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THE ENVIRONMENTAL GEOLOGY AND GEOMORPHOLOGY OF THE GULF OF ALASKA COASTAL PLAIN

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FINAL REPORT

FOR

GULF OF ALASKA

December 30, 1976

Project **Title:** The Environmental Geology and **Geomorphology** of the Gulf of Alaska Coastal Plain

Contract Number: 03-5-022-56

Task Order Number: 6

Principal Investigator: **Dr.** P. Jan Cannon

I. Task Objectives

A. To produce three maps of the coastal plain section of the Gulf of Alaska

B. To produce a report on the application of radar imagery to the environmental geologic mapping of coastal zones

C. To construct an annotated mosaic of the area from radar imagery.

D. To indicate the effects (beneficial and adverse) that oil and gas development might have in relation to the geologic setting.

"II; Introduction

This report presents information which can be used in an environmental assessment of the coastal plain of the Gulf of Alaska. It also contains an evaluation of radar imagery as a major information source for environmental geological mapping,

This report contains five maps which display certain baseline data necessary for an environmental assessment of the-coastal plain. During the planning stages of this project, it was thought that the data could be displayed on three maps. However, the number of maps had to be increased to five in order to adequately present the information concerning the environment.

It was necessary to increase the number of task objectives in order to improve the communication of information. Also, the presentation and discussion of task objectives have been arranged within this report in a manner which will increase the utilization of the information.

III. General Description of Area

The coastal plain of the Gulf of Alaska is a narrow strip of land (1 to 40 kmwide) which extends some 600 km from Icy Point to the western margin of the Copper River Delta. The upper or inland margin is bordered with the high mountains of the Chugach, St. Elias, and Fairweather Ranges, which extend in elevation from 3,650 to 5,800 meters. The area is usually overcast and cold, Obtaining aerial photographs of this area is almost impossible. Due to the geographic location of the Gulf of Alaska on the Earth and the fact that two ranges of the highest mountains on the North

American continent lie just to the north of the Gulf of Alaska, the area has a climate that is unusually warm for its latitude. However, this relative warmth is offset by the situation that the same factors that make temperatures warmer also help produce high amounts of precipitation (average 302 cm per year), almost continual overcast conditions, and an impact zone for some of the worst storms created on the entire planet.

The coastal plain has been described as having a diversified topography carved in Tertiary rocks. The assemblage of landforms in the area is indeed quite diverse which is unlike most coastal plains on this planet. However, this diversity is valuable in constructing a chronology of the geomorphic events which have occurred in the area. The coastal plain is crossed in several places by fiords and active glaciers. The assemblage of landforms includes: morainal belts, dead ice moraines, thermokarst pits, outwash plains, meltwater streams, marine terraces, abandoned beach ridges, large tidal flats in shallow bays, and the associated longshore features of bars, spits, and backwater lagoons. The materials of the coastal plain consist of till, gravels, sand, mud, ice, and various mixtures of these materials.

The portion of the coastal plain which will be the most involved with petroleum development is a section 255 km long, from Dry Bay westward to Cape Yakataga. This section, therefore, was the subject of this intense environmental geologic investigation as a part of the overall environmental assessment. The area can be divided into three physiographic zones separated by large fiords: the Yakutat District, the Malaspina District, and the Yakataga District (Fig. 1).

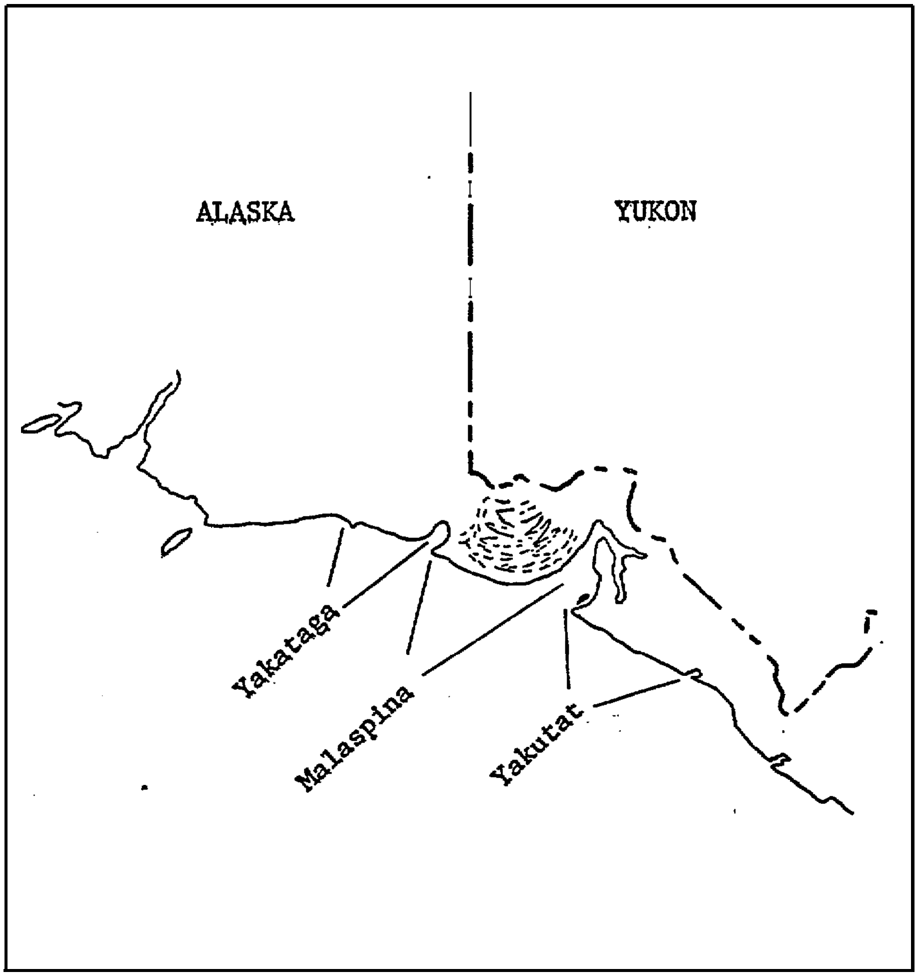


Figure 1. Index map showing the location of the Yakataga, Malaspina and Yakutat Districts. The three physiographic districts are separated by large fiords. The Yakataga District is a narrow strip of coastal plain between Icy Bay and Cape Yakataga. The Malaspina District is between Icy Bay and Yakutat Bay and consists of the Malaspina Glacier and the Malaspina Forelands. The Yakutat District is comprised of the coastal plain deposits that extend from Dry Bay and the Alsek River northwestward to Yakutat Bay.

IV. Introduction to Radar Imagery

Radar is an acronym devised from radio detection and ranging. It is an active system which means that it generates the energy that is ultimately recorded. Taking normal photographs in the dark with a flash bulb is an example of an active system. Of all the operating imaging sensors, radar operates at the longest wavelengths and the lowest frequencies. The wavelengths most commonly used for imaging radar systems are between 0.86 cm and 3.3 cm (Table 1). The radar frequencies range from 36.0 Gigahertz (GHz) to around 10.0 GHz. One Hertz is equal to one cycle per second and one GHz is equal to 10^9 cps. The present day radar systems are only a single wavelength of great spectral purity which means the systems are monochromatic.

Radar imagery is a spatial display of the relative differences in returns of radar energy from surface features. It should be kept in mind that although the radar imagery gives the appearance of a black-and-white photograph with low illumination, it is not a photograph, but an electronically constructed image of the various ways in which surface features reflect the radar energy. Some of the advantages of radar imagery are listed in Table 2.

Since radar imagery is acquired by an active system, the direction of illumination (called the look direction) can be oriented in a manner which provides the most useful results (Fig. 2). The altitude of imagery acquisition can be changed by altering the height of the aircraft, carrying the radar system, above the surface of the terrain. Also, the depression angle (the angle between a horizontal plane and the path of

TABLE 1

COMMONLY USED RADAR BANDS

"Barids	"Frequency	Wavelengths
F	300 MHz	1 meter
UHF	300 MHz-1 GHZ	1 meter - 30 cm
L	1-2 GHz	30-15 cm
S	2-4 GHz	15-7.5 cm
C	4-8 GHz	7.5-3.75 cm
X	8-12.5 GHz	3.75-2.4 cm
Kμ	12.5-18 GHz	2.4-1.67 cm
K	18-26,5 GHz	1.67-1.13 cm
K∝	26.5-40 GHz	1.13-0.75 cm
Mμ	40 GHz	0.75 cm

One Gigahertz (GHz) is equal to 10^9 cycles per second and one Megahertz (MHz) is equal to 10^6 cps. The wavelengths most commonly used for imaging radar systems are between 0.86 and 3.3 cm.

TABLE 2

SOME ADVANTAGES OF RADAR IMAGERY

1. Technique is independent of weather, time of day and time of year.

2. Landform recognition and identification is more rapid on radar imagery than on photographs or other types of imagery.

3. Provides immediate reconnaissance and interpretation.

4. Affords much greater areal coverage than cameras, like the aerial metric cameras, carried at the same altitude; provides a different perspective.

5. Does not produce the foreshortening or convergence effect seen in oblique aerial photographs.

6. Saves time and money in some cases due to the increased areal coverage per flight-line mile.

7. Commonly shows more stream detail than a topographic map at the same scale (this depends upon the system used).

8. Can provide quantitative geomorphic data.

9. By use of a synthetic aperture antenna system, radar resolution is (theoretically) rendered independent of height of the aircraft above the terrain.

10. Data can be stored on magnetic tape.

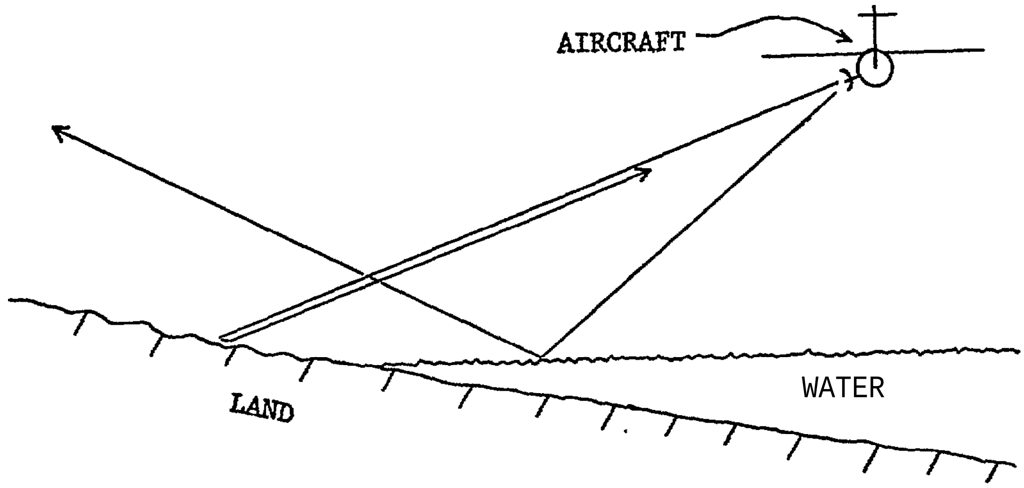


Figure 2. Diagram showing the correct antenna-look-direction for coastal studies. The antenna look-direction should be towards the coast. This means that the aircraft should be flying over the water. Having the look-direction towards the coast will enhance the minor relief features of the coastal plain and beach and will lessen the possible obscuration of important coastal features by shadow-effects from high relief features near the upper margin of the coastal plain.

the returning beam of radar energy which is to be recorded) can be altered to provide an increase or decrease in the shadow-effect, whichever is desired. The shadow-effect on features of relief is due to the side-looking nature (oblique illumination) of the radar Imaging systems. For simplicity, side-looking airborne radar (SLAR) imagery is referred to as just "radar imagery" throughout this report.

Radar imagery can be obtained by two different antenna systems referred to as real and synthetic aperture systems. Real aperture (sometimes called brute force) refers to radar systems using the physical size of the antenna to determine the region of ground that is discriminated by the beamwidth. Synthetic aperture radar systems use only a part of the beamwidth; the signals returned are stored, and then processed in the same way that a physically larger antenna would process them. In other words, the returned signals are electronically interpreted to the sum equivalent of the same return as would be received by a physically larger antenna. The imagery provided by the real aperture system is considered to be the optimum source of information for environmental geologic mapping and geomorphic reconnaissance because of its greater dynamic range relative to the synthetic aperture system and more useful resolution.

X-band, real aperture radar imagery was obtained of the Gulf of Alaska coastal plain at the scales of 1:500,000 and 1:250,000. The area was covered with one strip of imagery at the scale of 1:500,000, and with four overlapping strips of imagery at the scale of 1:250,000. The radar imagery was used as the most up-to-date data source and as a mapping base. Since radar imagery can be obtained nearly anytime a fully instrumented aircraft can fly (see Table 3 on acquisition conditions for remote

TABLE 3

ACQUISITION CONDITIONS FORR EMOTE SENSING DATA

Remote Sensing Data Types	Day Clear Sky	Day Overcast*	Night Clear Sky	Night Overcast*
Black and white photography - Visible range	Yes	No	No	No
Color Photography - Visible range	Yes	No	No	No
Infrared Photography - Black and white	Yes	No	No	No
Infrared Photography - False color	Yes	No	No	No
Multiband Photography	Yes	No	No	No
Radar Imagery	Yes	Yes	Yes	Yes
Thermal Infrared Imagery	Yes	No	Yes	No
Satellite Photography	Yes	No	No	No
Satellite Imagery	Yes	No	Yes	No

*Clouds between sensor and target

sensing data), radar imagery was used as the principle data source.

V. Application of Radar Imagery to Environmental "Geologic Mapping of Coastal Zones'

Since the acquisition of radar imagery is so flexible, it is important that the methods and parameters involved in acquiring radar imagery of coasts be accurately expressed and followed. The antenna look-direction should be towards the coast (Fig, 2). This means that the aircraft should be flying over the water. Having the look-direction towards the coast will enhance the minor relief features of the coastal plain and beach and will lessen the possible obscuration of important coastal features by shadow-effects from high relief features near the upper margin of the coastal plain.

The acquisition altitude for the radar imagery can be very important. Vegetation discrimination is important for most coastal investigations and the best information about vegetation is displayed on radar imagery which is acquired at altitudes below 3,000 meters above the terrain. Discrimination between beach materials of various coarse sizes is also possible at these low altitudes with radar imagery obtained in the K-band region of the wavelengths (Cannon, 1974a).

Coastal areas which are of extreme environmental importance, in relation to petroleum exploration and development, are usually broad flat plains. Because these coastal plains have such low relief features it is often difficult to identify the important landforms. The low relief landforms of coastal plains, having relief differences of less than three meters, can be enhanced on radar imagery acquired with small depression angles., The small depression angles increase the radar shadow-effect on low relief features, which helps in the identification of minor landforms.

The single most important factor in the amount of information displayed on radar imagery of a planetary surface is the physical interaction of the propagated radar energy with surface features. In other words, the physical size and geometry of surface features in relation to the wavelength of the radar energy determine the major differences in reflected radar energy which are indicated on radar imagery. The shorter the wavelength the greater the amount of information that can be obtained and displayed on the radar imagery. A comparison of the size of wavelength with the amount of information displayed on the resulting radar imagery of the most used radar systems is shown in Table 4. The type and amount of information needed in an investigation, therefore, prescribes the wavelength region to be utilized in obtaining radar imagery of any area.

The information in Table 4 is based on the optimum data types. The K- and X-band imagery is real aperture imagery and the L-band imagery is from a synthetic aperture system. For all geologic investigations real aperture imagery is superior to synthetic aperture imagery (Cannon, 1975).

Coastal plains in temperate or tropical regions especially lend themselves to the applications of radar imagery. These types of coasts are usually cloudy and the ability of radar imagery to record information through a cloud cover means that data can be collected most anytime.

The most important environmental information along these types of coasts is related to water bodies and vegetation differences. Therefore, the ability of the shorter wavelength radar system to discriminate between vegetation types and clearly delineate surface water features makes it a

TABLE 4

COMPARISON OF RADAR WAVELENGTHS AND THE INFORMATION PERTINENT TO COASTAL STUDIES WHICH IS DISPLAYED ON RADAR IMAGERY

Information Sources	K-Band*	"X-Band*	L-Band+
Beach Materials	good	inadequate	inadequate
Landforms	good	good	inadequate
Land-Water Contact	good	good	marginal
Minor-Vegetation	good	marginal	inadequate
Major-Vegetation	good	good	inadequate
Ice Surface Features	good	good	marginal
Ice Structure	good	good	good
Cultural Features	good	good	inadequate

*K- and X-band data from real aperture imagery
+L-band data from synthetic aperture imagery

Note: For a visual comparison of real aperture imagery with synthetic aperture imagery, see Cannon, 1974, pp. 764-766 (from Annual Report for Year Ending March 31, 1976).

very valuable technique. The units on an environmental geologic map are the components of natural systems and man-made features. K-band, real aperture, radar imagery of the coastal plain of Texas and Louisiana (Fig. 3) is a good example of the vegetation discrimination abilities of radar imagery (Cannon, 1974b). All land-water contacts, the coastline as an example, appear extremely sharp on radar imagery due to the strong contrast in reflective properties of the land and water.

VI. Mapping the Gulf of Alaska"Coastal Plain With Radar"Imagery

X-band, real aperture, radar imagery was obtained of the Gulf of Alaska Coastal Plain at the scales of 1:250,000 and 1:500,000. The area was covered with four overlapping strips of imagery at the scale of 1:250,000 (see Figs. 4, 5, 6, 7, and 8) and with one strip of imagery at the scale of 1:500,000 (see Fig. 9). The radar imagery was used *as* the most up-to-date data source and as a mapping base. The foremost factor influencing the choice of radar imagery as the major data source was the demand for neoteric data.

Two maps were made of the area showing data taken directly from the radar imagery. One is Map 1 which shows the major landforms of the area. The other is Map 3 which is a map of the major lineaments which cross the area. The information from Map 1 and Map 3 was combined to produce Map 2. Map 2 indicates the natural environmental geologic hazards of the Gulf of Alaska coastal plain.

The shoreline shown on the radar imagery and the shoreline shown in 1951 aerial photography of the area were compared to produce Map 4.

Figure 3. K-band, real aperture, radar imagery of the Sabine Pass area of Texas and Louisiana. This is a good example of the vegetation discrimination abilities of radar imagery (Cannon, 1974b). All land-water contacts, the coastline as an example, appear extremely sharp on radar imagery due to the strong contrast in reflective properties of the land and water. The most important environmental information along these types of coasts is related to water bodies and vegetation differences. Therefore, the ability of the shorter wavelength radar system to discriminate between vegetation types and clearly delineate surface water features makes it a very valuable technique. The units on an environmental geologic map are the components of natural systems and man-made features.

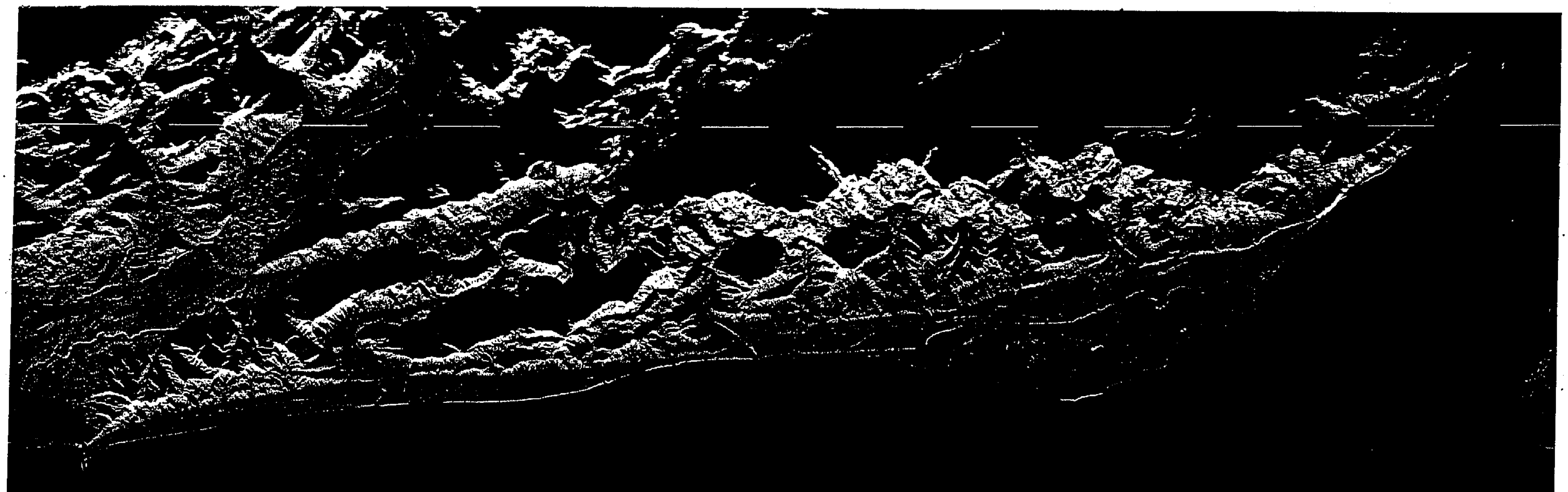
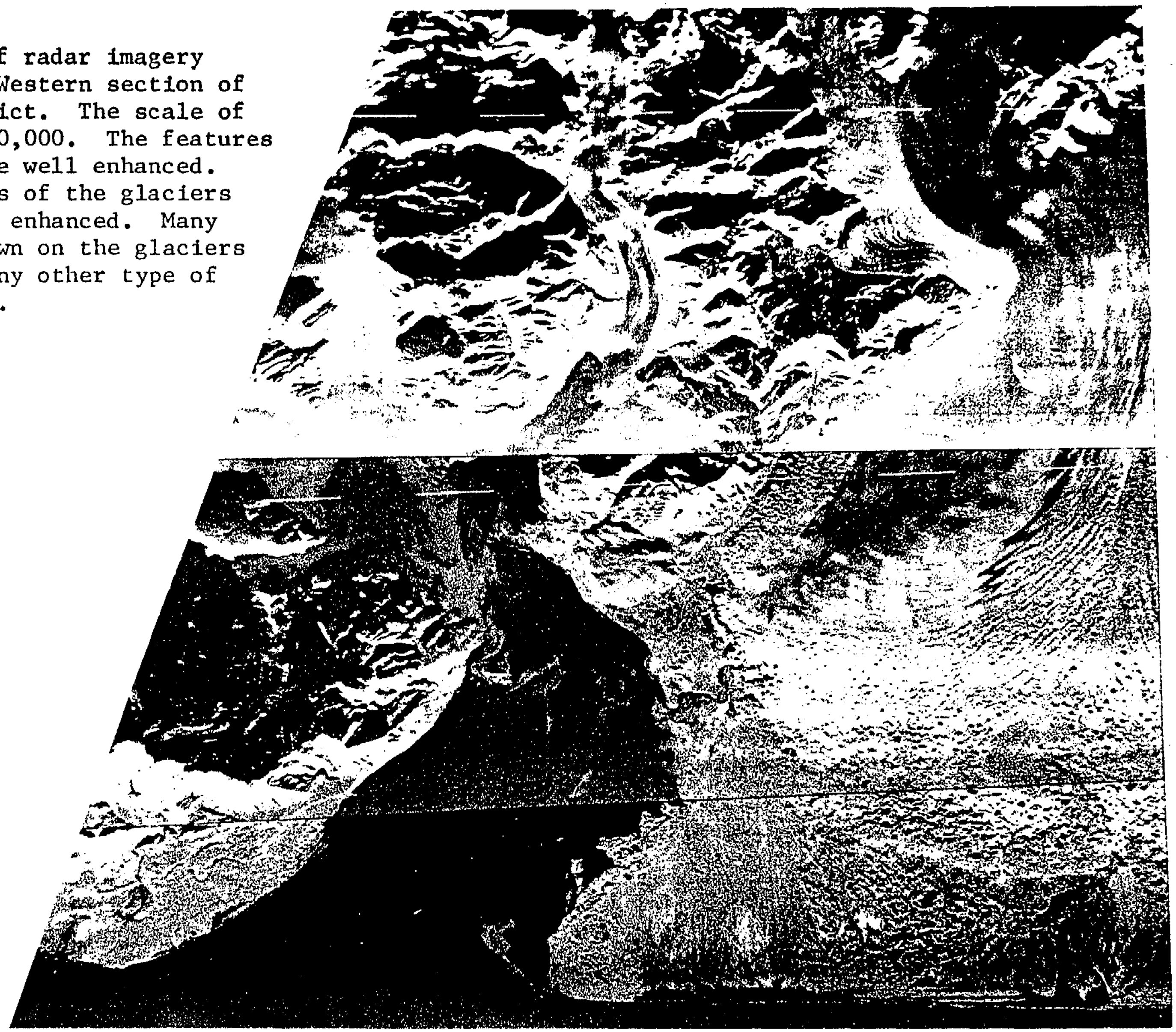


Figure 4. Radar imagery of the Yakataga District. This X-band, real aperture, radar imagery was acquired at a scale of 1:250,000. The data shown on Map 1 and Map 3 were taken from this imagery.

Figure 5. Mosaic of radar imagery of Icy Bay and the Western section of the Malaspina District. The scale of the imagery is 1:250,000. The features of the forelands are well enhanced. The various features of the glaciers themselves are also enhanced. Many of the features shown on the glaciers cannot be seen on any other type of remote sensing data.



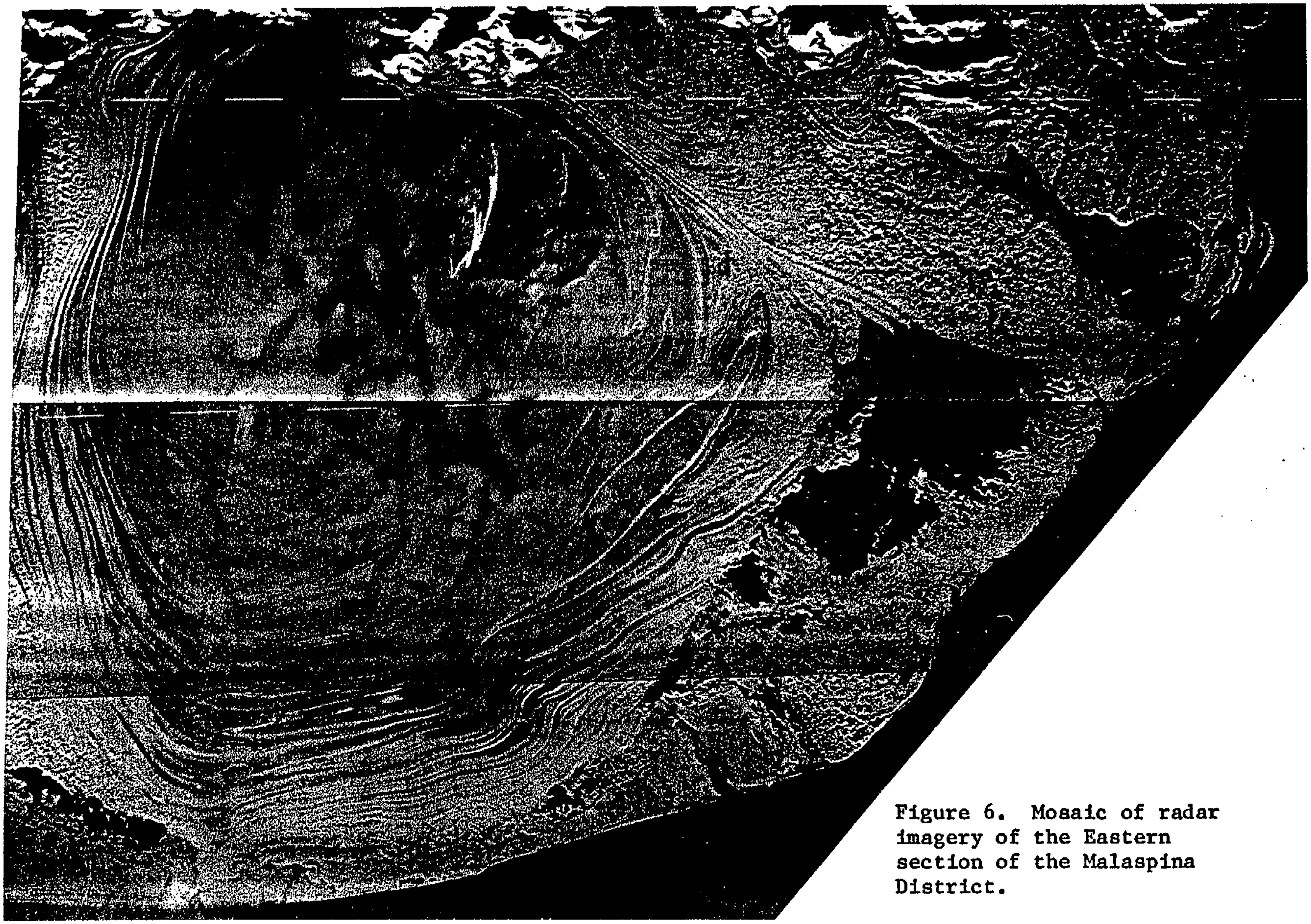


Figure 6. Mosaic of radar imagery of the Eastern section of the Malaspina District.

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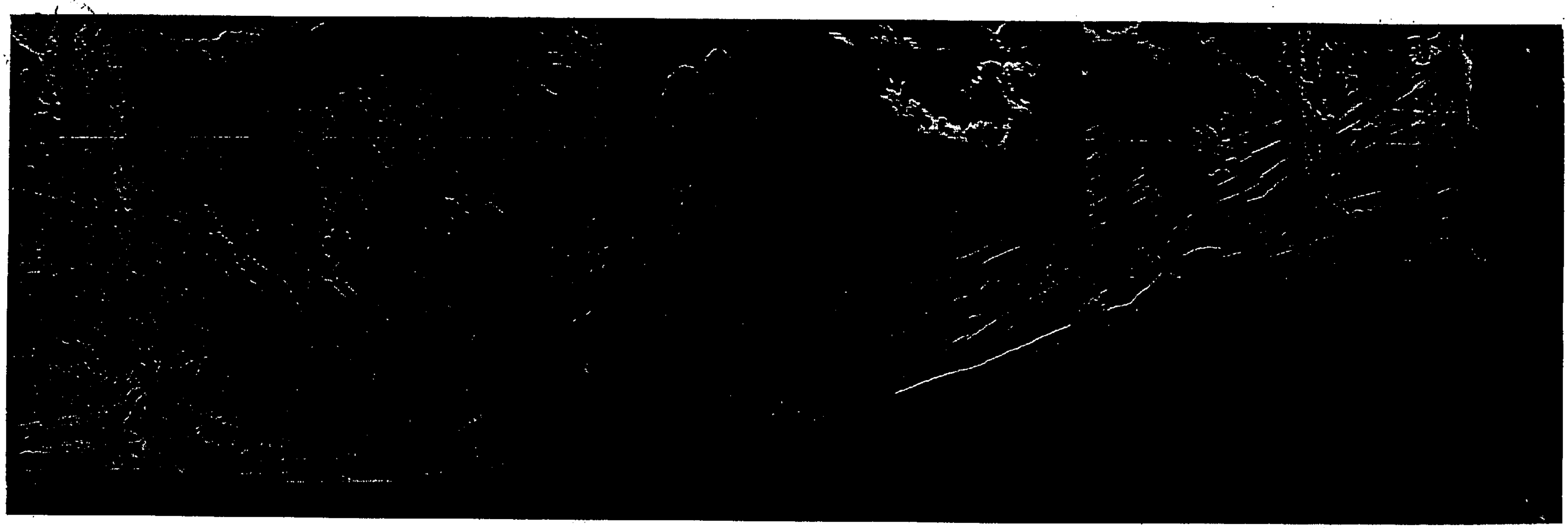

Figure 8. Radar imagery of part of the Yakutat District, showing Dry Bay. . This radar imagery was taken during a storm, through a solid cloud cover and a heavy rain. Note the beach ridges next to Dry Bay which are cut by the outburst flood features that radiate out from Harlequin Lake. This imagery was taken at a scale of 1:250,000.

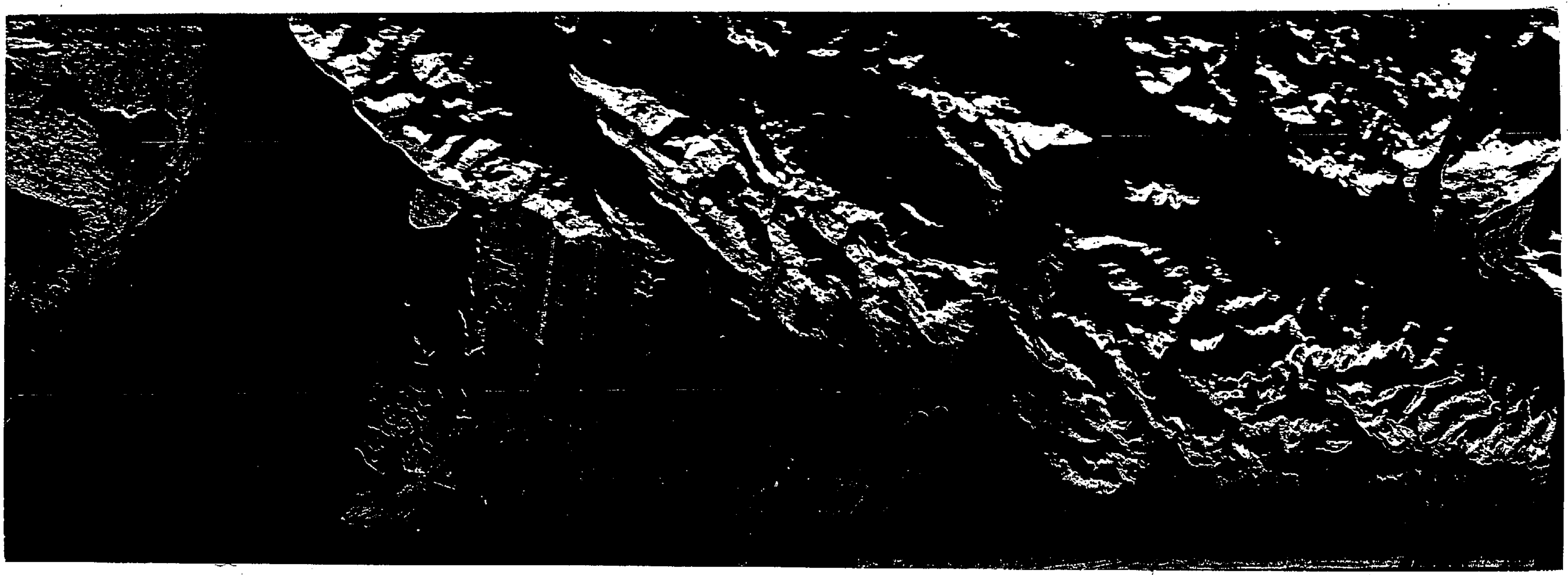

Figure 9. Radar imagery of the Yakutat District taken at the scale of 1:500,000. Compare this imagery with Map 1, Map 2, and Map 3.

Map 4 indicates the stability of the shoreline. Information obtained from low altitude aerial reconnaissance was added to the data to produce the indications of the direction of dominant longshore drift also shown on Map 4,

Map 5 shows the major beach materials along the Gulf of Alaska coastal plain. The information used to make this map was obtained from field work and low altitude aerial reconnaissance. If K-band, real aperture, radar imagery had been obtained instead of the X-band imagery, the beach materials could have been resolved from the radar imagery.

Map 1 exhibits 14 different units which are explained in Table 5. The map unit called Outburst Flood Deposits was the most unexpected feature mapped. This is an area radial to Harlequin Lake which has been crossed by an outburst flood of enormous extent, apparently within the last three or four hundred years. The freshness of the flood features and age of the vegetation indicates this time frame. The units of Map 1 can be located easily on the radar imagery of Figures 4 through 9.

Map 2 has five units which are explained on the map. The map unit which indicates areas where large rip currents are generated during storms was determined by observations made from radar imagery taken during storms and from low altitude aerial reconnaissance flights flown during storms. Map 2 should be the most useful of the five maps because it indicates the most severe hazards that should be considered in the development of the area. Map 2 should be used with Map 1 and Map 3 in order to fully understand the hazards indicated" on Map 2.

Map 3 was an unexpected result of this investigation. Several large lineaments were detected on the radar imagery (see Figs. 7 and 9), which extend completely across the coastal plain of the Yakutat District, These lineaments were discovered to be the traces of active faults which have been offset vertically as much as 2,5 meters within the last 80 years. The activity of these faults has been well documented (Tarr and Martin, 1912). An account of continuous and severe tectonic activity in the nearby Lituya Bay area over a period of 125-years (Mill1960) provides conclusive evidence as to the structural instability of the region.

Similar lineaments were mapped in the Malaspina and Yakataga Districts. The outstanding result of this mapping was the location of the lineaments which cross the Malaspina ice mass. The radar imagery used to locate the lineaments across the ice mass is shown in Figures 5 and 6. It appears that vertical tectonic movement along the lineaments is reflected in the overlying ice mass. This is of environmental importance because vertical movement of the ice mass influences the rate of ablation. The detection and location of the lineaments across the Malaspina ice mass is unique and can be done only by using the radar imagery.

VII. Conclusions

Landforms are the products of the manner in which the energy of geomorphic agents (such as wind, water, and ice) is expended upon terrestrial materials. Since geomorphic agents interact to various degrees at or near Earth's surface, a variety of landforms can be generated in almost any locality. Landforms are, therefore, a record of the geomorphic agents which have dominated or are presently dominating the patterns of energy interchange at some point on the Earth.

The assemblage of landforms and the geomorphic processes which are effected as a result of the creation of the assemblage forms that which is termed the environment of a particular area on the Earthrs surface. The identification of a landform or of an assemblage of landforms provides information about the environment which can be used to evaluate the natural history of the environment and to appraise the impact of induced changes.

The natural environments of Alaska contain or cover natural resources of food, wildlife and energy. The natural environments of Alaska are currently of economic importance from all aspects. Therefore, landforms which are studied in order to evaluate the natural environments and to appraise the impact of changes in the environment are termed "critical landforms". This is done so as to emphasize their relationship to situations currently of economic importance.

Environmental geologic data must be displayed in spatial format if a realistic evaluation is to be made of an area. If changes are induced, natural environments respond in all dimensions. Therefore, components of natural environments must be displayed in a spatial framework which portrays their degree of physical association. This makes it necessary to display environmental information on maps, because point values cannot convey a complete indication of the degree of interface between components.

Sequential information is needed if rates and magnitudes of change are to be included in an environmental evaluation. This demand of sequential observations makes it necessary that the most neoterical data be obtained of the area of investigation. In Alaska there are three major problems in obtaining sequential and neoterical data: inclement weather, winter darkness and inaccessible terrain, Therefore, the choice of a data source was partly influenced by the information listed in Table 3 on acquisition conditions,

Radar imagery is an adequate tool to use in the environmental evaluations of diverse types of coasts. There are three important factors to keep in mind when acquiring radar imagery of coasts. One, the look-direction should be towards the landward side of the coast away from the water. Two, the altitude of acquisition should be low in order to maximize the return of radar energy. Three, the depression angles should be small so that the important low relief features of coasts can be enhanced. The amount of information displayed on radar imagery is related to the wavelength of the radar energy used. Usually the greatest amount of information can be obtained with the shorter wavelengths. In mapping large regions, radar imagery would be less expensive than photographic coverage of the same area, and it would take less time to map "from radar imagery than it would from low- or intermediate-altitude aerial photographs. Aerial photographs must be viewed stereoscopically in order to observe what can be seen with the unaided eye on radar imagery, hence the difference in map compilation time.

X-band, real aperture radar imagery of the Gulf of Alaska coastal plain is adequate both as a mapping base and as a source of important environmental geologic data. It is essential to an environmental assessment of an area that information be as current as possible. In some areas the most current data can be acquired only with the use of radar imagery. The radar imagery of the Gulf of Alaska coastal plain indicates that severe environmental geologic hazards, such as earthquakes, surface movements along active faults, and outburst floods, have occurred recently and will continue to occur with a relatively high frequency.

Analysis of the geomorphic features of the coastal plain indicates that the seaward portion of the Yakutat District is comprised of sediments from the Alsek River. The continued existence of the area depends upon a continual supply of sediments from the Alsek River.

Natural processes are modifying parts of the coastal plain at a relatively rapid rate. These processes include the formation of large lakes by glacial ablation and the erosion of headlands due to changes in the sediment supply from glaciers. It is necessary to emphasize that the changes are natural and not the result of man's activities. In an area like the Gulf of Alaska, radar imagery is the only tool which can be used to adequately monitor the results of natural processes.

Radar imagery is being used successfully to map landforms in Alaska. It provides necessary neoteric data in spite of adverse weather conditions and the darkness of the Arctic winter. Radar imagery can provide information about glacial ice masses that cannot be obtained by any other remote sensing technique at present. It has been employed as a reconnaissance tool for some time, now radar imagery is being used as a mapping tool.

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TABLE 5

EXPLANATION OF MAP UNITS

(These units are shown on Map 1, Major Landforms of the Gulf of Alaska Coastal Plain)

Mo" Moraines of Old"Glaciers
Abandoned moraines of retreated glaciers which contain little or no ice. These areas support good stands of native timber and contain numerous lakes.

OF Outburst Flood Deposits
An area radial to Harlequin Lake which was crossed by an outburst flood of enormous extent, apparently within the last three or four hundred years. This could have been caused by a *surge* of the Yakatat Glacier and there are no indications that it could not happen again.

"Owd Outwash, well drained
Areas of higher, better drained, outwash on the Yakutat Foreland. These areas contain no ice and support good stands of native timber. The outwash is from retreated glaciers. These areas are the most stable and the most desirable of the region.

Opd Outwash, poorly drained
Extensive swampy, areas on the Yakutat Foreland which were formed of outwash from retreated glaciers.

A Alluvial materials
Areas where materials are in active transport by high runoff from streams. These areas *are* the most frequently flooded during storms.

OA Outwash and Alluvial materials
Areas where meltwater is or has created broad flats. These areas are also reworked by streams discharge but are not flooded with the frequent storms like the areas indicated as Alluvial materials.

Mp Moraines of Present Glaciers
Moraines marginal to the Malaspina ice mass which contains large amounts of ice. The ice is melting rapidly and new lakes are continually being formed. This terrain is chaotic and unstable.

HB1 High Beach series, 'oldest
The oldest, highest, and most discontinuous series of abandoned beaches on the Yakutat and Yakataga Forelands. The well drained soils support good stands of native timber.

TABLE 5 (Cont'd)

HB2 High Beach' series, 'intermediate
The discontinuous series of abandoned beaches on the Yakutat and Yakataga Forelands which physically lies between the uppermost and the lowest high beach series. This is a very distinctive series of beaches exhibited on the SLAR. The well drained soils support good stands of native timber.

HB3 High Beach series; 'youngest
The lowest and most continuous deposits of the High Beach series. The upper limit is marked by the gold bearing black sands of the Yakutat Foreland. In most areas this series of abandoned beach lines support good stands of native timber.

LB Lower Beach
The most unstable beach materials, which are in active transit along the shore. The materials are directly derived from the discharge of streams and outwash. These areas suffer minor changes daily and major changes during storms.

TF Tidal Flat, extensive
Extensive, low beach, materials on the Yakutat Foreland which are inundated with sea water during high flood tides and storms.

br Bedrock
Indicates some of the more important bedrock exposures in the area.

TK Thermokarst Terrain
Area on the margin of the Malaspina Ice Mass where the most active melting is occurring. The area is pitted with collapse features.

MAJOR LANDFORMS OF THE GULF OF ALASKA COASTAL PLAIN DETERMINED FROM X-BAND, REAL APERTURE, SLAR

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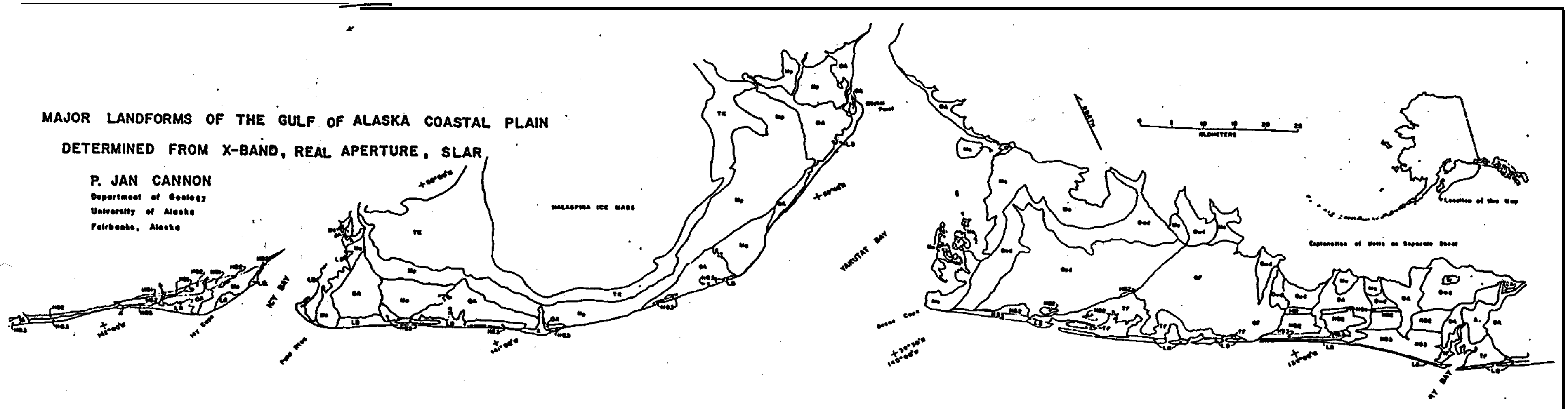

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