ice core or interstitial ice. These features are found at the base of extensive talus producing surfaces such as steep valley walls, headwalls of empty cirques or recent moraines. Includes inactive forms that may no longer contain ice.
- **Cl Slide:** A lobe or tongue-shaped deposit of rock rubble or unconsolidated debris that has moved downslope. Includes rock and debris slides, slump blocks, earth flows and debris flows.
- **Cm – Mudflow:** Unconsolidated debris deposited by the rapid downslope flow of saturated material. Usually occurs in fan- or lobe-shaped bodies at the mouths of gullies or tributary valleys.
- **Cs – Solifluction Deposits:** Solifluction deposits are formed by the slow downslope, viscous flow of saturated soil material and rock debris in the active layer. Frost creep is also a major component in forming these deposits. This unit is generally used only where obvious solifluction lobes are identifiable. Solifluction is also a major component of retransported deposits (See Fs).
- **Csf – Solifluction Colluvial Fan:** Formed where solifluction deposits (Cs) emerge from a confined channel on a hillside onto a level plain or valley. Commonly includes incorporated fine-grained alluvial fan material.
- **Ct – Talus:** Deposits of angular rubble and rock fragments accumulated by gravity at the base of cliffs and steep slopes.
- **Ctc – Talus Cone:** A deposit of talus accumulated at the mouth of a canyon or gully, forming a steep cone.
- **Ctp – Protalus Rampart:** An arcuate ridge of talus accumulated along the lower margin of a perennial snow patch lying at the base of a steep slope or cliff. May contain interstitial ice. If a rampart shows evidence of having moved downslope as a tongue of rock rubble, it is classified as a rock glacier (Cg).
- **Cx Basin Colluvium Arctic Slope:** Generally fine-grained, organic-rich deposits with variable amounts of granular material present in basins occurring between smoothly rounded slopes on the Arctic Slope. It is usually associated with frozen upland silt (Elx). The origin of this landform is not definitely known. However, the material appears to have moved into small basins from surrounding slopes by solifluction, creep and or slopewash. Other processes that could have a role in the genesis of this deposit are thaw basin formation and drainage, organic deposit development and perhaps eolian deposition. Nivation may also result in modification of basin margins and minor reworking of basin marginal deposits in some localities. Basin colluvium is differentiated from thaw lake materials by smooth gradation with surrounding slopes and the highly variable and thin character of accumulated deposits.

EOLIAN DEPOSITS, E: Materials deposited by wind

- **El – Loess:** Silt deposited by wind
- **Ell – Lowland Loess:** Wind blown silt deposited on poorly drained lowland locations, mixed with organic material and frequently with finer floodplain or other fluvial colluvial materials. It is normally frozen with a high ice content. The proportion of wind blown silt in this landform is usually low in relation to the organic material and ice that are present. This unit is also used for classifying surficial layers that are silty, organic and high in ice content but are of uncertain origin.
- **Elu – Upland Loess:** Wind blown silt deposited on well drained upland locations, generally used only for thick, unfrozen silt deposits (see Fss for further discussion).
- **Elx – Frozen Upland Silt:** The origin of this unit is not completely understood; it is probably eolian due to its uniform silty gradation. However, it differs from upland loess (Elu) for it consists of thick, frozen silt with organic rich zones and contains massive ice formations. It is similar in appearance to silty retransported deposits (Fss), yet it frequently occurs at the tops of ridges and hills where a transported origin is not possible. The presence of unoxidized organic rich zones indicates that the unit may be loess that has remained frozen since deposition. It may include silts colluvium in upland depressions or gullies.
- **Es – Eolian Sand:** Sand deposited by wind as sheets or discrete hills (dunes).

FLUVIAL DEPOSITS, F: Materials deposited by running water, such as rivers and streams.

- **Fd – Delta:** A deposit of alluvium laid down by a stream flowing into a standing body of water.
- **Ff – Alluvial Fan:** A gently sloping cone generally composed of granular material with varying amounts of silt deposited upon a plain by a stream where it issues from a narrow mountain valley. The primary depositional agent is running water (for solifluction fans, see Colluvial Landforms). Can include varying proportions of avalanche or mudflow deposits, especially in mountainous regions.
- **Ffg – Granular Alluvial Fan:** Used for granular alluvial fans. Not used for fans that contain significant amounts of incorporated colluvium such as avalanche and mudflow deposits (use Ff).
- **Ffs – Fine grained Alluvial Fans:** Used for alluvial fans composed of predominantly finer-grained materials (generally sand and silt). Deposits in these fans are laid down by stream action rather than by sheet flow and solifluction as in retransported deposit fans (Fsf) which are also composed of silt and sand.
- **Fp – Floodplain:** Deposits laid down by a river or stream and flooded during periods of highest water in the present stream regimen. It is composed of two major types of alluvium: 1) Fp-r, generally granular riverbed (lateral accretion) deposits and 2) Fp-c, generally fine-grained cover (vertical accretion) deposits laid down above the riverbed deposits by streams at bank overflow (flood) stages. Fp-c in some cases can be further subdivided into point bar deposits (Fp-cp) which are laid down on the inside of meander loops during floods which are lower than bank overflow stage. They are intermediate in soil texture between cover deposits (Fp-c) and riverbed deposits (Fp-r).
- **Fpb – Braided Floodplain:** Deposits of a stream or river with branching, anastomosing channels. Generally composed of coarse-grained alluvium, although modifiers "-c" and "-r" are used as above under Fp. These deposits are formed by streams that have a low flow in relation to their high sediment load.
- **Fpm – Meander Floodplain:** Deposits of a stream or river with broad S-shaped channels that are not extensively braided. Modifiers "-c", "-cp" and "-r" are used as above under Fp.
- **Fpa – Abandoned Floodplain:** An older, frozen portion of a floodplain with a surface layer of ice-rich "lowland" loess and fine-grained alluvium up to ten feet thick over granular alluvium (Fp-r). Generally has tussocks and stunted spruce vegetation and is used only as Fpa-c over Fp-r.
- **Fpc – "Creek" or Small Watercourse Floodplain:** Poorly sorted fine- to coarse-grained fluvial deposits laid down in narrow upland valleys. May include retransported colluvium.
- **Fps – Sandy Floodplain:** A floodplain composed of generally silty cover deposits (Fps-c) over sandy riverbed deposits (Fps-r) containing little or no gravel.
- **Fpt – Old Terrace:** An old, dissected floodplain surface no longer flooded. Only the older terraces, weathered sufficiently to change the character of the fluvial deposits, are included in this unit. Recent terrace and dissection remnants whose materials are relatively unaltered by weathering are indicated by the surface-phase symbol (ft).
- **Fs – Retransported Deposits:** Generally fine-grained, organic rich materials moved downslope by slopewash, solifluction and piping. This unit is generally frozen and commonly contains massive ice.
- **Fsf – Retransported Deposit Fan:** A gently sloping cone of retransported deposits (Fs) formed where confined channels emerge onto a level plain or valley. Commonly includes alluvial fan material.
- **Fsa – Sandy Retransported Deposits:** Retransported deposits derived from uplands composed of dune sand. Generally fine grained, frozen and ice-rich. Materials have been moved downslope by slopewash, solifluction and piping. Commonly includes organic material and eolian sand.
- **Fss – Silty Retransported Deposits:** Retransported deposits derived from loess mantled hills. This deposit is generally frozen and is composed of fine grained, ice-rich sediments which are commonly organic. Materials have been moved downslope by slopewash, solifluction and piping. Upland Loess (Elu) cannot always be distinguished from silty retransported deposits (Fss) using airphoto analysis and boring data alone. Therefore the Fss unit can contain some loess, especially in the transition zone on hill slopes between Elu and Fss.

UNDIFFERENTIATED GLACIAL AND NON-GLACIAL GRANULAR DEPOSITS, FG: This unit may be used when it is difficult to distinguish between the granular deposits found on 1) non-glacial floodplains (Fp) and alluvial fans (Ffg) and 2) glacial outwash (GFo). In proglacial environments (areas beyond, but adjacent to the limits of glaciation) glaciofluvial deposits grade downstream into non-glaciofluvial deposits.

GLACIAL DEPOSITS, G: Deposits formed in direct contact with glacial ice

- **Gg – Glacier:** Body of flowing ice consisting mainly of recrystallized snow
- **Ggm – Ice-cored Glacial Moraine:** A residual accumulation of till and remnant ice deposited by wastage along the margins and in the terminal zones of modern glaciers. These moraines commonly exhibit steep slopes, collapse features and high instability.
- **Gt – Till Sheet:** A heterogeneous deposit laid down by glacial ice and composed of materials varying from clay to boulders.
- **Gtd – Drumlins:** Till deposited in low linear ridges by the flow of glacial ice
- **Gto – Older Till:** Relatively older till sheets with subdued moraine morphology and more advanced basin fillings. May have higher ground ice content than younger till sheets.
- **Gty – Younger Till:** Relatively younger till sheets commonly exhibiting more pronounced moraine topography and less integrated drainage network than older till sheets.

GLACIOFLUVIAL DEPOSITS, GF: Deposits laid down by streams flowing on, under, or from glaciers

- **GFo – Outwash:** Relatively level floodplain of a stream flowing from a glacier
- **GFe – Esker Deposits:** Long ridges of granular ice-contact deposits formed by streams as they flow on or under a glacier
- **GFk – Kame Deposits:** Hills and masses of granular ice-contact deposits formed by streams as they flow on or under a glacier

MAN-MADE DEPOSITS, H: Deposits or surface modifications resulting from human activity (such as construction and mining)

- **Hc – Cut or Excavation:** Not used in mapping. This designation may be used for the estimated soil column not sampled in borings that are drilled in cuts or excavations rather than on natural terrain.
- **Hf – Fill and Embankments:** Road and foundation embankments, dikes and other artificial earth fills
- **Ht – Mine Tailings:** Coarse to fine-grained deposits resulting from placer mining activities
- **Hw – Water or Ice:** Not used in mapping. This designation may be used for portions of borings drilled through streams or lakes or on ice. Not used for buried massive ice zones which are included in the landform types in which they occur.

LACUSTRINE DEPOSITS, L: Generally fine grained materials laid down in lakes

- **Lt – Thaw Basins and Thaw Lakes:** Generally fine grained, organic rich deposits in lakes and depressions formed by thawing of ground ice

MARINE DEPOSITS, M: Materials laid down under an ocean and along its coasts

- **Mc – Coastal Plain Deposits:** Deposits of gravel and sand with varying amounts of silt laid down on a gently sloping surface that was formerly submerged beneath an ocean

ORGANIC DEPOSITS, O: Deposits of predominantly organic material such as peat bogs and fens

UNKNOWN ORIGIN ?: Complex or buried deposits for which insufficient information is available to allow classification

TERRAIN UNIT SYMBOLS

Terrain unit symbols appear as various combinations of individual landform types.

Surface phases are used in terrain unit symbols to indicate surface conditions that do not significantly affect soil properties at depth. For example, such surface conditions may include distinctive topography or vegetation, flooding conditions, microfeatures or lineaments etc. Because these types of surface differences generally do not reflect different soils they are not ranked at the same level as landform types or terrain units but are treated as subordinate phases of landforms. Surface phases may affect soil thermal state or ice content. They are symbolized with lower case letters in parentheses after the terrain unit symbols describing the deposits beneath the surface. For example, the symbol Ffg (ft) indicates that the map unit is a dissected alluvial-fan surface that is no longer active. The underlying deposit is coarse-grained alluvium.

The following surface phases are currently used:

- **(ft) Young Terraces or Dissected Remnants:** Former floodplain or alluvial fan surfaces that are no longer actively flooded. Terrace deposits in this phase are not significantly weathered (see landform type Fpt for older, weathered terraces).
- **(fk) – Permafrost Modified Floodplain:** A hummocky floodplain surface possibly modified by the formation and/or thawing of permafrost
- **(fa) – Aufeis Zone:** Floodplain areas affected by the formation of surface ice by the freezing of successive sheets of water emerging from springs and streams
- **(gm) – Moraine:** Irregular topography of discontinuous ridges, knolls and hummocks surrounding closed depressions on till sheets

$Gt + \frac{Gt}{Bx}$	Till sheet and till sheet over bedrock
$\frac{Fp}{GF \text{ or } L}$	Floodplain over glaciofluvial or lacustrine deposits
C + Gt?	Colluvium and questionable till sheet
$\frac{C + Cs}{Bx?}$	Colluvium and solifluction deposits over questionable bedrock
$\frac{C}{Bx} + Bx$	Colluvium over bedrock intermingled with areas of residual soil (Bx-r) over bedrock
Ffg (ft)	Dissected terrace remnant of an alluvial fan
Fp	Floodplain (Fp when used as a terrain unit is equivalent to Fp-c/Fp-r; if the Fp-c component is absent from the floodplain, as in a riverbed, Fp-r is used for the terrain unit.)
Bx	Bedrock (Bx when used as a terrain unit includes all Bx-r, Bx-w and Bx-u components, occurring as Bx-r, Bx-w, Bx-u)

Some definitions after American Geological Institute 1972 Glossary of Geology 805 p.

Portions of this explanation were prepared by Raymond A. Kreig and Associates Inc., Anchorage, Alaska

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

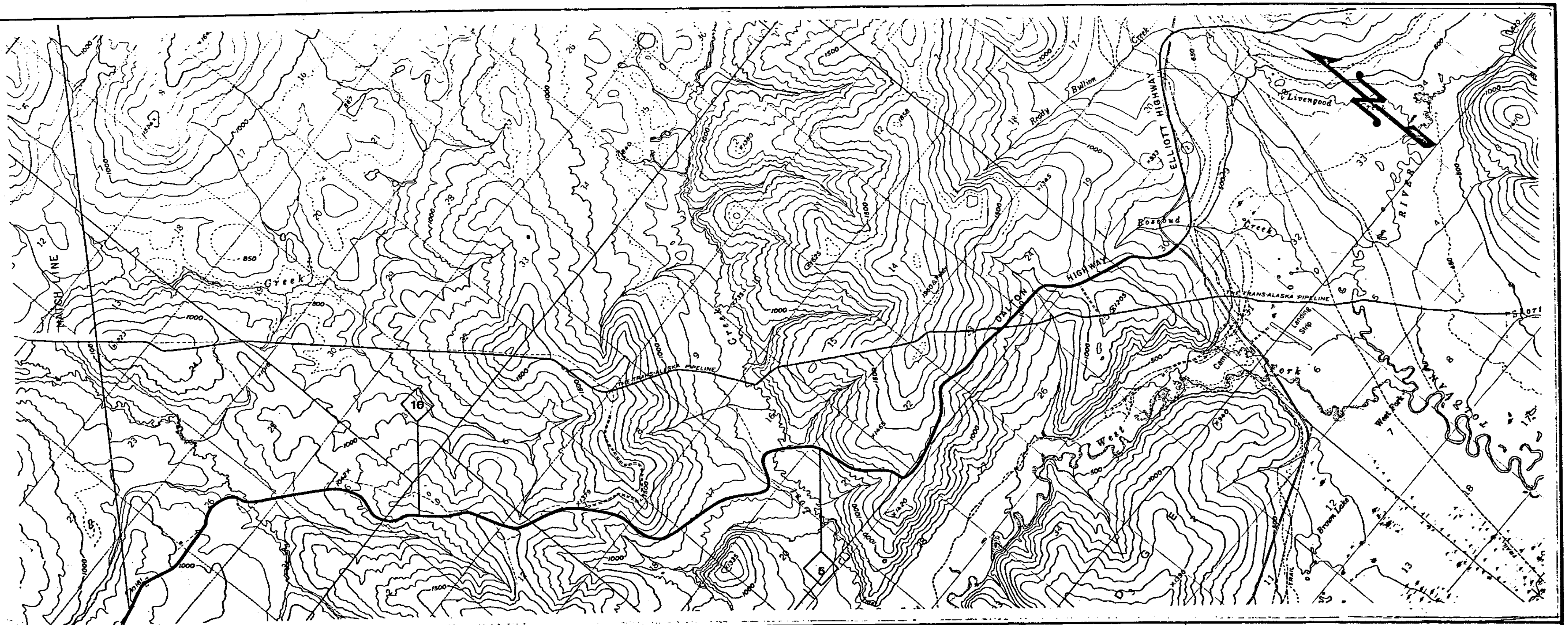
R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

TERRAIN UNIT EXPLANATION SHEET



		I-9	I-8	I-7	I-6	I-5	I-4	I-3	I-2	I-1	
SEGMENT NUMBER		I-9	I-8	I-7	I-6	I-5	I-4	I-3	I-2	I-1	
TERRAIN UNIT		Elx	Fs	Elx + Elx/Bx-w	Bx-w + Bx	Elx		Fs	Elx	Bx-w + Bx	
SOIL TYPE		ML			—	ML	—	ML (Fpa or Fpt)		—	
THERMAL STATE		GF									
FROST CLASSIFICATION		F4			—	F4	—	F4		—	
THAW STRAIN POTENTIAL		H			H,L	H				H,L	
COMMENTS				ICE-RICH SOILS AND SIDE-HILL GRADE							

PHYSIOGRAPHIC SUBPROVINCE (PSP)-3C

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abandoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

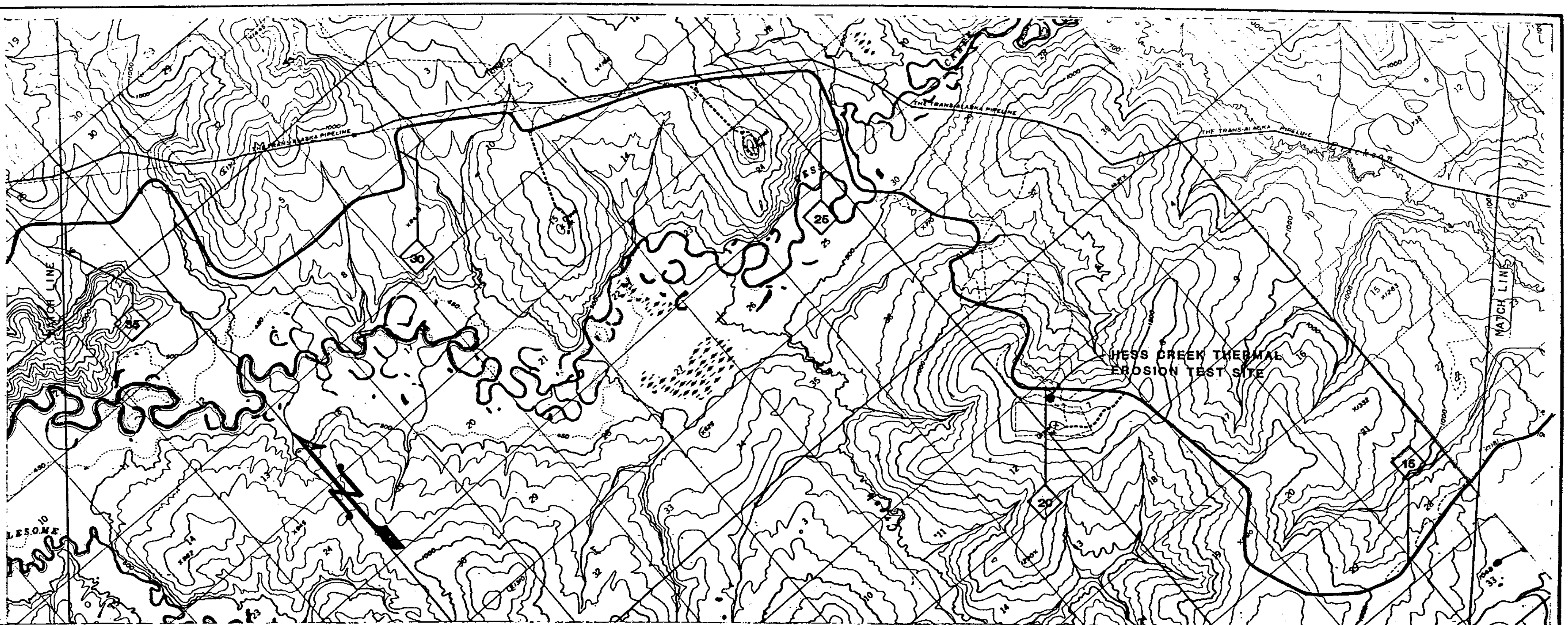
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984

SHEET 1 OF 26



SEGMENT NUMBER	2-15	2-14	2-13	2-12	2-11	2-10	2-9	2-8	2-7	2-6	2-5	2-4	2-3	2-2	2-1
TERRAIN UNIT	Fs	Bx-w+Bx	Fs	El?/Bx	Elx+Fs	Elx	Elx+Elx?/Bx	Elx		Fpm	Elx	Bx-w+Bx	Elx	Fs	Elx
SOIL TYPE	ML	—	ML						Bx-w+El	ML/SM,GM	ML	—	ML		
THERMAL STATE	GF				D	GF	D	GF							
FROST CLASSIFICATION	F4	—	F4						-	F4/F3	F4	—	F4		
THAW STRAIN POTENTIAL	H	H,L	H							M	H	H,L	H		

COMMENTS

Kokrine-Hodzana Highlands | Rampart Trough | PSP-3B | Livengood Upland

PSP-3A

26.3 MI

21.4 MI. — MASSIVE ICE AND SIDEHILL GRADE

PSP-3C

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

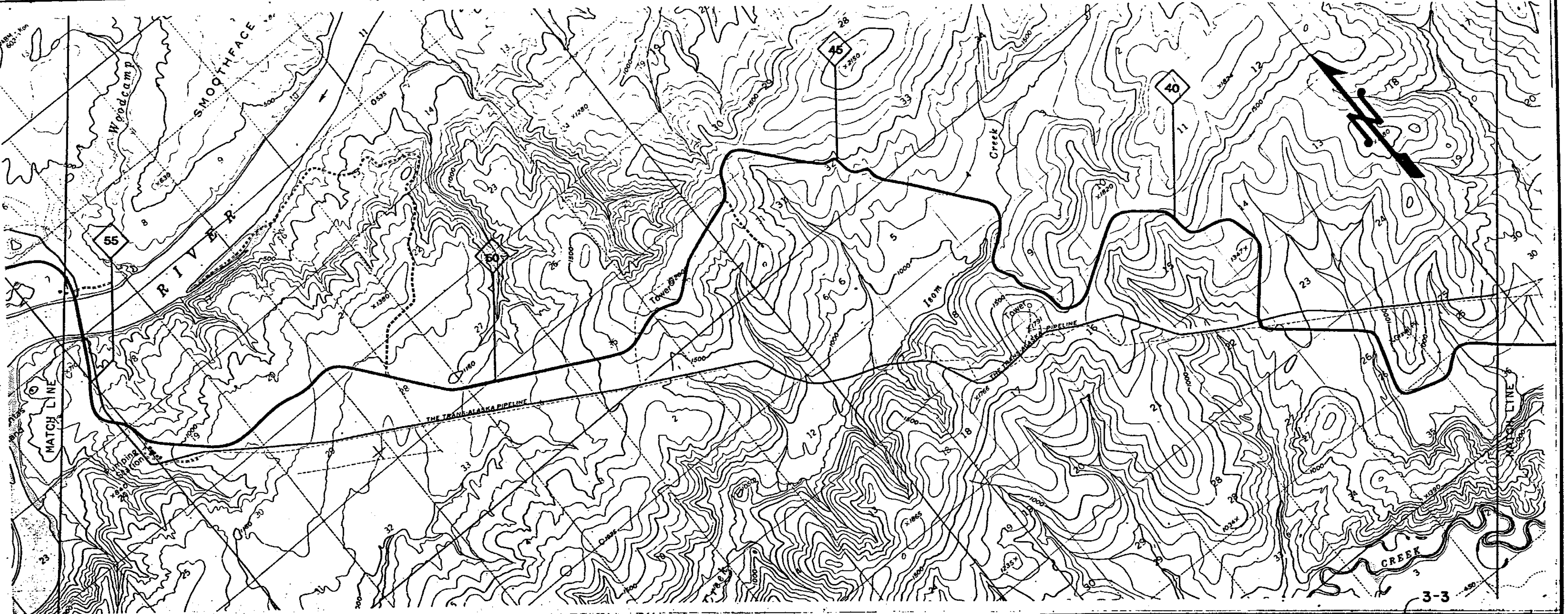
STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984



	3-15	3-14	3-13	3-12	3-11	3-10	3-9	3-8	3-7	3-6	3-5	3-4	3-3	3-2	3-1
SEGMENT NUMBER	3-15	3-14	3-13	3-12	3-11	3-10	3-9	3-8	3-7	3-6	3-5	3-4	3-3	3-2	3-1
TERRAIN UNIT	Fpa-c / Fp-r	Fp-r / Bx-w	Elx	Elx / Bx-w	Bx-w+Bx	Elx	Bx-w + Bx		Fs	Bx-w	Bx+Fs / Bx	Fs + Bx	Elx	Elx? / Bx	Fs
SOIL TYPE	ML / GW, GP-GM, SW, SP-SW	GW-, GP-GW, SW-, SP-SM	ML		—	ML	—	BX-W+Fs	ML	—	ML				
THERMAL STATE	GF	GA	GF												
FROST CLASSIFICATION	F4/FI	FI	F4		—	F4	—		F4	—	F4				
THAW STRAIN POTENTIAL	H/L	L/H	H		H,L	H	H,L	H		H,L	H				
COMMENTS															

PSP-3A

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

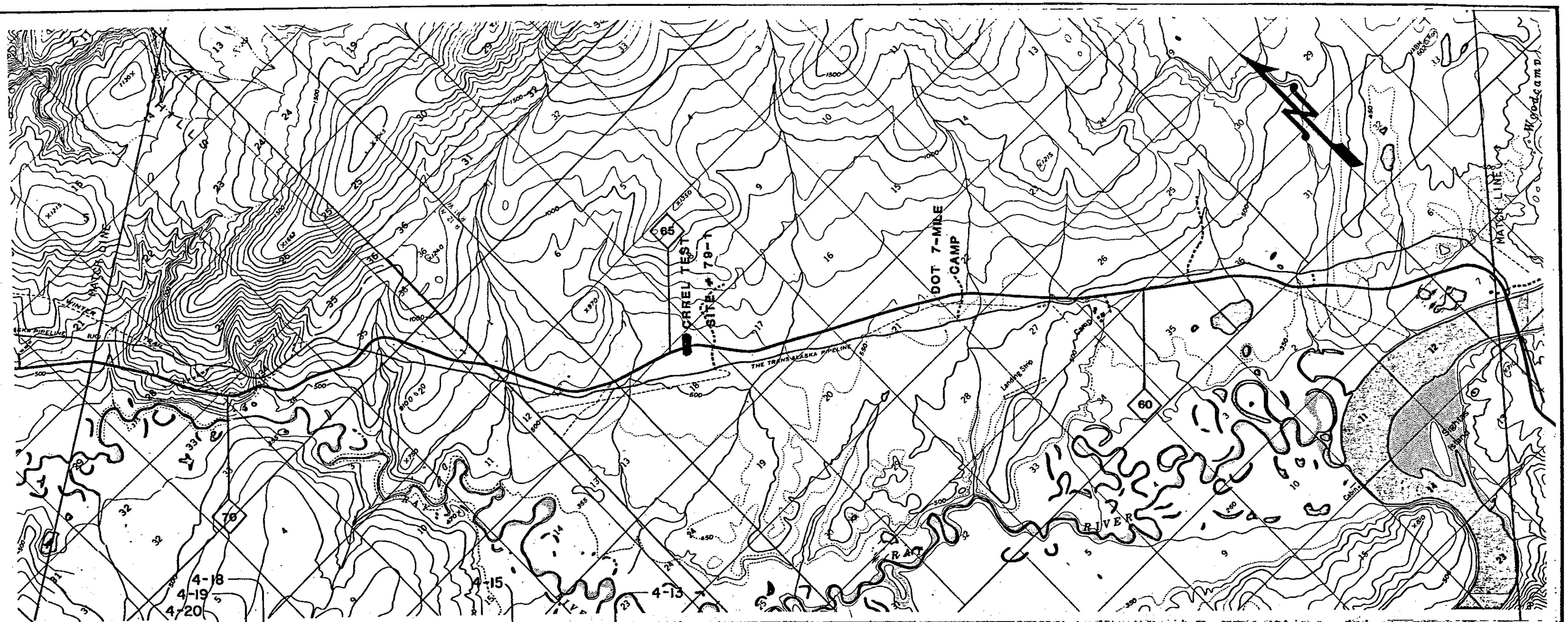
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984

SHEET 3 OF 26



SEGMENT NUMBER	4-23	4-22	4-21				4-17	4-16		4-14		4-12	4-11	4-10	4-9	4-8	4-7	4-6	4-5	4-4	4-3	4-2	4-1	
TERRAIN UNIT	Fs + Elx / Fpt or Bx	Elx + Fs	Bx	Fpt or Bx	Bx		Bx	Bx-r / Bx-w		Bx-w + Fs		Fs	Elx? / Bx-r?	Elx + Fs / Bx-r?	Fs+Elx / F?	Elx / Bx-r?	Fs + Elx / F?	Elx+Fs	Fs	Elx + Fs	Elx	Fs		Fpa-c / Fp-r
SOIL TYPE		ML	—			Fs / Bx	ML	—	Fs / F?	ML / SM;GM;ML	Elx / Bx	ML	ML / SM;GM;ML			ML	ML / SM;GM;ML	ML			ML / GW-,GP-GM, SW-,SP-SW			
THERMAL STATE		GF						D				GF				D	GF	D	GF					
FROST CLASSIFICATION		F4	—				F4 —	F4/F4,F3		—		F4		F4/F4,F3		F4	F4/F4,F3		F4					F4/Fl
THAW STRAIN POTENTIAL		H	L				H/L L	H		H/M		H			H/M	H	H/M		H					H/L
COMMENTS																								

PSP-3A

EXPLANATION

LEGEND

- ——— Dalton Highway
- ——— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

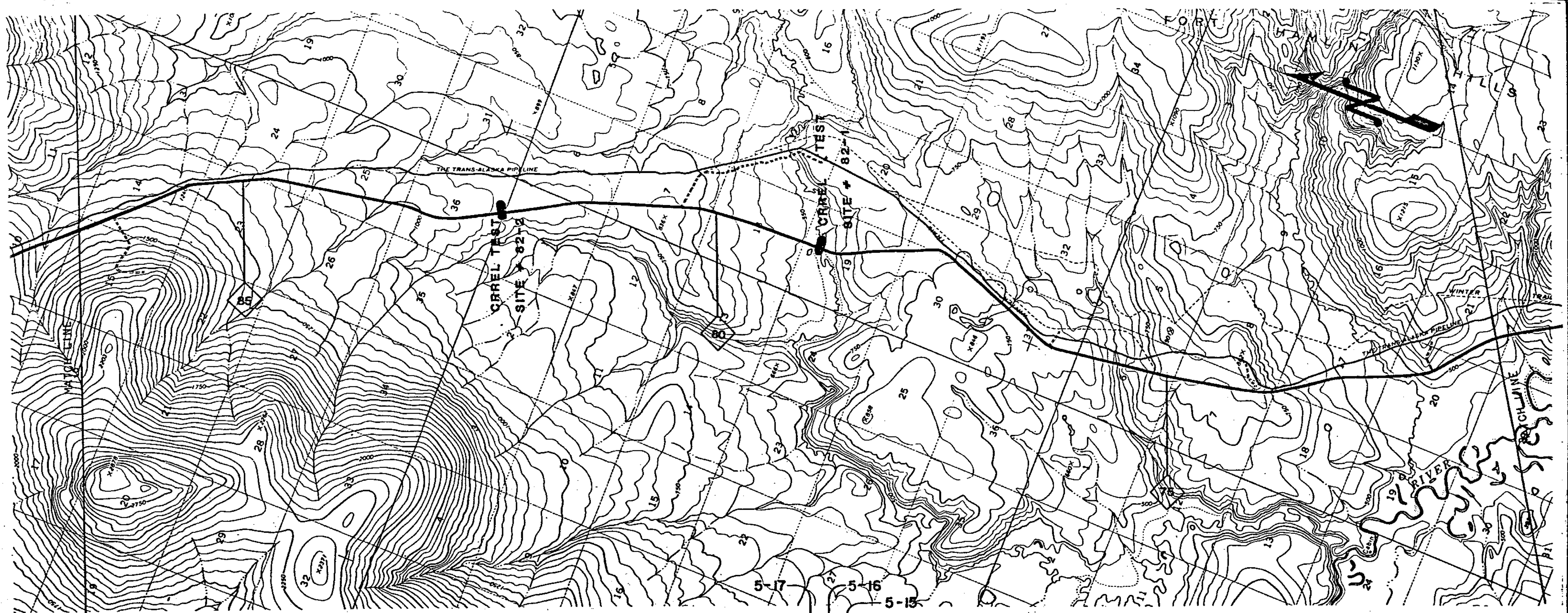
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES
1/2 0 1

REVISION 0

DATE September 1984

SHEET 4 OF 26



SEGMENT NUMBER	5-21	5-20	5-19	5-18	5-17	5-16	5-15	5-14	5-13	5-12	5-11	5-10	5-9	5-8	5-7	5-6	5-5	5-4	5-3	5-2	5-1	
TERRAIN UNIT	•	Fst + C?	Elx?	Fs	•	Fpa	Bx	Fpt	Elx / Fpt	Elx / Fpt	O+Fs / Fpt	Elx? / Fpt	Fpt / Bx	Fs / Bx	Fpt + Elx	Elx?	Fpt	Elx	Fpa-c? + Fs	Fs + Elx	•	Fs + Elx / Fpt or Bx
SOIL TYPE	—	Bx-r / Bx-w	ML	Fs / Elx? + Fpt?			—	ML														
THERMAL STATE	GF				GA		•	GF			D	GF	D	GF			D		GF			
FROST CLASSIFICATION	—	F4					—	F4														
THAW STRAIN POTENTIAL	L	H					L	H														
COMMENTS																						

PSP-3A

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

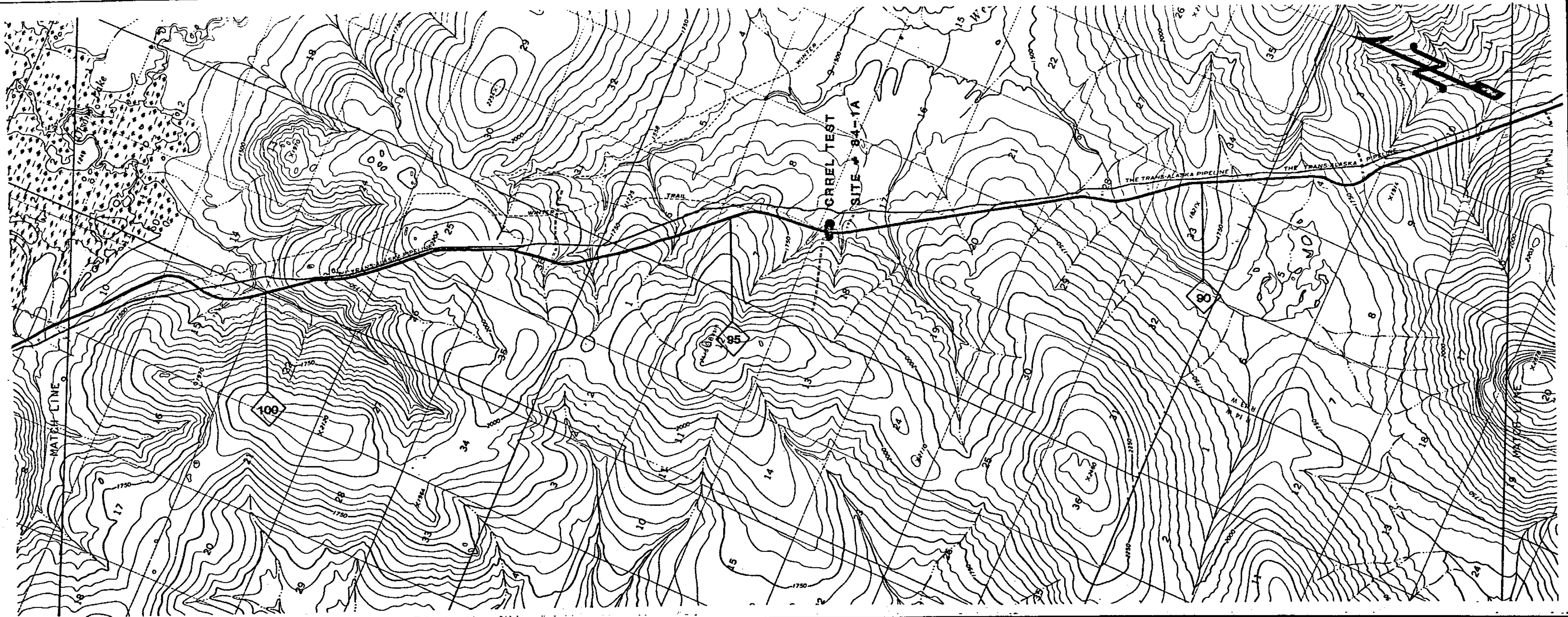
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES: 1/2 0 1

REVISION 0

DATE September 1984

SHEET 5 OF 26



SEGMENT NUMBER	6-15	6-14	6-13	6-12	6-11	6-10	6-9	6-8	6-7	6-6	6-5	6-4	6-3	6-2	6-1
TERRAIN UNIT	C?	Bx-r / Bx-w	Fs / Bx	Bx-r / Bx-w	Bx-r / Bx-w	Bx-r / Bx-w	Bx-r / Bx-w	Fs+C? / Bx-w	Bx-r / Bx-w	C?	Bx-r / Bx-w	Fs + C?	Bx-r / Bx	Fs + C?	Bx-r / Bx-w
SOIL TYPE	GM;SM	—	ML	—				ML	—	GM;SM	—	ML	—	ML	—
THERMAL STATE	GF												D	GF	
FROST CLASSIFICATION	F3,F4	—	F4	—				F4	—	F3,F4	—	F4	—	F4	—
THAW STRAIN POTENTIAL	M		H	L				H/L	L	M	L	H	L	H	L
COMMENTS															

PSP-3A

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- ElL - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

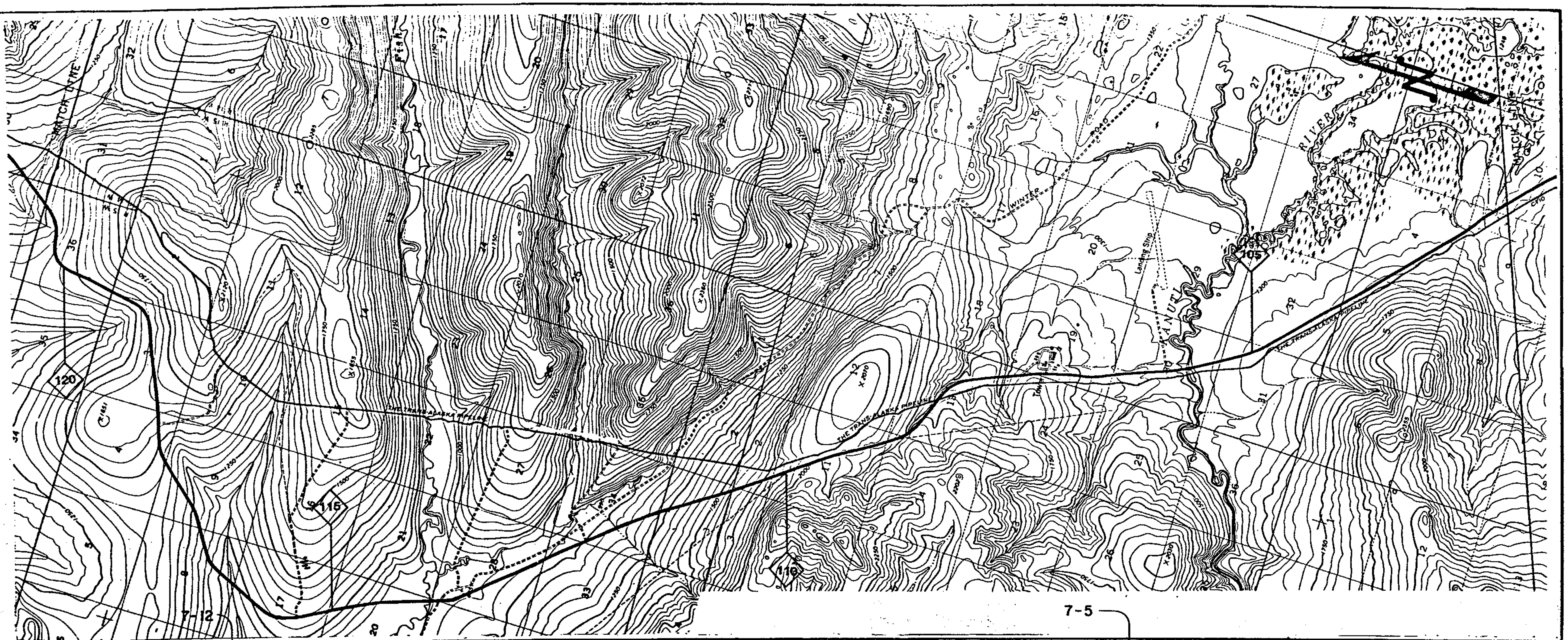
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES: 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 6 OF 26



SEGMENT NUMBER	7-14	7-13	7-12	7-11	7-10	7-9	7-8	7-7	7-6	7-5	7-4	7-3	7-2	7-1
TERRAIN UNIT	Bx-w	Bx + Bx-w		Bx-w + Fs / Bx	Fp + Fs	Fs / Bx + Bx	Bx + Bx-w	Bx-w + Bx	Bx-r / Bx	Bx-r	Fs + Fp-r / Bx-r	Bx-r / Bx-w	Fs / C? + F?	C
SOIL TYPE	—		Fs / Bx	ML			—				ML	—	ML / GM;SM	GM;SM
THERMAL STATE	D										GF	D	GF	
FROST CLASSIFICATION	—			F4			—				F4	—	F4/F3,F4	F3,F4
THAW STRAIN POTENTIAL	L		H/M	H/L	M	H/L	L				H	L	H/M	M
COMMENTS					114.0 Mi Fish Creek		PSP-3A				105.7 Mi Kanuti River			

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M

R&M CONSULTANTS, INC.

ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

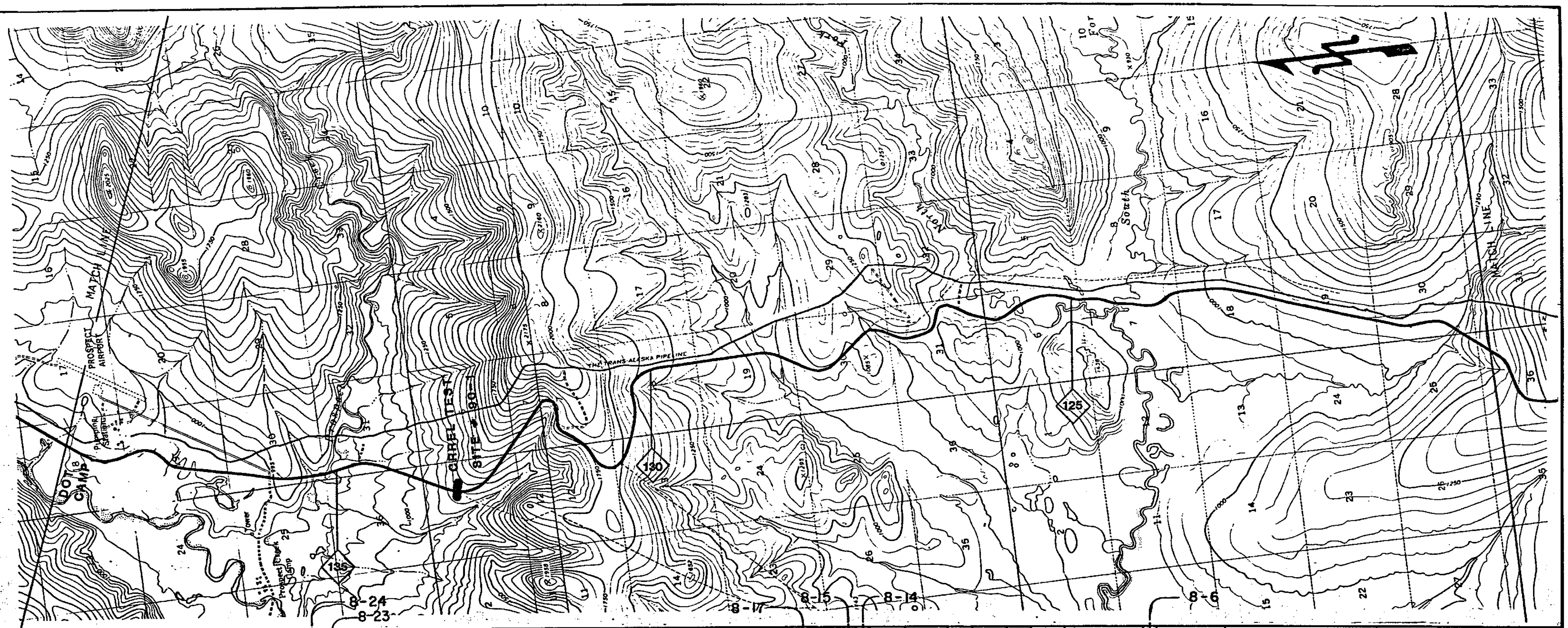
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES: 1/2 0 1

REVISION 0

DATE September 1984

SHEET 7 OF 26



SEGMENT NUMBER	8-26	8-25	8-24	8-23	8-22	8-21	8-20	8-19	8-18	8-17	8-16	8-15	8-14	8-13	8-12	8-11	8-10	8-9	8-8	8-7	8-6	8-5	8-4	8-3	8-2	8-1
TERRAIN UNIT	Fs / G+GF	Gt / Bx?		Fs / Bx	Fs / G+GF	Bx	Bx+Bx-w	Bx		Fs / Bx	Bx		Bx	Fs / Bx	Bx	Fs / Fp	Bx	Fpm	Fpa	Fpm		Bx+Bx-w	Bx-r / Bx-w / Bx	Bx+Bx-w	Fs	Bx
SOIL TYPE	ML / GM,SM SM,GM			Fs / GF	ML / GM,SM		—	Fp+Fs / Bx	Fs / Bx		—	ML		ML	—	ML	—		ML, SM		Fpa		—		ML	—
THERMAL STATE						GF												GA	D	GA			D			
FROST CLASSIFICATION	F4/F2,F3	F2–F4		F4/F2,F3							—	F4	—	F4	—	F4	—		F4, F3				—		F4	—
THAW STRAIN POTENTIAL	H/M	H/L		H/M			L		H		L	H	L	H	L	H	L		H				L		H	L
COMMENTS			135.1 Mi Prospect Creek					PSP-3A												124.7 Mi South Fork Bonanza Creek						

EXPLANATION

LEGEND

- Dalton Highway
- Trans-Alaska-Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

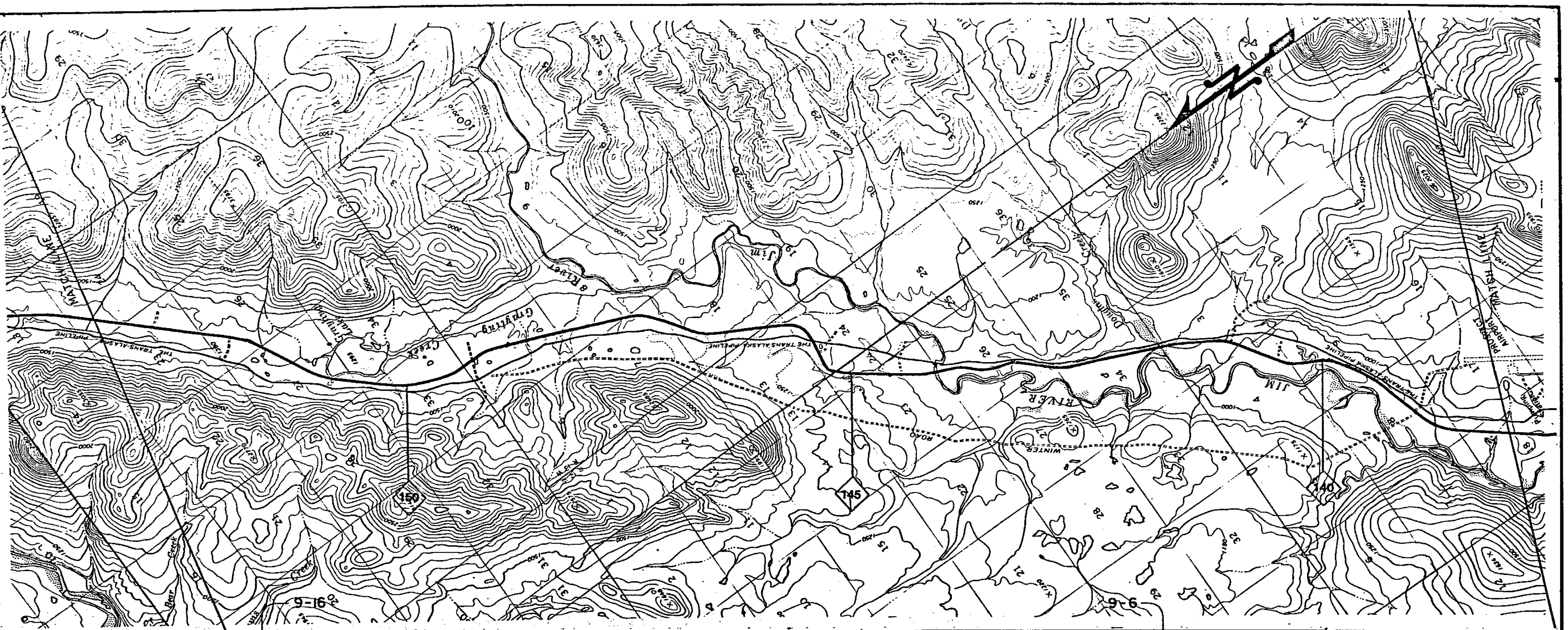
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES
1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 8 OF 26



SEGMENT NUMBER	9-17	9-16	9-15	9-14	9-13	9-12	9-11	9-10	9-9	9-8	9-7	9-6	9-5	9-4	9-3	9-2	9-1
TERRAIN UNIT	Fs / G+GF		Fs / G+GF	Fs / G+GF	Fs / G+GF	G+GF	G+ Fs / GF	Fs / Fp+GF	Fp / Fp+GF	Fs / Fp	Fs / GF?		Fs / G+GF	Fp / GF?	Fp? / GF?	Fsf / Fp	Fp / GF?
SOIL TYPE		Fs + Ff / G + GF		ML / GM,SM		GM,SM	ML / GW-, GP-GM, SW-, SP-SM					Fp + GF? / G + L				ML	
THERMAL STATE	GF																
FROST CLASSIFICATION	F4/F2,F3					F2,F3	F4/F1									F4	
THAW STRAIN POTENTIAL	H/M					M	H/M										
COMMENTS	PSP-3A								144.1 Mi Jim River					140.1 Mi East Fork Jim River			

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glacipfluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- \- Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

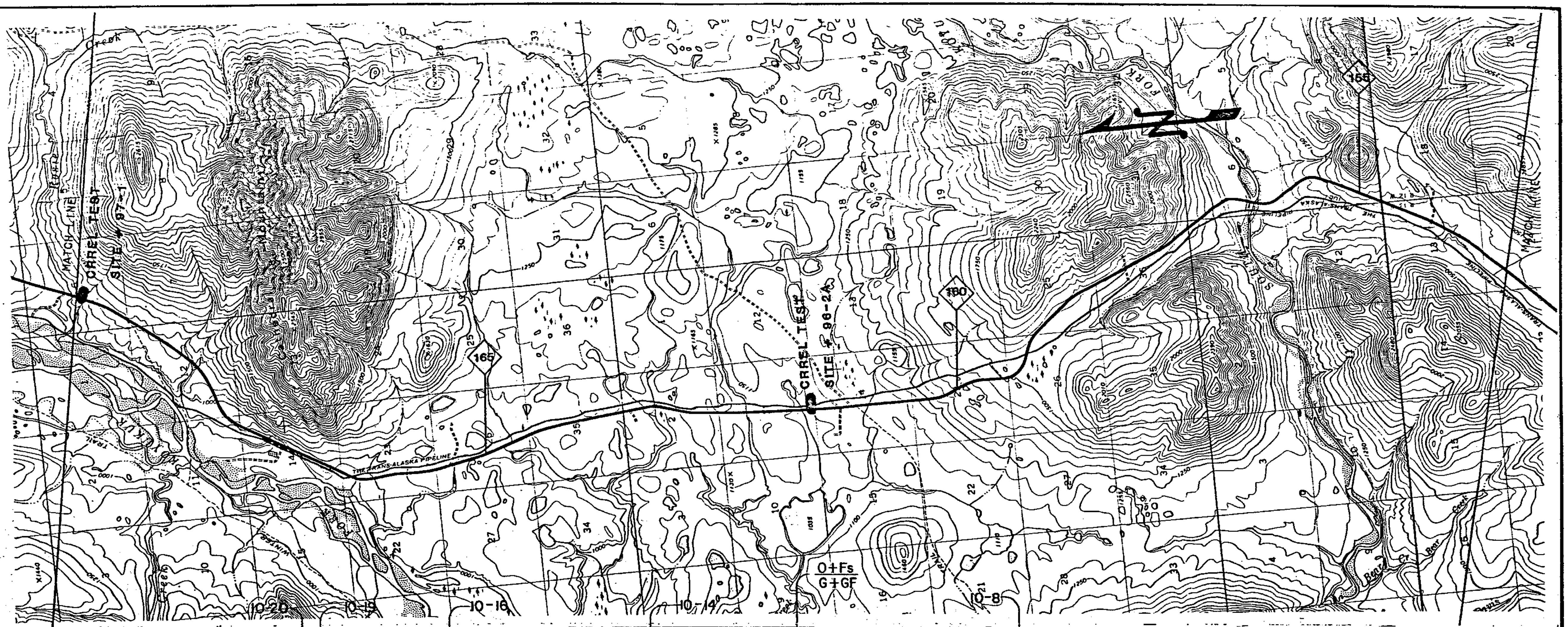
R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES	REVISION	SHEET
1 ½ 0 1	0	9 of 26
	DATE September 1984	



SEGMENT NUMBER	10-22	10-21	10-20	10-19	10-18	10-17	10-16	10-15	10-14	10-13	10-12	10-11	10-10	10-9	10-8	10-7	10-6	10-5	10-4	10-3	10-2	10-1
TERRAIN UNIT	Gt	Fp-c / Fp-r	Fp / Bx	Fs / G	Fp-c / Fp-r	Fs / G+GF	O / G	Fs / G+GF	O / G	Fs / G+GF		G+ GF	Fs / G+GF	GF	O / L	Fs / G+GF	G+GF / Bx	Fs? / G+GF	Fp / L?	Fs / G+GF	Fs / Gt?	Fs / G+GF
SOIL TYPE	SM,GM	ML / GW-,GP-GM,SW-,SP-SM				ML / GM, SM	OL / GM	ML / GM, SM	OL / GM	ML / GM, SM	OL / GM	GM, SM	ML / GM,SM	GW,SW	OL	ML / GM,SM	GM,SM	ML / GM,SM	GM,SM	ML / SM,GM		
THERMAL STATE	GA GF	D	S	GF	D	GF								F4/F2,F3	D	GF F4/F2,F3			D	GF		S D GF
FROST CLASSIFICATION	F2-F4	F4/F1-F4				F4/F2, F3								F2,F3		F4/F2,F3	F2,F3		F1	F4/F2, F3		
THAW STRAIN POTENTIAL	H	H/M												M F4	H	H/M	M	H/M	M/H	H/M		
COMMENTS	PSP-2D															Chandalar Ridge and Lowland Section			Kokrine - Hodzona Highlands 156.3 MI	PSP-3A		

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

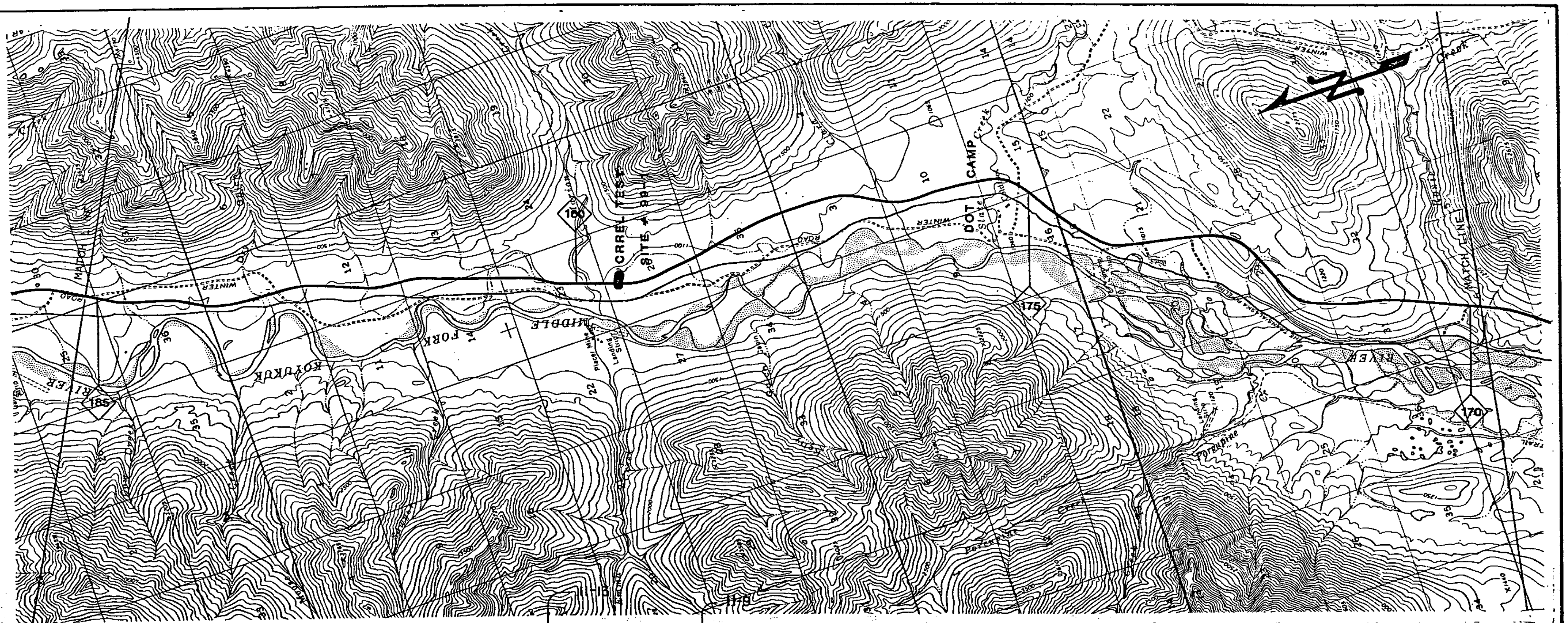
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 10 OF 26



SEGMENT NUMBER	11-19	11-18	11-17	11-16	11-15	11-14	11-13	11-12	11-11	11-10	11-9	11-8	11-7	11-6	11-5	11-4	11-3	11-2	11-1
TERRAIN UNIT	Fs / Gt	Fs / G+GF	Fs+Ff / G+GF	Fs / G+GF	Fp-c+Fs / Fp-r	Fp-r / GF		Fp-c / Fp-r	Fp-r	Fpa-c+Fp-c / Fp-r		Fs / Fp-r, Fs / GF	Ff	Fs / Ff+Fp	Fp	Fs / Fp+Fp-r	Fp-r	Gt / Bx	Gt
SOIL TYPE	ML / SM,GM	ML / GM,SM				SW-SP SM, GW-GP GM	Ffg	ML / SW,-SP SM, GW-GP GM					SM,GM,ML	ML / GM,SM	GM,SM	ML / SM,GM	SM,GM	SM,GM	
THERMAL STATE	GF	D		GF	S					GF	D	GF			GA	D		GF	
FROST CLASSIFICATION	←	F4/F2-F4	F4/F2,F3		F4/F1	F1		F4/F1	F1	F4/F1			F4,F3	F4/F1,F2	F1,F4	F4/F1	F1	F2,F4	
THAW STRAIN POTENTIAL	H	H/M			H/L	L/M	M	H/L	L	H/M							M	H/L	H
COMMENTS								180.0 MI Marion Creek		PSP-2C			175.3 MI Slate Creek		Central Brooks Range	Chandalar Ridge and Lowland Section 174.6 MI		PSP-2D	

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

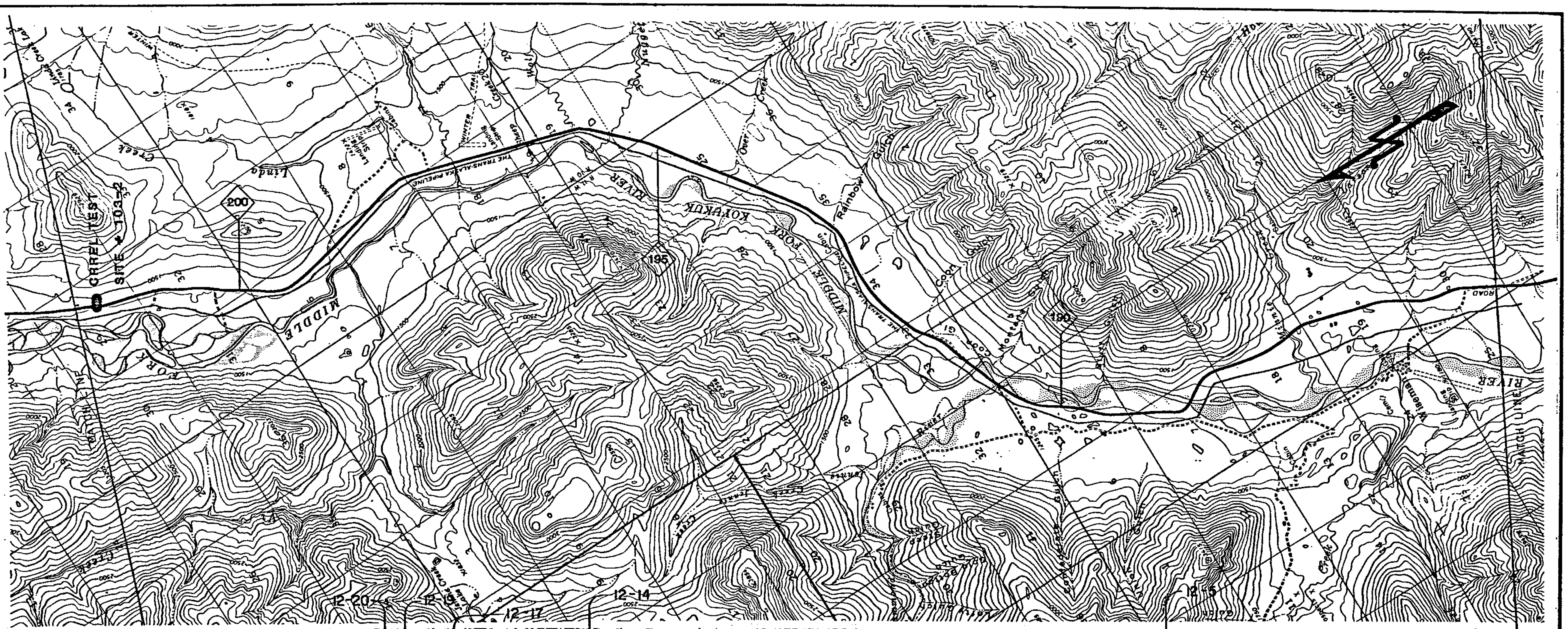
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1/2 0 1

REVISION 0

DATE September 1984

SHEET 11 OF 26



SEGMENT NUMBER	12-23	12-22	12-21	12-20	12-19	12-18	12-17	12-16	12-15	12-14	12-13	12-12	12-11	12-10	12-9	12-8	12-7	12-6	12-5	12-4	12-3	12-2	12-1
TERRAIN UNIT	Fs/Gt	Fs/Gt/Bx-w	Fs/Gt	Fs/Bx	Gt	Ffg	Fp	Ffg	Fs + Ff	Fs/Fp-r	Ffg/GF	Fs/GF	Fp-c+Fpa-c/Fp-r	Fs+Ff/GF	Fp-c/Fp-r/GF	Fp-c/Fp-r/L	Fp-r	Fp-c/Fp-r/L	Fp-r	Fs/Gt	Fp-r	Gt	Fs/Gt
SOIL TYPE	ML/SM, GM					SW-, SP-SM-, GW-, GP-GM-, ML										ML	GW-, GP-GM; SW-, SP-SM	ML		ML/SM, GM	GW-, GP-GM; SW-, SP-SM	SM, GM	ML/SM, GM
THERMAL STATE	GF				S	D	S	D	GF				D / GF		D	S	GA / S	S / GA	GA	D	S	D	
FROST CLASSIFICATION	F4/F2-F4		F1-F4		F1		•	F1	F4		F1	F4/F1			F4		F1	F4	F4/F2-F4		F1	F4/F2-F4	
THAW STRAIN POTENTIAL	H		H, M		M		•	M	H		M	H/M, L			H/M	H/L/H	L	H/L/H	L	H	L	H	

COMMENTS

MASSIVE ICE, PINGOS TALIKS AND CROSS DRAINAGE (12-23 to 12-19)

197.3 MI Gold Creek

196.5 MI Sheep Creek

PSP – 2C

191.0 MI Middle Fork Kuyukuk River

190.7 MI Hammond River

188.6 MI Middle Fork Kuyukuk River

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

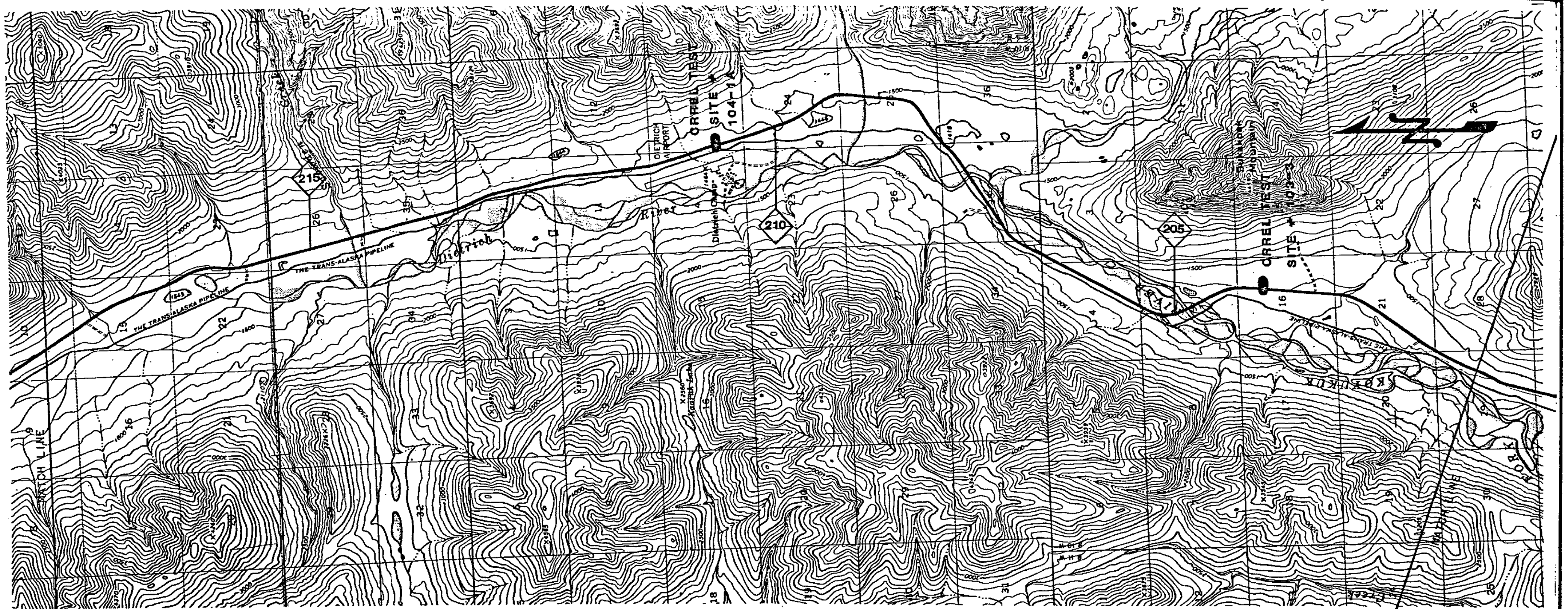
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 12 OF 26



SEGMENT NUMBER	13-24	13-23	13-22	13-21	13-20	13-19	13-18	13-17	13-16	13-15	13-14	13-13	13-12	13-11	13-10	13-9	13-8	13-7	13-6	13-5	13-4	13-3	13-2	13-1
TERRAIN UNIT	Fs/Gt	Ff	Fs/Gt	Ff+Fs/GF?	Ffg	Fs	Fs/Gt	Fs/Gt/Bx	Ffg	Fs/Ffg	Fpa-c/Fp-r	Fs/Ff+Ffg	Fs	Ffg	Fs/Ffg	G+F	Fp/GF+L	Ffg	Fp+Fs/GF+L	Fp/GF+L	Ff+Fs/Gt	Fs/Gt	Gt	Fs/Gt
SOIL TYPE	ML, SM, GM															GM, SM		ML/SM, GM					SM, GM	ML/SM, GM
THERMAL STATE	GF			S, GF	D	GF			S	GF				GA	GF		GA	D		GA	D		GF	
FROST CLASSIFICATION	F4/F1-F4															F2-F4		F4/F2-F4					F2-F4	F4/F2-F4
THAW STRAIN POTENTIAL	H/H,M				M	H/H,M			M	H/H,M				M	H/M	H,M		M	H					
COMMENTS	MASSIVE ICE (EXCEPT AT GRANULAR ALLUVIAL FANS) AND SIDEHILL EMBANKMENT									PSP-2C									205.1 MI Middle Fork	204.9 MI Koyukok River	MASSIVE ICE, PINGAS, TALIKS AND CROSS DRAINAGE			

EXPLANATION

LEGEND

- Dalton Highway
- Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

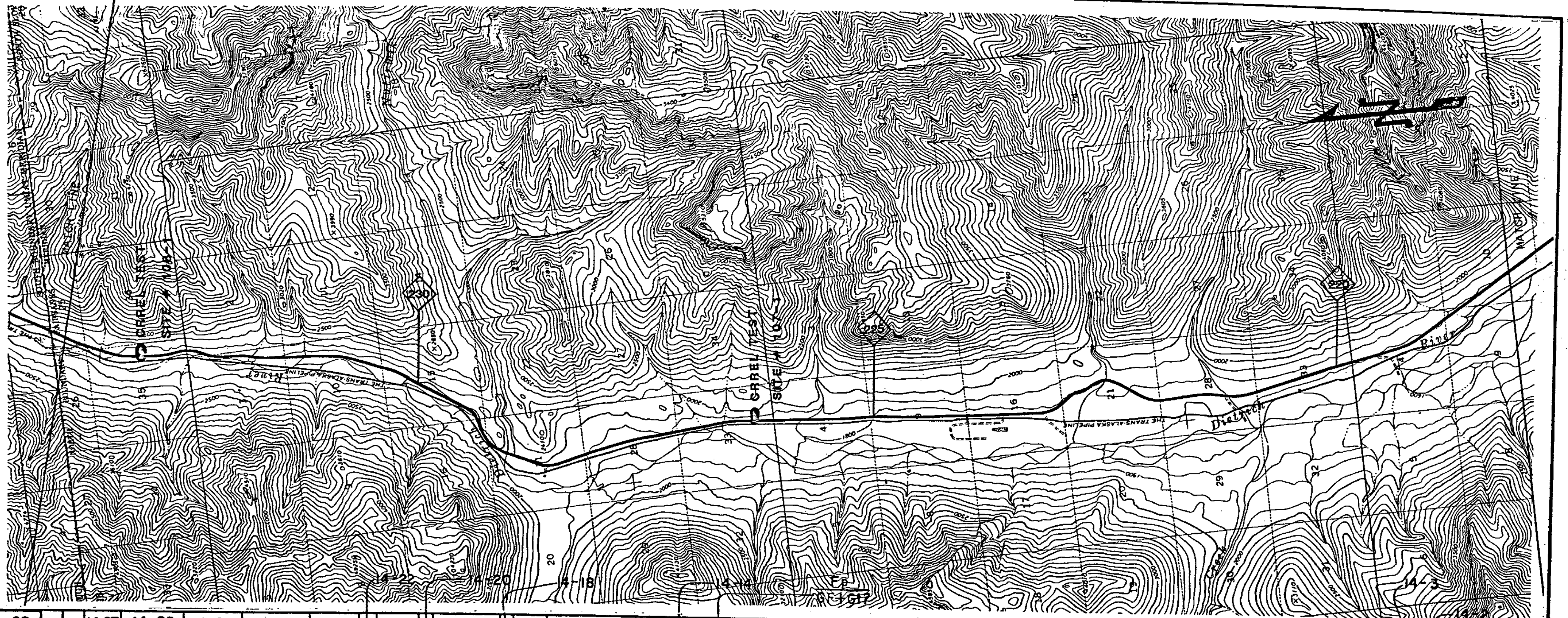
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984

SHEET 13 OF 26



SEGMENT NUMBER	14-28	14-27	14-26	14-25	14-24	14-23	14-21	14-19	14-17	14-16 14-15	14-13	14-12	14-11	14-10 14-9	14-8	14-7
TERRAIN UNIT	Fp-r / GF	Ffg	Ff + Fpc / Fp-r	Fpb-r / Bx	Ffg	C+Gt / Bx	C+Gt / Bx	Gt / Bx	Gt / Bx	Fpb / GF	Gt / Bx	Fpb-r / GF	Gt	Ffg	Fpb-r; Fs / Gt	Ffg	Gt
SOIL TYPE	SW-,SP-SM; GW-, GP-GM	GM, SM, ML	Fpb-r	ML / SW-SM, GW-GM	SM, GM	GW-, GP-GM, SW-, SP-SP	ML/SM	SM, GM									
THERMAL STATE	D	GA	D	GF	D	S	D	GF	D	S	D	GF					
FROST CLASSIFICATION	NFS - F3	F2-F4	F4/F2, F3	F1, F4	NFS, F1	F4	NFS, F1	F2-F4	F1								
THAW STRAIN POTENTIAL	L/M	M	H, M	M	H	M	H	M	H	M	H	H, M	M	H	M		
COMMENTS	PSP-2C																

SEGMENT NUMBER	14-6 14-5	14-4	14-3	14-2	14-1
TERRAIN UNIT	Fs / Gt/Bx	Fs / Gt/Bx	Fs / Ff	Ff	Fs / Gt
SOIL TYPE	Ffg / Bx	ML / SM, GM			
THERMAL STATE	S	GF			
FROST CLASSIFICATION	F4/F2-F4				
THAW STRAIN POTENTIAL	H				
COMMENTS	MASSIVE ICE (EXCEPT AT GRANULAR FANS) AND SIDEHILL EMBANKMENT				

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

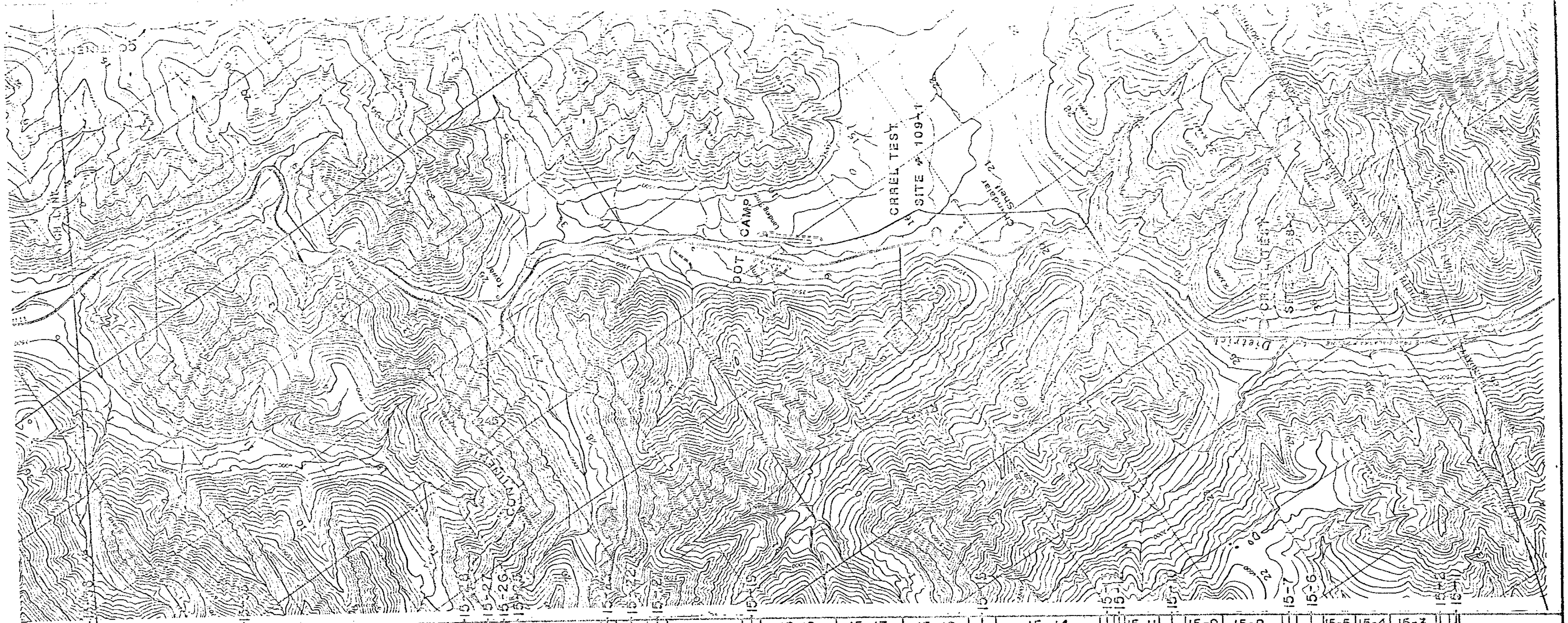
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1/2 0

REVISION 0

DATE September 1984

SHEET 14 of 26



Row	Entries (left to right)
SEGMENT NUMBER	15-35, 15-34, 15-33, 15-32, 15-31, 15-30, 15-29, 15-28, 15-27, 15-26, 15-25, 15-24, 15-23, 15-22, 15-21, 15-20, 15-19, 15-18, 15-17, 15-16, 15-15, 15-14, 15-13, 15-12, 15-11, 15-10, 15-9, 15-8, 15-7, 15-6, 15-5, 15-4, 15-3, 15-2, 15-1
TERRAIN UNIT	Ca + Gt + Ct; Ffg; (Gt + C + Ca) / Bx?; Fpb-r + Ct + Ff + Ca; Fpb-r / G or F; Gt; Gt / Bx; Gt / Bx + Bx; F + GF
SOIL TYPE	GM, SM, ML; ← SW-, SP-SM GW-, GP-GM GM, SM, ML; GM, SM, ML, SW-SM, GW-GM; SW-SM, GW, GM; SM, GM; SM; GM; ML; GW-, GP-GM, SW-, SP-SM
THERMAL STATE	GF; D; GF; D; GF; D; GF; S; GF; S; D
FROST CLASSIFICATION	F4; NFS-F4; FI-F4; FI-F4
THAW STRAIN POTENTIAL	H; H, M, L; H, M, L; H/M, L; H; H, M, L
COMMENTS	ATIGUN PASS: STEEPER GRADES, SIDEHILL, SOME UNSTABLE SIDE SLOPES; PSP-2C; SIDEHILL, STEEPER GRADE IN FROZEN GROUND

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

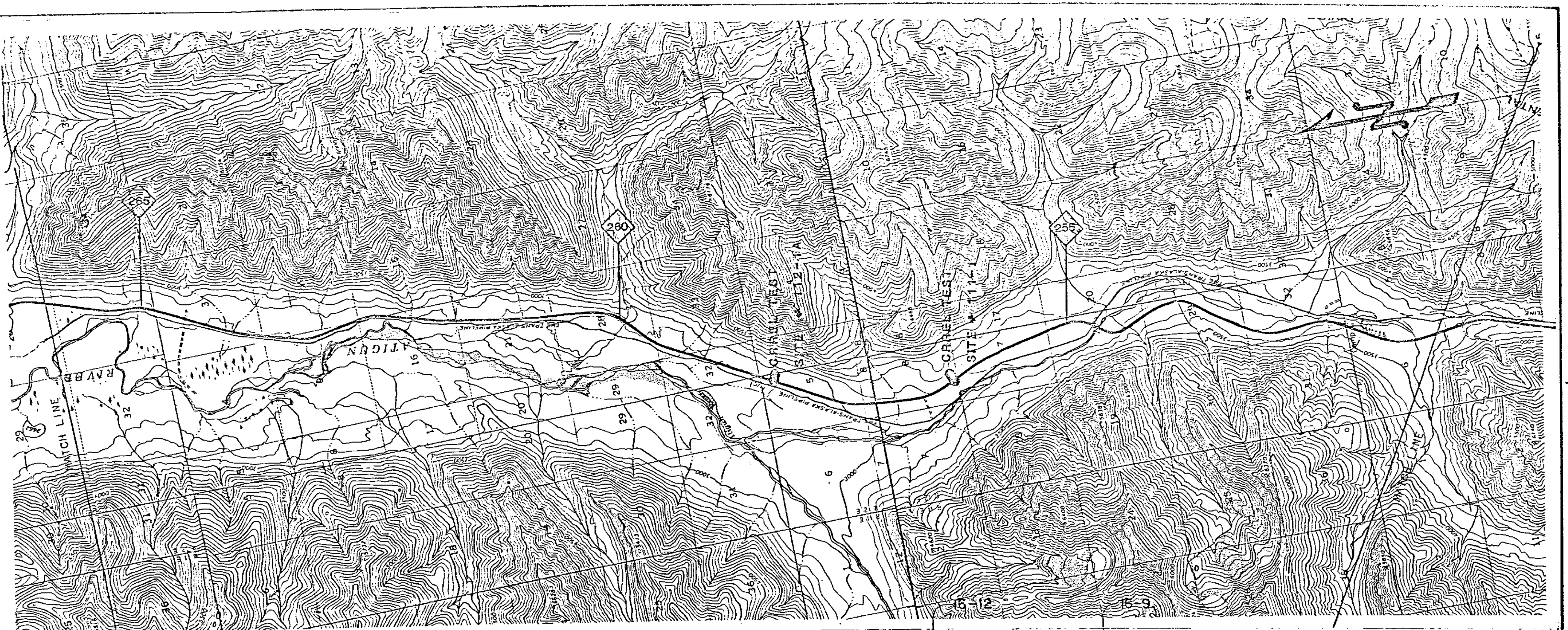
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1/2 0 1

REVISION 0

DATE September 1984

SHEET 15 OF 26



Row	Entries (left to right)
SEGMENT NUMBER	16-23 · 16-22 16-21 · 16-20 16-19 · 16-18 6-17 · 16-16 16-15 · 16-14 · 16-13 · 16-11 · 16-10 · 16-8 · 16-7 · 16-6 · 16-5 · 16-4 · 16-3 · 16-2 · 16-1
TERRAIN UNIT	Fs/F+L · Ff+Cm · Fs+Ff+Cm · Gt+C · Ff+Cm · Ffg · Fs+Gm · Ffg · Fs/Gt · Ffg · Ca+Ffg · C+Ca/Gt · Ffg+Ca · C/Gt · Fpb · Ca+Ffg
SOIL TYPE	ML/SM,GM · F+L · GM,SM,ML · SM GM · Fs+Cm+Ff · GM,SM,ML · Ff+Cm+Ffg · SW-,SP-SM; GW-,GP-GM · ML · SM,GM · Gt · Fpb · Ffg+Ca · C/Bx+Gt · GM,SM,ML
THERMAL STATE	GF · SW-,SP-SM; GW-,GP-GM · ML/SM,GM
FROST CLASSIFICATION	F4 · F4 · F2-F4 · F4 · F1 · F4 · F1 F2-F4 · F4/F2-F4 · F1 · F2-F4
THAW STRAIN POTENTIAL	H · M · H · M · H · H/M · M · H-M
COMMENTS	PSP-2C · 254 MI Atigun River

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

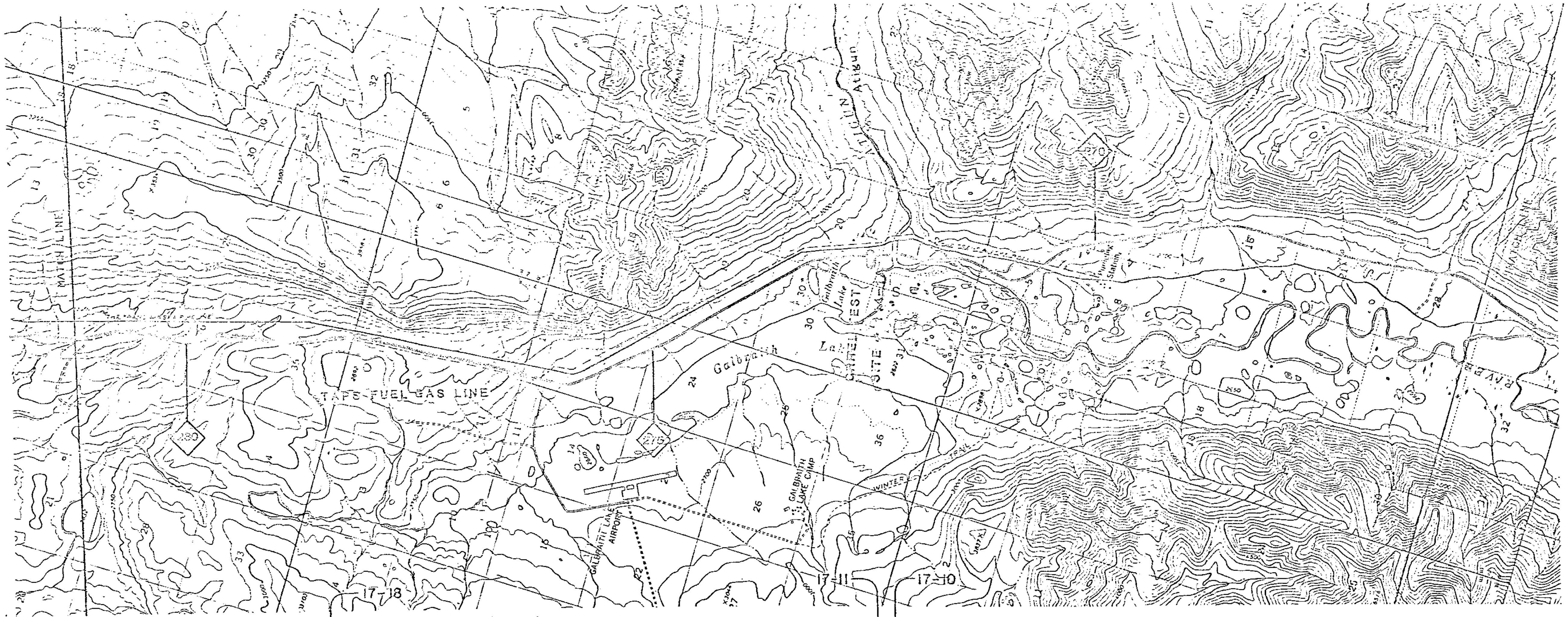
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984

SHEET 16 OF 26



	17-20	17-19	(17-18)	17-17	17-16	17-15	17-14	17-13	17-12	(17-11)	(17-10)	17-9	17-8	17-7	17-6	17-5	17-4	17-3	17-2	17-1	
SEGMENT NUMBER	17-20	17-19		17-17	17-16	17-15	17-14	17-13	17-12			17-9	17-8	17-7	17-6	17-5	17-4	17-3	17-2	17-1	
TERRAIN UNIT	Gty	Fs/Gt + Gt		Fs/Gt	Fs/Gt	Fs/F+L	Fs + Ff/Gt	Fs/Gt	F+L/Gt			F+L	Fps/L	Ff+Fs/F+L	O+Fs/F+L	Fs/Ff	Ffg	Fs/F+L+Ffg	Fs/F+L	Ffg	
SOIL TYPE	SM, GM	Fs/Gty → (17-18)		ML/SM, GM		ML	ML/SM, GM		SP/ML → (17-11)			ML	GM, SM, ML/ML		OL, ML/ML		ML/GM, SM	ML		→	SW-, SP-SM / GW-, GP-GM
THERMAL STATE	GF									Es/F+L	Fp/L ?						D	GF			
FROST CLASSIFICATION	F4, F3	F4/F2-F4				F4	F4/F2-F4		F1/F4 → (17-11)			F4	F4				F1	F4		F1	
THAW STRAIN POTENTIAL	H									M/H		H	H				M	H		M	
COMMENTS	← PSP-2B	Arctic Foothills (Southern) | 278.3 Mi		Central Brooks Range		MASSIVE ICE AND SOME SIDEHILL EMBANKMENT				→		PSP-2C									

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

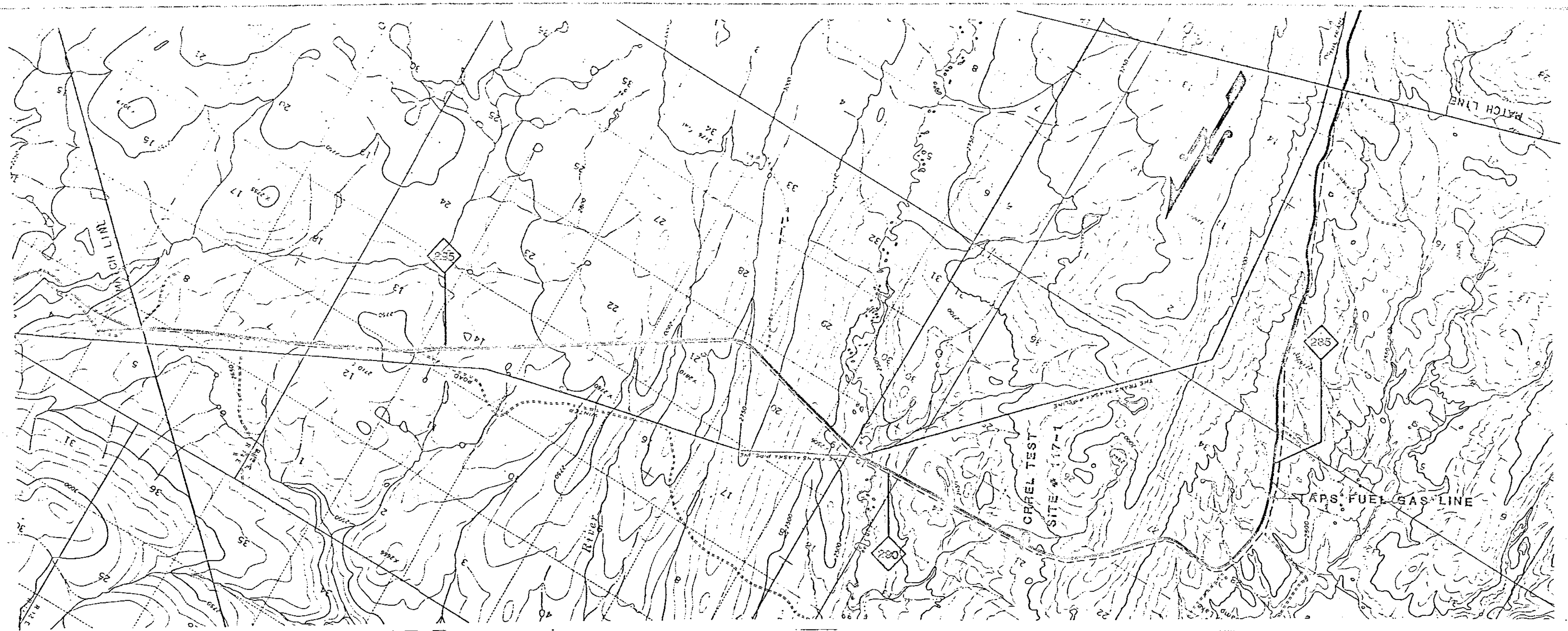
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES: 1/2 0 1

REVISION 0

DATE September 1984

SHEET 17 OF 26



	18-9	18-8	18-7	18-6	18-5	18-4		18-3	18-2	18-1
SEGMENT NUMBER	18-9	18-8	18-7	18-6	18-5	18-4		18-3	18-2	18-1
TERRAIN UNIT	Fs + Cx / Gty	Fs / Gty	Cx + Fs / Gty	Fs + Cx / Gty		Gty	Fp	Gty + Fs / Gty		Gty
SOIL TYPE			Fs + Cx / Gty	ML / SM, GM		SM, GM		GM, GW-GM / SM, SW-SM	SM, GM	
THERMAL STATE	GF									
FROST CLASSIFICATION	F4/F4-F3					F4, F3		F1-F4	F4, F3	
THAW STRAIN POTENTIAL	H							H / M, L	H	
COMMENTS	MASSIVE ICE AND SOME SIDEHILL EMBANKMENT; PSP-2B						290.2 MI Kaparuk River			

EXPLANATION

LEGEND

- Dalton Highway
- Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1/2 0 1

REVISION 0

DATE September 1984

SHEET 18 of 26

SEGMENT NUMBER		19-9		19-8	19-7	19-6	19-5	19-4	19-3	19-2	19-1
TERRAIN UNIT		Fp	Fpa		Ell/GFo + GFo	Ell/GFo	Ell/GFo	Gty	Fs/Gty	Fs/Gty	Fs+Cx/Gty
SOIL TYPE		GM, GW-GM, SM, SW-SM		ML/GM, SM				SM, GM	ML/SM, GM		
THERMAL STATE		GF									
FROST CLASSIFICATION		F1-F4		F4/F2, F3				F4, F3	F4/F4, F3		
THAW STRAIN POTENTIAL		H/M, L		H/M				H			
COMMENTS	Arctic Foothills (Northern)	Arctic Foothills (Southern)		MASSIVE ICE AND SOME SIDEHILL EMBANKMENT							
	PSP-2A → 312.9 MI			PSP-2B							

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

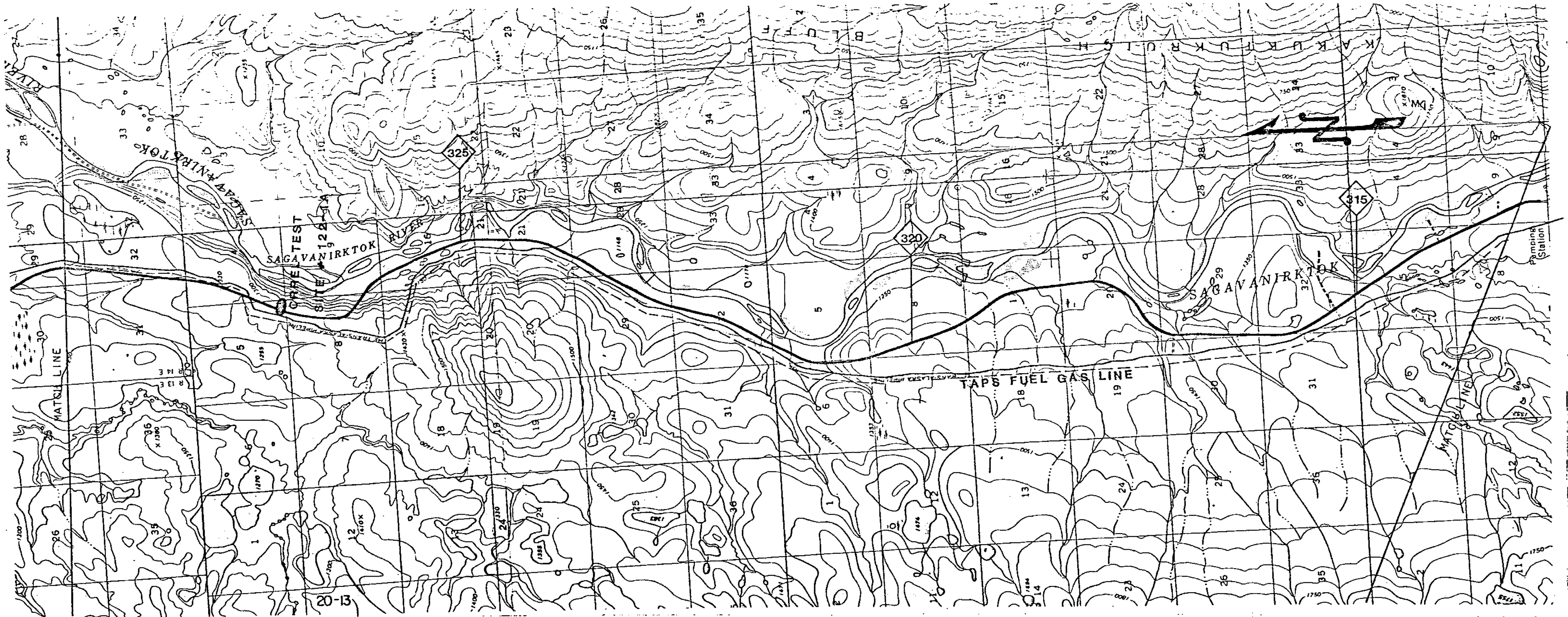
DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 ½ 1

REVISION 0

DATE September 1984

SHEET 19 OF 26



SEGMENT NUMBER	20-17	20-16	20-15	20-14	20-13	20-12	20-11	20-10	20-9	20-8	20-7	20-6	20-5	20-4	20-3	20-2	20-1
TERRAIN UNIT	Elx / Gto	Elx / Gto	Elx	Elx / Gto	Bx + C	Fp-c / Fp-r	Fp-c / Fp-r	Fp-c / Fp-r	Fpa-c / Fp-r	Fp-c? / Fp-r	Fs+Ell / Fp-r	Elx / Gto	Ell + Fs / Fp	Elx + Cx / Gto	Elx / Gto + Gto	Fpa	Fp
SOIL TYPE	ML / ML, SM					ML / GW-GP-GM, SW-SP-SM						ML / SM, ML				GM, GW-GM SM, SW-SM	
THERMAL STATE	GF																
FROST CLASSIFICATION	F4				F4/F1							F4				F1-F4	
THAW STRAIN POTENTIAL	H				H/M,L							H				H/M,L	
COMMENTS	MASSIVE ICE				THROUGH CUT IN ICE RICH MATERIAL WITH MASSIVE ICE			PSP-2A				MASSIVE ICE		MASSIVE ICE			

EXPLANATION

LEGEND

- ——— Dalton Highway
- ——— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
  - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

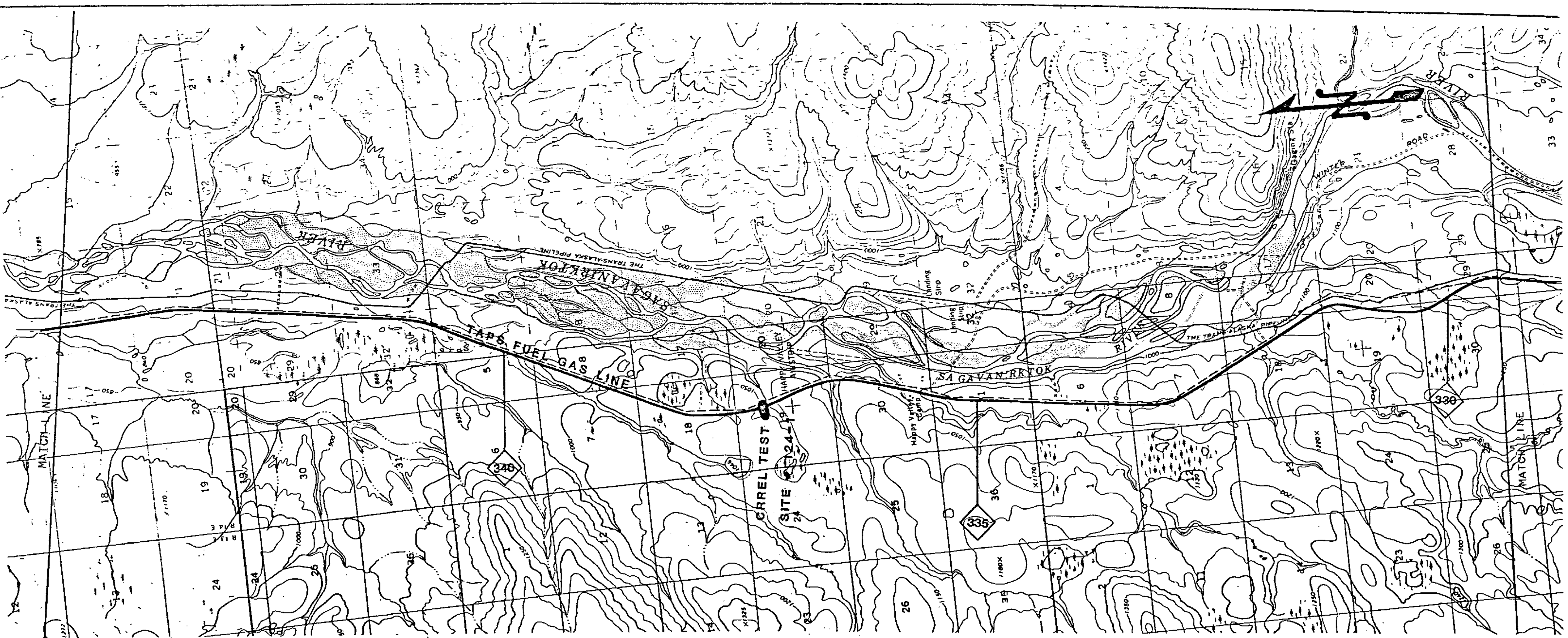
R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY: CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES	REVISION 0	SHEET
0 ½ 1	DATE September 1984	20 of 26



SEGMENT NUMBER	21-21	21-20	21-19	21-18	21-17	21-16	21-15	•	21-14 21-13	•	21-12	21-11	21-10	21-9	21-8	21-7	21-6 •	21-5	21-4	21-3	21-2 •	21-1
TERRAIN UNIT	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Elx + Fp-c / Fpb-r	Elx + Cx	Elx / Gto		Elx+Cx	Elx + Fp-r	Elx	Fp	Elx	Elx / Gto	Cx	Elx	Elx / Gto + Fp-r	Elx / Gto	Elx / Gto	Elx / Gto	Elx / Gto	Elx / Gto
SOIL TYPE	ML / GW-, GP-GM, SW-, SP-SM				ML / ML,SM																	
THERMAL STATE	GF																					
FROST CLASSIFICATION	F4/NFS				F4																	
THAW STRAIN POTENTIAL	H/M,L				H																	
COMMENTS					PSP-2A MASSIVE ICE																	

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp, - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

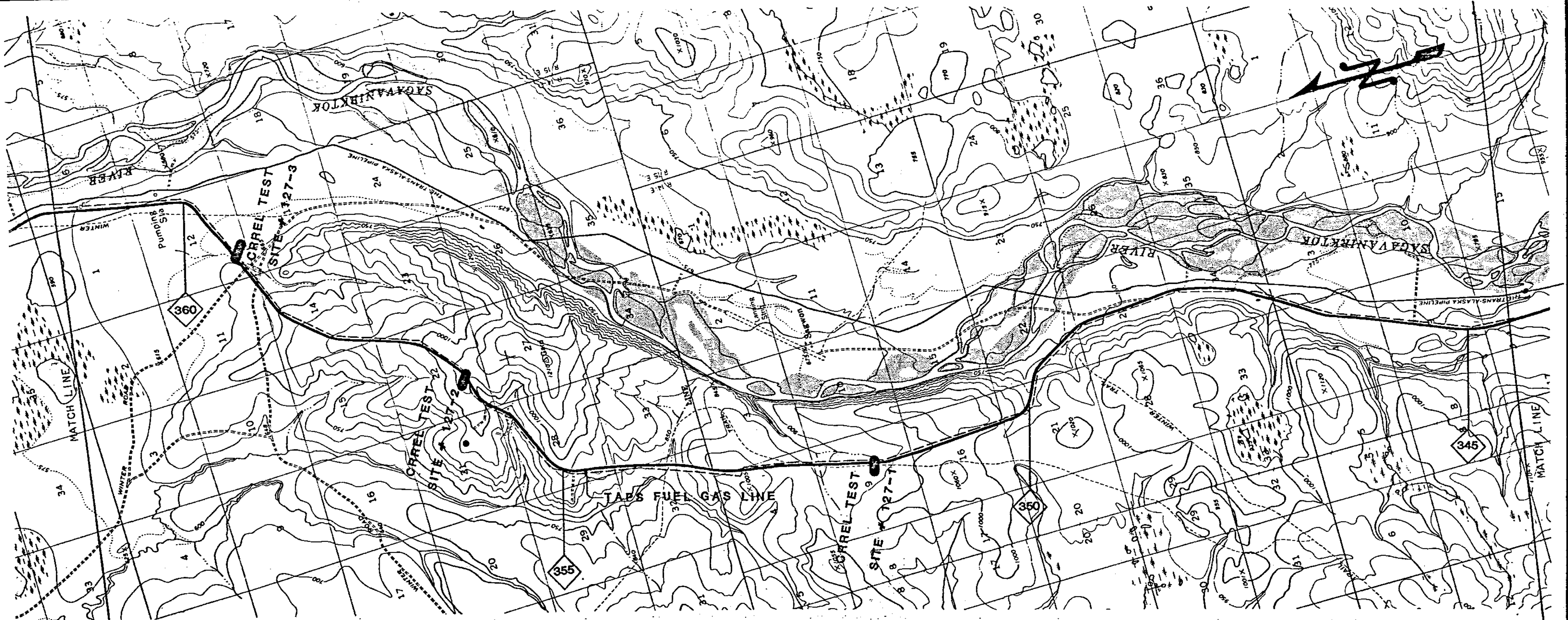
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 21 OF 26



SEGMENT NUMBER	22-16 22-15	22-14	22-13	22-12	22-11 22-10	22-9	22-8	22-7 22-6	22-5	22-4	22-3	22-2	22-1
TERRAIN UNIT	Ell + Fp-c? / Fp-r ?	Fs + Elx	Elx / Bx-r	Fs / Bx-r	Elx / Bx-r	Elx + Fs	Elx+Fs / Bx	Elx	Elx / Bx-r	Fpa-c + Fs / Fpb-r		Fpb-r	Fpb-c / Fpb-r
SOIL TYPE	Ell + Fp-c ?	ML				Elx / Bx-r		Elx / Bx-r		ML / GW-, GP-GM, SW-, SP-SM	Fpa-c + Fpb-c / Fpb-r		
THERMAL STATE	GF												
FROST CLASSIFICATION	F4									F4/NFS,FI			
THAW STRAIN POTENTIAL	H									H/M,L			
COMMENTS	White Hills Section / PSP-1B	Arctic Foothills (Northern) 359.6 MI				MASSIVE ICE (22-9 to 22-5) / PSP-2A							

EXPLANATION

LEGEND

- Dalton Highway
- Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

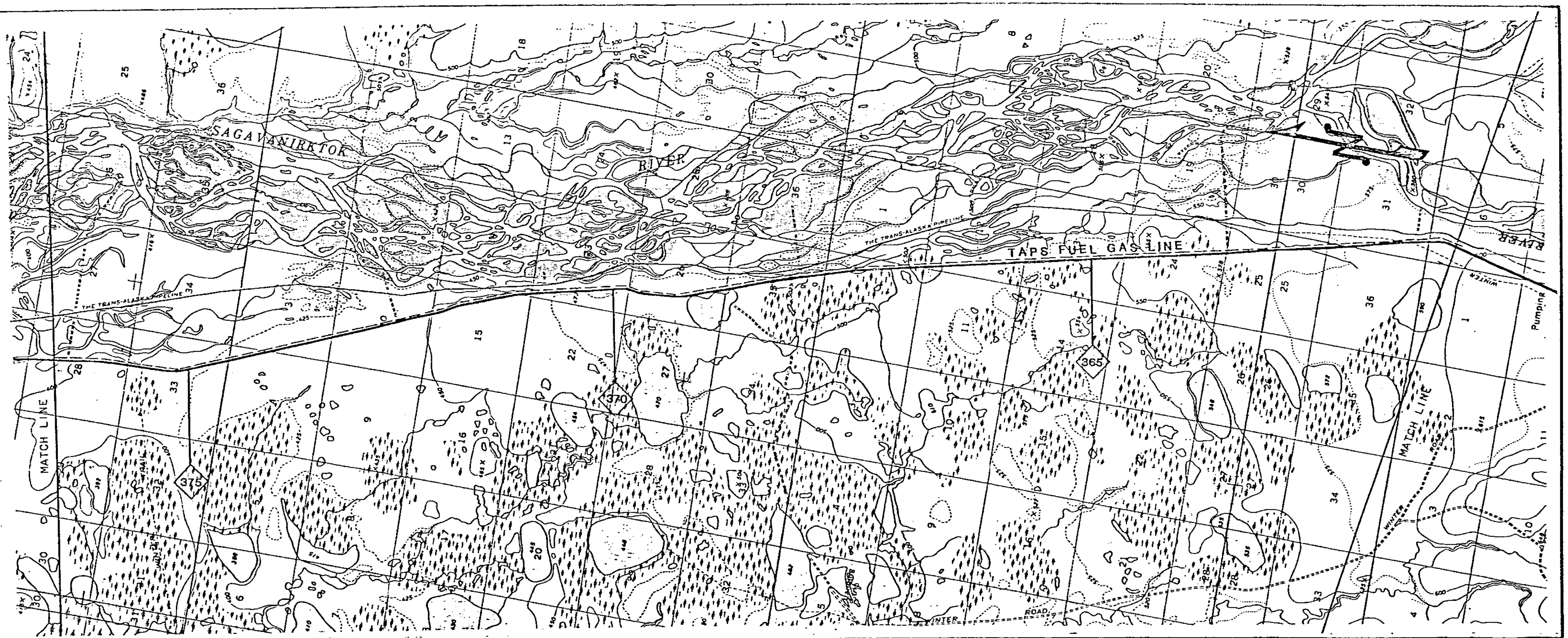
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 0 1/2 1

REVISION 0

DATE September 1984

SHEET 22 OF 26



SEGMENT NUMBER	23-7	23-6	23-5	23-4	23-3	23-2	23-1
TERRAIN UNIT	Fpb-c / Fpb-r	Ell + Lt / Fp-r?	Ell + Lt / Fp-r?	Ell + Lt / Fp-r?	Elx+Lt / Fp-r?	Ell+Fp-c? / Fp-c?	Ell + Fp-c / Fp-r?
SOIL TYPE	ML / GW-, GP-GM, SW-, SP-SM						
THERMAL STATE	GF						
FROST CLASSIFICATION	F4/F1						
THAW STRAIN POTENTIAL	H/M,L						
COMMENTS	PSP-1B						

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abandoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

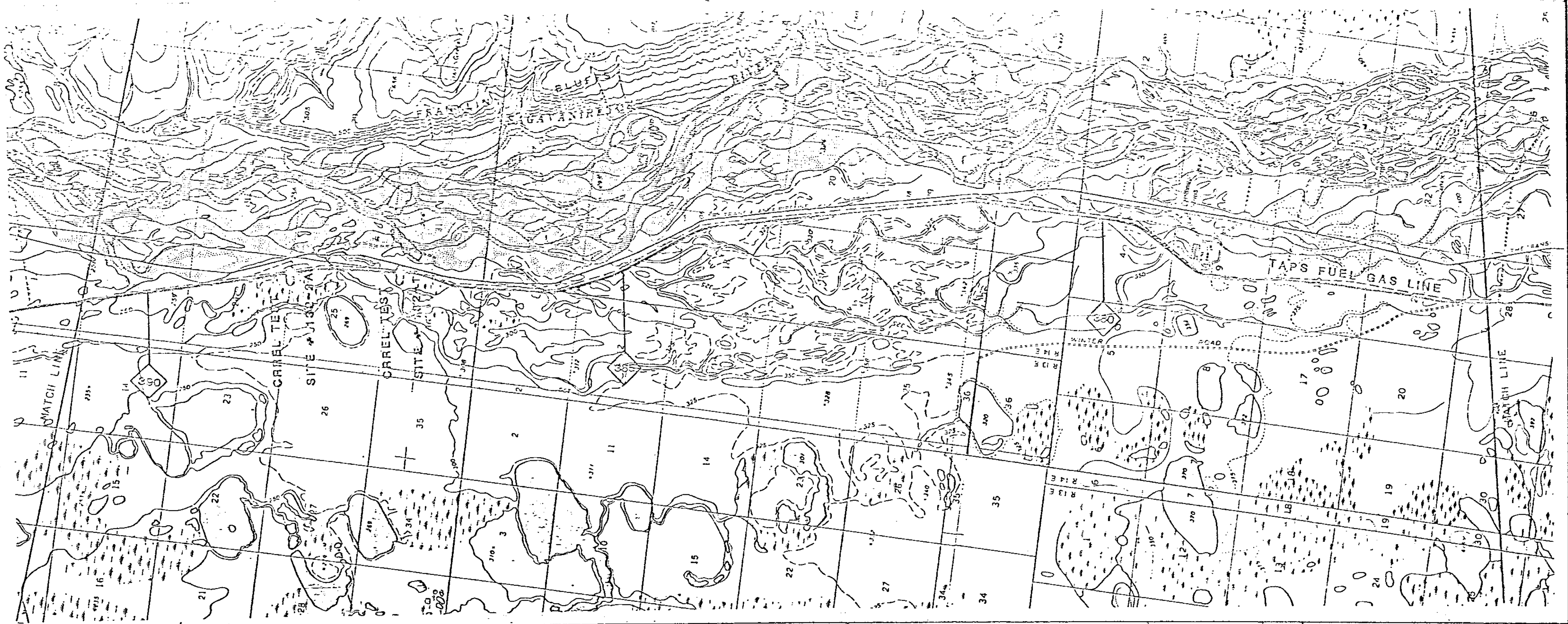
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 23 OF 26



SEGMENT NUMBER	24-9	24-8	24-7	24-6	24-5	24-4	24-3	24-2	24-1
TERRAIN UNIT	Fpa-c / Fpb-r	Fpa-c / Fp	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r	Fpb-c / Fpb-r
SOIL TYPE	ML / GW-, GP-GM, SW-, SP-SM								
THERMAL STATE	GF								
FROST CLASSIFICATION	F4/NFS-F4								
THAW STRAIN POTENTIAL	H/M,L								
COMMENTS	PSP-1B								

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abandoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY:

R&M

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

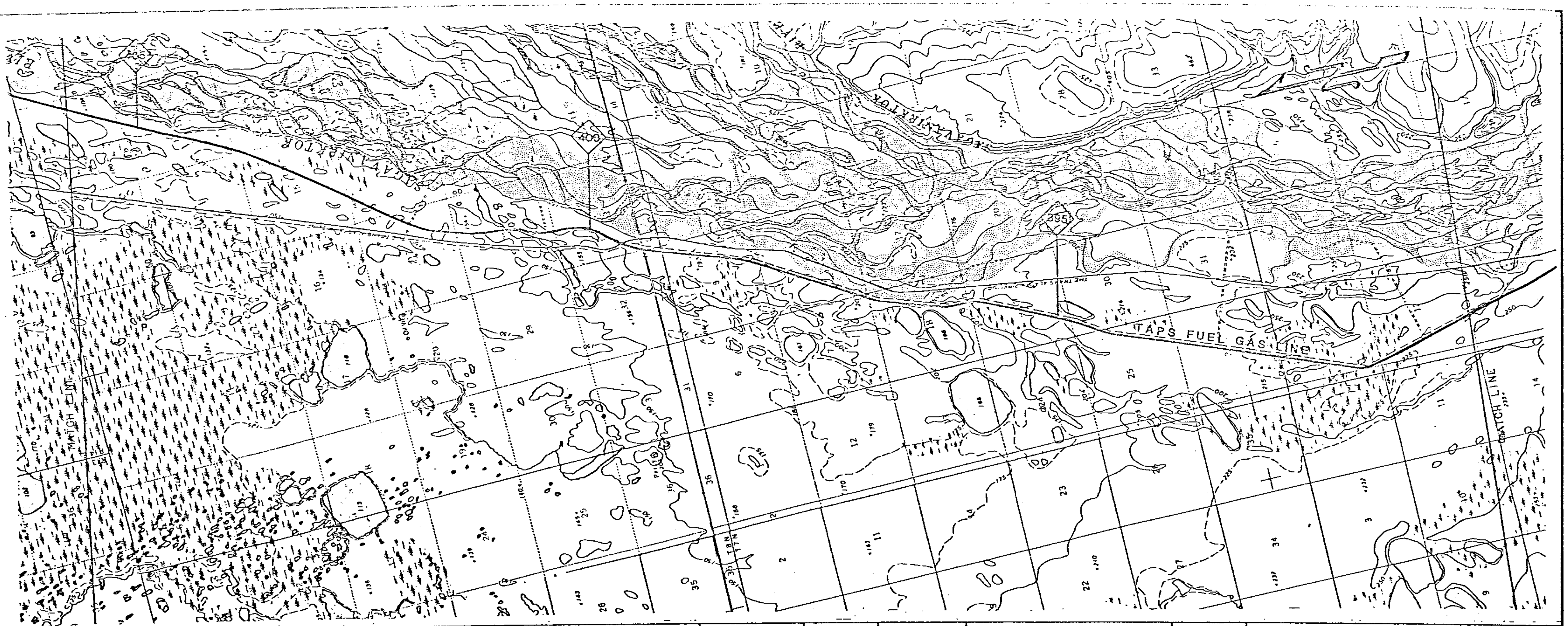
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES: 1 1/2 0 1

REVISION 0

DATE September 1984

SHEET 24 OF 26



SEGMENT NUMBER	25-12	25-11	25-10	25-9	25-8	25-7	25-6	25-5	25-4	25-3	25-2	25-1
TERRAIN UNIT	Ell+Lt / Fp	Fpa-c / Fp-r	Fpa-c / Fp-r	Fpa-c / Fp-r	Fpa-c / Fp-r	Fpa-c / Fp-r	Fpa-c / Fp-r	Ell+Lt / Mc?	Fpa-c / Fpb-r	Fpa-c / Fpb-r	Fpa-c / Fpb-r	Fpa-c / Fpb-r
SOIL TYPE	ML / GW-, GP-GM, SW-, SP-SM											
THERMAL STATE	GF											
FROST CLASSIFICATION	F4/FI-F4								F4/NFS-F4			
THAW STRAIN POTENTIAL	H/M,L											
COMMENTS	PSP-IA		Teshekpuk Lake Section 401.9 MI	White Hills Section	PSP-IB							

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- \- Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :
R&M
R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

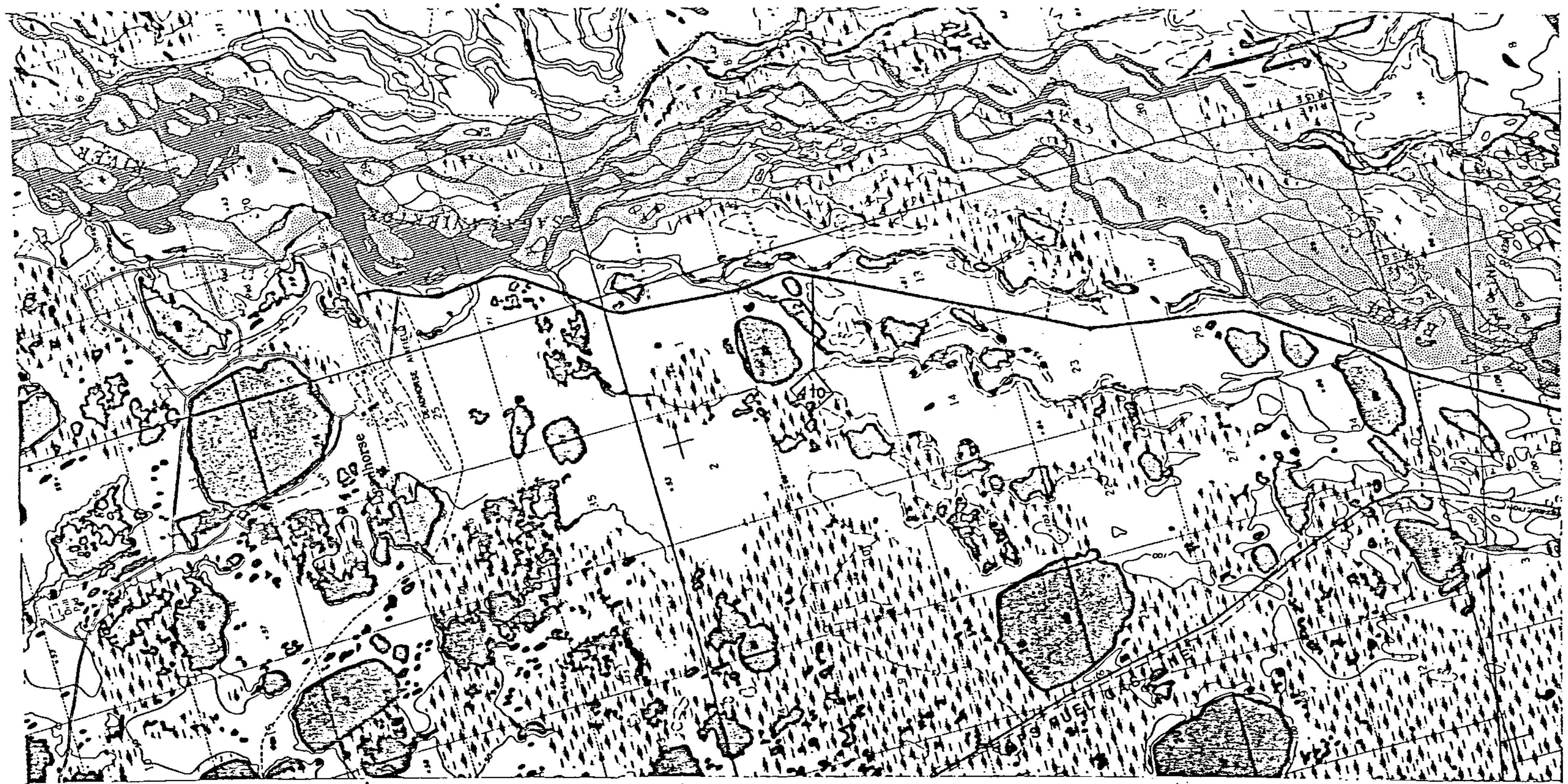
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES 1/2 1

REVISION 0

DATE September 1984

SHEET 25 OF 26



SEGMENT NUMBER	26-5	26-4	26-3	26-2	26-1
TERRAIN UNIT	Ell + Lt / Fp	Lt / Fp	Ell + Lt / Fp	Fpa-c / Fp	Ell + Lt / Fp
SOIL TYPE	ML / GM-, GP-GM, SM-, SP-SM				
THERMAL STATE	GF				
FROST CLASSIFICATION	F4/F1-F4				
THAW STRAIN POTENTIAL	H/M,L				
COMMENTS	End DALTON HIGHWAY 414.9 MI		PSP-1A		

EXPLANATION

LEGEND

- —— Dalton Highway
- —— Trans-Alaska Pipeline
- GF - Generally Frozen
- D - Discontinuous Permafrost
- S - Sporadic Permafrost
- GA - Generally Absent
- H - High
- M - Moderate
- L - Low

TERRAIN UNIT SYMBOLS

- Bx - Bedrock
- C - Colluvial Deposits
- Ca - Avalanche Deposits
- Cm - Mudflow
- Cx - Basin Colluvium Arctic Slope
- Ct - Talus
- El - Loess
- Ell - "Lowland" Loess
- Elx - Frozen Upland Silt
- Es - Eolian Sand
- F - Fluvial Deposits
- Ff - Alluvial Fan
- Ffg - Granular Alluvial Fan
- Fp - Floodplain
- Fpa - Abondoned Floodplain
- Fpb - Braided Floodplain
- Fpm - Meander Floodplain
- Fps - Sandy Floodplain
- Fpt - Old Terrace
- Fs - Retransported Deposits
- Fsf - Retransported Deposit Fan
- G - Glacial Deposits
- GF - Glaciofluvial Deposits
- GFo - Outwash
- Gt - Till Sheet
- Gto - Older Till
- Gty - Younger Till
- L - Lacustrine Deposits
- Lt - Thaw Basins and Thaw Lakes
- Mc - Coastal Plain Deposits
- O - Organic Deposits
- c - Finer Floodplain Cover Deposits
- r - Riverbed Deposits (when used with Fp)
- - Residual Soil (when used with Bx)
- W - Weathered or Poorly Consolidated Bedrocks
- ? - Uncertainty

PREPARED BY :

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

R&M Project Number 451099

ALASKA

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES

DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

SCALE IN MILES	REVISION	SHEET
1 1/2 0 1	0	26 OF 26
	DATE September 1984	

APPENDIX B

CRREL ROAD TEST SITES-LOCATION AND DATA SUMMARY

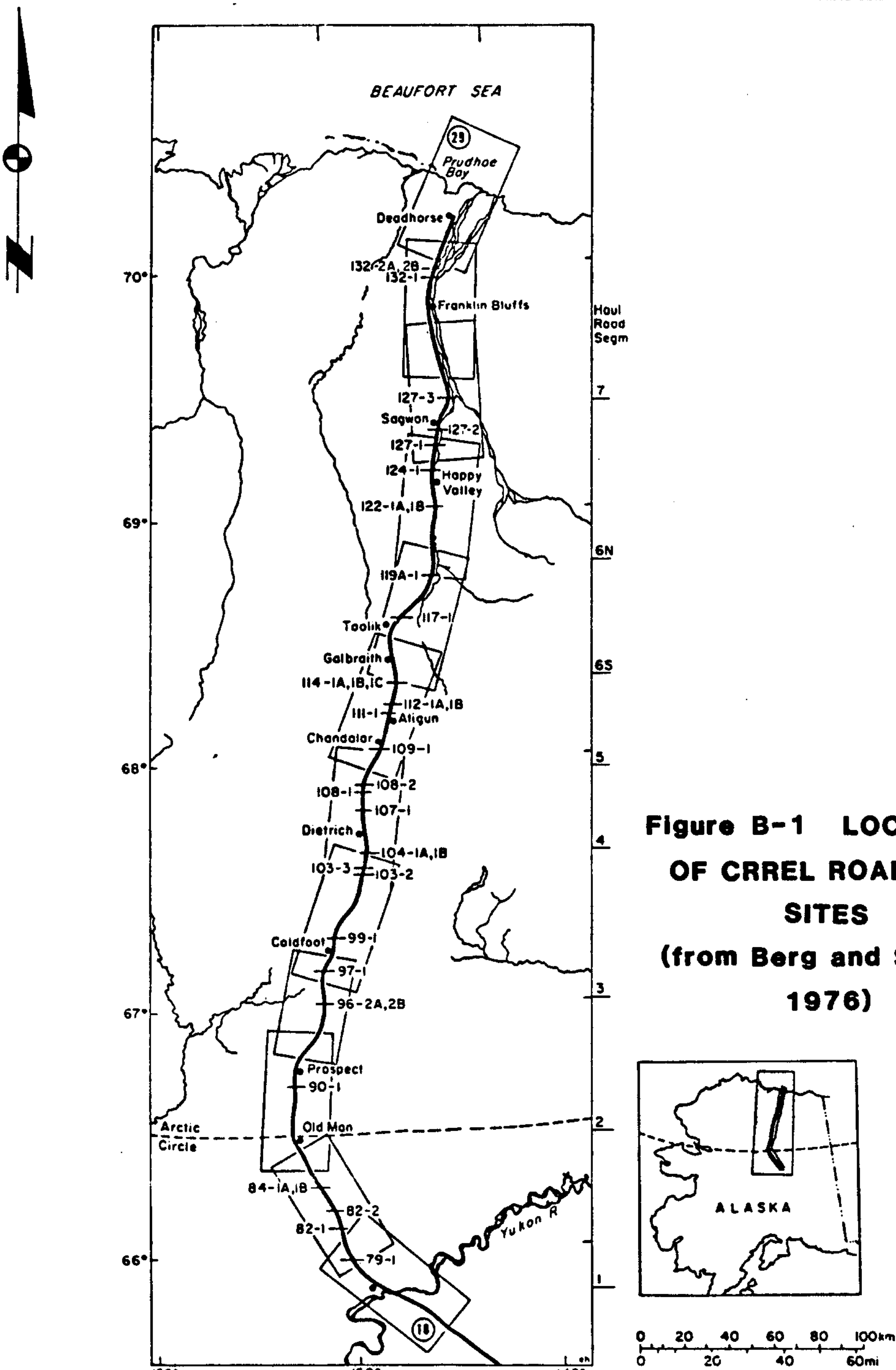


Figure B-1 LOCATIONS OF CRREL ROAD TEST SITES (from Berg and Smith, 1976)

DWN /OEP	R&M CONSULTANTS, INC. ENGINEERS GEOLOGISTS PLANNERS SURVEYORS	STATE OF ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES	F.B.
CKD /CHR		DALTON HIGHWAY:	GRID.
DATE. SEPT 1984		CHARACTERIZATION OF FOUNDATION SOILS	PROJ.NO. 451099
SCALE 1" = 40 mi			DWG.NO.

TABLE B-1

CRREL ROAD TEST SITES - LOCATION AND DATA SUMMARY

Report Segment No.	CRREL Site No.	Haul Road Segment	Station	Dalton Highway MP	Terrain Unit	Subgrade Soil Type	Approximate Embankment Thickness (m)	Recent Boreholes
4-12	79-1*	1T	560+89	64.8	Elx?/Bx-r?	Ice-rich silt	1.4	79-1(1),(2)&(3)
5-16	82-1	1	1341+89	78.8	Fpa	Sandy silt	1.9	N108-14
5-19	82-2	1	1537+49	82.3	Elx	Ice-rich silt	1.8	N109-13
6-8	84-1A*	1	2065+32	93.9	(Fs+C)/Bx-w	Ice-rich silt	1.9	N70-39
8-21	90-1	2	1046+07	133.6	Fs/Bx	Ice-rich silt	1.9	
10-12	96-2A	3	163+49	161.5	(O+Fs)/(G+GF)	Ice-rich silt	1.5	TH 64-27
10-22	97-1*	3T	593+44	169.8	(Fs/Gt)+Gt	Ice-rich silt	2.8	N72-9
11-10	99-1	3	1089+69	179.6	(Fpa-c+Fp-c)/Fpr	Silt	1.2	N71-11
12-23	103-2*	3	2277+02	201.5	Fs/Gt	Silt	1.7	N31-12
13-3	103-3	3T	2414+00	204.0	Fs/Gt	Ice-rich silty sand	2.1	N88-4
13-13	104-1A	3	2753+98	210.6	Fs/(Ff+Ffg)	Silt	2.1	N33-53
14-12	107-1	4T	3560+00	226.2	Gt	Silty gravel	2.1	N77-68
14-26	108-1	4	557+00	233.0	Ff+Fp-c/Fp-r	Gravelly silt	1.5	N81-34
15-8	108-2	4	704+84	235.8	Fp/GF	Silty gravel	2.3	
15-16	109-1	5	924+90	239.6	Gt	Gravelly silt	2.6	N81-21
16-11	111-1	5	524+00	256.3	Fs/Gt	Silty gravel	1.8	N70-24
16-14	112-1A*	5	604+00	258.3	Fs+Cm	Silt	1.2	N83-17
17-11	114-1A*	5T	1375+19	272.8	Es/F+L	Silt	1.0	N77-27,N77-28
18-2	117-1*	6-S	862+48	288.4	Gty+Fs/Gty	Silt	1.3	
19-7	119A-1*	6-ST	1758+68	308.5	Ell/GFo+GFo	Silt	1.8	N77-35
20-15	122-1A	6-NT	2828+56	327.1	Elx	Silt	1.5	N76-51
21-14	124-1*	6-NT	3334+00	337.2	Elx+Cx	Silt	1.9	N33-19
22-8	127-1*	6-N	4095+04	351.6	Elx+Fs/Bx	Silty sand	1.2	N32-17,N82-8
22-13	127-2	6-NT	4357+00	356.4	Elx/Bx-r	Silt	1.5	N33-28
22-14	127-3*	6-N	4493+76	359.3	Fs+Elx	Silt	1.3	N33-26
24-7	132-1	7	1782+54	387.4	Fpb-c/Fpb-r	Sandy silt	1.3	N33-7
24-8	132-2A	7	1838+04	388.5	Fpa-c/Fp	Sandy silt	1.5	N33-6

T - Subsurface temperature sensors installed in 1977.

* - Most active sites.

APPENDIX C

ASSESSMENT OF POTENTIAL FOUNDATION SOIL PERFORMANCE

APPENDIX C
ASSESSMENT OF POTENTIAL FOUNDATION SOIL PERFORMANCE

C.1 LANDFORM CHARACTERIZATION

Landform characterization results are summarized in Tables C-1 and C-2 for the principal landforms found along the Dalton Highway route. Estimates are shown in Table C-1 for frozen and thawed dry density (γ_{df} and γ_{dt}) and thaw strain potential ε (calculated from γ_{df} and γ_{dt} estimates). Table C-2 presents soil type (texture) and USACE frost classifications. Landform depths were estimated as part of the mapping efforts; results have not been shown on the Route Sheet Terrain Unit data band, but were previously provided as a separate tabulation.

Where information was considered adequate to do so, landform characterizations for frozen dry density (γ_{df}) were subdivided by physiographic subprovinces (PSP) to account for regional variations in landform properties. However, in many cases landforms occur in only one physiographic subprovince. Also, where information to distinguish significant differences between physiographic subprovinces was inadequate all PSP were characterized the same.

C.1.1 Soil Dry Frozen and Thawed Density (γ_{df}, γ_{dt})

Using available data (Refs. 5, 8, 9, 10, 16, 30) and geological inferences based on landform genesis, the principal landforms, (included in Table C-1), were evaluated for frozen dry density, γ_{df}.

In general (i.e., typically, but not always), frozen dry density increases with depth below natural ground surface. Where appropriate, depth differences were estimated in depth zones as follows, from (1) below the bottom of embankment (the zero depth datum) to five feet, (2) five to 10 feet, and (3) 10 to 15 feet (south of Atigun Pass). Frozen dry densities are characterized by an average or expected value $E[\gamma_{df}]$, and standard deviation $SD[\gamma_{df}]$, for each landform (and five-foot depth increment, as appropriate).

Estimated thawed dry densities, γ_{dt}, were evaluated for each landform using the landform soil texture and estimated thawed dry densities summarized in Table C-3 from available unfrozen dry density data (Refs. 5, 8, 9, 10, 16, 30). Thawed dry densities are characterized by an average or expected value, $E[\gamma_{dt}]$, and standard deviation, $SD[\gamma_{dt}]$, for each landform.

C.1.2 Thaw Strain Potentials (ε)

An average thaw strain potential, $E[\varepsilon]$, and standard deviation, $SD[\varepsilon]$, was calculated for each landform/physiographic subprovince/depth combination as given in Table C-1. Calculations were made using the fundamental relationship between thaw strain (ε), frozen dry density (γ_{df}) and thawed dry density (γ_{dt}):

$$\varepsilon = 1 - \frac{\gamma_{df}}{\gamma_{dt}} \qquad \text{(C.1)}$$

Mathematical details of the calculations are given in Appendix D.

C.1.3 Landform Soil Texture USCS Designation and USACE Frost Classification

A soil texture classification using one or more of the five basic soil types and corresponding USCS designations listed in Table C-3 was selected for each landform after evaluating available grain size distribution data and using geological inferences based on landform genesis. USACE frost classifications were matched with soil texture to yield one or more of the classifications (NFS, F1, F2, F3, F4) for each landform.

C.1.4 Surface Thickness (D)

Landforms change with depth below surface of natural foundation soil. The centerline profile of landforms occurring from the top of natural foundation soil below any embankment soils to a depth of 10 feet north of and 15 feet south of Atigun Pass is shown on the terrain unit band of the Route Sheets in Appendix A.

In nearly all cases either one or two landforms (a surface landform and another landform below) occur in a profile at a given point of the route. The single landform occurs from the top of foundation soil to the bottom limit of the profile (10 feet or 15 feet) in all cases where only one landform is shown. Where two landforms occur, the surface landform is characterized by an estimated average depth, E[D], and an estimated standard deviation, SD[D]. These are shown as E[D] ± SD[D] in the unpublished tabulation which accompanies this report. The underlying landform occurs to the bottom limit of the profile (10 feet or 15 feet). For example Fs(5'±½')/Ff indicates landform Fs occurs over landform Ff, the depth of Fs is an estimated average of 5' with a standard deviation of ½', and Ff occurs to the bottom of the profile.

C.1.5 Thaw Settlement (TS)

Thaw settlement is thaw strain potential integrated over (estimated or "potential") thaw depth. Clearly, given the thaw strain potential (predicted here by landform and depth), thaw settlement further depends on soil thermal properties and road thermal design, local climate, weather, drainage factors, and time.

For illustration, thaw settlement for a hypothetical thermal design/load has been estimated for one landform profile (or terrain unit). Results are given in terms of average thaw settlement, E[TS], and standard deviation, SD[TS], as shown in Appendix E, Figure E-1 (results are based on mathematical details given in Appendix E). Note Figure E-1 shows that thaw settlement estimates for a given road thermal design and thermal load can be related to landforms or terrain units.

C.2 SEGMENT-BY-SEGMENT CHARACTERIZATION PROCEDURES

As stated in Section 2 of this report, the route information developed in this study can be used at two general levels of detail. At Level I, the landform characterization can be used as is (without refinement) in analysis and design by matching the landform geotechnical parameter statistics with the landforms identified in the Route Sheets, Appendix A. At Level II, statistics from Level I can be used as prior information with segment/site-specific subsurface (borehole, trench, probe, etc.) data to make updated estimates of geotechnical variables. Formal mathematical techniques for making updated estimates are given in Appendix F.

C.2.1 Landform Statistics (Level I)

At this level of detail landform or landform/PSP statistics are used directly in analysis and design; segment/site-specific subsurface data is not used to update the landform/PSP statistics. This may be appropriate, for example, for design development analyses, preliminary optimization studies, preliminary design, route location refinement, etc.

C.2.2 Landform Segment (Level II)

Available segment/site-specific subsurface data are used to update the Level I characterization statistics. Updating is based on Bayesian statistical concepts (Appendix F).

UPDATING FROZEN DRY DENSITY.-- The formal methods of Appendix III can be used directly. Since γ_{df} is both critical in determining thaw strain and a field-observable variable, a formal updating approach may be most appropriate where maximum utilization of available data is desired.

UPDATING THAWED DRY DENSITY.-- Formal or informal methods may be appropriate, depending on the situation. However, where γ_{dt} is not measured but must be predicted (the usual situation) formal methods (Appendix F) may be an illusory refinement; if so, informal (geotechnical judgment) methods can be used for updating.

UPDATING SOIL TEXTURE.-- Informal methods are recommended for most cases. Formal methods can utilize the techniques for non-normal updating discussed in Appendix F.

UPDATING THAW STRAIN POTENTIAL.-- Because thaw strain is a known function of γ_{df} and γ_{dt}, we recommend that site/segment-specific updates to the landform thaw strain potential values (Table C-1) be made by first updating γ_{df} and γ_{dt} and then calculating an updated estimate of thaw strain potential (except where directly observed field thaw strain [via settlement] values are available). We recommend laboratory thaw strain data also be evaluated in terms of γ_{df}, γ_{dt} and applied in terms of Equation C.1, as further shown in Appendix D.

UPDATING LANDFORM THICKNESS.-- Informal updating based on terrain analysis using available subsurface data is most appropriate. Of course, the accuracy of the results (for given data) will depend on the quality of the terrain analysis.

UPDATING FROST CLASSIFICATION.-- Updated frost classification can be read-off directly from updated soil texture using Table C-3.

UPDATED THAW SETTLEMENT.-- Updated thaw settlement estimates can be calculated from updated variables used in estimating thaw settlement (see Appendix E).

C.3 APPLICATION OF THAW STRAIN CHARACTERIZATION RESULTS IN DESIGN

C.3.1 Interpretation of Thaw Strain Statistical Estimates

Route characterization for thaw strain, ε, is given in terms of estimates of the expected value (mean or average) and standard deviation of thaw strain: $E[\varepsilon]$ and $SD[\varepsilon]$. Estimates of $SD[\varepsilon]$ given in this report combine spatial and systematic uncertainity. $E[\varepsilon]$ and $SD[\varepsilon]$ can be used to estimate thaw settlement, TS, in terms of expected value, E[TS], and standard deviation, SD[TS], using the physics of thermal analysis and the statistics of point estimation techniques, (as outlined in Appendix E) and considering autocorrelation effects (Refs. 26, 28).

Expected value and standard deviation estimates are considered appropriate statistics for characterizing thaw strain potential or thaw settlement over a given segment length: $E[\varepsilon]$ and E[TS] are estimates of ε and TS (1) for any given point along the segment (where a borehole is not available) and (2) spatially averaged over the entire segment. $SD[\varepsilon]$ and SD[TS] are estimates of the average root mean square (rms) difference between ε and TS at a point and the mean values $E[\varepsilon]$ and E[TS] (but, conservatively, also including systematic uncertainity in $E[\varepsilon]$ and E[TS]). Roughly speaking, $SD[\varepsilon]$ and SD[TS] are related to the difference in ε and TS between non-adjacent points; at close separation distances they will generally over-estimate ε or TS differences because of spatial autocorrelation of soil properties (Refs. 26, 28).

Effects of thaw settlement (and thus thaw strain) on highway performance are generally related to the settlement average and spatial deviations from the average. Exact spatial patterns of thaw settlement (which can be very complex) are neither amenable to practical prediction nor necessarily useful in design. Therefore, for practical use a Thaw Settlement Index, TSI, can be defined as a simple measure of thaw settlement performance appropriate for design. For example one useful possibility is E[TSI] = E[TS] + SD[TS]; another definition, considering E[TS] and SD[TS] are positively correlated, is simply E[TSI] = E[TS]. Predictions of thaw settlement operating performance can then be made based on E[TSI].

C.3.2 Use of Thaw Strain Statistical Estimates

The following methodology (Ref. 24, 28) is used to outline a rigorous yet practical approach to thaw settlement design modeling. Emphasis here is on the process used to decide, segment-by-segment, which candidate design mode is most cost-effective for each design segment along the route. This methodology can also be used in the design development process: given a set of trial design modes, it can help ascertain the most cost-effective modes based on geothermal analysis of the mode performance for the expected geotechnical conditions, construction and operating costs. It can also be used to help prioritize field studies. The approach is outlined as follows.

(1) Estimate operating cost (OC) performance as a function of road thaw settlement index (TSI). The result will be defined as E[OC(TSI)]. Operating cost should include all maintenance and user costs. More than one E[OC(TSI)] estimate can be used if it is

desired to formally treat E[OC(TSI)] as a random variable; e.g., E[OC(TSI)] can be represented by a lower-bound estimate, $E[OC(TSI)]^-$, and an upper-bound estimate, $E[OC(TSI)]^+$.

(2) Calculate E[TSI] and estimate SD[TSI], mean and standard deviation of thaw settlement index, for the candiate design modes and thermal load for each segment along the route. Use either landform thaw strain estimates from Table C-1 or updated, segment-specific, estimates. Calculate $TSI^+ = E[TSI] + SD[TSI]$ and $TSI^- = E[TSI] - SD[TSI]$ (or, if desired, TSI could be defined by a probability density function).

Note that the same landform profile and thaw strain estimates will apply to many segments. Therefore, in practice many segments will not require new calculations. Also, similar segments can be grouped together for purposes of analysis (and design) to economize on calculations. Contiguous segments can be grouped into composite segments where segment lengths are too short for economical construction.

(3) Calculate expected operating cost, E[OC], for each (single or grouped) segment and corresponding candidate design mode/thermal load, where

$$E[OC] = \tfrac{1}{4}\{E[OC(TSI^+)]^+ + E[OC(TSI^-)]^- + E[OC(TSI^+)]^- + E[OC(TSI)^-]^+\} \quad (C.2)$$

(4) Calculate the expected construction and operating cost, E[COC], using the E[OC] from (3) and the expected construction cost, E[CC], for each candidate design mode:

$$E[COC] = E[OC] + E[CC] \quad (C.3)$$

(5) Select the mode with lowest E[COC] for each segment. Where E[CC] is influenced by segment length, combine contiguous segments into one "design segment" having the same design mode. Iterate as required to result in the most cost-effective segment design (by minimizing E[COC] for each design segment). Minimizing E[COC] for all design segments along the route will result in the most cost-effective design for the Dalton Highway (or any subsection).

C.3.3 Prioritization of Future Field Studies

As developed here, prioritizing future field studies (and associated analysis of results) uses the premise that data should be collected on the basis of maximizing cost-effectiveness to the limit of the available budget.

One reasonable and practical approach given a budget, B, is to allocate exploration and analysis efforts to each segment i on the basis of PEVCEAi, the preposterior (i.e., prior to actual exploration) expected value of complete exploration and analysis in segment i. The proportion of the total budget, B, spent in segment i, bi, should equal the proportion that PEVCEAi is to the sum total of PEVCEAi for all segments where exploration is contemplated, ΣPEVCEAi-- i.e.,

$$b_i = \left(\frac{PEVCEA_i}{\Sigma PEVCEA_i} \right) \cdot B \qquad (C.4)$$

where Σbi = B and PEVCEAi is calculated as E[COC]i - E[COC]i'''. E[COC]i''' is a preposterior E[COC], estimated from steps (2) through (5) of Section C.3.2 but with E[TSI] and SD[TSI] estimates based on an n'' = ∞.

Where b_i values by Equation C.4 are too small to be meaningful for the given budget the value of b_i becomes zero and the calculations reiterated to re-apportion the budget among only those segments where exploration is meaningful.

Values of b_i calculated by Equation C.4 assumes that the marginal or incremental rate of value/cost in exploration is constant. This simplification makes calculations easier, but tends to underestimate marginal cost-effectiveness at smaller efforts and over estimate marginal cost-effectiveness at large efforts. Useful refinements to Equation C.4 can be made if desired.

TABLE C-1

ESTIMATED STATISTICAL PARAMETERS FOR ROUTE LANDFORMS
BY PHYSIOGRAPHIC SUBPROVINCE

LANDFORM	PHYSIO-GRAPHIC PROVINCE	EXPECTED AVERAGE FROZEN DENSITY/STANDARD DEVIATION			EXPECTED THAW STRAIN/STANDARD DEVIATION			EXPECTED THAWED DENSITY
		$\hat{\gamma}_{df} = E[\gamma_{df}] / SD[\gamma_{df}]$ (pcf)			$\hat{\epsilon} = E[\epsilon] / SD[\epsilon]$ (%)			
Lf	PSP	0-5'	> 5'-10'	>10'-15'	0-5'	> 5'-10'	> 10'-15'	γ_{dt}(pcf)
Bedrock	Ice-Rich	85±30	100±25	100±25	28±18	15±11	15±11	115±15
C	2C	40±30	40±30	40±30	65±24	65±24	65±24	105±15
C?	3A	100±30	110±25	115±25	15±15	8±8	5±6	110±10
Ca	2C	40±30	40±30	40±30	63±25	63±25	63±25	100±15
Cm	2C	40±30	40±30	40±30	57±30	57±30	57±30	85±12
Cs	3A	60±30	70±30	70±30	45±24	35±23	35±23	105±10
Cx	2A,B	30±30	30±30		68±32	68±32		85±10
El	3A	55±20	60±20	65±20	37±18	31±17	25±16	85±9
Ell	1B,2B	30±20	30±20		67±20	67±20		85±9
Ell+Lt	1A	25±20	30±20		73±21	67±20		85±9
Elx	2A	30±20	30±20		67±20	67±20		85±9
	3A	60±20	70±20	70±20	31±17	19±16	19±16	85±9
	3B	60±20	60±20	60±20	31±17	31±17	31±17	85±9
	3C	50±20	55±20	55±20	43±18	37±18	37±18	85±9
Elx?	3A	65±20	75±20	75±20	25±16	14±14	14±14	85±19
Es	2C	85±20	90±20	95±15	20±13	15±12	10±7	105±9
F?	3A	105±30	105±30	105±30	12±12	12±12	12±12	110±12
F+L	2C	50±30	50±30	50±30	48±27	48±27	48±27	90±12
Ff	2C,D	85±25	90±25	95±25	28±13	23±13	19±12	115±15
Ffg	2C	95±25	115±20	125±20	22±14	6±7	2±3	120±12
Fp-r	1A	105±30	120±20		16±16	4±5		120±12
Fp	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fpa	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fpb	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fpm	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fpt	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fps	All	85±30	90±30	100±30	28±18	24±17	15±16	115±15
Fp-c	All	60±25	65±20	(75±20)	32±23	25±16	14±14	85±9
Fp-r	1B	105±30	120±20		16±16	4±5		120±12
	2A	115±25	125±20		9±9	2±3		120±12
	2C,3A	115±25	120±20	120±20	9±9	4±5	4±5	120±12
	2D	105±30	115±20	120±20	16±16	6±7	4±5	120±12
	3C	105±30	105±25	105±25	16±16	14±13	14±13	120±12
Fp-r?	3A	110±30	110±30	110±30	13±13	13±13	13±13	120±12
Fpa-c	1B	55±25	60±20		38±24	31±17		85±9
	2A	40±25	40±25		55±25	55±25		85±9
	2C	40±25	50±25	65±20	55±25	43±24	25±16	85±9

(CONTINUED)

TABLE C-1 (CONTINUED)

ESTIMATED STATISTICAL PARAMETERS FOR ROUTE LANDFORMS
BY PHYSIOGRAPHIC SUBPROVINCE

LANDFORM	PHYSIO-GRAPHIC PROVINCE	EXPECTED AVERAGE FROZEN DENSITY/STANDARD DEVIATION			EXPECTED THAW STRAIN/STANDARD DEVIATION			EXPECTED THAWED DENSITY
		$\hat{\gamma}df = E[\gamma df] / SD[\gamma df]$ (pcf)			$\hat{\epsilon} = E[\epsilon] / SD[\epsilon]$ (%)			
Lf	PSP	0-5'	>5'-10'	>10'-15'	0-5'	>5'-10'	>10'-15'	γdt(pcf)
Fpb-c	All	50±20	50±20	50±20	43±18	43±18	43±18	85±9
Fpb-r	1B	125±20	125±20		6±6	6±6		127±9
	2A	125±25	130±15		8±8	2±3		127±9
	2C	115±25	120±20	130±15	12±12	8±8	2±3	127±9
Fpm-c	3A	50±20	50±20	50±20	43±18	43±18	43±18	85±9
Fpm-r	3A	110±25	115±25	120±25	15±14	12±12	10±10	127±9
Fs	2C	40±25	40±25	45±25	55±25	55±25	49±25	85±9
	2D	40±25	55±25	60±25	55±25	38±24	32±23	85±9
	3C	50±25	60±25	60±25	43±24	32±23	32±23	85±9
	3A	40±25	55±25	65±25	55±25	38±24	26±22	85±9
Fs?	3A	50±25	55±25	65±25	43±24	38±24	26±22	85±9
Fsf	2D	45±25	55±25	60±25	47±25	38±24	32±23	85±9
G	2D	90±30	100±30	110±30	24±17	15±16	10±11	115±15
G+Gf	All	90±30	100±30	110±30	24±19	16±16	12±12	115±12
Gf+Gf?	All	110±25	115±20	120±20	14±14	9±9	7±7	125±9
Gf+L	All	100±30	100±30	100±30	15±16	15±16	15±16	115±15
Gfo	2B	110±30	110±30	(125±20)	16±16	16±16	(5±5)	125±9
Gt	2B	70±30	90±30		41±20	24±17		115±15
	2C	70±30	90±30	105±30	41±20	24±17	13±13	115±15
	2D	80±30	95±30	105±30	33±18	20±16	13±13	115±15
Gt?	2C	80±35	85±30	105±30	30±23	25±18	11±11	110±15
Gto	2A	60±35	70±35		46±27	37±25		105±15
Gty	2B	75±30	90±30		37±19	24±17		115±15
L	2C	40±25	50±25	75±20	58±24	46±23	18±15	90±9
L?	2C,3A	65±25	65±25	65±25	30±21	30±21	30±21	90±9
MC	1A	50±25	55±25		60±17	56±17		120±12
O	2C,D	20±20	20±20	20±20	75±26	75±26	75±26	70±10

TABLE C-2

DALTON HIGHWAY SOIL-TYPE LANDFORM CHARACTERIZATION

LANDFORM	PREDOMINANT ; SECONDARY* SOIL TYPES	PREDOMINANT ; SECONDARY* USC	PREDOMINANT FROST CLASS
C?	SiSa&Gr;Si	GM;Sm;ML	F3,F4
Cs	SiSa;Si	SM;ML	F4
Ell+Lt	Si;SiSa	ML;SM	F4
Elu	Si	ML	F4
F	SiSa&Gr;Cl,Sa&Gr;Si	SM;GM;SW-,SP-SM; GW-,GP-GM;ML	F4,F3
F?	SiSa&Gr,Si;ClSa&Gr	SM;GM;ML; SW-,SP-SM; GW-,GP-GM	F4,F3
F+L	Si;SiSa	ML;SM	F4
Ffg	ClSa&Gr;SiSa&Gr	Sw-,Sp-SM; GW-,GP-GM;SM,GM	F1
Fp-c, Fpa-c, Fpb-c, Fpm-c	Si;SiSa	ML;SM	F4
Fs	Si	ML	F4
Fs?	Si;SiSa	ML;SM	F4
Fp-r, Fp-r?	ClSa&Gr;SiSa&Gr	GW;SW;GW-,GP-GM; SW-,SP-SM;SM;GM	F1
Fpb-r, Fpm-r	ClSa&Gr;SiSa&Gr	GW,SW;GW-,GP-GM; SW-,SP-SM;GM,SM	NFS,F1
G+GF	SiSa&Gr;ClSa&Gr	GM;SM; GW,-GP-GM;SW-,SP-SM	F2,F3
GF, GF?	ClSa&Gr;SiSa&Gr	SW;GW; GW,-GP-GM;SW-,SP-SM; GM,SM	F1

(CONTINUED)

TABLE C-2 (CONTINUED)

DALTON HIGHWAY SOIL-TYPE LANDFORM CHARACTERIZATION

LANDFORM	PREDOMINANT ; SECONDARY* SOIL TYPES	PREDOMINANT ; SECONDARY* USC	PREDOMINANT FROST CLASS
GF+L	SiSa&Gr;ClSa&Gr;Si	SM,GM; GW-,GP-GM;SW-,SP-SM, ML	F3,F4
Gfo	ClSa&Gr;SiSa&Gr	SW;GW, GW-,GP-GM;SW-,SP-SM; GM,SM	F1
Gt	SiSa&Gr; ClSa&Gr;Si	SM,GM; GW-,GP-GM; SW,-SP-SM;ML	F2,F4
Gt?	SiSa&Gr,Si;ClSa&Gr	SM,GM,ML; GW-,GP-GM;SW-SP-SM	F4,F3
Gto	SiSa;Si	SM,ML	F4
Gty	SiSa&Gr;ClSa&Gr;Si	SM,GM;GW-,GP-GM; SW-,SP-SM;ML	F4,F3
Mc	ClSa&Gr;SiSa&Gr;Si	GW,SW GW-,GP-GM;SW-,SP-SM; SM,GM,ML	F1
Bx	NA	NA	NA

* NOTES:

(1) Si = Silts
(2) SiSa = Silty Sands
(3) SiGr = Silty Gravels
(4) ClSa = Clean Sands
(5) ClGr = Clean Gravel
(6) SiSa&Gr = Silty Sands and Gravels
(7) ClSa&Gr = Clean Sands and Gravels

TABLE C-3

BASIC SOIL TYPE, GRAIN SIZE
AND THAWED DRY DENSITY CHARACTERISTICS

SOIL TYPE	P200 (%)	USCS	ESTIMATED THAWED DRY DENSITY (pcf)
1) Silts (Si)	≥55	ML	85±10
2) Silty Sands (SiSa)	13-54	SM	105±15
3) Silty Gravels (SiGr)	13-54	GM	125±15
4) Clean Sands (ClSa)	≤12	SW, SP, SW-SM, SP-SM	115±15
5) Clean Gravels (ClGr)	≤12	GW, GP, GW-GM, GP-GM	130±10

APPENDIX D

THAW STRAIN ESTIMATING PROCEDURES

APPENDIX D
THAW STRAIN ESTIMATING PROCEDURES

Thaw strain potentials (ε) are estimated for each landform using the fundamental relationship:

$$\varepsilon = 1 - \frac{\gamma df}{\gamma dt} \quad (D.1)$$

where γ_{df} and γ_{dt} are frozen and thawed soil dry density. Results are shown in Table C-1. Because γ_{df} and γ_{dt} are not accurately known, they are random variables; and thus ε is also a random variable.

The average and standard deviation of ε were approximated numerically using a simple "point estimate method" (Ref. 28). Estimates were made numerically to avoid the erroneous effect of negative strain values that can occur for cases where γ_{df} is close to γ_{dt} when using an analytical approximation such as a Taylor series expansion (Ref. 23; where negative strain values do not occur results with Taylor series expansion are similar, e.g., they were identical in the case of Ref. 23, results.) Specifically, the expected value or average strain, $E[\varepsilon]$, and standard deviation, $SD[\varepsilon]$ (the square root of the variance), shown in Table C-1 were computed by:

$$E[\varepsilon] = \tfrac{1}{4}\{[(\varepsilon^{--}) + (\varepsilon^{++})]\ (1 + r) + [(\varepsilon^{+-}) + (\varepsilon^{-+})]\ (1 - r)\} \quad (D.2)$$

$$SD[\varepsilon] = (E[\varepsilon^2] - E[\varepsilon]^2)^{\frac{1}{2}} \quad (D.3)$$

where:

$$E[\varepsilon^2] = \tfrac{1}{4}\{[(\varepsilon^{--})^2 + (\varepsilon^{++})^2]\ (1 + r) + [(\varepsilon^{+-})^2 + (\varepsilon^{-+})^2]\ (1 - r)\} \quad (D.4)$$

$$\varepsilon^{++} = (1 - \frac{\gamma_{df}^{+}}{\gamma_{dt}^{+}}) \geq 0 \quad (D.5)$$

$$\varepsilon^{--} = \left(1 - \frac{\gamma_{df}^-}{\gamma_{dt}^-}\right) \geq 0 \qquad (D.6)$$

$$\varepsilon^{+-} = \left(1 - \frac{\gamma_{df}^+}{\gamma_{dt}^-}\right) \geq 0 \qquad (D.7)$$

$$\varepsilon^{-+} = \left(1 - \frac{\gamma_{df}^-}{\gamma_{df}^+}\right) \geq 0 \qquad (D.8)$$

$$\gamma_{df}^+ = E[\gamma_{df}] + SD[\gamma_{df}] \qquad (D.9)$$

$$\gamma_{df}^- = E[\gamma_{df}] - SD[\gamma_{df}] \qquad (D.10)$$

$$\gamma_{dt}^+ = E[\gamma_{dt}] + SD[\gamma_{dt}] \qquad (D.11)$$

$$\gamma_{dt}^- = E[\gamma_{dt}] - SD[\gamma_{dt}] \qquad (D.12)$$

r = correlation coefficient between γ_{df} and γ_{dt}

Whenever a strain component of E[ε] in Equation D.2 was computed as less than zero it was set equal to zero. All $E[\gamma_{df}]$, $SD[\gamma_{df}]$, $E[\gamma_{dt}]$, $SD[\gamma_{dt}]$ values, obtained by analysis of available data, are given in Table C-1.

The value of r (the correlation coefficient between γ_{dt} and γ_{df}) was assumed as 0.9 for all cases--based on re-analysis of published (Ref. 16) APSC laboratory thaw strain data. In our re-analysis of that data r was found to vary from 0.81 for silts to 0.98 for clean sands, with an average of 0.9 for all soils tested.

We consider the preceeding approach to estimating thaw strains superior to regression analysis approaches (Ref. 16) because (1) it is based on a fundamental physical relationship (not simply a statistical one as are regression curves), (2) it does not require as many (often questionable) statistical assumptions, and (3) it can fit the (laboratory) data "better" than regression curves, particularly at high (near 100%) and low (near 0%) strains.

APPENDIX E

THAW SETTLEMENT ESTIMATING PROCEDURES

APPENDIX E
THAW SETTLEMENT ESTIMATING PROCEDURES

Thaw settlement, TS, can be estimated from the general symbolic relationship:

$$TS = \Psi(\varepsilon\vartheta, L\vartheta, k\vartheta, C\vartheta, Z\vartheta, D, T, I, t, \text{etc.}) \qquad (E.1)$$

where:

$\Psi(\bullet)$ = thermal model of the physics of heat transfer in thawing and freezing soils, needing "$(\bullet)$" as input
$\varepsilon\vartheta$ = thaw strain potential ε of each of ϑ homogeneous soil layers
$L\vartheta$ = latent heat L of each of ϑ homogeneous soil layers
$k\vartheta$ = thermal conductivity k of each of ϑ homogeneous soil layers
$C\vartheta$ = specific heat C of each of ϑ homogeneous soil layers
$Z\vartheta$ = volumetric extent of each of ϑ homogeneous soil layers
D = thermal design configuration and details
T = thermal loads (at all boundaries)
I = initial temperature conditions
t = time
etc. = all other factors including convection effects

TS can be characterized as a random variable with estimates of expected value or mean, E[TS], and standard deviation, SD[TS]. In particular, if, for illustration, the uncertainty in TS is assumed to come only from thaw strain, then for a three layer soil profile (ϑ=3), E[TS] and SD[TS] can be estimated by:

$$E[TS] = 1/8 \{\Sigma\Psi_1(\varepsilon_1^+, \varepsilon_2^+, \varepsilon_3^+, \bullet\bullet\bullet) + \Psi_2(\varepsilon_1^-, \varepsilon_2^+, \varepsilon_3^+, \bullet\bullet\bullet) + \bullet\bullet\bullet + \Psi_8(\varepsilon_1^-, \varepsilon_2^-, \varepsilon_3^-)\} \qquad (E.2)$$

$$SD[TS] = \sqrt{E[TS^2] - E[TS]^2} \qquad (E.3)$$

$$\text{where: } E[TS^2] = 1/8 \sum_{i=1}^{8} \Psi_i^2 \qquad \text{(E.4)}$$

$$\varepsilon\vartheta^+ = E[\varepsilon\vartheta] + SD[\varepsilon\vartheta], \quad \vartheta = 1, 2, 3 \qquad \text{(E.5)}$$

$$\varepsilon\vartheta^- = E[\varepsilon\vartheta] - SD[\varepsilon\vartheta], \quad \vartheta = 1, 2, 3 \qquad \text{(E.6)}$$

with E[ε] and SD[ε] estimated as discussed in Appendix D.

An example set of thaw settlement (TS) estimates (average E[TS] and standard deviation SD[TS]) are given in Figure E-1. Estimates are for an assumed thermal design ("3") in the terrain unit Fpb-c/Fpb-r (fine-grained over coarse-grained braided floodplain deposits). Thaw settlement estimates are given as a function of the average depth ($\bar{D}$) of Fpb-c for a range (0, ½, 1 and 2 feet) of standard deviations of depth , SD[D]. Therefore, this one chart provides thaw settlement estimates for all cover depths of Fpb-c over Fpb-r and would be applicable to all occurrences of Fpb-c/Fpb-r (in PSP=IB) where the same illustrative thermal design and thermal load is contemplated.

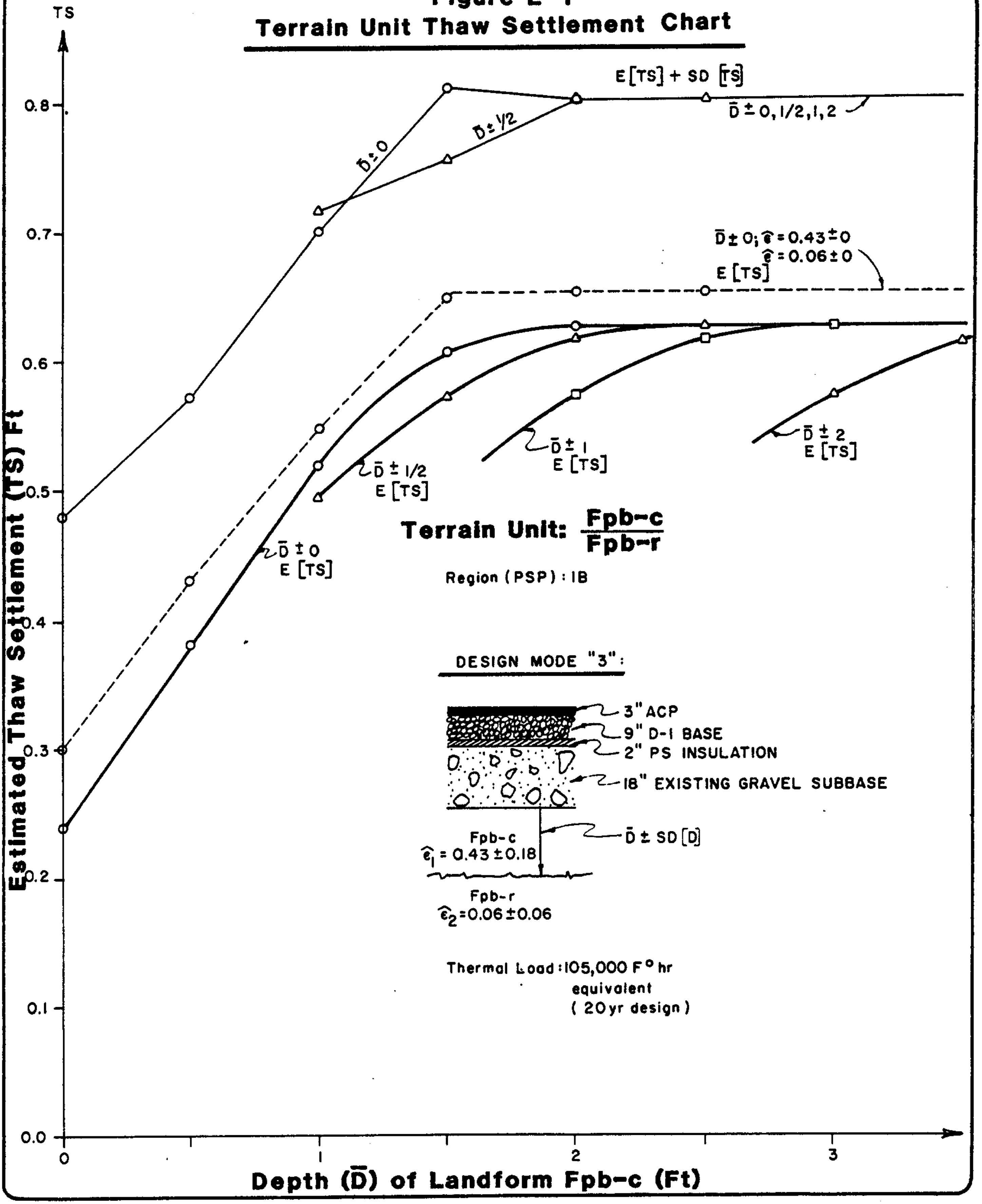
Figure E-1 shows that estimated thaw settlement, TS, increases with Fpb-c (silt) thickness (D), as could be expected. All thaw settlement estimates use the thermal properties appropriate for the hypothetical "Design Mode 3" shown in the drawing. The lower, heavy lines plot the expected value of thaw settlement, E[TS], vs. $\bar{D}$, the average depth of silty landform Fpb-c (which overlies landform Fpb-r) for four values of the standard deviation of D, SD[D]: 0, ½, 1 and 2 feet. E[TS] increases from a minimum of about 0.23 feet for no Fpb-c or zero silt (all thaw settlement being due to thaw in the gravel, Fpb-r) to about 0.61 feet for Fpb-c thicknesses greater than about 1.8 feet (all settlement being due to thaw in the Fpb-c silt, the Fpb-r remaining frozen).

The upper, lighter solid lines plot E[TS]+SD[TS] vs. $\bar{D}$; SD[TS] is the standard deviation of thaw settlement. For $\bar{D}$ greater than 1.8 feet E[TS]+SD[TS] is the same for all plotted values of SD[D] (0, $\frac{1}{2}$, 1, 2). For $\bar{D}$ less than or equal to 1.8 feet only SD[D]=0 and SD[D]=$\frac{1}{2}$ are applicable; they give different E[TS]+SD[TS] estimates, as plotted.

The middle, dashed line is for comparison: it represents the results of a deterministic anaysis using average properties. It plots E[TS] as if there was no uncertainity or variability in Fpb-c or Fpb-r thaw strain potentials (i.e., it assumes SD[ε]=0 in the foundation soil) or depth (i.e., it assumes SD[D] = 0). For this (impossible) situation SD[TS] = 0 so E[TS] and E[TS] + SD[TS] coincide.

These results suggest that for any candidate design in any terrain unit/physiographic province along the Dalton Highway route (as identified in the Route Sheets of Appendix A) thaw settlement could be estimated by simply reading-off E[TS] or E[TS]+SD[TS] from charts such as Figure E-1.

Figure E-1
Terrain Unit Thaw Settlement Chart



DWN	OEP
CKD	CLV
DATE	SEPT 1984
SCALE	SHOWN

R&M CONSULTANTS, INC.
ENGINEERS GEOLOGISTS PLANNERS SURVEYORS

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DALTON HIGHWAY:
CHARACTERIZATION OF FOUNDATION SOILS

F.B.	
GRID.	
PROJ. NO.	451099
DWG. NO.	

APPENDIX F

SEGMENT/SITE-SPECIFIC UPDATING EQUATIONS

APPENDIX F
SEGMENT/SITE - SPECIFIC UPDATING
MATHEMATICAL (FORMAL) PROCEDURES

This appendix presents and develops concepts and formal mathematical procedures of geotechnical updating for route characterizations (Refs. 22, 25, 27, 28). Updating can be approached either formally (as discussed here) or informally, the traditional approach. The basic difference between the two is that a formal method uses an explicitly defined quantitative model to help focus, guide and enhance judgement, and intuition, whereas informal methods are fundamentally more qualitative. Which method is "most appropriate" depends on the needs, goals, and limitations of the specific application and the quality of the methods. Informal methods will not be discussed here.

For any segment to be updated the landform profile is identified and a soil profile defined. Then soil property parameters for each stratum of the soil profile are updated using available sample data and statistically characterized landform prior information. Soil profiles should be discretized or standardized to eliminate any practically significant depth or lateral dependence of soil property parameters so that each stratum is reasonably statistically homogeneous. Soil profile development can be an iterative process with successive refinement of the soil profile geometry and parameter estimates. The segment/site soil profile is developed so that for each stratum all pertinent geotechnical property statistical parameters are characterized by an updated estimate of their mean and variance or standard deviation. Numerical examples of this updating approach can be found in Refs. 23, 25 and 27.

F.1 PROBABILISTIC (BAYESIAN) UPDATING: MATHEMATICAL PROCEDURES

Bayesian updating techniques can provide a rational and systematic basis for combining landform data obtained form different scales and locations (geographic updating) or additional, subject/site-specific data (informational updating). They require that the variability in the property (s) of interest, X (material and/or geometric), be describable by a known probability density function, PDF[X], having, in general, uncertain statistical parameters, θ, described by PDF[θ].

Subject/site-specific estimates of θ, $\theta(S)$, are made using prior data and available subject/site-specific sample data with Bayes' Theorem to make posterior, updated estimates of of $\theta(S)$, $\theta(S)''$ as follows: Subject/site specific parameters $\theta(S)$ are random variables (in the Bayesian sense) having prior distributions PDF[$\theta(S)$]' based on available prior data. Subject/site-specific sample data on property X, x(S), are summarized by a sample likelihood function, L[$\theta(S)/x(S)$], which gives the relative likelihoods of the uncertain values of $\theta(S)$ given x(S). If x(S) is composed of n random observations of X, following a PDF having parameters $\theta(S)$, then the sample likelihood function becomes:

$$L[\theta(S)/x(S)] = \prod_{j=1,n} PDF[x_j(S)/\theta(S)] \qquad (F.1)$$

Then, using Bayes' Theorem, the posterior, updated PDF of $\theta(S)$, PDF[$\theta(S)$]", is equal to the product of the prior PDF, PDF[$\theta(S)$]', and the sample likelihood function, L[$\theta(S)/x(S)$], normalized by a constant to ensure that PDF[$\theta(S)$]" integrates to unity:

$$PDF[\theta(S)]'' = \frac{L[\theta(S)/x(S)] \cdot PDF[\theta(S)]'}{\int L[\theta(S)/x(S)] \cdot PDF[\theta(S)]' \cdot d\theta} \qquad (F.2)$$

In all cases PDF[$\theta(S)$]" can be used to calculate the updated estimate of the mean and standard deviation of the marginal distributions of $\theta(S)$ for each parameter of PDF[X]:

$$E[\theta(S)]'' = \int \theta(S) \cdot PDF[\theta(S)]'' \cdot d\theta(S) \qquad (F.3)$$

$$Var\ [\theta(S)]'' = \int \theta(S)^2 \cdot PDF[\theta(S)]'' \cdot d\theta(S) - E[\theta(S)]''^2 \quad (F.4)$$

$$SD[\theta(S)]'' = (Var[\theta(S)]'')^{\frac{1}{2}} \quad (F.5)$$

If the prior distribution of $\theta(S)$ and the sample-likelihood function are conjugate pairs, posterior distribution of $\theta(S)$ are of the same mathematical form as the prior; then, the mean or expected value, $E[\theta(S)]''$, and variance, $Var[\theta(S)]''$, are simply related to the parameters of the prior distribution. Justification for using conjugate pairs can be based on physical reasoning, empirical evidence or solely on mathematical convenience and simplicity (unless they are not compatible with available evidence). Where conjugate pairs are not appropriate, $E[\theta(S)]''$ and $SD[\theta(S)]''$ can be obtained using Equations F.1 through F.5, for any $PDF[\theta(S)]'$ or $L[\theta(S)/x(S)]$.

Table F-1 presents the pertinent mathematics of two conjugate pair PDF models that are particularly useful for site characterization: (1) a normal probability model and (2) a binomial model (Refs. 22, 25, 27).

1. Observed PDF[X]s for soil density, moisture content, shear strength parameters, and compressibility parameters tend to follow bell-shaped Beta distributions. The central portions of the Beta distributions can be described by normal and lognormal or inverse lognormal distributions (by simple logarithmic transformations the latter two distributions can be transformed into normal distributions). Thus, practical updating of bell shaped distributions of any property X (subsequent to suitable transformation if necessary) can be done assuming PDF[X] is normal (defiend by the two parameters mean of X, $\overline{X}$, and standard deviation of X, σ) and using the normal PDF model updating equations presented in Table F-1.
2. The soil property parameter of interest in grain size characterizations is commonly associated with the proportion,

u, compared to a critical value, U, of a soil which is finer than a specified grain size (gravel, sand, silt, clay, or any particular grain size fraction). The probability of the number, Z, of fundamentally sized, effectively homogeneous soil volumes composing a site (or stratum) of volume V and having $u < U$ can be modelled by the binomial distribution. The number of effective soil volumes comprising V is the effective number of trials, η, so that Q, the estimated probability that $u < U$ in any effective soil volume can be estimated using the binomial PDF model updating equations presented in Table F-1. Updating parameters can use the more general (but more numerically cumbersome) Equations F.1, F.2, F.3 and F.4 directly if the normal or binomial conjugate models in Table F-1 are not appropriate. In all cases, proper use of these techniques requires judgment and understanding of their application-specific limitation.

WEIGHTING OF LANDFORM PRIOR DATA--In the mathematics of the updating presented in Table F-1 prior site information on property X is based on (1) aggregating available X data (on a landform basis) into a set of landform sample statistics and (2) weighting these by a numerical factor n', which represents a prior sample size; n' is proportional to the relevance of the landform statistics to site characterization of property X. These are combined, through updating (using Bayes' Theorem), with site-specific sample statistics weighted by the available site sample n. This aggregating and weighing approach to using priors is compatible with data bases formed by combining useful results from all available site exploration programs where the quality, quantity, detail, and geographic extent of the exploration programs may be quite diverse. In general, n' is dependent on site size, landform geological characteristics, and the quality, quantity, and statistical uncertainity of available prior data; establishing suitable values for n' requires both analysis and geotechnical judgment.

As an inspection of the equations in Table F-1 suggest, if prior information, measured by n', is adequate, estimates of $\theta(S)$ can be made with any amount of site-specific data (n)--including no data (n=0). However, uncertainity in all estimates, measured by Var[$\theta(S)$]", decreases with increasing site-specific data (increasing n). In all cases, as n increases the influence and importance of landform prior information on the estimates $\theta(S)$" decreases.

Bayesian updating can be used for sites where landform prior information must be evaluated on a site-specific basis. Site-specific priors may be necessary where (1) available numerical data are inadequate (e.g., because of limited subsurface exploration or testing of previous sites in the landform) to be of practical value in estimating landform prior parameters by mathematical analysis (particularly as concerns variability between sites) or (2) geotechnically, site conditions are qualitatively different from available landform prior data. In practice, evaluating site-specific priors necessarily required geotechnical knowledge, experience and judgement; it can encompass analysis and synthesis of all available prior data (qualitative and quantitative) with specific relevance to the particular site in question, including geotechnical details of the exploration and testing programs and landform and site geological characteristics. Because of the complexities involved, prior data can be usefully evaluated and summarized in various ways, depending on practical needs and constraints (Refs. 22, 24, 27 and 28).

F.2 UPDATING FROZEN DRY DENSITY (γ_{df}), THAW STRAIN POTENTIAL (ε), AND THAW SETTLEMENT (TS)

The estimates of γ_{df} and $\varepsilon = f(\gamma_{df})$ given in Table C-1 are landform and landform/region (PSP) statistics. We judge the effective sample size of these γ_{df} statistics to be about 15; therefore, for informational updating, where new landform information of sample weight n is added to the statistics of Table C-1, we recommend a prior weight for these statistics of n'=15. Where Table C-1 landform/PSP statistics are used as prior information for geographical updating with segment-specific data, we judge the prior effective sample size to be about n'=15 for standard deviation or variance (Equation I.3, I.4 and I.5 in Table F-1) statistical parameter estimates but n'=6 for statistical estimates of the mean (Equation I.1 and I.2 in Table F-1).

Updating with segment-specific data must consider autocorrelation effects. Updating cannot generally reduce uncertainity from inherent spatial variability (unless trend surfaces are used, e.g., Refs. 4, 28), but will decrease statistical uncertainty. However, due to spatial autocorrelation, the information content applicable to a given segment will be less for closely-spaced samples than for widely-spaced samples. Although mathematical techniques are available for dealing with these effects (e.g., Ref. 28), a judgement-based site-specific approach is recommended for most cases at this time. As some rough, tentative guidelines: (1) the effective sample size (n) for any borehole should not exceed about 1 per 5 feet in the same stratum, and (2) the effective sample size for borehole clusters (3 or more boreholes all within 100 feet of each other and not being used to sub-segment) should not exceed about 2 per cluster for segments longer than roughly 500 feet.

To be most appropriate, formal updating should be done on γ_{df} statistics and then the effect of updating γ_{df} propogated through to ε and TS by calculating updated estimates, using the techniques of Appendices D and E.

TABLE F-1
UPDATING EQUATIONS FOR SOIL PROPERTY PARAMETER ESTIMATING

Assumed Soil Propety PDF Model and Uncertain Parameters of Model	Prior and Posterior PDF of Parameters	Updated Estimates of Mean and Variance of Parameters for Site	
NORMAL With uncertain parameters: mean, $\bar{X}$, and standard deviation, σ, of property X $PDF(X)=\frac{1}{\sqrt{2\pi}\sigma}\exp[-\frac{1}{2}(\frac{x-\bar{X}}{\sigma})^2]$	STUDENT, INVERTED-GAMMA-2 $PDF(\bar{X})=\{\frac{(n-1)^{\frac{1}{2}n-\frac{1}{2}}}{\sqrt{\pi}\ \ s/\sqrt{n}}\cdot\frac{\Gamma[n/2]}{\Gamma[\frac{1}{2}n-\frac{1}{2}]}$ $\cdot[n-1+n\cdot(\bar{X}-\bar{x})^2/s^2]^{-\frac{1}{2}n}\}$ $PDF(\sigma)=\{\frac{2(\frac{1}{2}n-\frac{1}{2})^{\frac{1}{2}n-\frac{1}{2}}}{s\cdot\Gamma[\frac{1}{2}n-\frac{1}{2}]}\cdot(\frac{s^2}{\sigma^2})^{\frac{1}{2}n}$ $\cdot\exp[-\frac{1}{2}(n-1)s^2/\sigma^2]\}$ $PDF': \bar{x}=\bar{x}(Lf),\ s^2=s(Lf)^2, n=n'$ $PDF'': \bar{x}=\bar{x}'', s^2=s''^2, n=n''$ $s''^2=\frac{[(n-1)\cdot s(S)^2+(n'-1)\cdot s(Lf)^2+n\cdot n'[\bar{x}(lf)-\bar{x}(S)]^2/n'']}{(n'+n-1)}$	$E[\bar{X}(S)]''=\bar{x}''=\frac{n'\cdot\bar{x}(Lf)+n\cdot\bar{x}(S)}{n'+n}$ $Var[\bar{X}(S)]''=\frac{s''^2\cdot(n'+n-1)}{(n'+n)\cdot(n'+n-3)}$ $E[\sigma^2(S)]''=\frac{s''^2\cdot(n'+n-1)}{(n'+n-3)}$ $E[\sigma(S)]''=\sqrt{\frac{s''^2\cdot(n'+n-1)}{2}}\cdot\frac{\Gamma[(n'+n-2)/2]}{\Gamma[(n'+n-1)/2]}$ $Var[\sigma(S)]''=E[\sigma^2(S)]''-E^2[\sigma(S)]''$	(I.1) (I.2) (I.3) (I.4) (I.5)
BINOMIAL With uncertain parameter: the probability, Q, property u is below a critical value U $PDF(Z)=\binom{\eta}{z}Q^z(1-Q)^{\eta-z}$	BETA $PDF(Q)=\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\cdot\Gamma(\beta)}Q^{\alpha-1}(1-Q)^{\beta-1}$ $\alpha=n'\cdot Q(Lf)+n\cdot Q(S)+1$ $\beta=n'\cdot[1-Q(Lf)]+n\cdot[1-Q(S)]+1$	$E[Q(S)]''=\frac{n'\cdot Q(Lf)+n\cdot Q(S)+1}{n'+n+2}$ $Var[Q(S)]''=E[Q(S)]''\cdot[\frac{1-E[Q(S)]''}{n'+n+3}]$	(II.1) (II.2)

$\bar{x}(Lf), s(Lf)^2$ = sample mean and variance of landform (or any) prior
$\bar{x}(S), s(S)^2$ = sample mean and variance of site
Q(LF) = Estimated probability u<U based on landform data
Q(S) = Estimated probability u<U based on site data

(Lf) identifies information from landform (or any) prior
(S) identifies site-specific information
n' = landform (or any) prior sample weight; n = site sample weight
n" = n'+n = posterior sample weight