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ARCTIC AND SUBARCTIC ENVIRONMENTAL ANALYSES UTILIZING ERTS-1 IMAGERY

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ERTS-1 IMAGERY
Arctic and Subarctic Environmental Analysis

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Dr. Harlan McKim and Thomas L. Marlar

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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16. Abstract
This investigation is designed to evaluate the utility and effectiveness of satellite imagery in synoptic surveys of coastal sedimentation and related processes in Cook Inlet, Alaska and of the distribution, and environmental interrelationships of permafrost terrain. Imagery from the ERTS MSS scanner is the primary data source for this investigation. Aerial underflight imagery and ground observations of selected sites are secondary data sources. Results are compared with published maps and charts. Of the repetitive imagery received to date the major cloud-free portion is of central Alaska. Therefore, early emphasis was placed on evaluating the feasibility of mapping permafrost terrain from textural and tonal patterns related to surficial geology and vegetation. The feasibility of rapidly producing accurate thematic maps directly from ERTS-1 imagery was demonstrated. A surficial geology map at a scale of 1:1,000,000 has been prepared. Eight geologic units were defined and delineated in a 13,000 sq. mile area in north central Alaska. Vegetation and permafrost distribution maps at the same scale also have been prepared. Four vegetation cover and five permafrost terrain units were defined and mapped. In addition, many geomorphic features unique to this area were recognized. Thaw lakes, glacial moraines, cirques, and abandoned glacial valleys are among the most discernible.

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Classic stream features such as oxbows, meander scars, point bars, braided channels and chutes also are remarkably well defined. Because of the lack of cloud-free imagery, only the most preliminary analysis of the regional hydrologic and oceanographic processes in Cook Inlet has been possible. However, it is evident from the brief observations that the distribution of sediments and the regional circulation patterns can be monitored using satellite imagery. Computer-oriented, pattern-recognition and change detection techniques presently are being developed to aid in detailed analyses of hydrologic and coastal processes in Cook Inlet.

PREFACE

This investigation is designed to evaluate the utility and effectiveness of satellite imagery in synoptic surveys of coastal sedimentation and related processes in Cook Inlet, Alaska and of the distribution, and environmental interrelationships of permafrost terrain. Imagery from the ERTS MSS scanner is the primary data source for this investigation. Aerial underflight imagery and ground observations of selected sites are secondary data sources. Results are compared with published maps and charts.

Of the repetitive imagery received to date the major cloud-free portion is of central Alaska. Therefore, early emphasis was placed on evaluating the feasibility of mapping permafrost terrain from textural and tonal patterns related to surficial geology and vegetation. The feasibility of rapidly producing accurate thematic maps directly from ERTS-1 imagery was demonstrated. A surficial geology map at a scale of 1:1,000,000 has been prepared. Eight geologic units were defined and delineated in a 13,000 sq. mile area in north central Alaska. Vegetation and permafrost distribution maps at the same scale also have been prepared. Four vegetation cover and five permafrost terrain units were defined and mapped. In addition many geomorphic features unique to this area were recognized. Thaw lakes, glacial moraines, cirques, and abandoned glacial valleys are among the most discernible. Classic stream features such as oxbows, meander scars, point bars, braided channels and chutes also are remarkably well defined.

Because of the lack of cloud-free imagery, only the most preliminary analysis of the regional hydrologic and oceanographic processes in Cook Inlet has been possible. However, it is evident from the brief observations that the distribution of sediments and the regional circulation patterns can be monitored using satellite imagery. Computer-oriented, pattern-recognition and change detection techniques presently are being developed to aid in detailed analyses of hydrologic and coastal processes in Cook Inlet.

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ILLUSTRATIONS

1.0 Introduction

This report documents technical progress and scientific results of the project "Arctic and Subarctic Environmental Analyses Utilizing ERTS-1 Imagery" (GSFC ID DE-329, contract S-70253-AG) during the period 23 June - 23 December 1972.

Problems of resource utilization have been dramatized in Alaska, where a severe lack of basic environmental data and understanding has collided with rapidly mounting pressures for extensive development of extractive industries, transportation systems, and population centers. The existing information on hydrology, in the broadest sense, and on the distribution, properties and behavior of permafrost terrain is insufficient for an understanding of the various environments and their interrelationships. The history of construction and technological development in these areas not only dramatically illustrates the difficulties caused by environmental extremes but also the possibility of serious unforeseen consequences of disturbing established environmental equilibria.

Gemini and Apollo photography clearly illustrated the importance of satellite data in study of marine processes. Many coastal processes, such as sedimentation flow patterns, can be observed, analyzed, and monitored using satellite imagery. When the proposal for this investigation was developed it seemed apparent that the analysis of data acquired during the ERTS program will greatly increase our ability to understand these processes and their interplay throughout Alaska and other cold regions. As will become evident, this expectation already to a large degree has been realized.

An overriding problem in arctic and subarctic environmental research has been the absence of long-term observational data and sparseness of geographical coverage of existing data. Studies of synoptic environmental events over regional-sized areas have been either impossible or prohibitively expensive. The launching of ERTS-1 on July 23, 1972 provides for the first time a means of accomplishing many types of investigations that were not feasible previously.

The objectives of this investigation, briefly stated are (Reference NASA Contract dated 14 June 1972):

* Analyze and map the sediment deposition in harbors, inlets, and docking facilities in the Cook Inlet.

* Map the permafrost areas of Alaska as inferred by vegetative patterns. Compare major tonal and textural permafrost patterns with Mariner imagery.

* Correlate the snowpack cover of Caribou-Poker Creek with stream runoff.

* Map and inventory winter icings in the Chena River watershed

The geographical areas of interest of this investigation are related to the sites of on-going studies by USACRREL or by the Alaska District, Corps of Engineers. The study sites have been selected to maximize opportunity for coordination and cooperation with the ERTS-1 program of the University of Alaska. The area of interest for the study of coastal processes is Cook Inlet; it includes a number of sites of present Corps activity. Primary areas of interest for the permafrost terrain and environmental phases of the proposed study are areas near Fairbanks and Eagle Summit, all in Alaska. Environmental studies have been underway at these sites for many years.

2.0 Thematic Mapping

2.1 Surficial Geology

The first scene of Alaska that became available for analysis was MSS scene 1003-21355 acquired during orbit 44 on July 26; it is shown in Figure 1. This image is a composite made from data acquired in the green, red, and infrared band of the multi-spectral scanner. This scene is a 115 mile square area located 250 miles northwest of Fairbanks. The resolution varies with the shape and tone contrast of a particular feature. Linear features such as road networks and streams 50 meter or more in width are observable. Rounded features such as water bodies larger than about 150 m (500 ft) in diameter can also be resolved. Registration accuracy of the color printing process causes features that are distinct on single-band photos to become somewhat blurred on composites, but the resolution is still remarkably good and a thorough interpretation of the regional features has been made (see Appendix 1).

Usable images of the Cook Inlet area and Fairbanks, Eagle Summit area did not become available until relatively recently. Meanwhile, selected ERTS-1 MSS images have been examined in detail to evaluate the utility of ERTS data in the identification and interpretation of geomorphic features throughout Alaska. MSS image 1058-21421-7 (Fig. 2)

Fig 1. **ERTS-1 image of 115-mile-square area 250 miles N.W. of Fairbanks, Alaska.**

1. Clouds
2. Cloud shadows
3. Kugarak River
4. Kobuk River
5. Ambler River
6. Shungnak River
7. Selby River
8. Rabbitt River
9. Selawik River
10. Dakli River
11. Koyukuk River
12. Kateel River
13. Kawichiark River
14. Tagagawik River
15. Kuchuk Creek
16. Cosmos Creek
17. Kiliovilik Creek
18. Shinilikrok Creek
19. Shiniliaok Creek
20. Wheeler Creek
21. East side of Great Kobuk Sand Dunes
22. Little Kobuk Sand Dunes
23. Pitkik Lake (Oxbow Lake)
24. Meander scars
25. Lakes and ponds
26. Sand bars
27. Solsmunket Lake
28. Tekeaksakrak Lake
29. Forest fire smoke
30. Smoke shadows
31. Recently burnt areas
32. Drainage patterns (stream erosion valleys)
33. Pah River Flats
34. Norutak Hills
35. Lockwood Hills
36. Mountain slope vegetation
37. Pick River
38. Cleared areas (cabins with clearings)
39. Birch Lakes
40. Zane Hills
41. Bedrock outcrops or valley shadows
42. Kobuk village
43. Dahl Creek Airstrip
44. Shungnak Village
45. Swampy, flatland
46. Jade Mountains
47. Waring Mountains
48. Sheklukshuk Range
49. Old burned area
50. Shungnak Airstrip
51. Nogahabara Sand Dunes
52. Hogatza River
53. Babantaltlin Hills
54. Three-Day Slough
55. Cutoff Slough
56. Mid-Channel Islands
57. Mauneluk River
58. Kogoluktuk River
59. Purcell Mountain

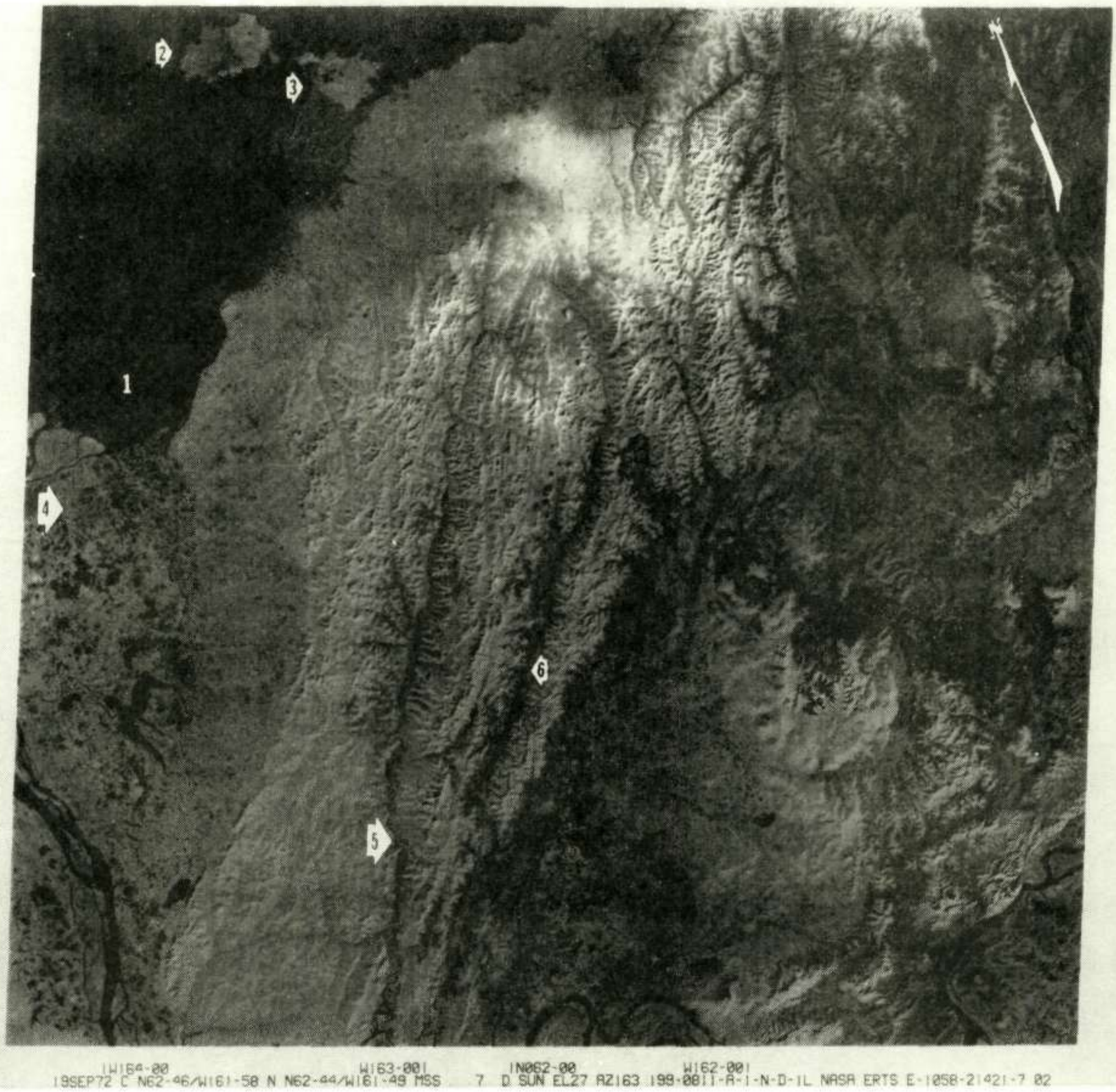

Fig. 2. Southern coast of Norton Sound. Pastol Bay (1), Stuart (2) and St. Michael (3) Islands. Note the polygonal ground (4) in the swampy land south of the coast. The patterns are approximately 500 ft. across. The drainage patterns of the Andreafsky (5) and East Fork (6) Rivers, in the hilly areas, are a structurally controlled trellis patterns. The geologic structure in these hills is predominantly oriented in a NE-SW direction.

of the southern coast of Norton Sound shows patterned ground in the swampy, lowland of the Yukon River delta. The distinct polygonal patterns are approximately 300-500 m across, and occur in a region generally underlain by moderately thick to thin permafrost

The unusually large size of these polygons is remarkable and of possible significance in relationship to Mariner 71 imagery showing, polygonal patterns on Mars (image number PLYBK P177, picture 35B). The relationship between coastal morphology and near shore currents is well illustrated in image 1010-22153-7 (Fig. 3) of the west coast of Seward Peninsula. The predominant direction of flow along this coast is northerly as inferred from the orientation of the spits, baymouth bars, barrier islands, and cuspate forelands along the shore. Meander scars, oxbow lakes, bars, sloughs, and chutes, formed by stream erosion or deposition are apparent in frame 1002-21324-7 of the Yukon River, 160 km northeast of Bethel (Fig. 4). In image 110-20335-7 of the Wrangell Mountains, volcanic cones, calderas, and craters modified by glacial activity are well illustrated (Fig. 5). A striking example of inversion topography with anticlinal valleys and synclinal hills is shown on MSS image 1010-22142-7 (Fig. 6). The Kukpowruk and Kikolik rivers in this scene are superimposed streams eroding across the geologic structures. Glaciers, glacial moraines, glacial valleys, hanging valleys, cirques, and aretes in the Wrangell and Chugach Mountains are clearly shown on image 1062-20221-7 (Fig. 7).

The Kobuk and Koyukuk River Valleys (Fig. 1) are covered with surficial deposits that are principally of glacial, eolian, fluvial, and lacustrine origin. These deposits are easily discerbable on the ERTS image based on differences in texture, tone and patterns.

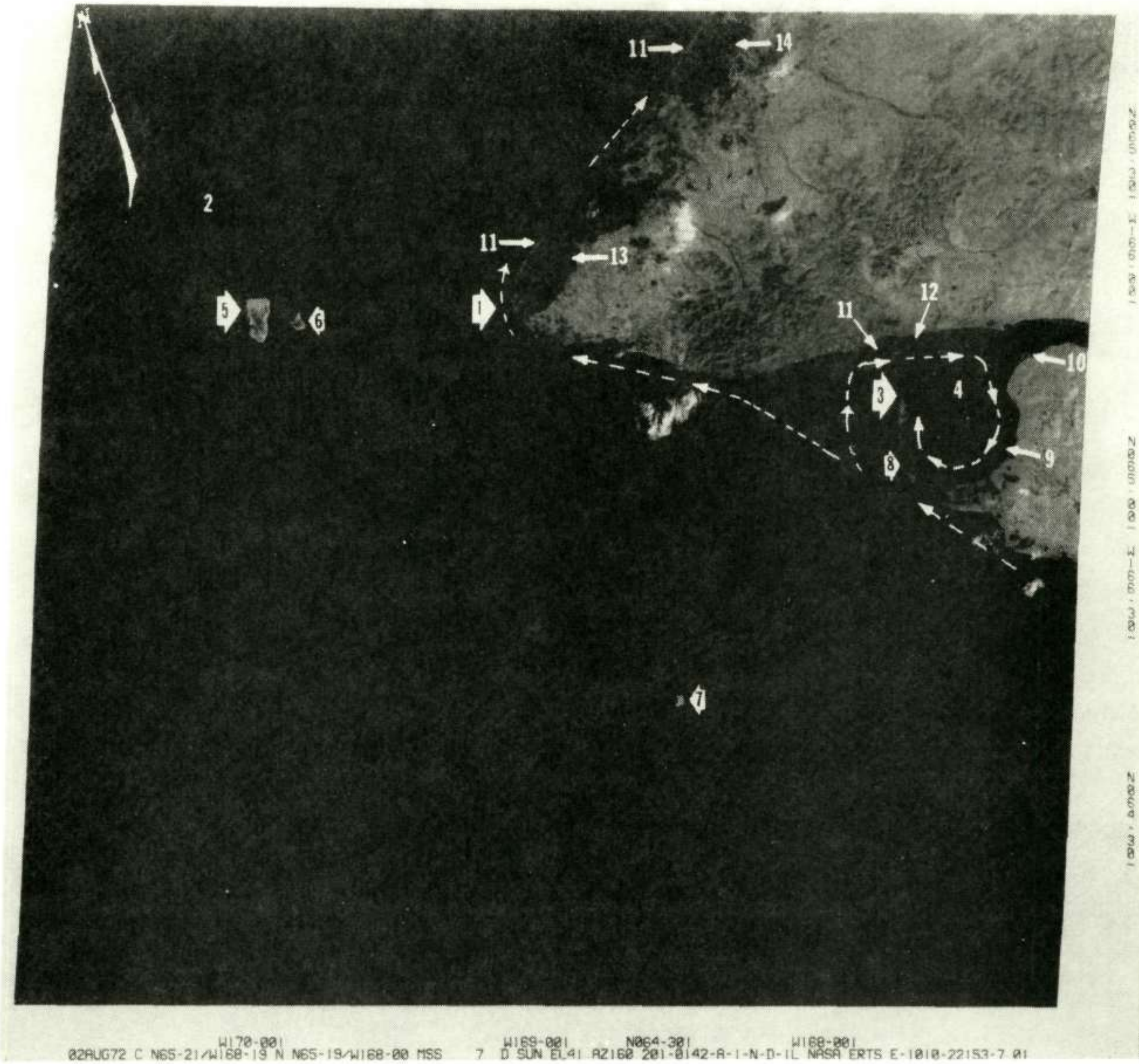

Fig. 3. Coastal features along the west coast of Seward Peninsula. Cape Prince of Wales (1) in the Bering Strait (2), Point Spencer (3) in Port Clarence (4), Big Diomede (5), Little Diomede (6), and King (7) Islands are apparent. Pt. Spencer Spit (8) indicates a northern current flow along the coast and the Jones Pt. Spit (9) indicates circular flow pattern within Port Clarence (current flow is shown with dashed arrows). Teller, Alaska is located on a cuspate foreland (10). Baymouth bars (11) have formed seaward of older coastlines to form Breving (12), Lopp (13), and Arctic (14) Lagoons.

Fig. 4 Yukon River (1), 160 km northeast of Bethel. Stream features shown: meander scars (2); oxbow lakes (3); dendritic tributary patterns (4); mid-channels bars (5); point bars (6); sloughs (7), and chutes (8). Kuskokwim River (9), Innoko River (10). The numerous thaw lakes are an indication of continuous permafrost.

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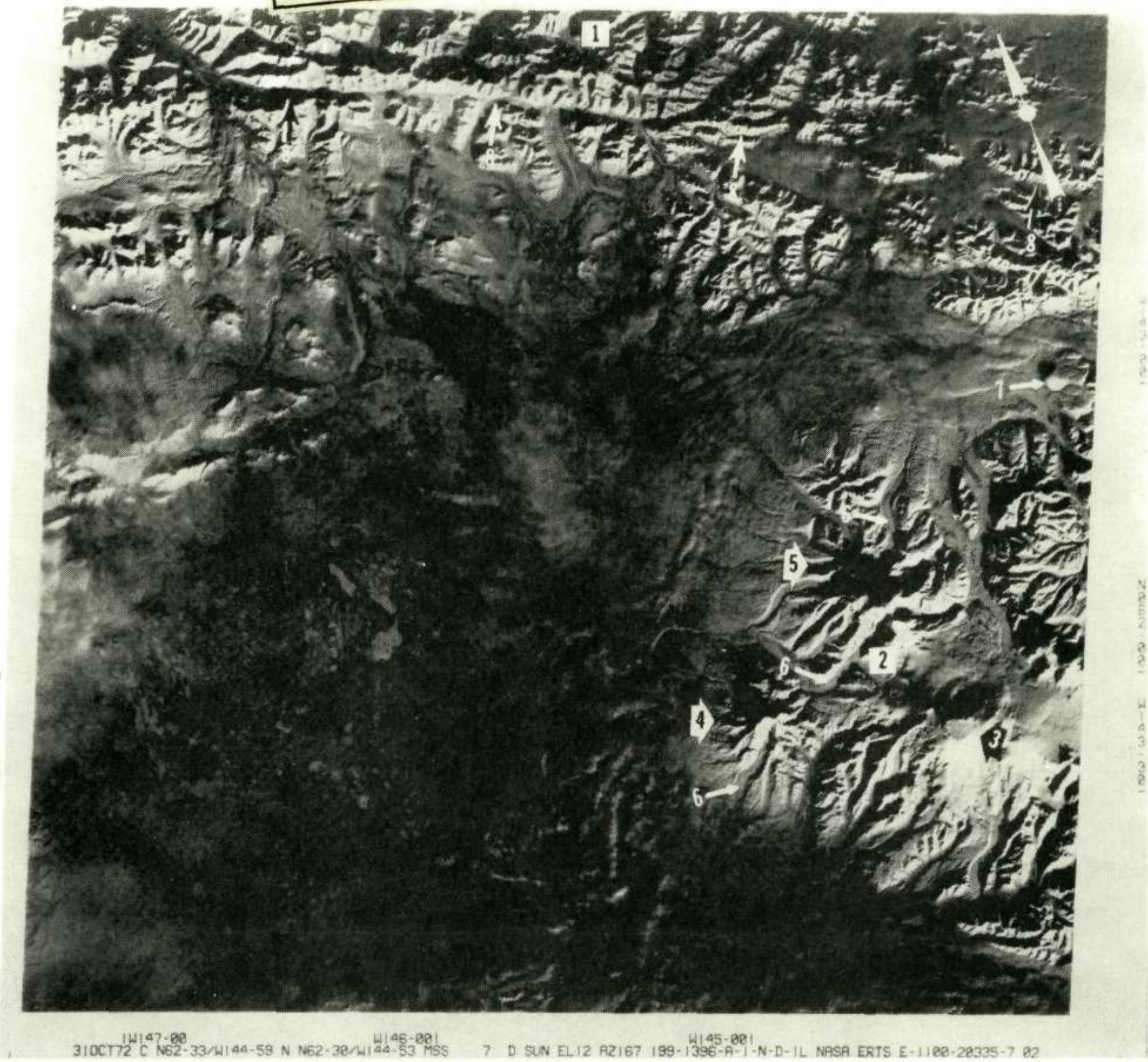


Fig. 5. Alaska Range (1) and the Wrangell Mountains (2) 170 km (100 mi) northeast of Valdez. Volcanic features shown: Mt. Wrangell (3) with caldera and side vent; Mt. Drum (4) and Mt. Sanford (5), both volcanic cones. Note the following: radial drainage patterns on Mt. Sanford and Drum; snow covered glaciers (6); possible small volcanic cone (7); fault (8) extending 100 miles across northern portion of photo.

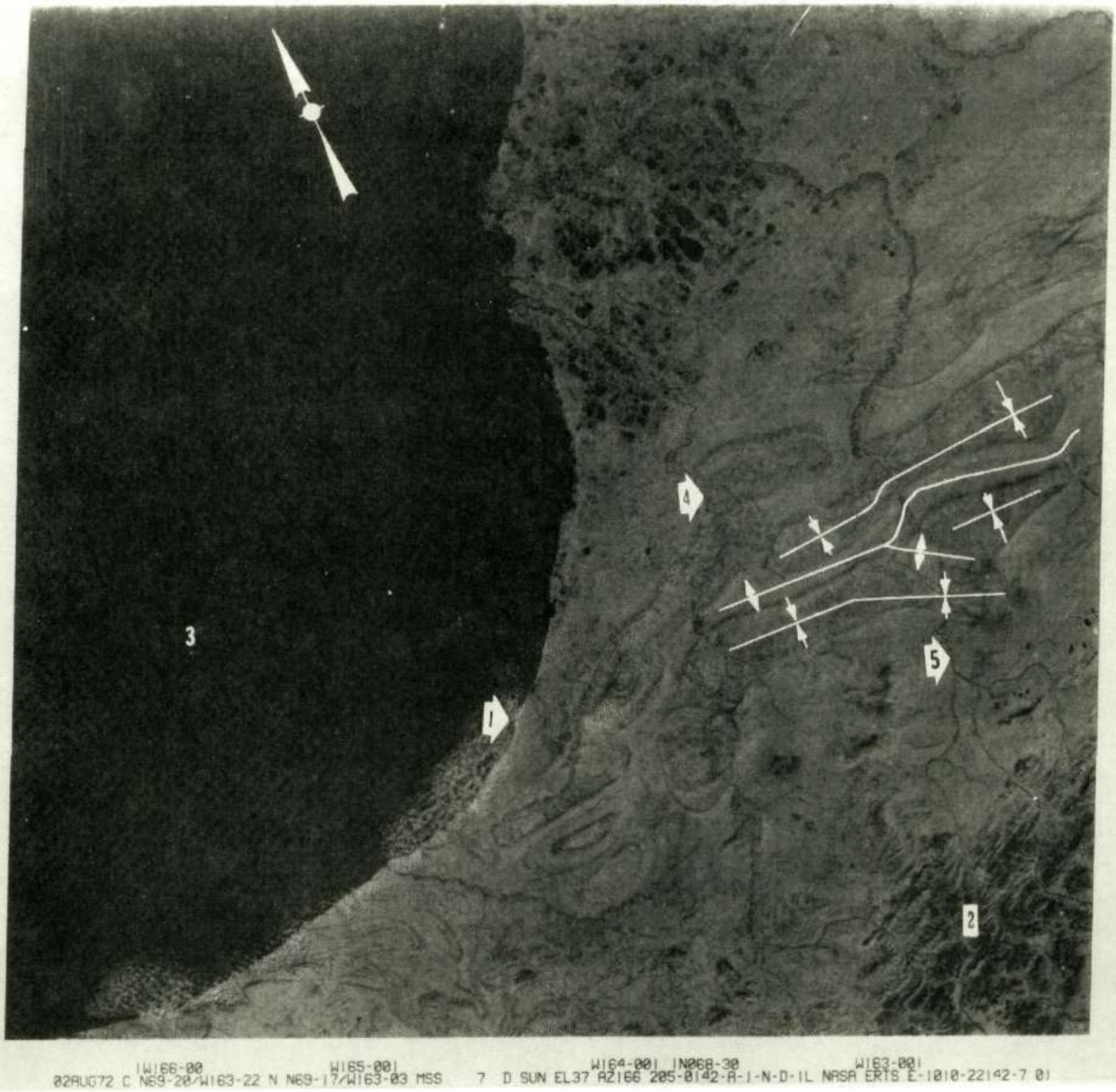


Fig. 6. East of Cape Beaufort (1) on the Chukchi Sea (3) and west of the Delong Mountains (2). Note the inversion topography with synclinal hills and anticlinal valleys (refer to U. S. G. S. Oil and Gas Investigations Map, OM-126, Geology of the Arctic Slope of Alaska). The bedding planes are apparent in most of these structures. The Kukpowruk (4) and the Kokalik (5) Rivers eroding across the geological structures are probably superimposed streams. (Atwood and Atwood, 1938, Working Hypothesis of the Physiographic History of the Rocky Mountain Regions: Bull. Geol. Soc. Amer., v 49, p. 957-980). The numerous thaw lakes are an indication of continuous permafrost.

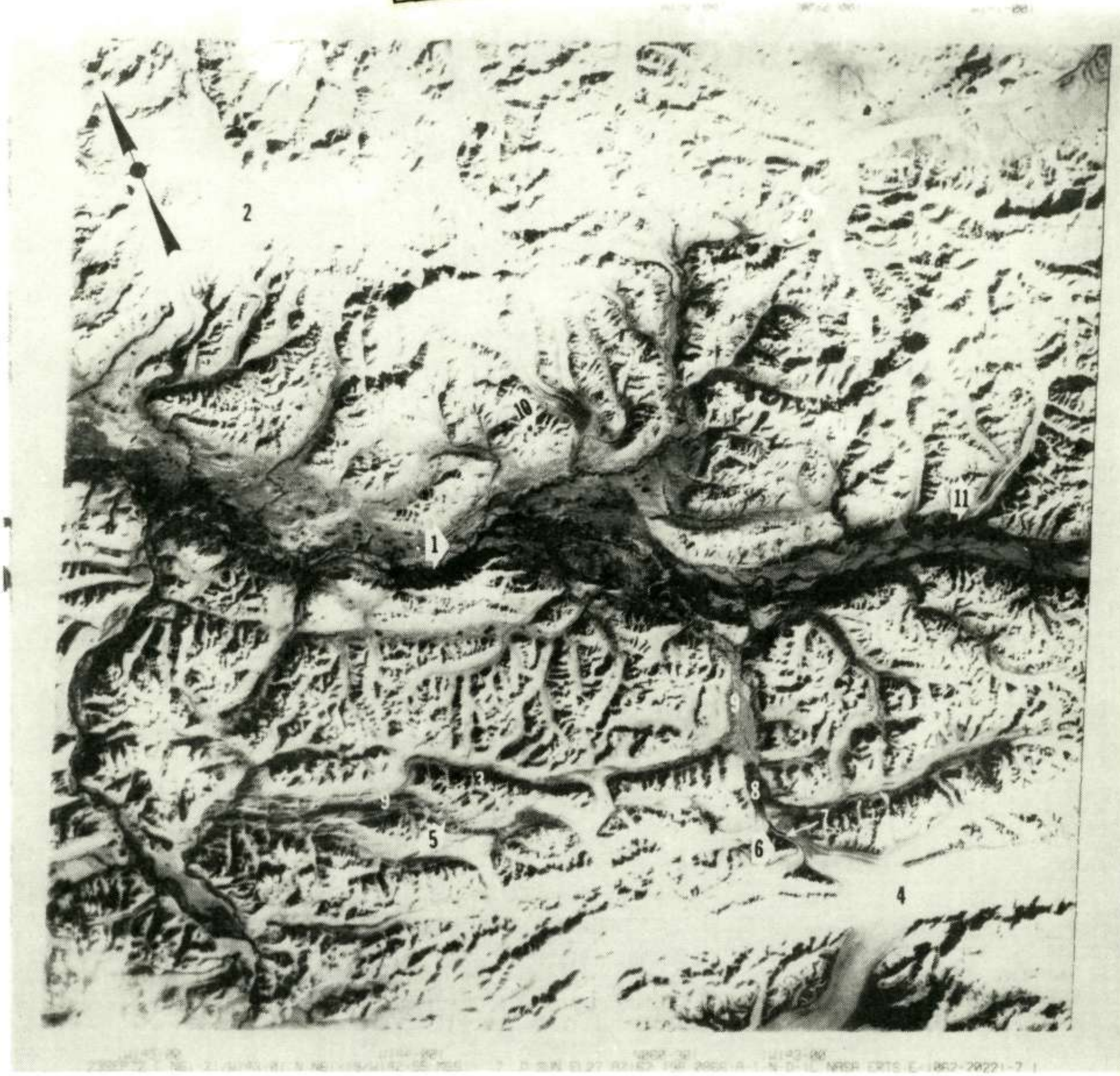


Fig. 7. Chitina River (1) 370 km (220 mi) east of Anchorage. Wrangell Mountains (2) to the north and Chugach Mountains (3) to the south. In the Chugach Mountains, Bagley Ice Field (4) and Bremner (5) and Tana (6) Glaciers with well-developed medial (7), terminal (8), and recessional moraines are apparent. Abandoned glacial valleys (9), Gates glacier (10) with well defined medial and lateral moraines. Bernard Glacier (11) also has well developed moraines.

Initial mapping of the surficial geology was accomplished without the aid of stereo pairs, reference to published maps or other available ground truth. Eight recognizable units have been delineated on Figure 2 (see Appendix 2). Bedrock-Colluvium (b) consists of coarse and fine grained deposits associated with moderate to steep-sloped mountains and hills; bedrock exposures are largely restricted to upper slopes and crestlines. Outwash deposits (Q_o) are fine and coarse grained alluvial deposits associated with lower highly dissected mountainous terrain. Solifluction appears to be an important process on this landscape. Undifferentiated alluvial-glaciofluvial deposits (Qag) are dominantly fine-to-coarse grained deposits associated with gentle to moderate sloping backslope positions; there are few bedrock outcrops. Fluvial-lacustrine deposits (Q_{fl}) are generally fine grained sands and silts associated with low-lying swampy areas. Undifferentiated alluvium-lacustrine deposits (Q_{al}) are fine grained and associated with gently sloping footslope and terrace positions. Eolian deposits (Q_e) are sand and loess present as active dunes. Fluvial deposits (Q_f) are modern floodplains and low-lying terrace deposits; sediments would be fine-grained and generally well-rounded, an indication of significant particle movement. Undifferentiated deposits (Q_u) are coarse to fine grained deposits occurring on rolling uplands and consist primarily of colluvium mixed with some loess from the sand dune area to the northwest.

The units defined for mapping surficial geology from the ERTS image were subsequently compared to the Surficial Geologic Map of the Central Kobuk River Valley (Bull. 1181K) and the 1:1.5 million State of Alaska map. The following similarities and differences were found:

1) Five drift and three outwash units were defined on the USGS map based on glaciation periods. The drift units are composed primarily of till and outwash sands and gravels, whereas the outwash units contain chiefly gravels and sand. On this ERTS image it was not possible to differentiate between glaciation periods. Therefore, previously mapped drift areas were found to occur in our unit Qag (undifferentiated alluvial-glaciofluvial deposits) and the outwash area in Q_o (outwash deposits).

2) The water bodies in the image are primarily, but not exclusively, thaw lakes. Lacustrine sediments, not defined in this area on the 1:1.5 million scale surficial geology maps, are included in units Qal and Q_{fl}.

3) Eolian deposits include sand dunes and loess which can not be easily discriminated on ERTS imagery. On the MSS color image active sand dunes show as light blue irregularly shapped features north of the Waring Mts. and are the only deposits mapped as Q_e. Vegetated sandy areas were not included in this unit because on the basis of the imagery alone, they do not appear as distinct eolian sediments. These deposits are included in Qag, east of the Waring Mts. Subsequent ground truth verifed that this area is a sparsely vegetated, stable dune field with relatively small, locally active dunes. However, Q_{ag} is defined in our legend as undifferentiated alluvial-glaciofluvial deposits.

In summary, the amount of detail available from the 1:1.3 million scale ERTS-1 image compared favorably in most respects to the available 1:250,000 map and was superior to the 1:1.5 million State of Alaska map.

2.2 Vegetation

Vegetation is one of the most important indicators of permafrost characteristics of an area, but the relationship is complex and must be examined in detail. Vegetation type and density in a permafrost region are most directly related to soil type and drainage conditions. As an indicator of permafrost, its most reliable value lies in its indication of the depth of seasonal thaw.

This ERTS scene shown in Figure 1 is predominantly within the interior Alaska white spruce forest, a vegetative association confined to the well drained upland areas. Poorly drained lowland areas are largely of treeless bogs with sedges, grasses, and small willows, alders and birches. Better drained lowland areas grade from moist tundra to open black spruce forest to birch and aspen on low ridges. Alpine tundra exists above the local timberline at about 600 m.

Vegetation differences are apparent on the MSS color composite primarily by tonal rather than textural patterns. This results from the approximately 50 m. limit of resolution. The tonal differences would appear to be primarily related to vegetation density, and species composition. Four density levels have been identified and mapped in this scene. The highest density tone is a dark red identified as a closed spruce-hardwood forest. It is believed to consist of tall to moderately tall white and black spruce, together with paper birch, aspen, and balsam poplar and occurs on moderate to well drained sites such as active flood plains, mountain slopes, and highland areas. It is seen in a galaria forest pattern along several streams, including the Selawik and the Kobuk Rivers.

The next lightest tone is a bright red associated with a low to hilly area, and is representative of moist tundra grading to low black spruce and well developed birch-aspen growth on the best drained slopes. This unit also contains a number of the forest fire scars. The wet lowlands appear as a reddish gray, punctuated by the many thaw lakes typical of poorly drained permafrost alluvial areas. These areas are essentially treeless bogs and have a cover of sedges and grasses, with an abundance of willows, alders, and resin birch, locally with widely spaced spruce and tamaracks. Two small areas, identified from geological mapping as formerly active sand dune areas, exhibit a unique gray tone with a faint red coloration suggesting revegetation with shrubs or other open vegetation, with the bluish cast of sand still apparent.

The main influence of vegetation on permafrost terrain is that it affects the thermal exchange between the atmosphere and the lithosphere, and the moisture regime in the soil. Vegetation has the effect of retarding soil warming in the summer and cooling in the winter, but the depth of the active layer also depends on other variables, such as the depth of winter snow and drainage conditions during summer. A vegetation association-depth of thaw relationship where permafrost is present in the discontinuous permafrost zone is shown in Table 1.

TABLE 1.

Vegetation	Depth of Thaw (m.)
Tall willows on flood plains	2.4
Mixed alder, willow, white birch	1.2
Mixed stands of white spruce and white birch	0.6-0.9
Black spruce in tundra or muskeg	0.3

The vegetation association map in which the 4 mapping units are defined and delineated also appears in Appendix 2.

2.3 Permafrost

Permafrost, its occurrence and properties, is a major environmental factor in Alaska and other high latitude regions. The existence of permafrost is the result of complex interactions among environmental factors such as local microclimate, plant cover, the insulating qualities of the organic and vegetative layers, texture and moisture content of the soil, and topographic position. In central Alaska, the distribution of permafrost is discontinuous because the present climate in this area is near the threshold values for the continued existence of permafrost. Only in well protected locations, such as north-facing slopes, shaded valley bottoms, or high elevations within the region does permafrost exist. Minor changes in the thermal regime, whether natural or man-induced, can produce major alterations in permafrost landscapes.

In the continuous permafrost zone, permafrost lies beneath all land areas, but it is absent directly beneath large water bodies, which provide a sufficient heat reservoir to keep underlying materials unfrozen. The thickness of permafrost in this zone ranges from several hundred feet in the south to an extreme of 600 m. in northern Alaska. The boundary that separates these two zones is theoretically distinct but imperfectly known. Climatically, it approximates the mean southern position of arctic air in summer; it is close to the southern limit of the tundra, and is the effective limit of active ice-wedges and pingos. The discontinuous permafrost zone is a complex mosaic of frozen and unfrozen ground with permafrost thickness decreasing in a southerly direction.

The geographical distribution of permafrost in a particular area is dependent upon its past and present environmental regimes. The depth of the active layer is dependent on present relationships of soil type, drainage, moisture content, vegetative cover, topographic setting and climatic regimes.

The Upper Koyukuk-Kobuk River area lies at the northern edge of the discontinuous permafrost zone and is predominantly underlain by perennially frozen ground. Extrapolations from the nearest climatic stations suggest a mean annual temperature of about -4° C, and a mean annual precipitation of about 50 cm. Because of the proximity of the ocean, summers are cooler and the winters somewhat warmer than at equal latitudes further inland. This smaller seasonal amplitude is conducive to permafrost development.

Existing maps of permafrost distribution are general, primarily due to lack of more extensive and detailed data. The delineation of permafrost boundaries from conventional aerial photography is difficult and requires extensive ground studies to confirm. Moreover, it does not lend itself conveniently to the mapping of large areas. There is no precedent study on the distribution of permafrost terrain utilizing imagery of the scale and resolution available with ERTS. Subtle tonal and textural changes apparent with the multi-spectral ERTS sensors provide indications of large scale patterns not otherwise discernible.

Five permafrost units have been mapped based on the interpretation of surficial geology and the probable depth of thaw inferred from the vegetative cover. Bedrock and colluvium (m_1) is characterized by scattered taliks, a thaw depth of 0.5 m - 2.0 m and alpine vegetation that grades into white spruce forest below timberline. Dissected alluvial deposits (u_1) contain numerous taliks, have indications of active solifluction, are characterized by alpine vegetation and a 0.5 m. - 2.0 m. thaw depth. Active floodplains (l_1) have numerous taliks, dense tree and shurb vegetation and a thaw depth of more than 2.0 m. Abandoned floodplains (l_2) with many small lakes and fine grained soils have grass, sedge, small shrubs and open spruce vegetation and a thaw depth less than 0.5 m. Alluvial-colluvial deposits (u_2) are characterized by continuous permafrost, birch-aspen forest on well-drained slopes grading to moist tundra in less well drained sites and a thaw depth less than 0.5 m. in areas of poor drainage and 0.5 m. -2.0 m. on south facing, well drained slopes. This map also is presented in Appendix 2.

The accuracy of this interpretation of MSS scene 1003-21355-457 has been field checked. To the extent that it is found to be possible to utilize ERTS-1 imagery and extrapolate from existing maps of vegetation and surficial geology and from earlier observations, an improved and more detailed permafrost map of the area can be quickly produced. On the basis of this preliminary analysis this methodology and approach is being extended to an area including the foothills of the North Slope and the Brooks Range.

3.0 Coastal Sedimentation and Related Processes in Cook Inlet, Alaska

Information on sediment deposition and distribution, surface currents and circulation patterns, nearshore hydrography and coastal landforms in Cook Inlet, Alaska is most easily extracted from MSS bands 4, 5 and 7. During this reporting period, ERTS-1 had completed 7 cycles over the Inlet. A few of the earliest images, those taken during cycles 1 and 2 in August and cycles 3 and 4 in September, clearly show landforms, suspended sediment distribution and circulation patterns. The high concentration of suspended sediment in Cook Inlet acts as a natural coloring agent by which the surface circulation of tidal and long-shore currents can be traced.

On MSS frame 1015-21022-5, taken 7 August, for example, (Fig. 8) the currents along the west shore of the Inlet between Tuxedni Bay and MacArthur River are clearly visible. The glacial streams flowing from the Chigmit Mountains along the shore have a distinct tone related to their high suspended sediment load. Current direction in the inlet can be inferred from the shape and location of the sediment plumes. Relative differences in sediment concentration of the Inlet water also are evident. Lighter, grey tones occur farther from shore and indicate either deposition, mixing or rapid sediment transport. Relict sediment patterns are visible far off shore and indicate the direction of tidal currents and net water movement through several tide cycles.

MSS scene 1049-20512-1, taken 10 September 1972, shows a counter clockwise circular current pattern around Kalgin Island in the central portion of Cook Inlet (Fig. 9). This pattern was verified by direct observation from 6,000 ft. at the time the satellite passed and this image was acquired. The tide front in Cook Inlet progresses from the inlet mouth to Anchorage (nearly 150 miles) in approximately 4.5 hours. It moves faster along the east shore, being diverted in that direction by the Coriolis force. The tidal front moves past the East Foreland, a large peninsula protruding some 10 miles into the Inlet and is partially diverted across the Inlet, where it abuts the West Forelands. At this point, part of the diverted front moves south of the West Forelands and the remainder moves north. This circulation pattern is repeated twice daily, and these two daily flood tides produce the counterclockwise pattern.

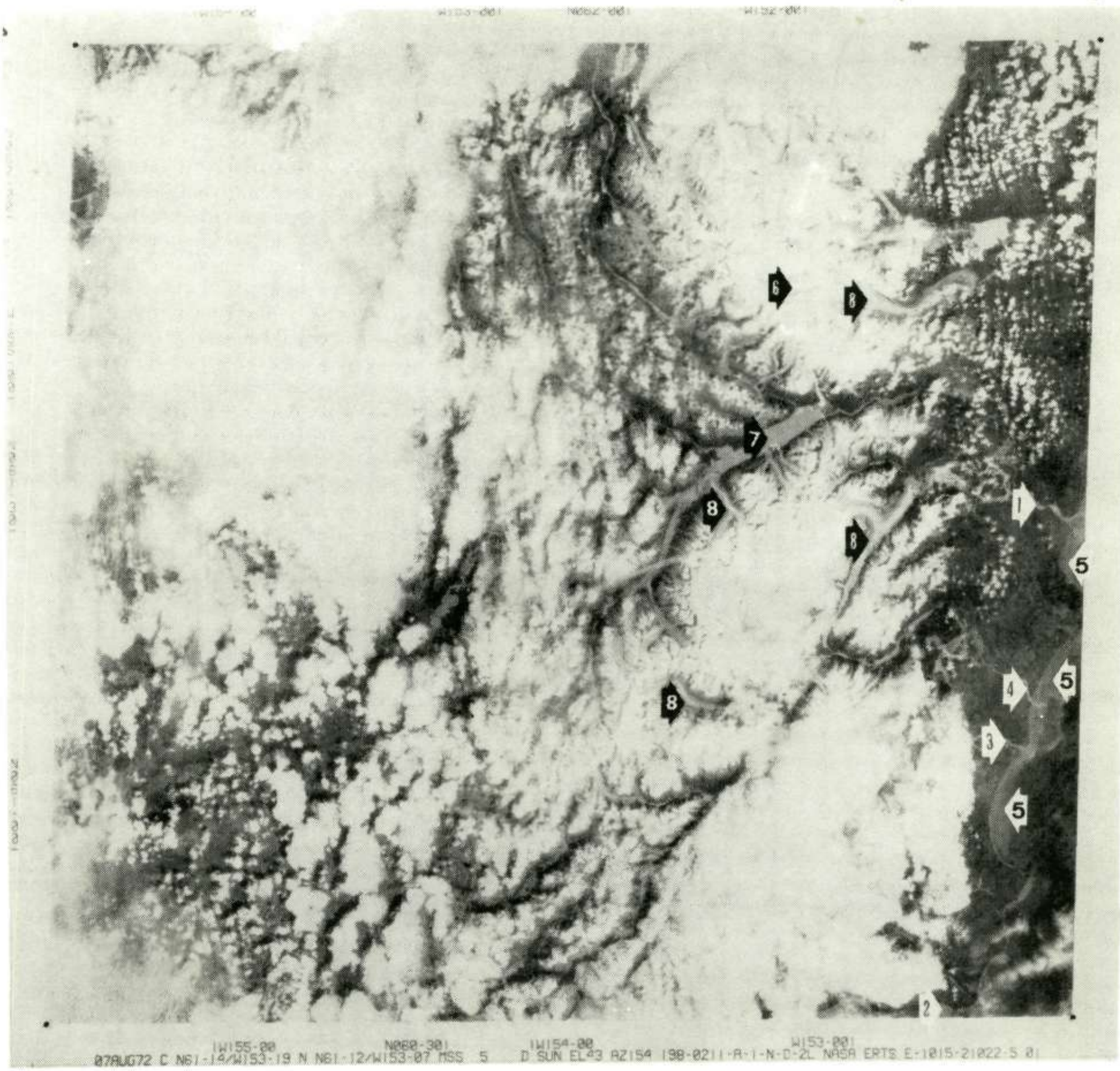


Figure 8. The west shore of Cook Inlet between the MacArthur River (1) and Squarehead Cove (2). A later view of this area appears also in Figure 2. Figure 1 taken on 7 August 1972 gives a clearer view of the suspended sediment distribution and current directions probably because of the higher sun elevation. Currents appear to be moving in a northerly direction as seen by the sediment plumes from the Drift (3) and Katnu (4) Rivers. Tidal flats (5) are apparent as a grey border on the coastline. Mt. Spurr (6) one of many volcanoes in the northern Aleutian Range bordering Cook Inlet on the West. Chakachamna Lake (7) appears grey due to a high concentration of suspended glacial sediment. Numerous glaciers (8) are visible.

Figure 9. Central portion of Cook Inlet, Alaska, approximately 100 miles (60 km.) southwest of Anchorage. Snowcapped Kenai Mountains (1) east of the Kenai Lowland (2), a flat, swampy glacial plain, are visible through the clouds. The East (3) and West (4) Forelands geographically divide the Inlet. Sediment plumes at the mouths of the Katnu (5) and Drift (6) Rivers indicate the direction of the nearshore current in Redoubt Bay (7). There is a counterclockwise current (8) faintly visible around the northern and western portions of Kalgin Island (9). Extensive Tidal flats (10) are visible along the west shore from the West Foreland past Harriet Point (11) to Tuxedni Bay. A large amount of suspended sediment is being deposited by the Tuxedni River (12) and is transported between Chisik Island (13) and the mainland. Sediment plumes indicating a southern flow are visible at the mouths of the Kasilof (14) and Kenai (15) Rivers. The grey tone of Lake Tustumena (16) is due to high suspended sediment concentration.

Images taken during cycle 5 in October and cycle 6 in November do not show the oceanic processes as clearly. The sun elevation had decreased to 20° or less by the beginning of October and the surface of the Inlet appears very dark in all bands. Only water with very high sediment concentrations can be differentiated which makes for less detailed analysis. By the end of January the sun angle will have increased to 20° or more and the quality of the imagery for this application will begin to significantly improve.

The richness of the ERTS satellite imagery in providing information on ocean circulation and coastal processes, thus is clearly evident. Due to frequent cloudy days and the low sun angle during four months of the year it will take considerable time before enough imagery is acquired to fully work out the oceanic relationships.

4.0 Program for Next Reporting Period

The analysis and mapping of the sediment deposition in harbors, inlets, and docking facilities in Cook Inlet will continue. Surficial geology, vegetation and permafrost maps will be completed for the extended test area shown by the photo mosaic in Figure 10. Major tonal and textural permafrost patterns will be compared to Mariner imagery. The icings on the Chena River watershed will be mapped and monitored during the spring thaw. The snow cover of the Caribou-Poker Creek watershed will be correlated with stream runoff during this period. Using MSS, band 5 and 7 images, attempts will be made to construct a regional, reconnaissance soil association map and a tectonic fabric map for the area around Cook Inlet, Alaska. This is a region of high seismic risk which is periodically subjected to strong earthquakes. The soil and lineation maps might be used in conjunction with existing data on regional earthquake epicenters to produce a regional "seismic intensity microzonation"

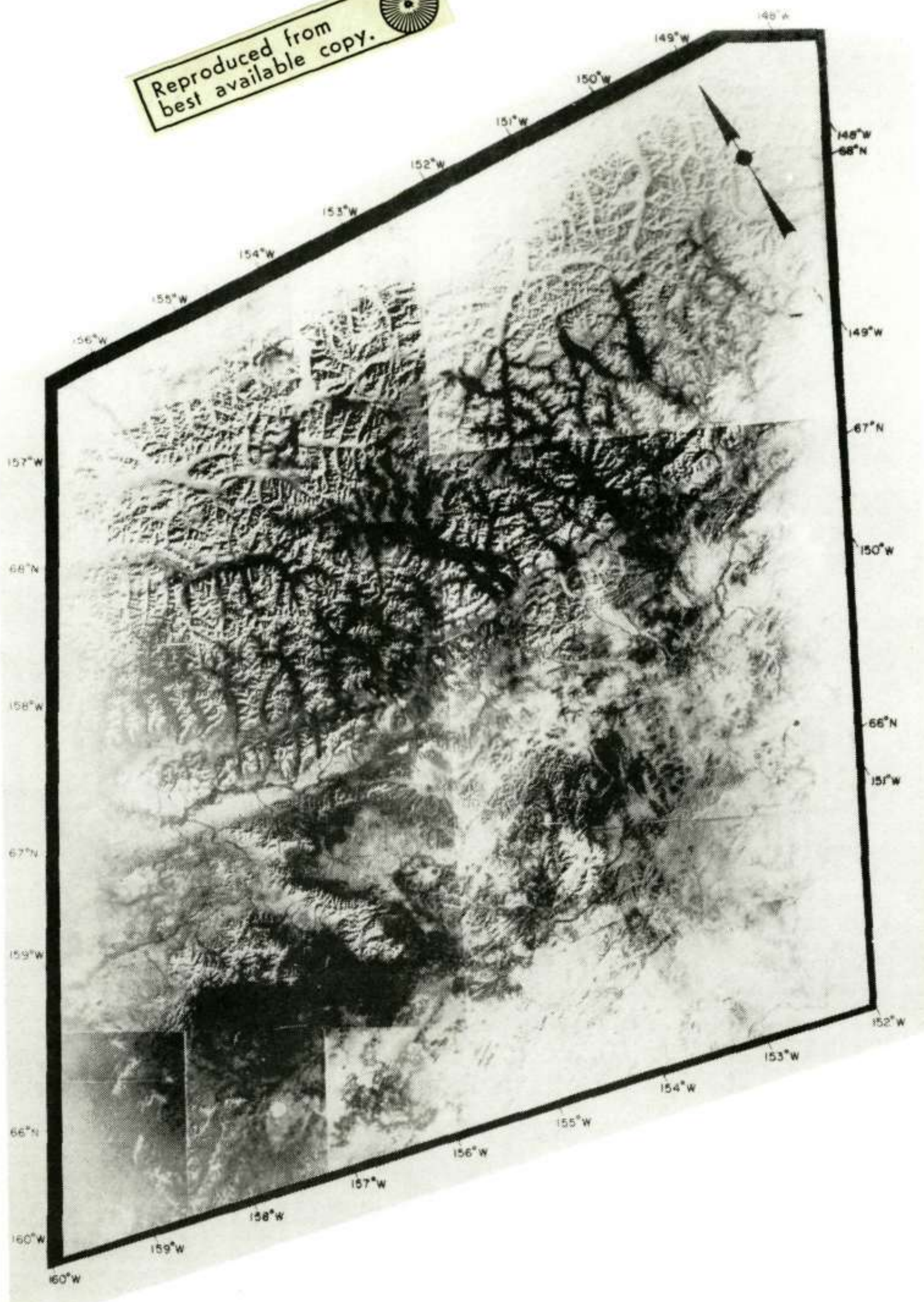


Fig. 10. Uncontrolled photo mosaic of a 59,000 square mile area in north central Alaska. MSS band 5 images were used. Scale: 1:≈2,424,000

or "earthquake geologic hazards" map for the area. The map will contain data on the distribution of thixotropic soils which have a high liquefication potential and are most susceptible to failure during seismic events. These maps will provide badly needed data to insure improved land use planning and development of the Cook Inlet region. No departure from the approved Data Analysis Plan (ref. letter dated 26 December 1972) will be required for the remainder of this investigation.

Ground-truth field investigations will take place and underflight imagery acquired primarily during the spring and early summer. The intent of the field investigations will be to verify correlation of tonal and textural patterns from ERTS imagery with larger-scale underflight imagery at the specified experimental sites and to make a detailed examination of interpretations through direct observation and ground measurements. Corollary laboratory analyses now planned include color densitometry and digital processing of magnetic tapes of selected scenes utilizing equipment and techniques developed at the Rome Air Development Center and Waterways Experiment Station. Ground and Aerial photography will be utilized as needed to furnish comparative and correlative data and to document specific features or conditions.

5.0 Conclusions

The ERTS-1 system performance exceeds expectations. The feasibility of rapidly producing accurate thematic maps using ERTS-1 imagery has been demonstrated for arctic and subarctic regions.

Using stereographic mapping techniques, it became immediately apparent that more geologic detail could be seen on the ERTS-1 imagery than could be mapped at a scale of 1:1,000,000. All major geomorphic features such as mountain ranges, drainage patterns, glaciated valleys, moraines, modified morainal topography, thaw lakes, floodplains, alluvial fans and terraces, and eolian deposits were recognizable.

A surficial geology map at a scale of 1:1,000,000 has been prepared utilizing MSS scene corrected imagery. Eight surficial geology units, four vegetative units and five permafrost units were delineated in 13,000 sq. miles of the Kobuk-Koyukuk-Yukon area of Alaska. The detail available from the ERTS-1 image at 1:1.3 million scale compared favorably to the detail available on U.S. Geological Survey Miscellaneous Geologic Investigation Maps 290, 437, 459 and 554 at a scale of 1:250,000. It was established that the surficial geology results correlated closely with these published surficial geology maps. Equally good vegetation distribution and permafrost maps have been prepared.

Although sufficient cloud free coverage of the Cook Inlet area is not yet available to complete the objectives of this investigation, it is clear from the useable imagery we have received that boundaries between major water types, river plumes, tidal currents and major circulation patterns can be seen. Assuming continued operation of the ERTS-1 multispectral scanner, there is no doubt that it will be possible to deduce major sediment distribution and deposition patterns in the inlet and near the harbors and docking facilities at Anchorage, Homer, Seldovia, Kenai, Ninilchik and Nikiski.

6.0 Recommendations

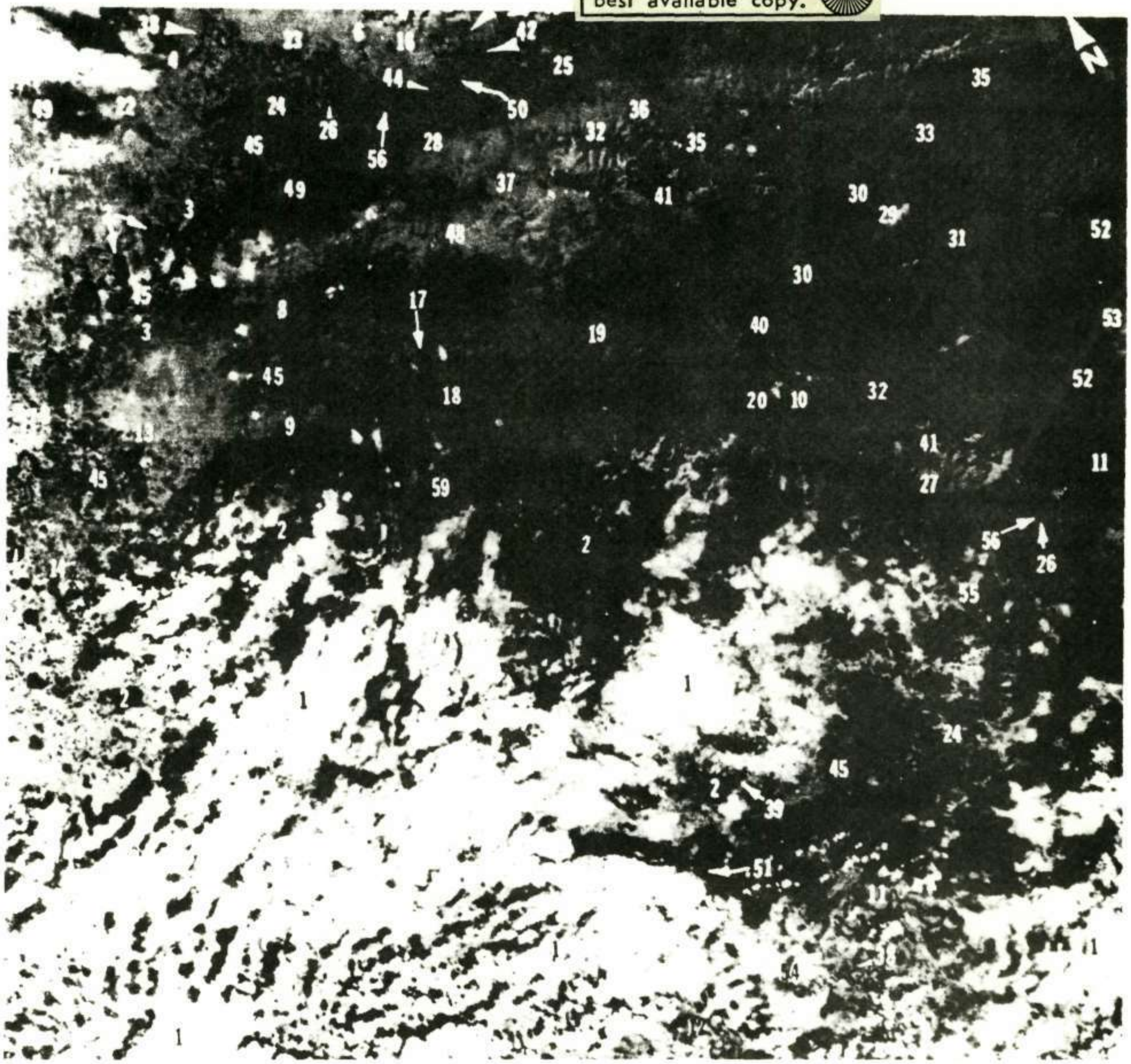
None

APPENDIX 1

ERTS-1 Imagery... Arctic and Subarctic Environmental Analysis

APPENDIX 2

Cold Regions Environmental Analysis Based on ERTS-1 Imagery (presented at the Eighth International Symposium on Remote Sensing of Environment, 2-6 October 1972; reference NTIS Weekly Abstracts 9 October 1972).



ERTS-1 imagery of 115-mile-square area 250 miles N.W. of Fairbanks, Alaska.

1. Clouds
2. Cloud shadows
3. Kugarak River
4. Kobuk River
5. Ambler River
6. Shungnak River
7. Selby River
8. Rabbitt River
9. Selawik River
10. Dakli River
11. Koyukuk River
12. Kateel River
13. Kawichiark River
14. Tagagawik River
15. Kuchuk Creek
16. Cosmos Creek
17. Kiliovilik Creek
18. Shinilikrok Creek
19. Shiniliaok Creek
20. Wheeler Creek
21. East side of Great Kobuk Sand Dunes
22. Little Kobuk Sand Dunes
23. Pitkik Lake (Oxbow Lake)
24. Meander scars
25. Lakes and ponds
26. Sand bars
27. Solsmunket Lake
28. Tekeaksakrak Lake
29. Forest fire smoke
30. Smoke shadows
31. Recently burnt areas
32. Drainage patterns (stream erosion valleys)
33. Pah River Flats
34. Norutak Hills
35. Lockwood Hills
36. Mountain slope vegetation
37. Pick River
38. Cleared areas (cabins with clearings)
39. Birch Lakes
40. Zane Hills
41. Bedrock outcrops or valley shadows
42. Kobuk village
43. Dahl Creek Airstrip
44. Shungnak Village
45. Swampy, flatland
46. Jade Mountains
47. Waring Mountains
48. Sheklukshuk Range
49. Old burned area
50. Shungnak Airstrip
51. Nogahabara Sand Dunes
52. Hogatza River
53. Babantaltlin Hills
54. Three-Day Slough
55. Cutoff Slough
56. Mid-Channel Islands
57. Mauneluk River
58. Kogoluktuk River
59. Purcell Mountain

ERTS-1 IMAGERY . . .

Arctic and Subarctic Environmental Analysis

By Dr. Duwayne Anderson, Richard Haugen, Lawrence W. Gatto, Dr. C. W. Slaughter, Dr. Harlan McKim and Thomas Marlar

Wise utilization of the earth's resources is now acknowledged to be a primary concern of our society. Problems of resource utilization have been dramatized in Alaska, where a severe lack of basic environmental data and understanding has collided with rapidly mounting pressures for extensive development of industries, transportation systems and population centers.

Existing information on Alaska's water cover and distribution, properties, and behavior of permafrost terrain is insufficient for an understanding of its various environments and their interrelationships.

The history of construction and technological development in Alaska dramatically illustrates the difficulties caused by environmental extremes; it also shows the possibility of serious unforeseen consequences of disturbing established environmental balances.

Scientists at the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, N.H., are studying the arctic and subarctic environments of Alaska, using the information from the NASA Earth Resources Technology Satellite, ERTS-1, launched July 23, 1972.

(For a detailed explanation of the over-all scope of ERTS-1, see lead feature article beginning on page 38 of the August 1972 edition of the *Army R&D Newsmagazine.*)

Since its inception in 1961, CRREL has continued an active role in basic and applied research and engineering in cold regions. A major objective of the ERTS study is the development of practical knowledge that permits man to live in greater harmony with the cold regions environment, and to identify and utilize its existing resources in the most favorable manner.

In the ERTS-1 program, the CRREL will study a number of aspects of the Alaskan environment. The relationship of snow pack and river icing hydrology is one of the more important areas of investigation. A comparison of the major tonal and textural permafrost geomorphic patterns on ERTS imagery will be made with that of Mariners 6, 7, and 9 to present a plausible interpretation of the various terrain patterns of Mars.

ERTS-1 imagery will be used in another major effort to study surface circulation and coastal sedimentation processes in Cook Inlet, Alaska, which leads to Anchorage harbor. The information derived will be applied to the maintenance and improvement of navigable waters, harbor construction and siltation problems.

ERTS imagery will be used in a third area of primary concern to evaluate permafrost-vegetative relationships, permafrost distribution, its seasonal thaw regime and environmental relationships in interior Alaska. Permafrost is a major environmental and engineering factor in Alaska and other high-latitude regions.

This perennially frozen ground is a result of complex interaction among such environmental factors as local microclimate, the insulating qualities of organic and vegetative cover, and the texture and moisture content of soils. In central Alaska, the distribution of permafrost is discontinuous because the present climate in this area is near the threshold values for the continued existence of permafrost.

Only in well-protected locations, such as north-facing slopes, shaded valley bottoms and high elevations within the region does permafrost exist. Minor changes in thermal regime, whether natural or man-induced, can produce major alterations in permafrost landscapes.

In all of these studies, interpretation of the ERTS imagery will be accomplished through comparison with photographs of selected areas taken by low-flying aircraft and by actual ground-level observations.

ERTS-1 utilizes multispectral scanner and return vidicon cameras that record information in seven spectral bands. The data is returned to the three main ERTS tracking stations: Fairbanks, Goldstone and Goddard.

One of the initial scenes of Alaska, acquired during orbit 44 on July 26, is shown in Figure 1. The image is a composite made from data acquired in the green, red and an infrared band of the multispectral scanner.

Shown is a 115-mile square located 240 miles northwest of Fairbanks that includes Kobuk and Shungnak villages. The resolution varies with the gross shape and tone contrast of a feature. Rounded features (i.e. streams) to 150 feet wide are visible. The resolution of this composite and the individual bands is considerably better than anticipated prior to launch.

Registration accuracy of the color printing process causes features that are distinct on single-band photos to become somewhat blurred on composites, but the resolution is still remarkably good and a thorough interpretation of the regional features can be made. Clouds (1) cover a large portion of the lower half of the photograph. Cumulus clouds at approximately 8,500 feet altitude cap the higher peaks of this area while cirrus clouds occur at a higher level. Cloud shadows (2), reflecting the cloud shapes rather well, may be confused with the ponds and lakes (25) of this area.

The areas burned by forest fires are very prominent features. At the time this photograph was taken a forest fire was burning in the Pah River flats (33) area. By July 26, 1972, this fire had burned 81,000 acres. The smoke (29) and smoke shadows (30) are readily apparent. The recently burned areas (31) appear black while old burned areas (49) show some evidence of revegetation.

Evidence of a variety of human activity in this area is visible. Two bush airstrips can be seen, the Shungnak airstrip (50), and the Dahl Creek airstrip (43). Both are located near small villages along the Kobuk River, Shungnak village (44) and Kobuk village (42), respectively. A number of cleared areas (38) were located. These may be homestead sites and the presence of cabins was verified with underflight photography.

Kugarak River (3) and its tributaries, Kawichiark River (13), Kuchuk Creek (15), and Rabbitt River (8) are well-defined by the contrast between the vegetation bordering the streams and the surrounding vegetation. They drain a significant portion of the photographed area, including the Waring Mountains (47), the Sheklukshuk Range (48), and the swampy flatlands bordering the Waring Mountains on the south and east and the Sheklukshuk Range on the north, west and southwest.

The Kobuk River (4), one of the major rivers shown, flows westerly into the Hotham Inlet of Kotzebue Sound, about 80 miles west of the photo area. Along the stream course, meanders are abundant and meander scars (24) and oxbow lakes, such as Pitkik Lake (23), mark channel positions of a former time.

Erosion along the river is evidenced by the deposition of sands and gravel on the inside of meanders. These deposits in some places occur as sand bars (26), point bar deposits, which appear as lighter areas along the stream course, and as mid-channel islands (56) in braided streams.

Some of the more obvious rivers and streams tributary to the Kobuk River are: Ambler River (5), Shungnak River

(Continued on page 30)

Arctic and Subarctic Environmental Analysis

(Continued from page 29)

(6), Cosmos Creek (16), Koguluktuk River (58), Mauneluk River (57), Pick River (37) and the Selby River (7). The banks of these are outlined by distinct vegetation patterns along the stream course. Trees are more abundant and dense along the streams' banks but scattered in the bordering lowland areas.

Dendritic drainage patterns are obvious throughout the photo, but the best example is present on the south and east slopes of the Waring Mountains (47). Here the alternating dark and light vegetation patterns respectively reflect the stream and inter-stream areas.

Another major river, the Selawik (9), flows in a westerly direction to Selawik Lake, an embayment of Kotzebue Sound, not shown on the photo. This river has numerous meanders and drains the western portion of the Zane Hills (40), the mountainous region around Purcell Mountain (59), and the swampy flatland are (45) in the photo.

Some of the tributaries of the Selawik are defined by the dark vegetative patterns along the stream courses: Tagagawik River (14), Kiliovilik Creek (17), Shinilikrok (18), and Shiniliaok Creek (19). The area around the Kugarak-Selawik River junction is swampy flatland with numerous lakes and ponds.

Dakli River (10) and its tributary Wheeler Creek (20), which are defined by the distinct vegetative patterns along these streams, are 4th- and 3rd-order streams, respectively, according to the Strahler-modified Horton classification. These streams drain the southwestern portion of the Zane Hills (40), and the northeast portion of the mountainous area around Purcell Mountain. At the southern portion of the Dakli River, near its junction with the Koyukuk River (11), the surrounding area is swampy, with many ponds and lakes.

The Koyukuk River (11) shows extensive meandering and has numerous meander scars and sloughs along its course. Three-Day Slough (54) and Cutoff Slough (55) are two examples. The Koyukuk and its tributaries (e.g. Kateel River) (12) drain most of the area in the lower right quarter of the photo. It flows over very flat, swampy land characteristic of a geomorphically old-age area.

The Babantaltlin Hills (53) and the meandering Hogatza River (52) are located Southeast of the Pah River flats fire. The area is extensively forested, with many lakes. Along the Hogatza River are numerous point bar deposits.

The Lockwood Hills (35), Zane Hills (40), Jade Mountains (46), and the Norutak Hills (34) show extensive bedrock exposures (41) on the peaks and crest lines. These appear as dark areas outlined by lighter vegetation. Extensive stream erosion valleys (32) with dendritic drainage patterns are visible on the mountains.

Vegetation tones in the photo are attributable to the type of surface material, climatic parameters and slope. Mountain slope forests (36) are visible in the hilly areas, while the bog vegetation in the swampy areas is a lighter shade and also quite distinctive. The dark vegetation tones following stream valleys are very useful in tracing the river courses on the photo.

The numerous lakes and ponds on the photo are varied in size and shape. Tekeaksakrak Lake (28), nearly two miles long, and Solsmunket Lake (27), slightly larger than two miles, are two of the larger lakes on the photo. They are similar in shape with an elongate N-S axis. Birch Lakes (39) is one mile across with a circular shape. The multitude of lakes and ponds indicates poor drainage in the lowlands and a proximity to base level.

Wind deposition was active during the Pleistocene in the photo area. Sites of sand deposition are apparent as irregular-shaped, light-colored areas; the Little Kobuk Sand Dunes (22), the east side of the Great Kobuk Sand Dunes (21), and (somewhat hidden by clouds) the Nogahabara Sand Dunes (51) southwest of Birch Lakes. These deposits result from wind erosion across extensive periglacial outwash plains, with subsequent deposition in areas where the wind-borne materials are retained.

In view of the lack of environmental information in arctic and subarctic areas, the advantages of surveys by polar-orbiting satellites are obvious. Until now, obtaining environmental data in polar regions has been very difficult and the launching of the ERTS satellite comes at a most opportune time.

Scientists at CRREL look forward to an immediate yield of information vital to a more rational, safe and productive program of development of arctic and subarctic areas, by methods that will have a minimal impact on the environments found in Alaska.

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COLD REGIONS ENVIRONMENTAL ANALYSIS BASED ON ERTS-1 IMAGERY

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by

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INTRODUCTION

An overriding problem in arctic and subarctic environmental research has been the absence of long-term observational data and sparseness of geographical coverage of existing data. Studies of synoptic environmental events over regional-sized areas have been either impossible or prohibitively expensive. The launching of ERTS-1 on July 23, 1972 provides for the first time a means of accomplishing many types of investigations that were not feasible previously.

The distribution of permafrost in central Alaska, where its occurrence is discontinuous, is not well known. Small area studies of permafrost distribution and seasonal thaw regime based on large scale air photo interpretation have been done, but this method requires extensive ground examination and cannot readily be applied to large area surveys. The most important environmental variables for the analysis of discontinuous permafrost distribution are surficial geology, vegetation cover, soil type, topographic position, and microclimate. Except for climate, these parameters can be mapped with ERTS-1 imagery within limitations imposed by resolution and cloud cover, but with the added advantage of regional scale coverage.

Presented here is an analysis of the Upper Koyukuk-Kobuk River area located in NW Alaska (Fig. 1). The image analyzed (1003-21355-457) is a color composite made from data acquired in the green, red and infrared bands of the multispectral scanner (Fig. 1). The area is devoid of cultural features except for several small villages and bush airstrips near the rivers. Documented information on the environment of the area is limited, consisting largely of statewide coverage of geology, vegetation, permafrost and climate. Therefore, a substantial challenge is provided in the interpretation of regional permafrost distribution and regimes in Alaska.

Resolution on the image varies with the shape and tone contrast of a feature. Rounded features such as lakes or ponds as small as 80 m. in diameter can be seen. Linear features such as streams or landing strips about 50 m. across are visible. Even though the three images comprising this color composite were classified as "poor" by NASA, the resolution of the composite is remarkably good and a thorough interpretation of the regional features can be made.

SURFICIAL GEOLOGY

The Kobuk and Koyukuk River Valleys are covered with surficial deposits that are principally of glacial, eolian, fluvial, and lacustrine origin. These deposits are easily discernable on the ERTS image based on differences in texture, tone and patterns.

Initial mapping of the surficial geology was accomplished without the aid of stereo pairs, reference to published maps or other available ground truth. Eight recognizable units are delineated on Figure 2. Bedrock-Colluvium (b) consists of coarse and fine grained deposits associated with moderate to steep-sloped mountains and hills; bedrock exposures are largely restricted to upper slopes and crestlines. Outwash deposits (Q_o) are fine and coarse grained alluvial deposits associated with lower highly dissected mountainous terrain. Solifluction appears to be an important process on this landscape. Undifferentiated alluvial-glaciofluvial deposits (Qag) are dominantly fine-to-coarse grained deposits associated with gentle to moderate sloping backslope positions; there are few bedrock outcrops. Fluvial-lacustrine deposits (Q_{fl}) are generally fine grained sands and silts associated with low-lying swampy areas. Undifferentiated alluvium-lacustrine deposits (Q_{a1}) are fine grained and associated with gently sloping footslope and terrace positions. Eolian deposits (Q_e) are sand and loess present as active dunes. Fluvial deposits (Q_f) are modern floodplains and low-lying terrace deposits; sediments would be fine-grained and generally well-rounded, an indication of significant particle movement. Undifferentiated deposits (Q_u) are coarse to fine grained deposits occurring on rolling uplands and consist primarily of colluvium mixed with some loess from the sand dune area to the northwest.

The units defined for mapping surficial geology from the ERTS image were subsequently compared to the Surficial Geologic Map of the Central Kobuk River Valley (Bull. 1181K) and the 1:1.5 million State of Alaska map. The following similarities and differences were found:

1) Five drift and three outwash units were defined on the USGS map based on glaciation periods. The drift units are composed primarily of till and outwash sands and gravels, whereas the outwash units contain chiefly gravels and sand. On this ERTS image it was not possible to differentiate between glaciation periods. Therefore, previously mapped drift areas were found to occur in our unit Qag (undifferentiated alluvial-glaciofluvial deposits) and the outwash area in Q_o (outwash deposits).

2) The water bodies in the image are primarily, but not exclusively, thaw lakes. Lacustrine sediments, not defined in this area on the 1:1.5 million scale surficial geology maps, are included in units Q_{a1} and Q_{f1} (Fig. 2).

3) Eolian deposits include sand dunes and loess which can not be easily discriminated on ERTS imagery. On the MSS color image active sand dunes show as light blue irregularly shaped features north of the Waring Mts. and are the only deposits mapped as Qe. Vegetated sandy areas were not included in this unit because on the basis of the imagery alone, they do not appear as distinct eolian sediments. These deposits are included in Qag, east of the Waring Mts. Subsequent ground truth verified that this area is a sparsely vegetated, stable dune field with relatively small, locally active dunes. However, Q_{ag} is defined in our legend as undifferentiated alluvial-glaciofluvial deposits.

In summary, the amount of detail available from the 1:1.3 million scale ERTS-1 image compared faborably in most respects to the available 1:250,000 map and was superior to the 1:1.5 million State of Alaska map.

VEGETATION

Vegetation is one of the most important indicators of permafrost characteristics of an area, but the relationship is complex and must be examined in detail (Hopkins and others, 1955). Vegetation type and density in a permafrost region are most directly related to soil type and drainage conditions. As an indicator of permafrost, its most reliable value lies in its indication of the depth of seasonal thaw (Tyrtikov, 1959).

This ERTS scene is predominantly within the interior Alaska white spruce forest, a vegetative association confined to the well drained upland areas (Vierick, 1972). Poorly drained lowland areas are largely of treeless bogs with sedges, grasses, and small willows, alders and birches. Better drained lowland areas grade from moist tundra to open black spruce forest to birch and aspen on low ridges. Alpine tundra exists above the local timberline at about 600 m.

Vegetation differences are apparent on the MSS color composite primarily by tonal rather than textural patterns. This results from the approximately 80 m. limit of resolution. The tonal differences would appear to be primarily related to vegetation density, and species composition. Four density levels have been identified and mapped in this scene. The highest density tone is a dark red identified as a closed spruce-hardwood forest, labeled "F" in Figure 3. It is believed to consist of tall to moderately tall white and black spruce, together with paper birch, aspen, and balsam poplar and occurs on moderate to well drained sites such as active flood plains, mountain slopes, and highland areas. It is seen in a galaria forest pattern along several streams, including the Selawik and the Kobuk Rivers. The next lightest tone is a bright red associated with a low to hilly area, and is representative of moist tundra grading to low black spruce and well developed birch-aspen growth on the best drained slopes. This unit, labeled "M" in Figure 3, also contains most of the burn scars, labeled "B". The wet lowlands appear as a reddish gray, punctuated by the many thaw lakes typical of poorly drained permafrost alluvial areas. These areas are essentially treeless bogs ("W" in Figure 3) and have a cover of sedges and grasses, with an abundance of willows, alders, and resin birch, locally with widely spaced spruce and tamaracks. Two small areas, identified from geological mapping as formerly active sand dune areas, exhibit a unique gray tone with a faint red coloration, suggesting revegetation with shrubs or other open vegetation, with the bluish cast of sand still apparent. "A" is alpine tundra, predominantly barren, locally dominated by low heath shrubs, prostrate willow, and dwarf herbs.

Recently burned areas, one still burning, appear black and lie in the upland spruce-hardwood forest or in the less well drained black spruce - birch and aspen associations. The active burn is identified as the Pah River fire. The Bureau of Land Management estimated the area of this burn at 60,000 acres on July 8, 1972. At the time of this ERTS image, July 26, 1972, the burned area was measured by color densitometer planimetry to be 81,000 acres. This measured increase of 21,000 acres in 18 days compares favorably with the other methods used in calculating the size of burned areas.

The main influence of vegetation on permafrost terrain is that it affects the thermal exchange between the atmosphere and the lithosphere, and the moisture regime in the soil (Tyrtikov, 1959). Vegetation has the effect of retarding soil warming in the summer and cooling in the winter, but the depth of the active layer also depends on other variables, such as the depth of winter snow and drainage conditions during summer. A vegetation association-depth of thaw relationship where permafrost is present in the discontinuous permafrost zone has been given by Hopkins and others (1955); it is shown in Table 1.

In the following section, vegetation associations delineated in Figure 3 are considered in combination with surficial geology units (Figure 2) to provide the basis for an estimate of thaw depths within each permafrost mapping unit.

PERMAFROST

Permafrost is defined solely on a temperature basis. It is rock or soil material, with or without moisture or organic matter, that has remained continuously below 0°C for two or more years (Ferrians,1969). It occurs where the depth of winter freeze exceeds the depth of summer thaw, and is classified into two broad categories: continuous and discontinuous. In the continuous permafrost zone, permafrost lies beneath all land areas, but it is absent directly beneath large water bodies, which provide a sufficient heat reservoir to keep underlying materials unfrozen (Williams,1970). The thickness of permafrost in this zone ranges from several hundred feet in the south to an extreme of 600 m. in northern Alaska. The boundary that separates these two zones is theoretically distinct but imperfectly known. Climatically, it approximates the mean southern position of arctic air in summer (Bryson,1966); it is close to the southern limit of the tundra (MacKay,1972), and is the effective limit of active ice-wedges and pingos (Pewe, 1966). The discontinuous permafrost zone is a complex mosaic of frozen and unfrozen ground with permafrost thickness decreasing in a southerly direction.

The geographical distribution of permafrost in a particular area is dependent upon its past and present environmental regimes. The depth of the active layer is dependent on present relationships of soil type, drainage, moisture content, vegetative cover, topographic setting and climatic regimes. Figures 4 and 5 illustrate typical permafrost settings and the nomenclature in current use.

Standard, well-established, photogeologic methods and procedures for delineations of interpretation were used. Permafrost areas have been defined based on the patterns of vegetation, surficial geology, and drainage. Results were compared with documented information on vegetation, climate, climatic history and existing permafrost maps.

The Upper Koyukuk-Kobuk River area lies at the northern edge of the discontinuous permafrost zone (Hopkins and others, 1955) and is predominantly underlain by perennially frozen ground. Extrapolations from the nearest climatic stations suggest a mean annual temperature of about -4°C, and a mean annual precipitation of about 50 cm. Because of the proximity of the ocean, summers are cooler and the winters somewhat warmer than at equal latitudes further to the interior. This smaller seasonal amplitude is conducive to permafrost development (Saltykov, 1959).

Areas without permafrost within this scene are localized, and generally occur in coarse gravels along streams, near lakes and ponds, and on steep slopes with coarse, permeable, talus deposits. Areas mantled with a dense vegetative mat such as mosses, grasses or sedges have a shallow thaw depth (< 0.5 m).

Five permafrost regions were mapped based on the interpretation of surficial geology and the probable depth of thaw estimated on the basis of the vegetative cover (Fig. 6). Bedrock and colluvium (m_1) is characterized by scattered taliks, a thaw depth of 0.5 m. - 2.0 m. and alpine vegetation that grades into white spruce forest below timberline. Dissected alluvial deposits (u_1) contain numerous taliks, have indications of active solifluction, are characterized by alpine vegetation and a 0.5 m. - 2.0 m. thaw depth. Active floodplains (l_1) have numerous taliks, dense tree and shrub vegetation and a thaw depth of more that 2.0 m. Abandoned floodplains (l_2) with many small lakes and fine grained soils have grass, sedge, small shrubs and open spruce vegetation and a thaw depth less than 0.5 m. Alluvial-colluvial deposits (u_2) are characterized by continuous permafrost, birch-aspen forest on well-drained slopes grading to moist tundra in less well drained sites and a thaw depth less than 0.5 m. in areas of poor drainage and 0.5 m. - 2.0 m. on south facing, well drained slopes.

Although vegetation association boundaries usually conform to surficial geology units, there are many cases where this is not true. For instance, the u_2 unit may have alpine or forest vegetation depending upon elevation and/or exposure.

Using the criteria of surficial geology and vegetation, a permafrost distribution map has been prepared with considerably greater detail than was previously available. The accuracy of this interpretation of MSS scene 1003-21355-457 is being field checked. To the extent that it is found to be possible to utilize ERTS-1 imagery and extrapolate from existing maps of vegetation and surficial geology and from earlier observations, an improved and more detailed permafrost map of the area can be quickly produced. On the basis of this hasty and preliminary analysis we are optimistic.

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TABLE I

Vegetation	Depth of Thaw (m.)
Tall willows on flood plains	2.4
Mixed alder, willow, white birch	1.2
Mixed stands of white spruce and white birch	0.6-0.9
Black spruce in tundra or muskeg	0.3

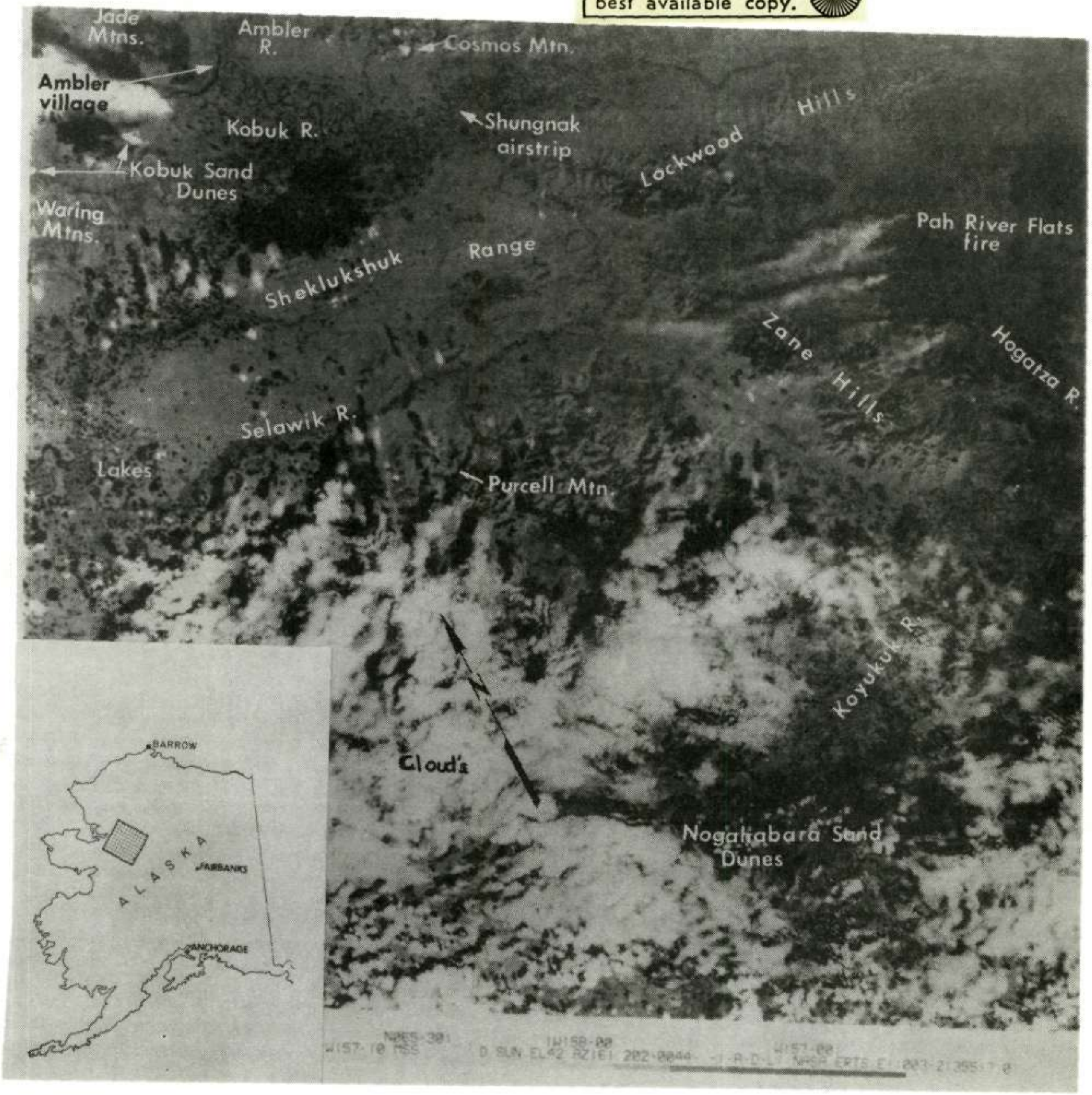

FIGURE 1. Image Area, 240 miles NW of Fairbanks, with major features and locations.

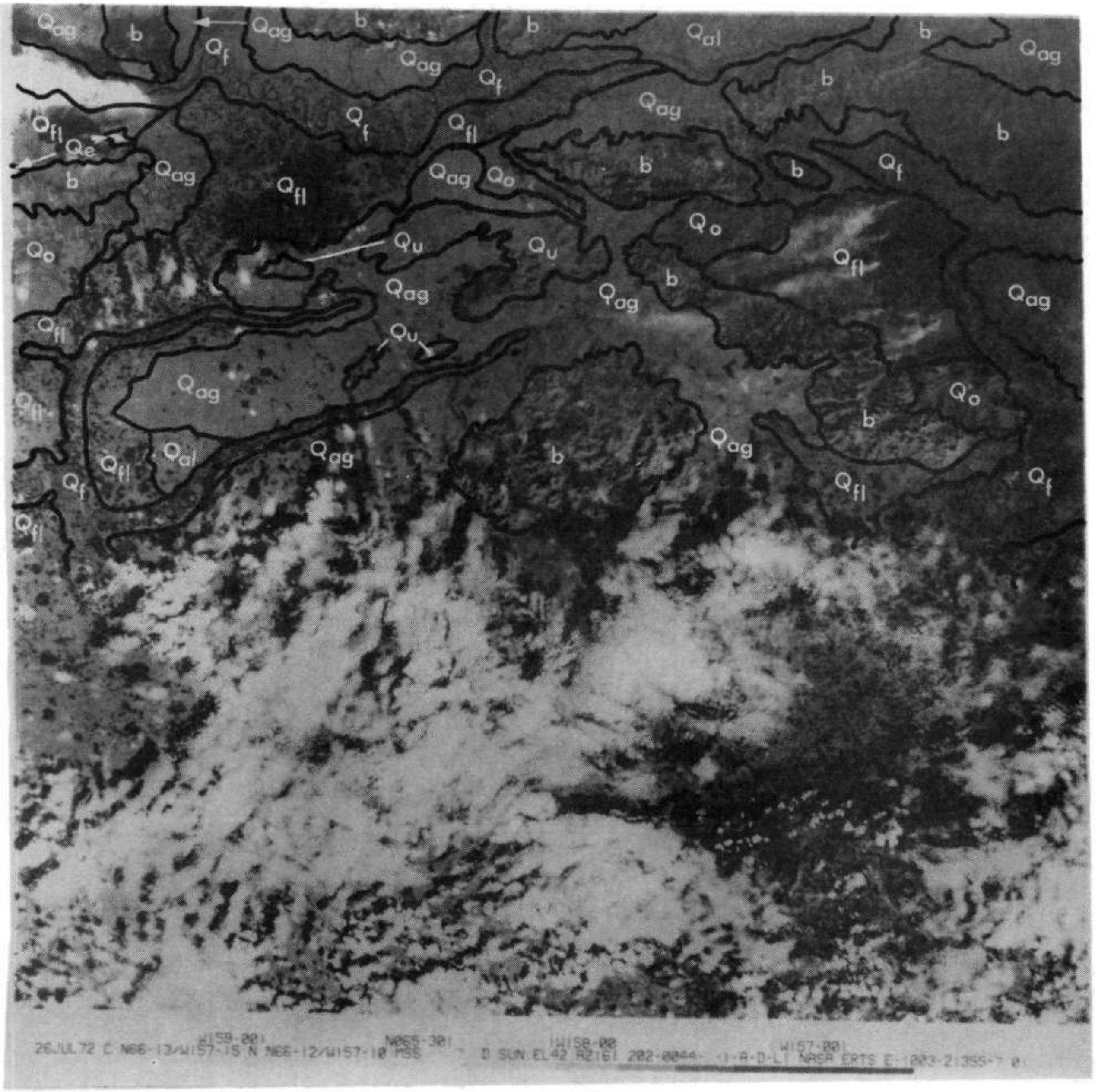

FIGURE 2. Distribution of surficial geologic units: b, bedrock-colluvium; Q_o, outwash deposits; Qag, undifferentiated alluvial-glaciofluvial deposits; Q_{fl}, fluvial-lacustrine deposits; Q_{al}, undifferentiated alluvium-lacustrine deposits; Q_e, eolian deposits; Q_f, fluvial deposits; and, Q_u, undifferentiated deposits.

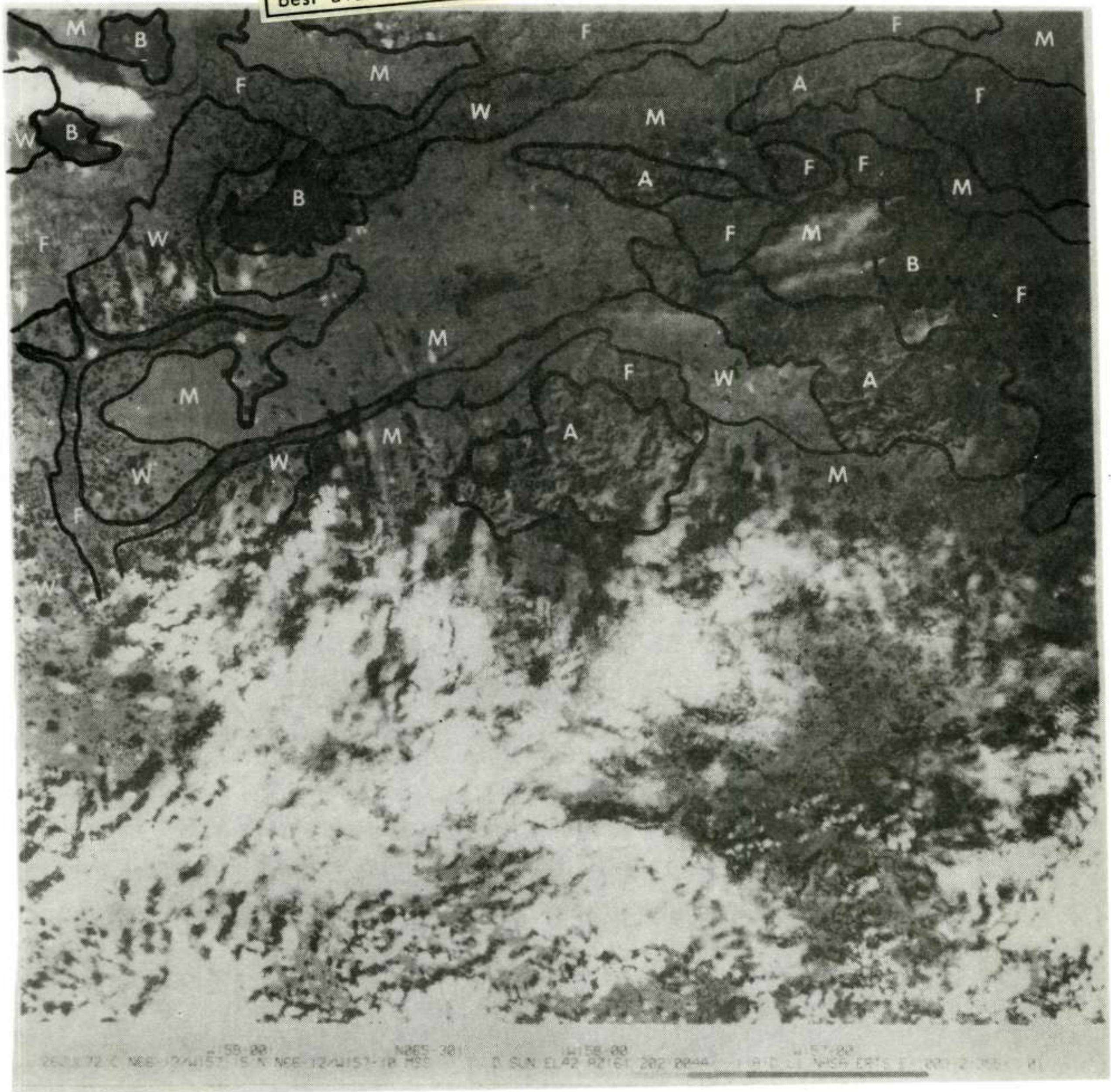

FIGURE 3. Vegetation associations. W, treeless bogs, M, moist tundra, B, burn scars, F, upland hardwood and spruce forest, A, alpine tundra.

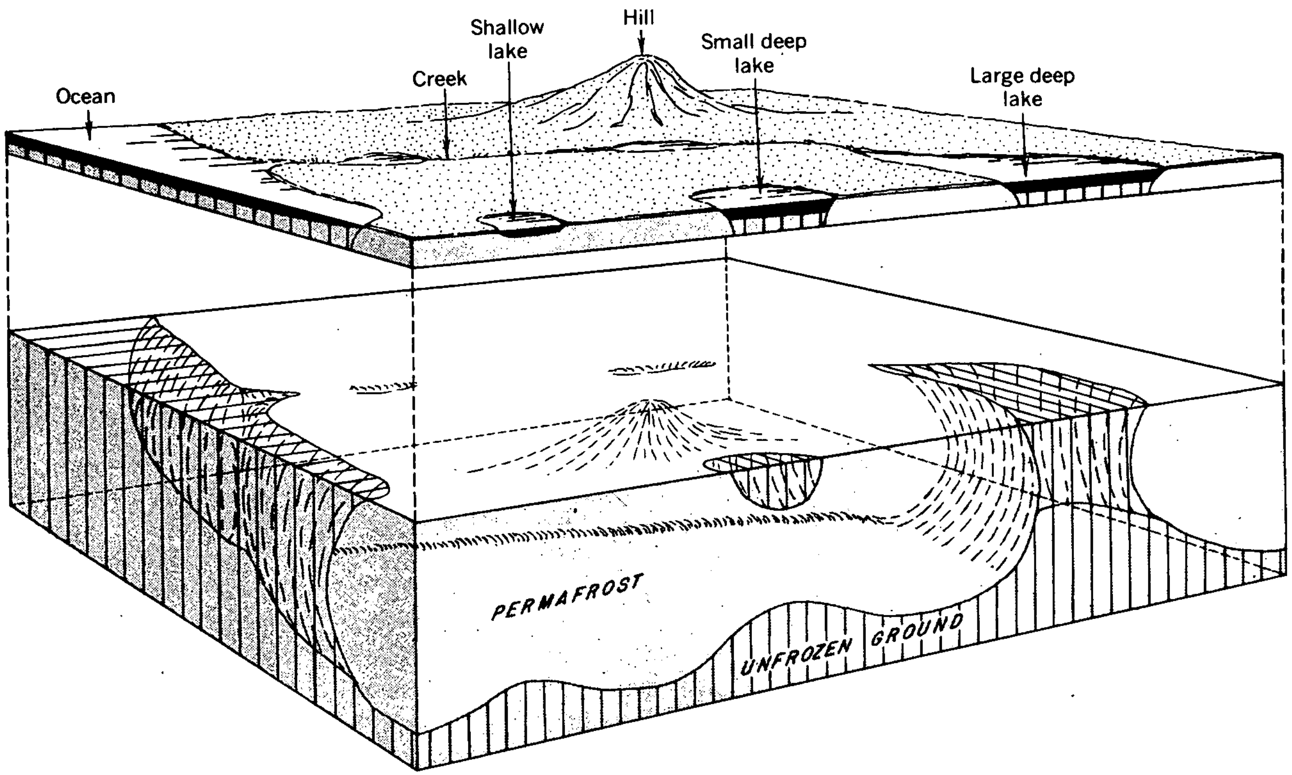

FIGURE 4. The effect of surface features on the distribution of permafrost in the continuous permafrost zone. After Lachenbruch (1968).

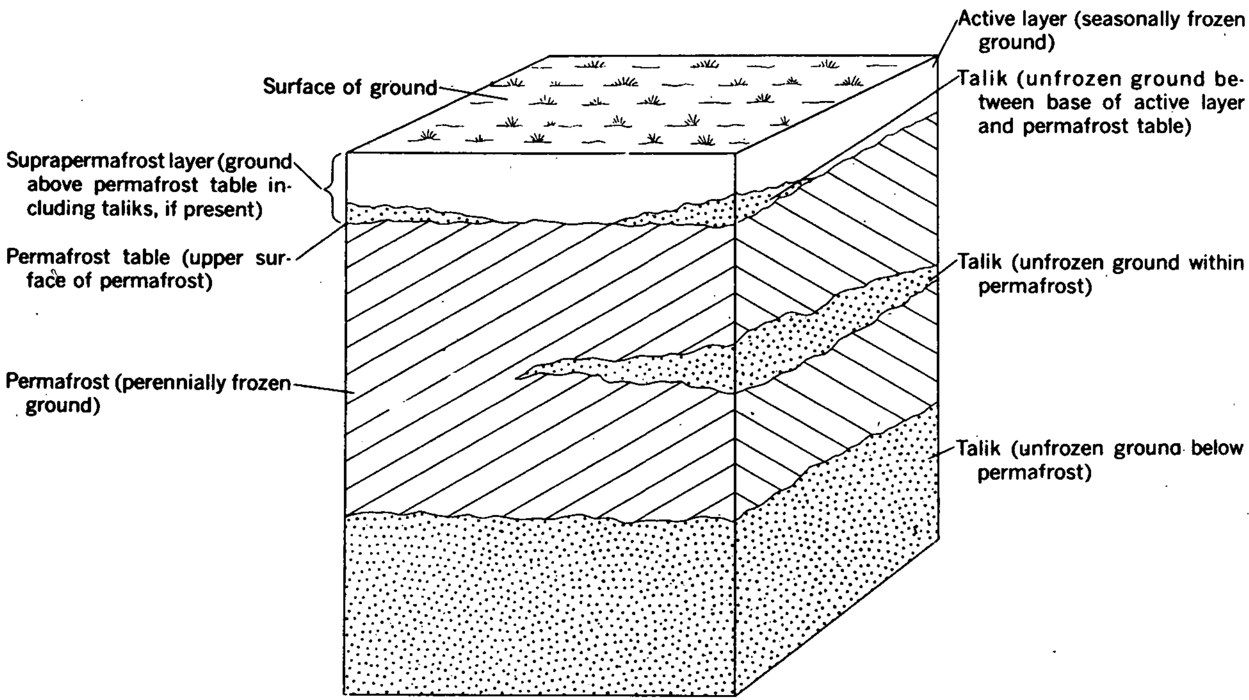

FIGURE 5. Occurrence of taliks in relation to the active layer, suprapermafrost zone, permafrost table and permafrost. From Ferrians (1969).

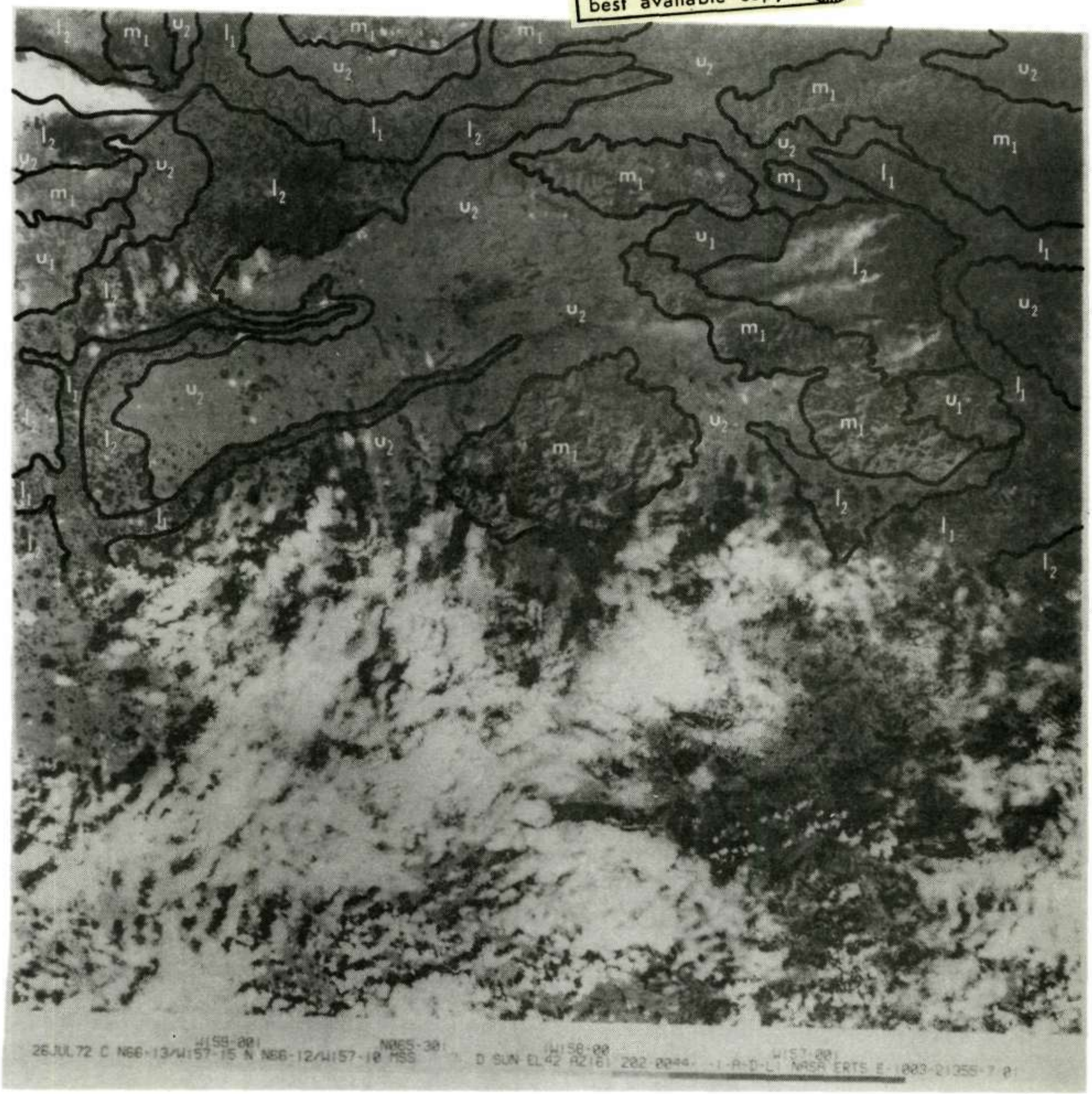

FIGURE 6. Permafrost units and distribution.

<u>Mountainous areas:</u> m_1, bedrock and colluvium

<u>Upland areas:</u> u_1, dissected alluvial deposits

u_2, alluvial-colluvial deposits

<u>Lowland areas:</u> l_1, active floodplains

l_2, abandoned floodplains