The Use of Aerial Photographs for Engineering Soil Reconnaissance in Arctic Canada

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ABSTRACT: *Soil and vegetation features that indicate unstable soil and detrimental permafrost, as well as the identification of rock type, are summarized and illustrated on aerial photographs. The engineering quality and photographic recognition of a variety of Arctic landforms is treated in detail.*

THE advantages of aerial photograph analysis as a prerequisite to field investigation in Arctic[1] engineering geology are well recognized. This photographic interpretation must never replace the detailed field study, but our knowledge of permafrost geomorphology is now sufficiently advanced to allow significant locational decisions, especially those involving topographic control.

Canadian large-scale photographs are available for a few settlements only and not for areas of potential settlement. Accordingly the interpreter must be content with the incomplete coverage of the 1/40,000 of the trimetrogon series of 1948 to 1952 or the more recent, nearly complete coverage of the 1/60,000 verticals. Modern interpretation for engineering purposes utilize photographs of 1/6,000 or larger, so the scale of available Canadian Arctic photographs is too small for an accurate, detailed assessment. General judgements regarding the location of airstrips, roads and building sites can be made.

This paper attempts to suggest the extent of interpretation available with these small-scale photographs.

IDENTIFICATION OF DETRIMENTAL PERMAFROST

A deep active layer (thaw zone) is necessary for a stable structure, especially asphalt runways whose black color causes it to absorb considerable heat. Frost (1950), Sager (1951) and Black (1956) have discussed detrimental permafrost and its identification by aerial photograph features. The photographs included in this paper illustrate many of these features. In summary, construction sites in the Arctic that have the following features should be avoided.

	Aerial Photograph Identification	
	Small-scale	*Large-scale*
(a) Many rounded of rectangular-shaped lakes	Yes	Yes
(b) Sorted Circles	No	No
(c) Low-center polygons	Yes	Yes
(d) Small high-center polygons	No	Yes
(e) Lowland vegetation	Yes	Yes
(f) Beaded (not braided) streams	Yes	Yes
(g) Solifluction lobes and stripes	Yes	Yes
(h) North-facing slopes		

IDENTIFICATION OF ROCK TYPE

Although in middle latitude climate it is often possible to identify soil texture by the cross-sectional shape of gullies, in the Arctic the presence of permafrost usually produces steep gully sides regardless of soil composition. The Geological Survey of Canada is rapidly issuing geological maps; therefore with accurate photograph interpretation of rock type, vegetation and drainage, the soil composition and related stability can be predicted. It is also helpful that strata of different rock types are not too mixed in the Canadian Arctic.

Several conclusions regarding the identification of rock type can be drawn. Inspection of Table 1 in conjunction with the illustrative photographs should prove helpful in identifying relationships of photo tone,[2] rock,

[1] "Arctic" is usually defined as that portion of the high latitudes lying within the area of continuous permafrost, Koeppen's *ET* climate and treeless, tundra vegetation.

[2] Statements of photographic tone in this paper apply to late summer when construction is favored by drier soils and deeper active layer. During spring and early summer even coarse-grained soils will be somewhat damp and photograph darker than later in the thaw season.

TABLE 1

AIR PHOTOGRAPH TONE AND TEXTURE OF ROCK, SOIL AND DRAINAGE

Rock Type	*Rock Tone*	*Average Soil-Vegetation Tone*	*Drainage*		*Distinctive Features*
			Type	*Density*	
Gneiss	Even medium gray	Even to slightly mottled medium gray; usually lighter than rock	Confused	Variable; usually coarse; many lakes	Faults with elongated lakes; rugged landscape or rock exposed through drift
Granite	Even light to medium gray; usually lighter than gneiss; but depends on rock color	Usually darker than rock; light gray if sandy.	Same	Same	Same as gneiss; colored granite may be interpreted as gneiss
Diabase	Medium to dark gray, in places black	Even light to medium gray	Modified dendritic	Medium	Linear dikes with vertical sides; crescentic sill with rounded smooth textured dip slopes, steep scarps
Limestone; Dolomite	Light to very light gray; lightest of all rock except white sandstone	Mottled light to medium gray (grassy vegetation rare except where soil very wet all summer)	Dendritic	Medium to coarse	Often found in form of plateau or mesa with vertical cliffs; fractures common
Shale; Siltstone	Medium gray	Dark gray to black; (Attracts vegetation)	Dendritic	Medium to fine	Poor drainage; thermokarst; little relief and gentle slopes
Sandstone	White to dark gray depending on rock color	Medium to dark gray, (Grassy vegetation not common)	Dendritic	Medium to coarse	Light tones in river valleys; steep, jagged (not vertical) cliffs
Sand and Gravel	N.A.	Light gray interfluves; dark gray stream valleys, (vegetation concentration)	Dendritic to Parallel	Fine to very fine	If flat, many rounded lakes; no lakes if in slope; striking tonal contrasts—valley to interfluve
Metasediments	Medium gray, usually between granite and gneiss	Similar tone to that of rock	Confused; sometimes rectangular	Medium to coarse	Look for evidence of folding. Identification of type of metamorphic rock is very difficult

soil and vegetation type.

Bedrock type can sometimes be identified by drainage pattern and density. Shale produces a fine-textured, intricate dendritic pattern with long streams. Quaternary gravels and sands have a light tone with a distinctive very fine-textured, somewhat parallel pattern with vegetation mostly within the narrow stream valleys. The interfluves are comparatively free of vegetation. Sandstone and

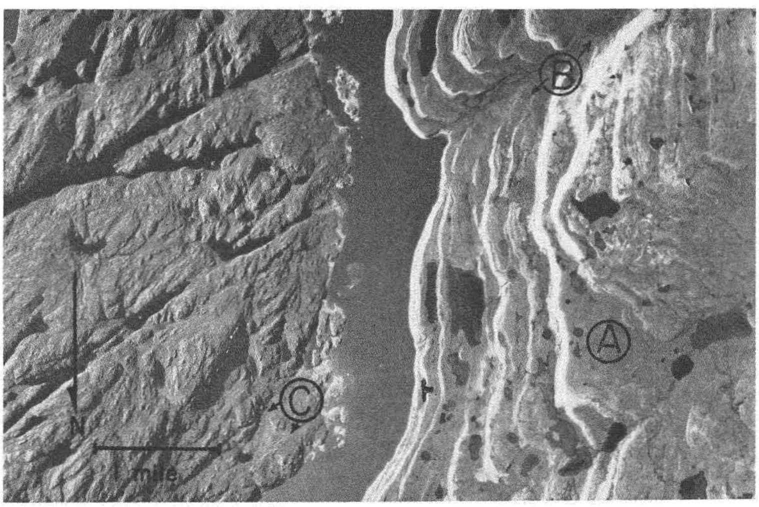

FIG. 1. Eastward dipping limestone overlies gneiss on Simpson Peninsula, Keewatin. Raised beaches are outstanding on the limestone but not on the gneiss. The medium-gray tone indicates varied vegetation (*A*) but grassy, wet solifluction stripes are at (*B*). Water and soils with a high percentage of fines are found behind the beaches because the dipping bedrock prevents adequate drainage. Sand and gravel in the gneiss area is available at (*C*). (Photograph courtesy R.C.A.F.)

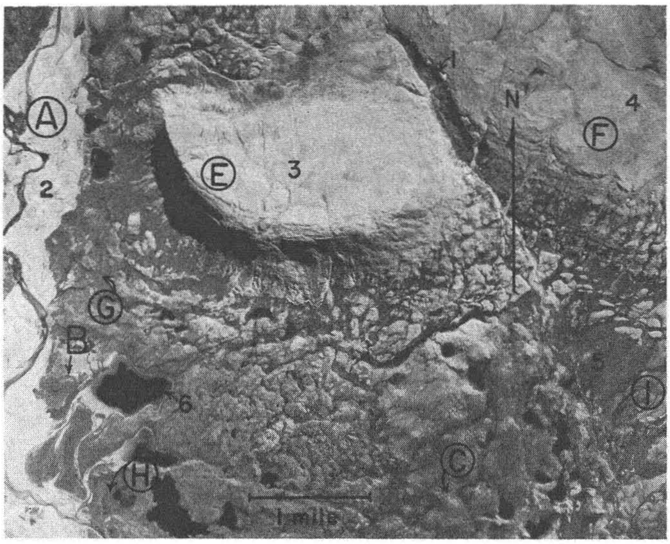

FIG. 2. Paleozoic sedimentary rocks overlay Precambrian granitic gneiss at the south end of Milne Inlet, northern Baffin Island. This photograph shows a full range of gray tones: 1. White (snow patch), 2. Very-light, 3. Light, 4. Medium, 5. Dark, 6. Black (deep water). All areas of medium-gray or darker are vegetation, the darkest being grass and moss in wet soil. Typical light tone and vertical cliffs of limestone (*E*) lies on a colored rock that appears to be sandstone (*F*) which lacks the steep slopes of the limestone. Grassy solifluction stripes surround the mesas. High centre polygons at (*G*) and low centre polygons at (*H*) are small but easily identified. The soil of the area is sandy, with dry and wet areas having quite different tones due to vegetation contrasts (see *I*). Patterns at (*C*) are high-centered and four-sided, therefore represent eroded limestone fractures, not soil polygons. Area (*A*) is a sand-covered area on both sides of the stream. It is not an alluvial floodplain. Note the sandy flat at (*B*) with fissures. (Photograph courtesy R.C.A.F.)

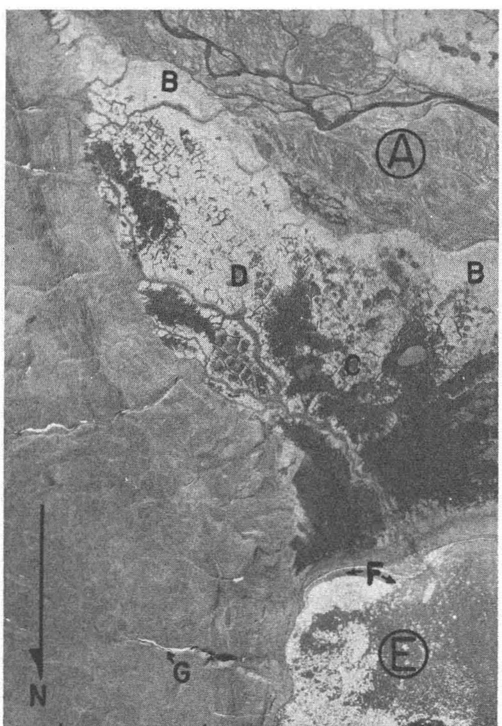

FIG. 3. An alluvial floodplain and terrace are shown in a broad, deep valley on north-central Devon Island where a major river enters Thomas Lee Inlet. The floodplain (*A*) has a medium-gray tone because of rock color, a light vegetation cover and probably high soil moisture. The terrace is relatively well drained at its southern end (*D*) and is covered with high centered polygons. At (*B*) the polygon borders are barely discernible and the active layer is likely deep. The dark gray tone in the vicinity of (*C*) is grass and moss. Shallow water (*E*) extends offshore but ice floes can get to the beach so the depth must be over six feet. Unless there is evidence of ice grounding on the bottom or the tonal break at deep water is sharp, the light-gray tone of the water may not be caused by shallowness but by silt brought by the river. Very shallow water at (*F*) allows entrance of only very small floes. Snow in gullies (*G*) has the characteristic white tone. The floodplain tone is darker than common with limestone soil and investigation of geology maps indicates shale, siltstone and limestone in the drainage basin. (Photograph courtesy, R.C.A.F.)

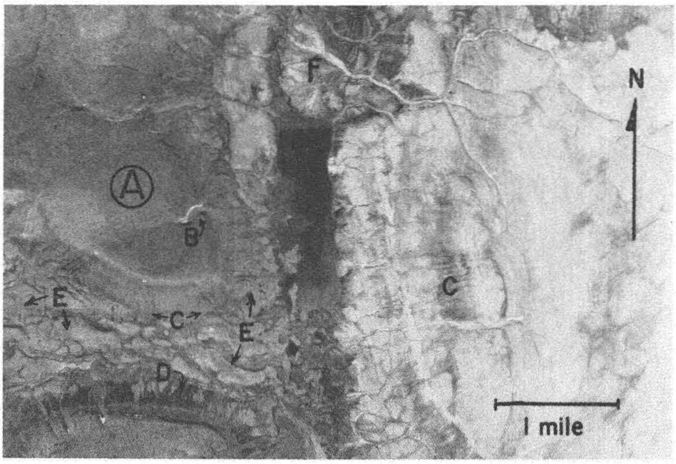

FIG. 4. On northeastern Prince of Wales Island a major fault separates conglomerate and sandstone of medium-gray tone from limestone of much lighter tone. The white of small snow patches contrasts with the black of the small rectangular lake's deep water. The small conglomerate (granite) mesa (*A*) has the characteristic gully shape at (*B*). It is surrounded by solifluction stripes (*C*) which are not as wet as those at (*D*). Sand and gravel which lies at (*E*) has a medium to light-gray tone with smooth texture except for small stream valleys. A small alluvial fan (*F*) of limestone sand and gravel has a light cover of lichen and moss. The upland areas of limestone and conglomerate are almost devoid of vegetation. (Photograph courtesy R.C.A.F.)

conglomerate gullies are large, short, V-shaped and not numerous (see Figure 4). Limestone has a coarse-textured, rudimentary dendritic pattern. Although jointing is common in all Paleozoic rock, it is most readily identified in limestone even though glacial drift completely covers the bedrock (see Figures 2 and 5).

Since most rocks other than shale and siltstone are resistant to erosion in the Arctic environment, the photographic texture of escarpments aids in differentiation. Limestone upland and escarpment often meet at right-angles, dropping vertically to the tallus beneath. Conglomerate mesas have relatively steep sides but the photographic texture is remarkably smooth. Slopes in sandstone are less abrupt and have a jagged, yet concentric, texture (compare Figures 2 and 4). Diabase dikes intruding metasediments are more resistant to erosion and thus topographically positive but through granitic rock they appear as depressions. Sills in this rock have a moderate to gentle dip slope and steep, jagged scarps. Granite and gneiss have steep-sided, round-crested, sub-parallel and very faulted ridges. Unless the drift mantle is deep, numerous elongated lakes are common. Metamorphic sedimentary rock has more rounded forms with folds or other lineation diagnostic. Here also, steep slopes are associated with faults or steep folds.

TABLE 2

SUMMARY OF THE TONAL ASPECTS OF ARCTIC PHOTOGRAPH INTERPRETATION

Gray Tone	*Exposed Bedrock or Beach Ridges*	*Vegetation*	*Depositional Landform*
1. *White*	Never	No vegetation	Ice or snow
2. *Very light*	Seldom seen; may be (3) below	No vegetation	Wind-blown loose sand, gravel or till
3. *Light*	Limestone, dolomite; much less commonly white sandstone, quartzite, granite	Minor lichen and moss	Swells in clay-silt till, eskers limestone braided streams, alluvial fans and raised beaches
4. *Medium*	Colored sandstones and conglomerates (tone varies with color); light granite	Various lichens, minor moss and grass	Swells in sandy till, gneiss-granite till, limstone terraces, raised deltas
5. *Dark*	Gneiss, dark granite, diabase, shale, siltstone; much less commonly dark colored sandstone	Complete cover of grass, moss, and other vegetation; often with lakes and polgons. May be black lichen only	Stabilized sand plain
6. *Black*	Seldom seen but may be diabase or (5) above	Water or heavy grass cover with saturated soil	Never seen

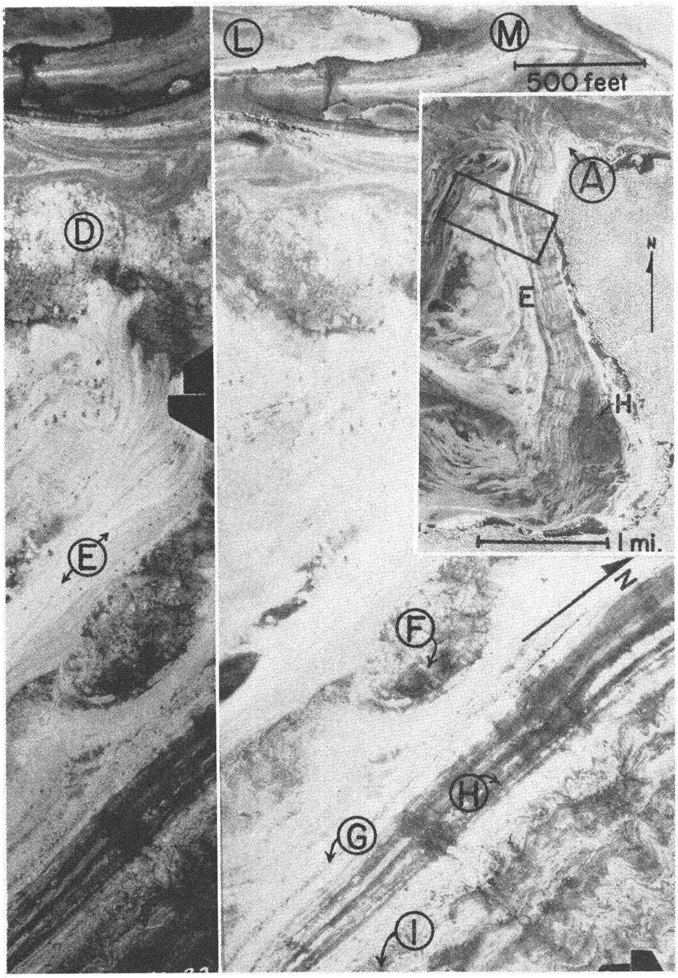

FIG. 5. This large-scale stereoscopic pair with small-scale insert showing the same area, covers part of a potential airstrip site on a horizontal limestone raised beach of Igloolik Island. Igloolik settlement is at (*A*). The very light-gray tone of the raised beaches (*E*) is replaced by the darker tone of vegetation (*H* and elsewhere). Solifluction lobes of "flowing" soil is shown at (*I*) while soil polygons at (*D*) and (*M*) are small and not well developed. Limestone bedrock is exposed at (*G*) and rock fractures at (*F*). The feature at (*L*) is a very shallow lake (only a foot or two deep). Notice the tonal variations due to photograph processing. (Photograph courtesy R.C.A.F.)

Landforms Favorable for Construction

Similar landforms in the same lithic and climatic environment should have soils of very similar engineering qualities. The greater precipitation of the mountainous eastern Canadian Arctic will provide additional water to the soil. Also, insolation, thus the number of thawing degree days, increases equatorward. Therefore the active layer will be thicker in dry soils, and vegetation more luxuriant in damp soils. Because construction sites will usually be located on well-drained soils, the climatic differences within the Arctic will not be of sufficient magnitude to warrant detailed consideration in this paper. Microclimate and local vegetation variations will be influential and they can be identified or estimated on the aerial photograph.

The following discussion of landforms, their engineering significance and aerial photograph interpretation is based partially on field studies undertaken by the author on Prince of Wales Island.

The contour-like texture of *Raised Beaches* is readily identified on photographs. Tones are light, although slightly darker than the modern beach. Tonal differences reflect rock color rather than vegetation amount which is usually minor. If a lowland is adjacent to the beach but raised strands are not well de-

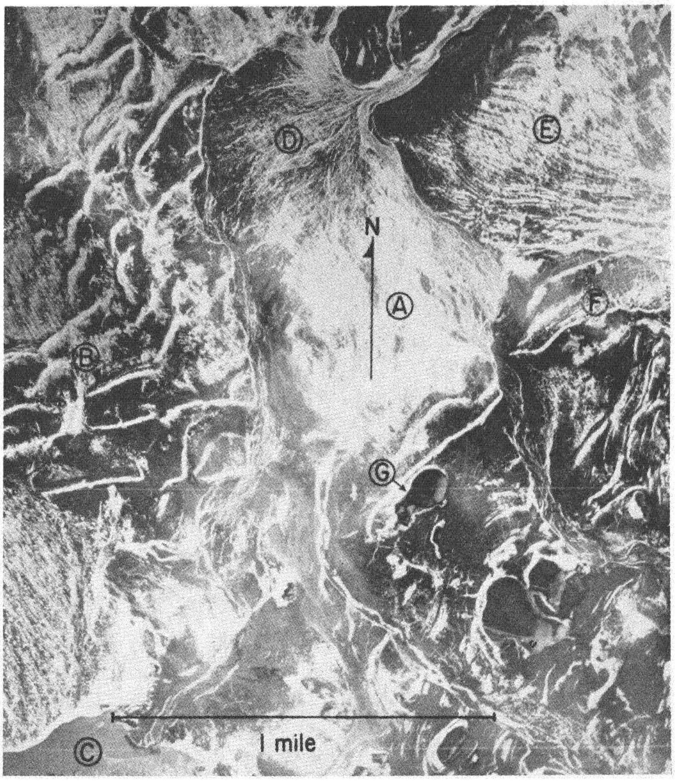

FIG. 6. With the aid of a medium-scale and snow to outline micro-features, many patterns can be identified on this photograph of the Radstock Bay-Erebus Bay lowland on southwestern Devon Island. On a small-scale, 1/60,000, photograph this area has an almost consistent light to medium-gray tone. Here the areas of recent deposition, such as the fan at (*A*) and (*D*), show light-gray while the flattest areas are almost black. Terraces, such as (*B*), are not nearly as common in the Arctic as the Strandlines at (*E*). Note frost fissures at (*F*) and very shallow lake at (*C*). (Photograph courtesy R.C.A.F.)

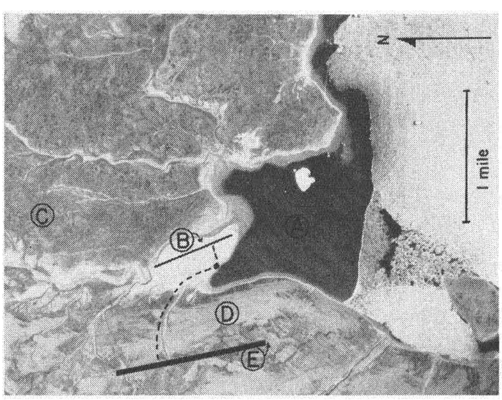

FIG. 7. About six miles southeast of Figure 4 is Back's Bay (*A*) with a small river and very flat raised delta of sand and silt. The surrounding bedrock is limestone but the river headwaters are eroding an area of sandstone. The sandy lowland at (*C*) shows only a few remnant beach ridges and is covered with black lichen (medium-gray tone). Where the sand is being eroded by river or wave action, the tone is very light. The delta (*B*) is windswept and nearly devoid of vegetation. Although an airstrip could easily be constructed here, the foundation would be soft. The limestone strands at (*D*) are composed of sand and gravel. The light-gray tone reflects the slight cover of moss and lichens. A long airstrip could be constructed at (*E*) although a small area of vegetation must be crossed. On the southwest side of the delta deep water comes close to the shore and the landing beach area is extensive. A road could easily be constructed to the upland airstrip site. (Photograph courtesy R.C.A.F.)

veloped or appear as "islands," the tone may be darker because of a cover of lichen. This is especially noticeable with stable sandy soils (see Figure 7). The dark gray to black tone of grassy vegetation may be found in the wetter beach swales. Solifluction may occur on a raised beach but is not a common association (see Figure 5).

Although tone and texture of separated beaches may appear identical on a small-scale photograph, on rare occasions the strands are not relatively flat but are very

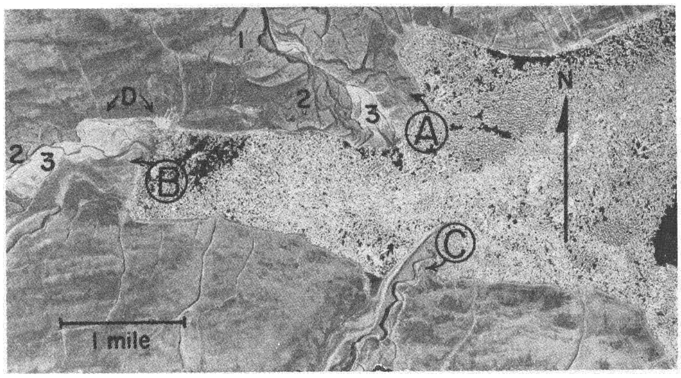

FIG. 8. In Kennedy (Transition) Bay, Prince of Wales Island are located a raised delta (*A*), floodplain (*B*) and esker (*C*), all composed of limestone sand and gravel. On the delta three levels can be identified, tonal differences being the result of vegetation differences. Grass is located in the old channel scars, light moss and lichen cover (about 10 per cent) the remainder of the delta and no vegetation is on the active portion (*3*). The floodplain (*B*) exhibits similar tonal patterns to the delta with a terrace at (*2*) and the most recent alluvial deposition at (*3*). The steep-sided, relatively flat-topped esker (*C*) has been reworked as the sea-level dropped. Tone and vegetation is similar to the higher portions of the delta and floodplain terrace. The amount of silt is greatest in the floodplain and at (*D*) it is several feet thick and grass-covered. Note the even dark gray tone here. (Photograph courtesy R.C.A.F.)

hummocky. This feature is caused probably by ice floes shoving up on the beach before uplift. The local relief is two to six feet. These irregularities can prove a barrier to vehicular traffic and thus are not acceptable as emergency landing fields. Formation of an airstrip would require considerable leveling and thus adjustment of the permafrost table. A related phenomenon, the storm ridge, may be ten or fifteen feet high and several miles in length. They are usually lower than this and can easily be identified on large-scale, although not small-scale, photographs.

Any beach may have large glacial erratics exposed because it is often composed of reworked till. Smaller boulders may come to the surface and collect at the base of a strand or terrace. Due to their marine origin beaches may contain deleterious salts, and deflation has left a gravel surface not indicative of the composition of the underlying soil.

Beaches in granitic and gneissic rock areas have a soil high in sand and gravel-size particles and are therefore relatively stable. Strands containing soil high in fines, except those near the modern beach, are quickly destroyed by solifluction. Similarly, well preserved beaches on shale are rarely found. In sandstone areas the beach strands are not well preserved where slopes are gentle. Here, the soil may be composed largely of sand with only a little gravel and silt mixed. Unfortunately, although dry, it may not be able to support heavy vehicles. Higher strands are better drained, contain gravel and are more stable.

Many Arctic settlements (especially D.E.W. Line stations) have been constructed on raised beaches of limestone or dolomite shingle. A veneer of pebbles lies on top of finer particles in reworked till from one to thirty feet thick. Investigation of six widely separated limestone beaches on Prince of Wales Island indicated considerable variation in the amount of clay- and silt-size particles which may be as high as 25 per cent of the soil by weight. However, gravel sizes make up on the average over 50 per cent and sand over 25 per cent. Gravel is sub-rounded to angular and frost fissures are common. Permafrost lies at a depth of two or three feet.

Raised beaches, if they do not display indications of detrimental soil and permafrost, should provide a stable foundation. Gravel is abundant but may be rather "dirty." Bedrock is often close to the surface. Considerable experience has already been gained in techniques of construction on Arctic beaches.

River Channel Deposits are commonly subrounded, partially-sorted sands and gravels, but the composition will depend on the type of source rock and distance of its transport. In limestone areas the gravel composition may change to silt and sand where the gradient becomes slight, especially where a lake or the sea is receding. Here vegetation cover may be complete and photograph a solid to "stringy" black (see Figure 3). If the river and its tributaries is draining an area of soft limestone, siltstone or shale, the channel deposits, terraces and delta will contain much silt. Sandstone and granitic bedrock will produce depositional sands and gravels with little problems from buried ice or inadequate drainage.

Braided streams indicate a relatively steep gradient and are composed of gravel and sand (see Figure 8). Dormant portions of gravel floodplains have a slight vegetation cover and exhibit photograph tones similar to that of the source rock, while active areas will have a lighter tone.

Permafrost and soil conditions may show much variation, being unfrozen many feet deep adjacent to the river and less fortunate in the backwater areas such as abandoned meanders and other depressions (Frost and Mintzer, 1950). Although the portion of the floodplain not experiencing deposition will have the greatest amount of fines and the most vegetation, it is less susceptible to spring flooding. Gravel for construction should be abundant although locally rather angular and silty. Generally, floodplains are a good source of gravel but may not offer acceptable construction sites. Determination of the type of bedrock in the drainage basin, distance of transport and aerial photograph indications of a shallow, wet active layer is very important.

River Terraces and Raised Deltas are identified by their step-like flat surfaces with steep edges, topographically raised position, lack of youthful stream gullies and usual light tone (see Figures 3 and 8). They are composed of sand and gravel which is stratified, graded and somewhat rounded. The soil is usually dry and has a deep active layer. Current scars which contain more soil moisture and thus vegetation, indicate formation by swift water and a gravel composition. Frost and Mintzer (1950) suggest that the portion of the terrace nearest the valley wall may have a cover of fine soil while the edge nearest the river is most favorable for construction (see Figure 3).

Recent detailed soil studies (Davies, 1961) in Greenland have indicated favorable terrace construction sites in a variety of soils. Where the soil is clay and silt in north Greenland it is exceptionally stable because the precipitation is very light. In the wetter Canadian Arctic such a soil would be unacceptable as a road or airstrip surface. If dried out in its upper portion the soil would be covered with desiccation cracks and should support light vehicles in late summer.

Similar in appearance and soil composition to the river terrace, the raised accurate delta commonly contains gravel and lesser amounts of sand and silt. On Prince of Wales Island are two deltas which have a soil composition of 50 per cent subangular limestone gravel, 25 per cent sand and 25 per cent silt. Similar deltas on Cornwallis Island contain little silt. Another delta investigated by the author in a sandstone-limestone area contains 5 per cent gravel, 60 per cent sand and 35 per cent silt-clay. Below three feet is silt and clay only. A sandy soil, although well drained, is not able to support heavy loads. A D.E.W. Line airstrip on King William Island which was constructed on a similar sand delta has offered very poor traction for aircraft.

If the delta is at the downwind end of a valley the surface may be almost devoid of

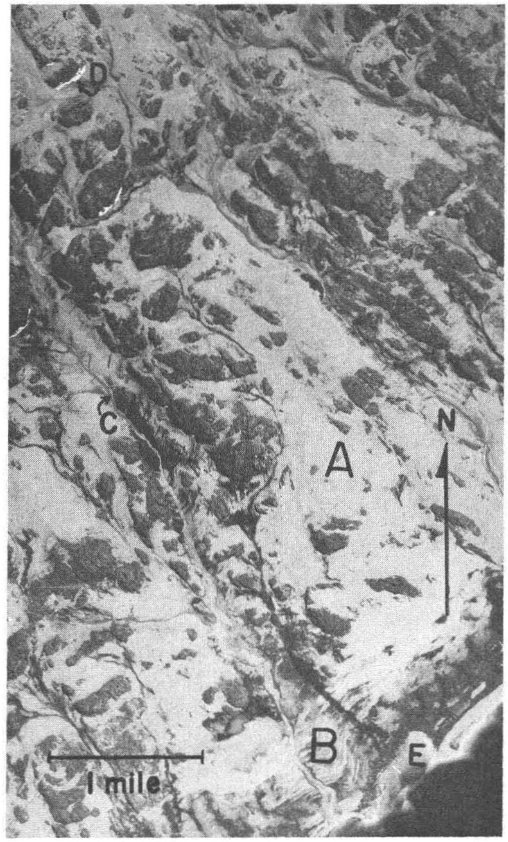

FIG. 9. In windy areas where the glacial till (*A*) is sandy it may be kept sufficiently in motion to prevent lichen growth. The tone of the barren soil is light to very light gray. Some barely distinguishable raised beaches can be seen at (*B*). Grassy solifluction stripes are at (*C*) and show a black tone while a snow patch at (*D*) is white. Shallow water (*E*) shows a light tone. Southeast of this is the black tone of deep water. This photograph covers a small area of Boothia Peninsula composed of gneissic rock (see the dark-gray tone where the rock outcrops). (Photograph courtesy R.C.A.F.)

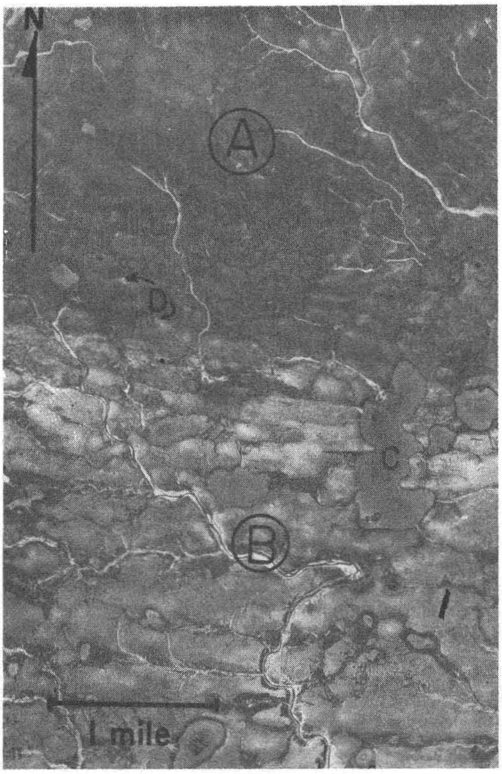

FIG. 10. About 10 miles north of the area shown in Figure 8 the bedrock changes from sandstone and greywacke (*A*) to limestone (*B*). Rock crops out only in river beds or the occasional erosional remnant such as at (*D*). The tonal contrast reflects differences in vegetation and rock color with red rock at (*A*) supporting an almost continuous cover of black and gray lichen. Similar medium-gray tones in area (*B*) are usually grasses rather than lichen. Note the sandy, light-toned river beds which extend southward into the limestone area but not beyond the letter (*B*). The feature at (*C*) is a shallow lake with only minor vegetation associated.

vegetation and have a white photograph tone (see Figure 7). The photograph texture of loose sand and gravel is very even and the tone is only slightly darker than that of snow. Such a landform must be very inhospitable during winds because of blowing snow or sand.

Deltas in gneiss and granite areas are composed of sand and gravel, especially the former. The Burnside River delta in Bathurst Inlet has heath-covered sand dunes in the higher parts and vegetation-free sand at the lower elevation (Canada, Geographical Branch, 1955). Photograph tones are dark-gray and very light-gray respectively. Composition of the Coppermine River delta is similar although the tone is medium gray (Canada, Geographical Branch, 1954).

Accurate deltas should provide superlative construction sites although most are not large enough to permit a long airstrip and some are too sandy. Little study has been made of bird's-foot deltas in the Arctic but they are usually composed of fine-grained soils. They are often located at the mouths of rivers in shale, siltstone or silty limestone areas and vegetation is locally abundant.

Although most *Alluvial Fans* are too small for the construction of an airstrip, they provide a well-drained foundation of angular to sub-angular coarse gravel. Fines can be expected at their lowest portions. Road and airstrip will most often be built at right angles to the stream course to take advantage of gentle slopes, but the subsurface flow and spring runoff may be disturbed. Flash rainstorms are uncommon in the Arctic, nevertheless a washout is possible. Stable portions of a fan can often be identified by their slightly darker tone and cover of rock lichen.

The *Esker* is one of the easiest land forms to identify on aerial photographs, yet often is illusive at the ground surface (especially if it has been reworked by waves during emergence). Their sinuous, sometimes discontinuous, form is light in tone regardless of the rock type, because it is relatively free of vegetation or surface moisture. They are composed of sand and gravel with a deep active layer but minor seams of clay, till and very large boulders are to be expected (Fraser and Hennock, 1959). The esker at Transition (Kennedy) Bay which is shown in Figure 8 has a slope to the sea of five degrees and sides of 27 degrees. The limestone soil is about half sand and half gravel (maximum size four inches) with about five per cent silt. Its drainage, stability and support strength is very favorable.

Only a few eskers are sufficiently flat or wide for the construction of an airstrip but many will provide an excellent road bed across otherwise unfavorable terrain. The Transition Bay esker with little surface alternation would provide a ready-made highway from the water to an upland airstrip.

Drumlins and similar elongated depositional glacial landforms contain till. Frost (1960, p. 378) suggests that they are found in areas where clay is abundant in the glacial debris. On aerial photographs they have a light-gray tone and often appear to be well-drained. If a roadbed of gravel several feet thick is laid over the vegetation-free till, the drumlin should continue to drain properly. Unfortunately, most drumlinoid features are too small for an airstrip.

The soil of *Till Plains* and *End Moraines* contains large amounts of silt and clay; therefore drainage and related permafrost conditions will vary within short distances. If significant quantities of clean gravel is available for fill, an acceptable road or runway can be constructed but will probably require periodic leveling. An asphalt surface is not recommended unless the amount of fines in the subsoil is low. In Figure 10 the boundary between clayey till and sandy till can easily be recognized. Knowing the local bedrock is important here.

A low-lying till plain reworked by waves will appear at ground level as a gravel plain although the aerial photograph pattern would be similar to the more typical silt-clay-sand variety; a medium to dark gray tone of mottled texture (see Figure 10). Isolated light-toned beach ridge remnants will help identify this landform modification. In limestone till, swales will be rather wet and swells drier and light-toned. The tone and texture of reworked sandy till is darker and less mottled.

The soil on *Uplands* may be so shallow that permafrost is not present (except in the bedrock) but if high in fines it will experience frost heaving if disturbed. Studies on Prince of Wales Island show that limestone uplands contain equal amounts of gravel, sand and fines with fair to poor gradation. Soils formed on sandstone is high in sand-size particles with gravel and silt content low. Drainage is good and solifluction phenomena not widespread. Similar soil exists on gneiss and granite although a greater amount of gravel is expected. Since soil collects in depressions only, water content may be high here (see Figure 1).

Erosional surfaces of the felsenmeer type are common only where the bedrock is tilted almost vertically or intensely ice-scoured. Because of the nature of its composition, coarse conglomerate will produce a similar upland surface. Detrimental permafrost and inadequate drainage are not a problem, but in most cases a gravel cover will have to be applied. The unprepared felsenmeer surface is difficult to traverse, even on foot. The ground may be so covered with angular boulders that the bedrock, although very close to the surface, is not exposed. Such surfaces, if sufficiently flat to facilitate construction, are usually several hundred feet in elevation and a road from the adjacent lowland is difficult to build. Air photograph inspection will not confirm the existence of a felsenmeer but topographic position and knowledge of the bedrock is helpful.

A summary of Arctic engineering geology and related aerial photograph interpretation will not be attempted, other than to offer a table of general tone-texture relationships and to suggest the most superlative landforms for construction. They are beach ridges, river terraces, raised deltas and eskers composed of a sandstone, dolomite, granite, gneiss or diabase gravel-sand mixture.

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