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Terrain analysis for the Trans-Alaska Pipeline

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The Trans-Alaska Pipeline crosses mountains, an earthquake zone, and treacherous permafrost. Design restrictions for a hot oil pipeline across permafrost terrain required more detailed geotechnical information than had ever been needed for previous Alaska projects. Special, detailed attention should be given to the "natural surroundings" of this project because it is just this environment that has made it unique and has created the engineering challenges that had to be overcome.

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THE TRANS-ALASKA PIPELINE (TAPS) is the largest and most expensive private construction project in history. It crosses 800 mi (1,287 km) of varied and adverse terrain including three major mountain ranges and 590 mi (949 km) of permafrost. Because of the permafrost, the pipeline is held above ground for much of its length on piles, thousands of them.

Before project design was possible, specific geotechnical parameters such as soil and bedrock types, groundwater occurrence, permafrost, and other environmental conditions had to be determined. Normally, experience from previous engineering projects and geologic mapping in the area of a new construction job could be utilized, but this information was not available for most of the TAPS route which crosses large uninhabited and undeveloped areas, particularly north of the Yukon River.

Such investigations, usually based on soil borings, are a part of just about every engineering project and there has been little change in the basic approach to them in a long time. Traditionally, the information obtained from a soil boring is considered in a site-specific manner—little is done to evaluate deviations from other information obtained in the same general landform. But the tens of thousands of borings that would be required on an 800-mi (1,287-km) pipeline made this technique too costly. The very high costs, vast area to be investigated, and the poorly known and adverse character of the geologic materials on this route forced a change of thinking that resulted in a new approach to such investigations.

Airphoto analysis

There is significance in the fact that this is the largest engineering project to use the landform-airphoto approach for terrain investigation. Airphoto analysis identified the major geologic units (landforms) along the route. However, there was a problem: while aerial photography, conventionally used, could reliably tell for the majority of the pipeline route where thaw unstable permafrost requiring elevated systems was present, in many geologic settings there are no surface indicators of where permafrost begins or ends. To predict conditions in these areas the range of physical properties expected in each landform was defined during field investigations which included many soil borings.

Landform analysis, in conjunction with a data bank of field and laboratory soil information, assisted project design and construction planning. Very expensive delays due to geotechnical surprises were minimized as a result.

Terrain Unit Maps were prepared on a photo mosaic base at a scale of 1:12,000 to show the landform units expected in a 2-mi (3.2-km) wide strip along the project route in addition to locations of soil borings (see Fig. 1). This document served as a basis for designing the pipeline and for determining construction techniques to be used in each landform unit along the route. It was also useful in locating materials sources.

In addition to the aerial mapping of landforms on the Terrain Unit Maps, a profile of geotechnical conditions expected to a depth of 50 ft (15 m) along the pipeline centerline was prepared. Landform units are shown on this

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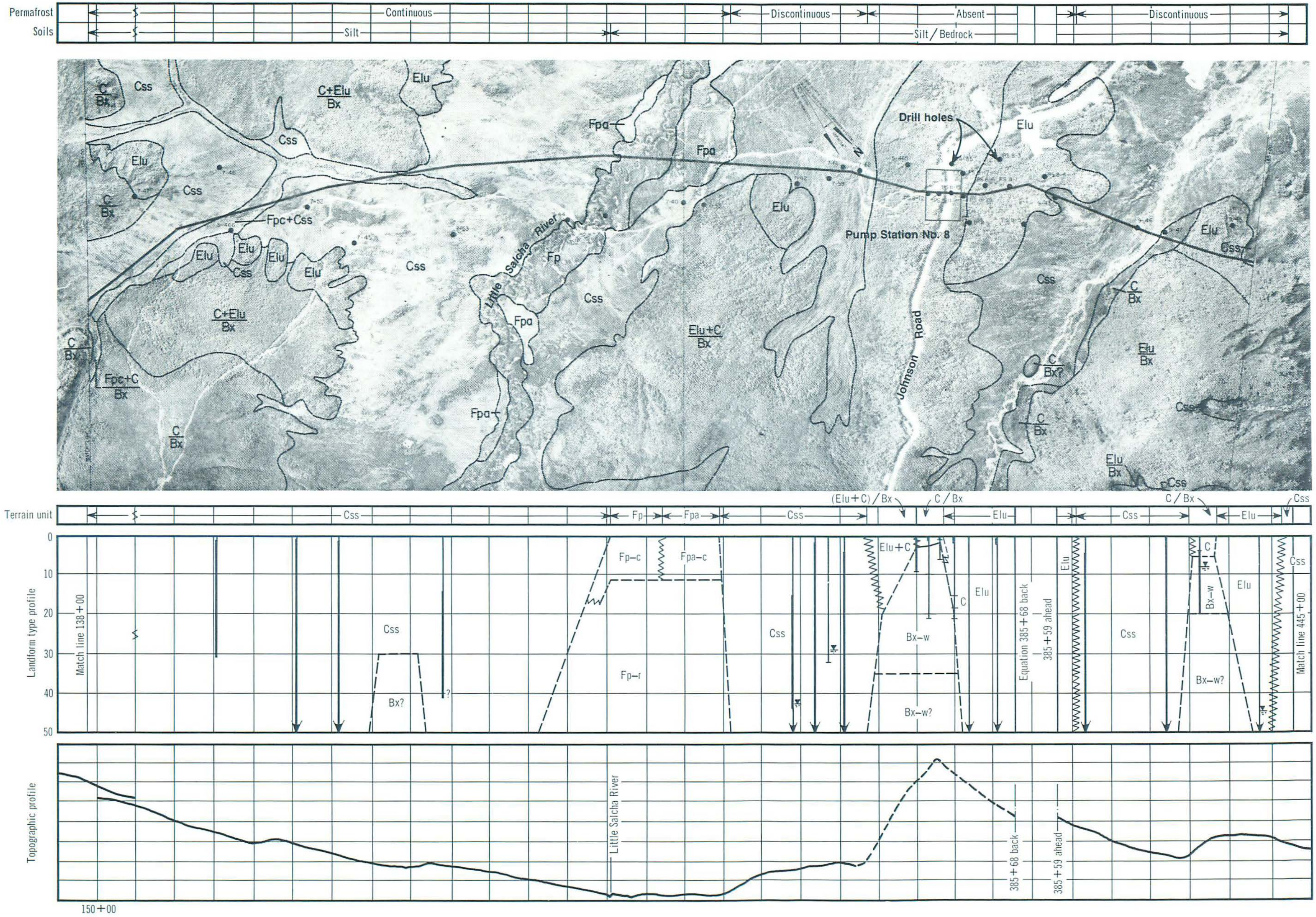
Fig. 1. A typical terrain unit map prepared during the preconstruction terrain evaluation of the Trans-Alaska Pipeline route from airphoto interpretation. It shows all borings, surficial soil types, landform units expected along centerline to a depth of 50 ft (15.2 m), permafrost occurrence, and groundwater conditions along pipeline corridor 2 mi (3.2 km) wide. The landform approach to terrain analysis is based on the premise that each landform is formed by a single geologic process or a combination of processes that commonly function together. Therefore, each landform has a characteristic range of soil properties and presents similar geotechnical problems.

***Ice** masses frequently have no surface indication in natural, undisturbed terrain. This photo shows a 20-ft (6.1-m) cut slope in glacial till on the Arctic Slope about 85 mi (136.8 km) south of Prudhoe Bay.*

TERRAIN UNIT MAP



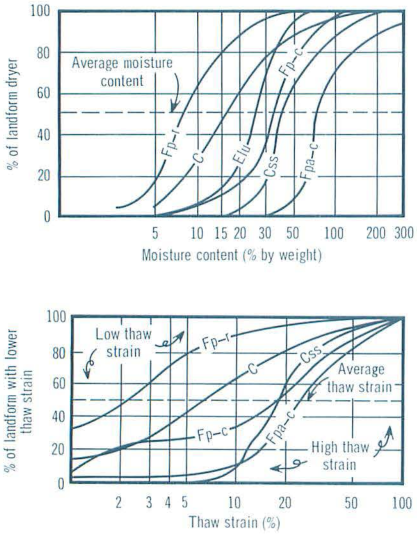


Fig. 2. Comparison of moisture content and thaw settlement for landforms on a typical Terrain Unit Map as taken from data bank summaries. The use of the computer data bank in optimizing engineering design is illustrated by these thaw strain distributions for selected common landforms. Thaw strain, which is the percentage of settlement in a column of frozen soil upon thaw, is indicated on the horizontal axis. The vertical axis indicates the percentile of samples tested from each landform. Thus, the curves can be used to determine for each landform at any given confidence level what thaw strain must be designed for.

profile because borings were not spaced close enough to allow correlation of individual soil strata. Permafrost, surface soil types, and groundwater conditions expected are also indicated.

This profile was used as a geologic reference by the design group and others for many purposes such as the determination of pipeline construction method and the estimation of soil resistivity for corrosion protection design. It was distributed to contractors for bidding purposes, and to government agencies and consultants who were reviewing the project.

Computer data bank

Since there were not enough soil borings to allow designs based on site-specific interpretations, a computer-based data bank was set up. It stored geotechnical information resulting from field investigations and laboratory tests of over 34,000 samples from 3,500 soil borings. Information stored in the IBM 360-40 computer not only applied to specific locations along the route but included tabulations of engineering geologic interpretations of conditions between borings where no field data were available. New information was continually added to the bank as field and office studies progressed. Data were readily retrieved from the computer and quickly distributed, resulting in substantial savings of time and labor. Slow and error-prone retyping of data tables each time new information became available was avoided.

Both the landform in which each field observation or boring was made and the soil or other environmental properties encountered were incorporated into the data bank. Thus, summaries could be prepared for a quantitative picture of the natural variation in critical soil characteristics for each landform.

Such data bank summaries were useful for many purposes including the comparison of conditions in different landforms (Table 1) and the allocation of exploration expenditures. For example, the number of boreholes made during field programs was usually limited due to high costs and difficult access problems. The drilling program was more efficiently planned using the known variability of different landforms so that few holes were drilled in the uniform landforms and more holes were programmed for highly variable landforms. Had the drilling program been predicated on uniform spacing without regard to landform, exploration expenditures would have been used inefficiently. Once the properties of a landform were fairly well known, preliminary soil studies in new areas such as reroutes were done from airphotos and quantitative estimates of expected soil conditions were made from previously developed data bank summaries.

The data bank was particularly useful in assessing soil conditions which have no surface expression. For example, it was not possible to determine the distribution of all ice masses along the route without drilling an excessive number of test holes. Data bank summaries were used to estimate the percentage of massive ice (by volume) in landforms that could be identified from airphoto analysis of topography, vegetation, and drainage pattern.

Only 8% of the soils in landform Css, retransported silt (see stereo photo), have ground ice contents low enough to have less than 10% thaw strain. Therefore, it is unlikely that a drilling program in Css would be successful in delineating sizable thaw-stable areas.

Use in construction planning

One of the most important applications of the data bank was its use in computerized construction planning where input of soil conditions was required. For instance, a preliminary estimate of the amount of excavated material suitable for use as embankment on a mile-by-mile basis was prepared for the entire route. This was done by adding the geometry of units in the landform profile, and the final grading elevations and cut slope configurations to the data base thus making it possible to compute the volume of earthwork for each landform encountered in the cuts. The proportion of this excavated material suitable for embank-

There is too much helter-skelter gathering of data from borings and field observations in many geotechnical studies without subsequent analysis of the information obtained to determine natural geologic variation.

Table 1. Comparison of data bank summaries of Soil Type, Permafrost, and Embankment Suitability for landforms on a typical Terrain Unit Map (Figure 1). Figures represent percent of soils in each landform in given class. (*) Soils considered usable for embankment if containing less than 5% fines (silt + clay) in summer or less than 12% fines in winter.

		LANDFORM					
Generalized Soil Description	Unified Soil Class	C	Css	Elu	Fp-c	Fp-r	Fpa-c
Peat & Organics	Pt		0.9				7.7
High Plasticity Organic Soils	OH		1.0				1.8
Low Plasticity Organic Soils	OL	2.8	10.3		4.1	0.2	22.9
High Plasticity Silts	MH	0.3					
Low Plasticity Silts	ML	19.7	82.8	100.0	54.8	0.8	59.6
Low Plasticity Silty Clays	ML-CL	0.9					
Low Plasticity Clays	CL	0.9					
Sandy Clays & Silts	SM,SC,SM-SC	46.2	2.8		26.2	6.3	3.6
Sands with 6-12% fines	SP-SM,SW-SM, SP-SC,SW-SC	2.0			11.8	6.2	4.4
Clean Sands	SW,SP	0.7			1.9	12.4	
Gravelly Clays & Silts	GM,GC,GM-GC	16.0	0.1			14.7	
Gravels with 6-12% fines	GP-GC,GW-GC, GP-GM,GW-GM	3.7			0.2	21.6	
Clean Gravels	GW,GP	5.6			1.0	37.5	
Permafrost (% of Landform with Frozen Soils)		62	95	0	64	54	99
Ground Ice Content	Massive Ice (100% ice)	0.5	2.0	0	0	0	0
	Soil + Ice (50% ice)	3.3	3.4	0	1.1	0.5	15.5
Suitability for Embankment*	Summer Construction	35	0	10	0	80	0
	Winter Construction	10	0	0	0	50	0

Little Tonsina Valley

In many geotechnical investigations there is too much helter-skelter gathering of data from field observations and test borings and a lack of analysis effort correlating the soil information obtained to determine natural geologic variation. This can result in geotechnical surprises encountered during construction that force costly and time consuming delays while the project design is changed to reflect new conditions.

The pipeline route through the Little Tonsina Valley crosses unfrozen, granular alluvial fans (Ffg) and outwash deposits (GFo) suitable for a standard buried pipe design. It also crosses a 4-mi (6.4-km) section of sporadically frozen, silty glacial tills and lacustrine (lake) deposits (G+L). Where frozen, these deposits require that the pipe be elevated on pilings and that special construction techniques be utilized to protect the surface vegetation and prevent the thaw of ground ice. The use of this mode of construction costs a great deal more than that of the standard burial techniques. Because the Little Tonsina area is located at the southern limit of permafrost occurrence, ground temperatures are near freezing and permafrost distribution is erratic and sensitive to minor variations in terrain conditions: groundwater movement, soil type, vegetation, topography, etc.

Therefore, the soil borings planned for this area were spaced closer than the normal practice for other sections of the pipeline project. Only one preconstruction drilling program was originally planned in contrast to normal procedures of starting with (1) widely spaced reconnaissance borings 2-3 mi (3.2-4.8 km) apart followed by (2) a detailed program 2,000-4,000 ft (610-1220 m) apart and where necessary (3) a final series as close as 1000 ft (305 m) apart.

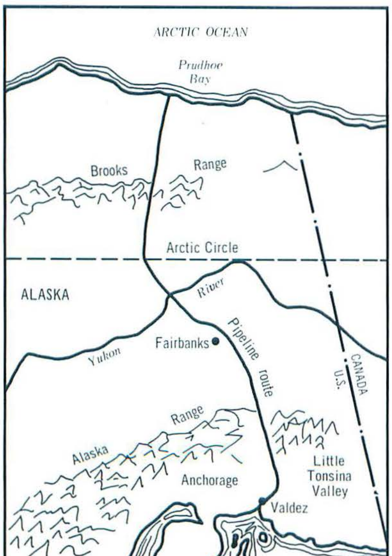


Fig. 3. Little Tonsina Valley lies at the southernmost limit of permafrost occurrence making the area extremely sensitive to all parameters affecting thaw conditions.

The results of the initial field investigations indicated that a small 7,000-ft (2,134-m) section of elevated pipe would be required in an apparently frozen area of landform G+L. At this point in time the situation appeared straightforward because the frozen borings were clustered together and remaining terrain suitable for burial did not appear to contain small inclusions of frozen ground.

A primary objective of terrain analysis is to define relationships between landforms and the characteristics of the materials composing them. The borings drilled in the Little Tonsina Valley indicated that the natural variation in soil properties within landform G+L was high and that the distribution of permafrost, which was critical, did not correspond with any obvious surficial landscape features.

To be sure that unknown inclusions of frozen soils were not present between unfrozen borings in landform G+L it was necessary to establish a genetic relationship between permafrost occurrence and surface landscape features. If this could not be done, either very closely spaced borings or condemnation of the entire G+L landform to elevated construction would be necessary to be conservative in pipe design.

After additional field study of groundwater movement, terrain microfeatures, vegetation patterns, and intensive airphoto analysis such a relationship was confirmed by additional borings put down later in locations thought most likely to contain frozen soils. These locations turned out to be somewhat better drained, to have taller and denser forest growth, and to occupy the higher parts of the 3 to 4-ft (0.9-1.2 m) microrelief. Groundwater movement in the other areas of this landform caused stunted vegetation growth and prevented permafrost formation.

It was necessary to specify an elevated mode for the entire section of reroute across landform G+L as a result of the additional landform-soil property variation study. The final results indicated that the thawed soil areas were too small and/or too widely spaced to make below ground construction economical. Transitions from above to below ground construction are costly as well as time consuming.

Had this approach not been taken and the original design used, which had appeared satisfactory based on the initial soils investigation with site-specific interpretations, unanticipated frozen soils would have been uncovered in trench excavation during construction. Placing the spread of pipe-laying equipment on standby can cost on the order of $200,000 a day or more while design changes, which must be approved by several state and federal agencies, are in progress and construction schedules are adjusted.

Additional delays while unexpected material requirements are filled and the need for costly terrain restoration activities—trench filling, revegetation, etc.—point out the necessity of avoiding field design changes due to geotechnical surprises if at all possible. If every scrap of useful information resulting from terrain investigations is used in a coordinated manner to determine natural geologic variations through the landform-data bank approach, many of the unwelcome discoveries during excavation of trenches, cuts, and foundations can be foretold and possibly avoided all together.

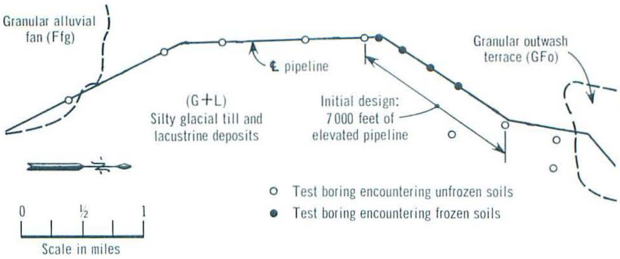


Fig. 4. The initial soil borings encountered an apparently short section of frozen soils.

Little Tonsina Valley

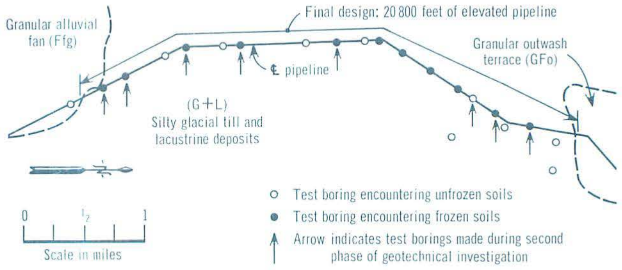
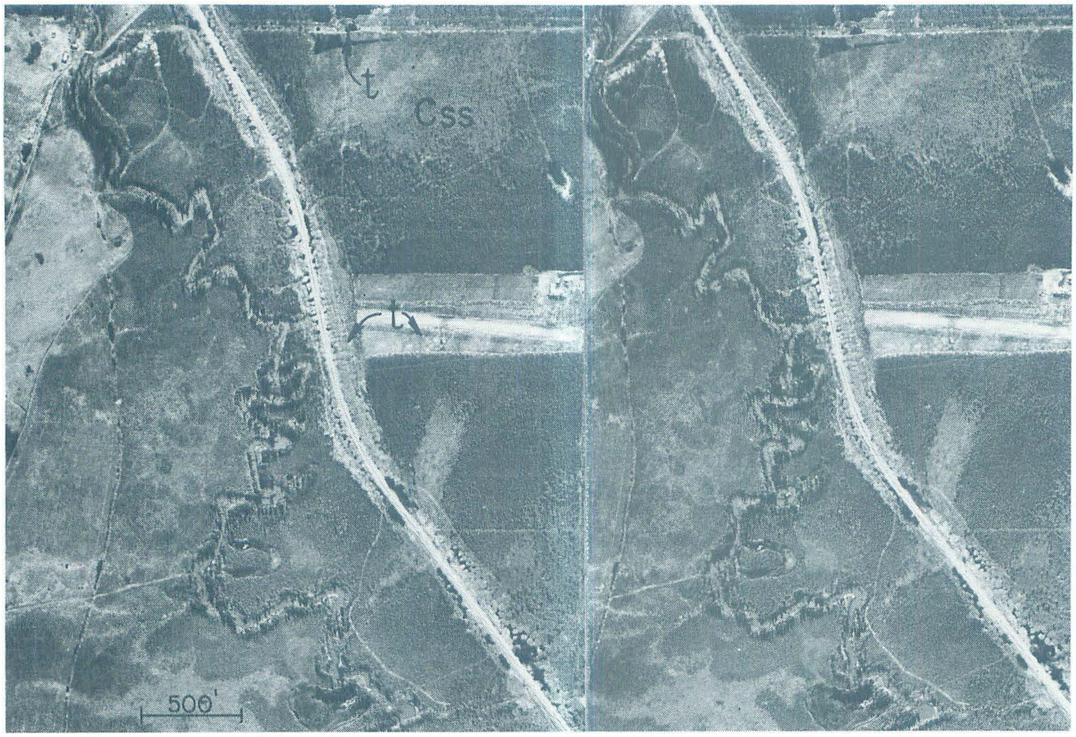


Figure 5

Additional soil borings located from landform-soils variation analysis disclosed erratic occurrance of frozen ground previously undetected.



Thermokarst development in retransported silt landform Css at Happy Hill, 7 mi (11.3 km) northwest of Fairbanks. Massive ice networks occur throughout this entire stereo pair, but surface indications are evident only where Alaska Railroad cuts, bulldozer trails, or cleared fields have initiated thaw (t). Annual thaw settlement of up to 2 ft (0.61 m) or more has required continual track maintenance for over 50 years at this location.

ment use was then obtained by calculating the percentage of soils estimated to be usable from each landform based on the moisture and soil texture data gathered from boring programs and stored on the data bank (Table 1).

Data bank summaries were also used to estimate ditching and pile drilling rates in each landform. When tabulated on a mile-by-mile basis this information was used to schedule construction activities and order equipment. Timely preparation of these construction planning estimates would not have been possible if manual examination of all soil borings and field data had been required.

Airphoto analysis and landform mapping, when combined with a data bank, can be very useful to engineers who must predict terrain conditions over large areas with limited field reconnaissance. The methods described are applicable anywhere, not only to large projects in arctic regions such as the Trans-Alaska Pipeline, but also to geotechnical investigations in temperate and tropical regions.

The author's appreciation is extended to Alyeska Pipeline Service Company for permission to publish this article. ▽

Raymond A. Kreig, in a paper jointly written with Richard D. Reger, presented a highly detailed description of the preconstruction terrain evaluation for the Trans-Alaska Pipeline at the Seventh Annual Geomorphology Symposium in SUNY at Binghamton, N.Y. For those of you who would like further information, the paper is published in: Geomorphology and Engineering, *Ed., Donald R. Coates, 360 pp., 1976, Dowden, Hutchinson and Ross, Inc., (Wiley), $27.50. Also, the State of Alaska is compiling an Atlas of stereo pairs giving information and examples of landform terrain analysis. Publication dates have not been yet set.*

Raymond A. Kreig, a CE specializing in natural resources studies and terrain evaluation from airphotos, also worked on soil reconnaissance and route location for the proposed 800-mile Alaska Railroad extension to Prudhoe Bay. He is currently doing similar work for Donald J. Belcher & Assoc., Inc., in Caracas, Venezuela.