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IDENTIFICATION OF GEOSTRUCTURES OF THE CONTINENTAL CRUST PARTICULARLY AS THEY RELATE TO MINERAL RESOURCE EVALUATION

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16. Abstract ERTS Investigation SR 180 was undertaken to test the effectiveness of ERTS data in improving existing and developing new concepts of geologic history and mineral resource potential, and in enhancing medium- and small-scale geologic mapping in Alaska. Positive results were obtained in both categories as well as in application of ERTS to monitoring of environmental change due to resource exploitation. Results include recognition of a pattern of very old, possibly crustal, geostructures in Alaska, and throughout the northern Cordillera as well; development of a new metallogenic hypothesis that provides an additional mineral exploration guide for Alaska; recognition of possible buried structures in northern Alaska that may have potential for oil and/or gas accumulation; and use of ERTS images in field study and office compilation of medium- and small-scale geologic maps of numerous areas in Alaska.

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SUMMARY

Objectives

The objectives of this investigation were:

1. To improve existing regional analyses and develop new regional analyses and concepts of geologic history and mineral resource potential employing the unique capability of ERTS images to portray regional relations of fundamental geologic structures, and to depict features and relations whose regional extent is too large to be recognized in conventional field or aerial photographic study.

2. To enhance medium- and small-scale geologic mapping through the synoptic and orthographic view of structural relations afforded by ERTS images and through detection of lithologic differences by ERTS multi-band sensing, and to extend geologic mapping into unmapped areas using these characteristics.

Scope of work

This is an unfunded investigation; ERTS data were supplied by NASA, and investigations were funded by Interior Department. The work performed involved two levels of study, commensurate with the two objectives set out above. Analysis of ERTS images of the entire state of Alaska (586,000 mi^2) to determine the regional pattern of geostructures, and of selected areas to determine more local variations was performed by the Principal Investigator, E. H. Lathram, assisted in the last few months by N. R. Albert. Analysis of the relation of subsurface geology to the linear pattern, and evaluation of mineral resource significance were part of these studies. At a less regional level, various geologists of the Alaskan Branch of the Geological Survey, among them I. L. Tailleur, W. W. Patton, Jr., E. M. MacKevett, R. L. Detterman, W. P. Brosgé, H. N. Reiser, Béla Csejtey, G. D. Eberlein, George Plafker, H. C. Berg, D. A. Brew, J. G. Smith, B. L. Reed, D. H. Richter, and R. M. Chapman, used individual images at scales up to 1:250,000 to plan field geologic investigations, to extrapolate observations into unmapped areas and record data in the field, and to compile geologic maps and study the geology of problem areas in the office. These efforts were designed to enhance medium- and small-scale geologic mapping.

In addition, the Principal Investigator employed the results of the investigation in numerous public talks and discussions both in the U.S. and abroad, as examples of remote sensing methods in resource and environmental management.

Conclusions

The results of the investigation demonstrate conclusively the practical application of ERTS data to the study of the geology of Alaska, and to the analysis of its mineral resource potential. Significant results are:

1. Recognition of a pattern of very old geostructures that may reflect structures in the crust, a pattern that is not peculiar to Alaska, but can be recognized throughout the northern Cordillera..

2. Development of a new metallogenic hypothesis for Alaska, based on the relationship of space image linears to known mineral deposits, that will provide an additional guide to those exploring for new sources of minerals.

3. Recognition, by analysis of image linears, of regional geologic features that may guide in the location of hitherto undiscovered oil and/or gas accumulations in northern Alaska.

4. Demonstration of the effectiveness of ERTS data in enhancing medium- and small-scale mapping.

5. Demonstration of the use of ERTS data in recognizing and monitoring the state of large-scale vehicular scars on Arctic tundra.

Recommendations

ERTS data, now in operational use by many geologists and companies involved in mineral resource exploration, should be made a routine tool of investigation by all geologists. In addition, concerted effort should be made by geologists versed in the regional geology of large areas of North America, individually or as teams, to analyse the giant linears and circular features visible on ERTS images, to determine their significance in terms of the fundamental geologic structure of the continental mass, and to apply this knowledge in developing concepts of the origin of continents that will render more universal the newly developing ideas of the formation and deformation of the earth as a whole.

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FINAL REPORT OF INVESTIGATIONS

In line with the objectives of the investigation, results are reported in terms of their significance to (A) tectonic and mineral resource studies, and (B) enhancement of geologic mapping. A third category, that of significance in environmental monitoring, arose serendipitously, and is reported under (C) environmental analysis of vehicular scars to the Arctic tundra. Category A is best summarized in a paper presented to the 1st International Conference on the New Basement Tectonics at Salt Lake City, Utah, June, 1974 (Lathram and Albert, in press); consequently that paper is largely reproduced here. Category C is best expressed in a paper presented at the Third Earth Resources Technology Satellite-1 Symposium at Washington, D.C., December, 1973 (Lathram, 1973), and is largely reproduced here.

A. TECTONIC AND MINERAL RESOURCE SIGNIFICANCE OF SPACE IMAGE LINEARS

INTRODUCTION

This study of space image linears in Alaska, an area of over 1.5 million km^2 (586,000 mi^2), was focused on the evaluation of the significance of these linears in regional analyses of mineral resource potential and tectonic history. Emphasis was placed on the identification of regional linears and lineated areas and the qualitative comparison of these with geologic and geophysical data, rather than on the quantitative analysis of linear populations. Because of the regional emphasis, and the abundance in Alaska of linears whose length exceeds the dimensions of a single ERTS-1 image, much of the interpretation was made on the Soil Conservation Service ERTS-1 mosaic of Alaska (scale 1:1,000,000), supplemented by mosaics of smaller areas made by the University of Alaska and by this project, single Nimbus IV images and individual ERTS-1 images.

Results of the study encompass a survey of linears affecting the shape and orientation of lakes in the lowland lake areas north of latitude 64°, analyses of the relationship between linears and subsurface geology and geophysics in the Umiat area and in the area of the Yukon-Tanana Upland (fig. 1), and a preliminary recognition of the pattern of giant linears in Alaska. These data suggest that the linears are significant in evaluating mineral resource potential and in analysing the tectonic history of Alaska and possibly of other areas within the northern Cordillera.
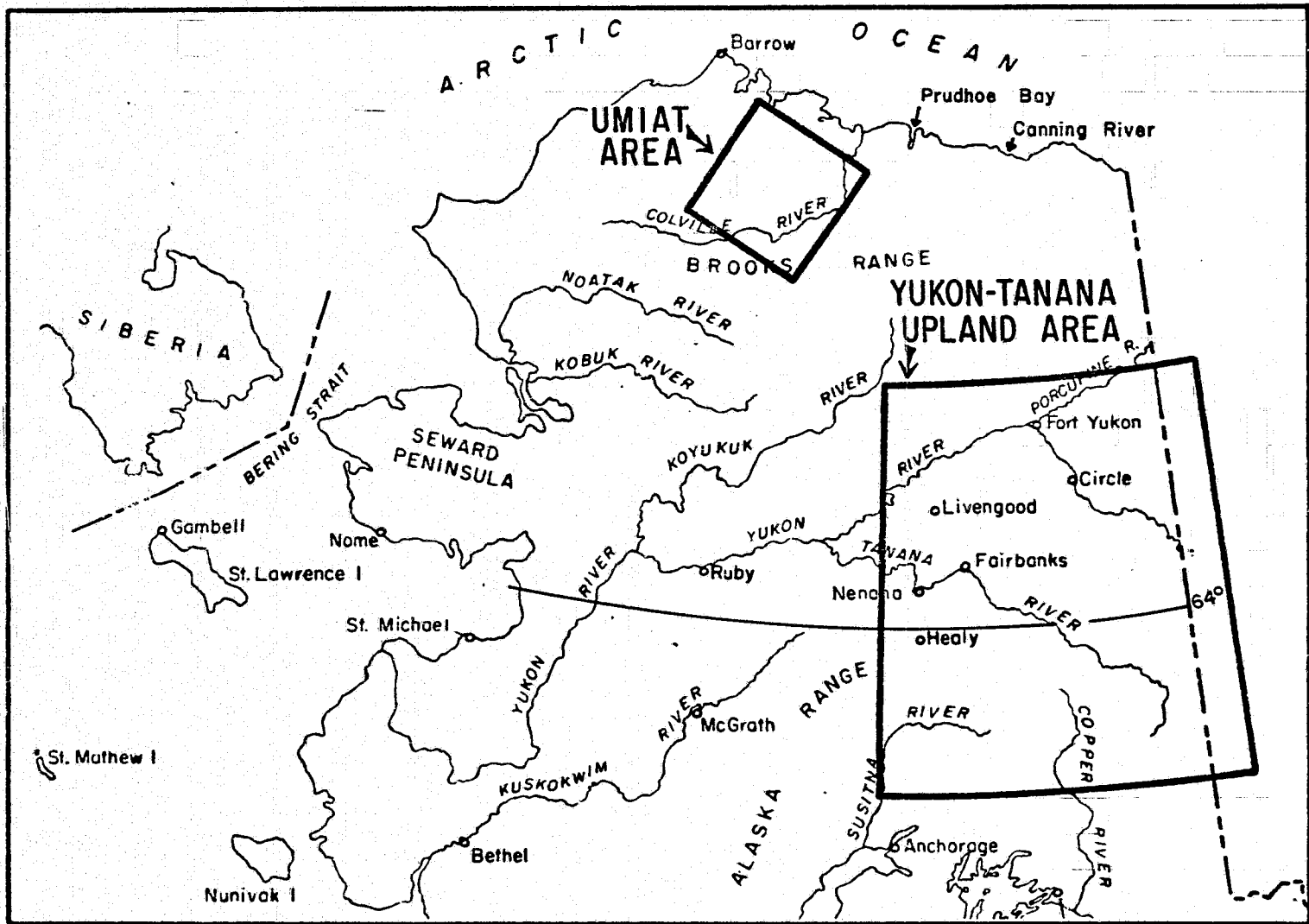
Figure 1. Index map of northern and central Alaska showing location of areas of study.

Much discussion in the remote sensing field has focused on the need for a uniform classification of linears. Suggestions have included classifications based on supposed origin, type of expression and size of the linears. From the experience gained in this study, short linears commonly reflect a single geomorphic, vegetational or soil characteristic, and on field examination, may be ascribed to a single geologic cause, i.e., fault, fold, joint, bedding plane, etc. Longer linears, however, and particularly those that extend for hundreds of kilometers, commonly are expressed by a number of surface features. In addition, a part of the trace of a long linear may coincide with one type of exposed geologic feature, whereas another part may coincide with a different type of geologic feature, yet neither feature may correspond to the fundamental geologic cause in the underlying rock materials.

If a classification is adopted, one based on the length of the linear would be most practical and least restrictive. For example, most of the linears recognized in this study can be classed generally into three groups according to size--10 to about 200 km, about 200 to 1000 km, and >1000 km. A useful classification could be one based on the concepts expressed by Gold and others (1974, Table 1). Construction of a rigorous classification scheme at this stage in Alaskan studies seems unwise. Consequently, in this report the term linear will be used without implication as to origin or type of expression, with qualifiers, such as short, long or intermediate, and giant, to express the size grouping.

LINEAR PATTERN IN LOWLAND LAKE AREAS

A qualitative analysis of the trend of rectilinear shores of lakes and of other linear features associated with lakes in lowland areas of central and northern Alaska as seen on ERTS images revealed a relatively consistent pattern of north, northwest, northeast and east trends (fig. 2). Although no single trend is dominant in all areas, and some of the trends vary slightly from area to area, a plot of the total number of linears versus azimuth shows a dominant set with characteristic strikes of 165° and 65° (fig. 3D).

In northern Alaska, numerous workers have recognized a dominant N. 9° W. elongation of lakes; they concur that the elongation is due to erosion at right angles to the prevailing wind direction (Black, 1969). Detailed study of ERTS-1 images reveals that the dominant northerly trend is generally limited to the area west of the Ikpikpuk River (approximately 155° W.). To the east of the river, an easterly linear trend in the lake area is dominant (Lathram, in press). The areal restriction in dominance of the northerly elongation suggests that although the prevailing wind direction may have been a contributing factor, it was not the primary determinant of the northerly elongation. This conclusion is substantiated by the apparent structural control of the easterly linear trend in the Umiat area (see below) and the variation in prominence of the northerly elongation of lakes in other parts of northern and central Alaska, where the wind direction is similar.

3
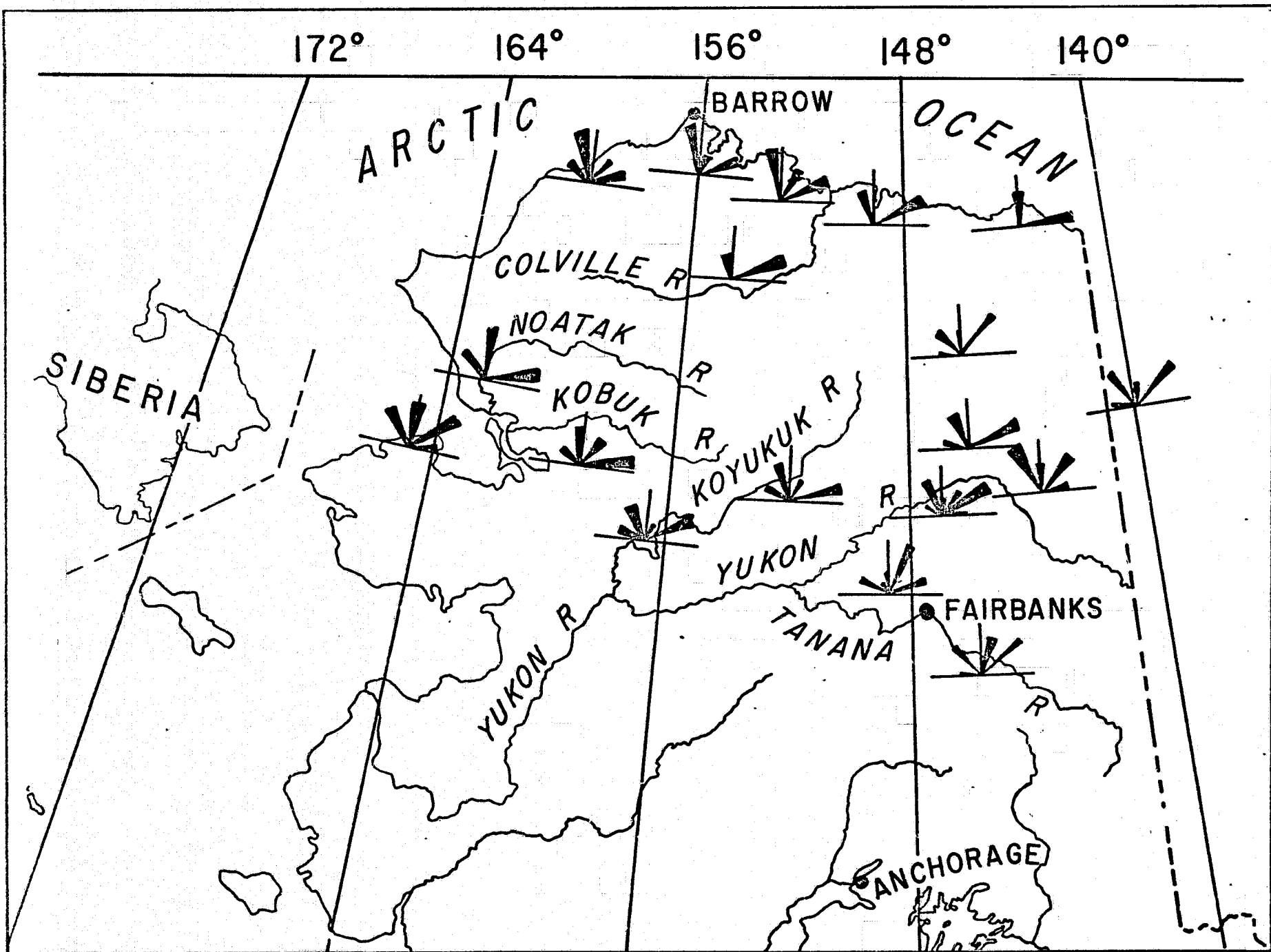
Figure 2. Map qualitatively showing linear trends in shape and alinement
of lakes in northern and central Alaska.

GIANT LINEARS OF ALASKA

A

90 110 130 150 170 10 30 50 70 90
W   E

LINEARS >100 MI. IN YUKON-TANANA
AREA

B

90 110 130 150 170 10 30 50 70 90
W   E

LINEARS <100 MI. IN YUKON-TANANA AREA

C

90 110 130 150 170 10 30 50 70 90
W   E

LINEAR TRENDS OF LAKES NORTH OF 64°

D

90 110 130 150 170 10 30 50 70 90
W   E
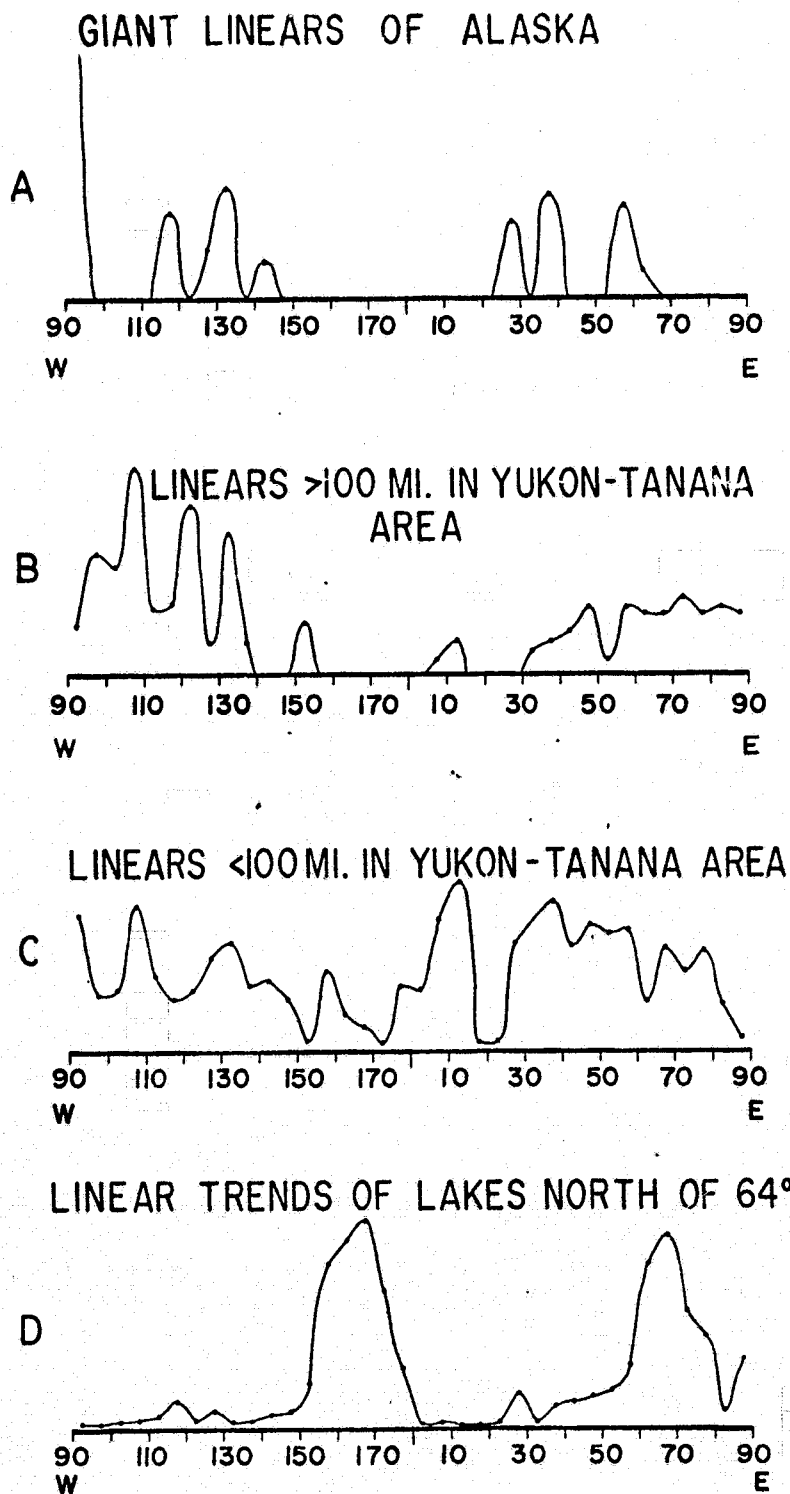
Figure 3. Cartesian histograms showing trends of selected
groups of linears in Alaska. A,B,C are trend
versus length of linears, D is trend versus number.

Along the northern margin of Seward Peninsula, northeasterly oriented linears are dominant and trend more northerly than in other areas. These linears parallel the northwestern shore of the peninsula, a constructional shoreline forming an acute angle with the probable basement margin of a Tertiary basin in the Chukchi Sea (Grantz et al., 1970). The present orientation of the Seward Peninsula shoreline may only reflect the direction of wind and ice movements north of Bering Straits.

Along the southern flank of the Brooks Range, dominant east-trending linears probably reflect the easterly trends of Paleozoic facies lines (Brosgé and Tailleur, 1971; Lathram, 1973) and of structures in the deformed northern margin of the Yukon-Koyukuk Mesozoic volcanic-sedimentary terrane (Patton, 1973).

Linears seen in the lowland lake areas surrounding the Yukon-Tanana Upland correlate well with the major linears observed in the Upland (see below), suggesting that control of oriented lake development in this area is primarily due to subsurface geologic features similar to those controlling linear development in the Upland itself.

LINEAR DOMAIN IN THE UMIAT AREA

The Arctic Coastal Plain of Alaska is developed on a nearly flatlying mantle of Quaternary Gubik formation, which overlies a thick Cretaceous molasse basin. This basin is bordered on the north, around Barrow, by a basement of middle Paleozoic and older rocks, and on the south by a complex of thrust faulted late Paleozoic and early Mesozoic orogenic sediments comprising the Southern Foothills of the Brooks Range. The Brooks Range itself, to the south, is composed of north-transported imbricate thrust plates of Paleozoic strata. Because of extensive petroleum exploration in northern Alaska, geologic and geophysical data are commonly adequate to compare the linears with subsurface conditions.

Previously unrecognized regional linears in the Arctic Coastal Plain north of Umiat, Alaska, trending about N. 78° E., are clearly shown on ERTS-1 image 1004-21395 (Fischer and Lathram, 1973; fig. 4).

The linears are expressed as: (1) straight nearly east-trending alinements of small lakes, of distortions in the shorelines of larger lakes, and of linear areas between groups of lakes; and (2) curvilinear alinements of small lakes, locally enclosing large elliptical areas.

Although the alignment of some lakes, particularly those at the southern margin of the plain near the Colville River (fig. 5) may be due to shoreline features left by the northward-regressing Gubik sea, general control by old shoreline features does not explain the regional extent of the straight linears, nor the elliptical form of some curved linears. Study of geological and geophysical evidence suggests control by subsurface structure as follows:

6

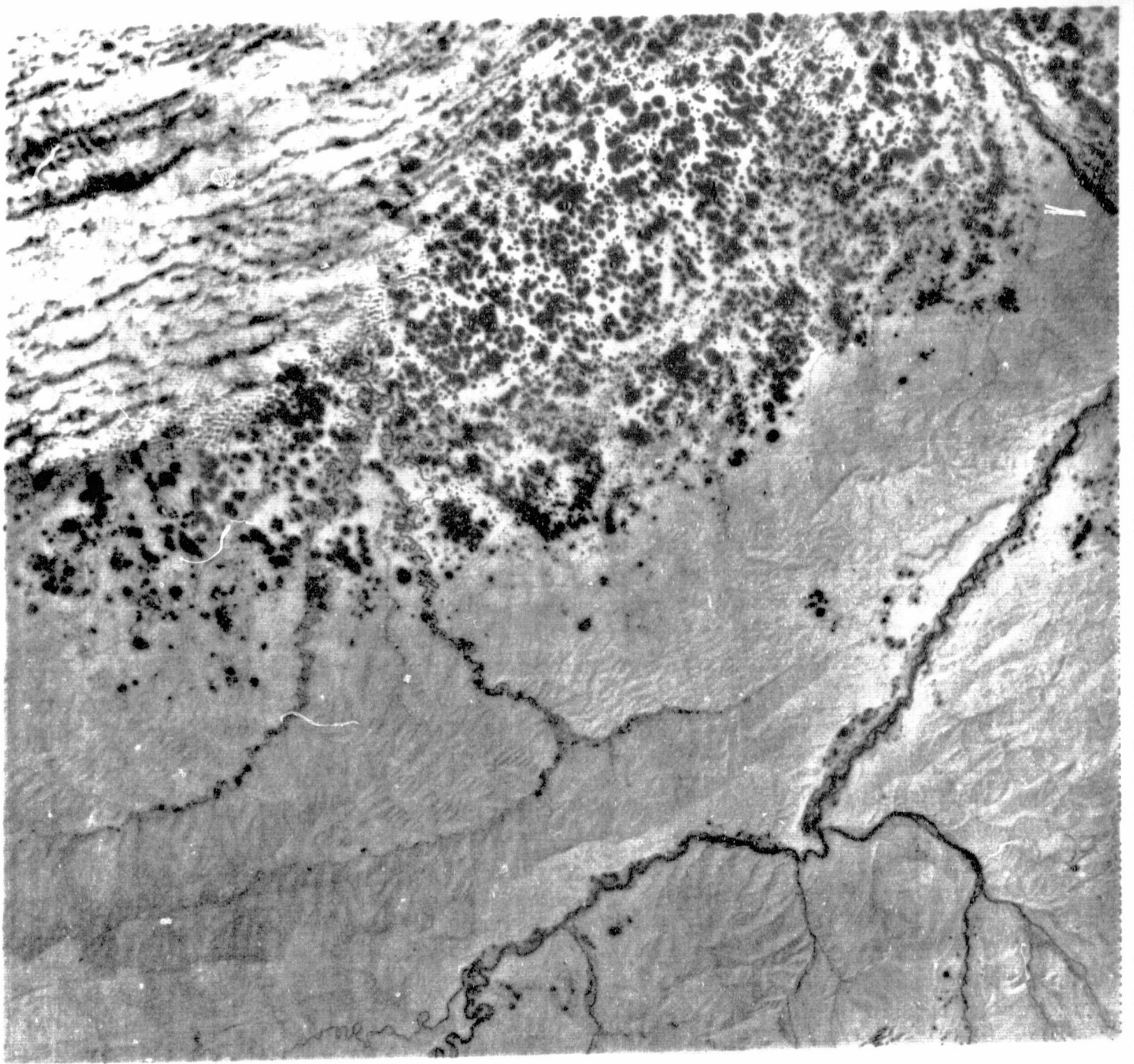Figure 4.   ERTS image (1004-21395) of Umiat area, band 7.
Lakes are in black.
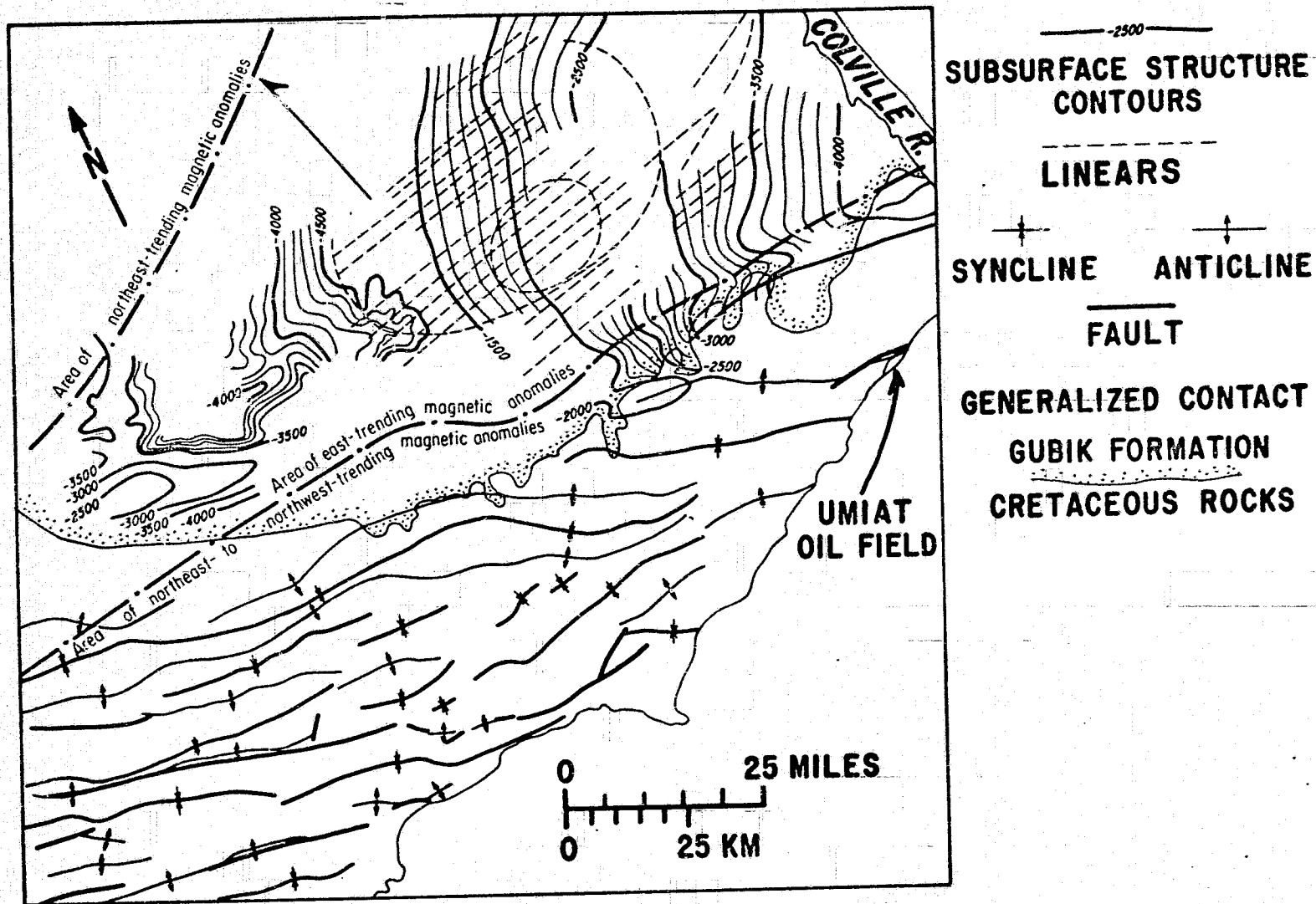
Figure 5. Map showing geologic features in the Umiat area.

1. The axial trend of most folds that extend to or near the boundary between foothills and plain (approximately the southern boundary of the Gubik formation) changes from northwest to a trend that is parallel, or nearly parallel, to the trend of the straight linears (fig. 5).

2. Seismic-reflection data, sparse in the area of linears, suggests a smooth easterly dip, and detailed contours of the western area show numerous small reversals superimposed on the regional dip (fig. 5; Woolson and others, 1962). Most of the seismic data are confined to the upper 1200 to 1800 m (4000 to 6000 ft) of strata.

3. A contour map of magnetic intensity from Woolson and others (1962, plate 3) shows three areas of magnetic anomalies with differing trends (fig. 6). In areas "A" and "C", anomalies trend variously north-west, north and northeast. In area "B", anomalies trend nearly east, parallel to the trend of the straight linears. The longer elliptical linears seem to define an area bounded by local magnetic highs on all but the northeastern portion of area "B's" perimeter.

4. Deflections in contours of an observed gravity map (Woolson and others, 1962, plate 2) in area "B" also trend parallel to the straight linears (fig. 7). The suggested line separating areas "A" and "B" on the magnetic contour map, figure 5, generally lies along deflections in gravity contours or alinements of gravity lows. The area described by the longer elliptical linear coincides with a local terrace in a regional gravity high. The terrace itself is elongated in a direction parallel to the straight linears.

The lineated area is bounded on the south by the foothills, on the west by the Ikpikpuk River, and on the north by a line trending east along the southern shore of Teshekpuk Lake (fig. 6) nearly coinciding with the boundary between aeromagnetic anomaly areas "B" and "C" as shown by Brosge and Tailleur (1971) in this area. East of the Colville River, the area of east-trending linears extends to the Canning River (see fig. 1).

The parallelism of deflections in trends of known folds, of alinement of magnetic anomalies, of deflections in gravity contours, and of the trend of the linears, coupled with seismic data suggesting dip reversals in shallow strata, and the coincidence between areas of linears and of distinctive aeromagnetic anomalies, all suggest that the linears represent concealed geologic structures.

The nature of these structures is difficult to assess, as the geologic and seismic data are confined to the upper 1200 to 1800 m (4000 to 6000 ft) of strata, whereas the gravity and magnetic data probably reflect basement character and morphology, at depths ranging from 4600 to 6100 m (15,000 to 20,000 ft) in this area. The pattern of linears and of local seismic re-flectors and regional seismic contours suggests minor regionally linear crenulations superimposed on a broad gentle dome, or the nose of a broad

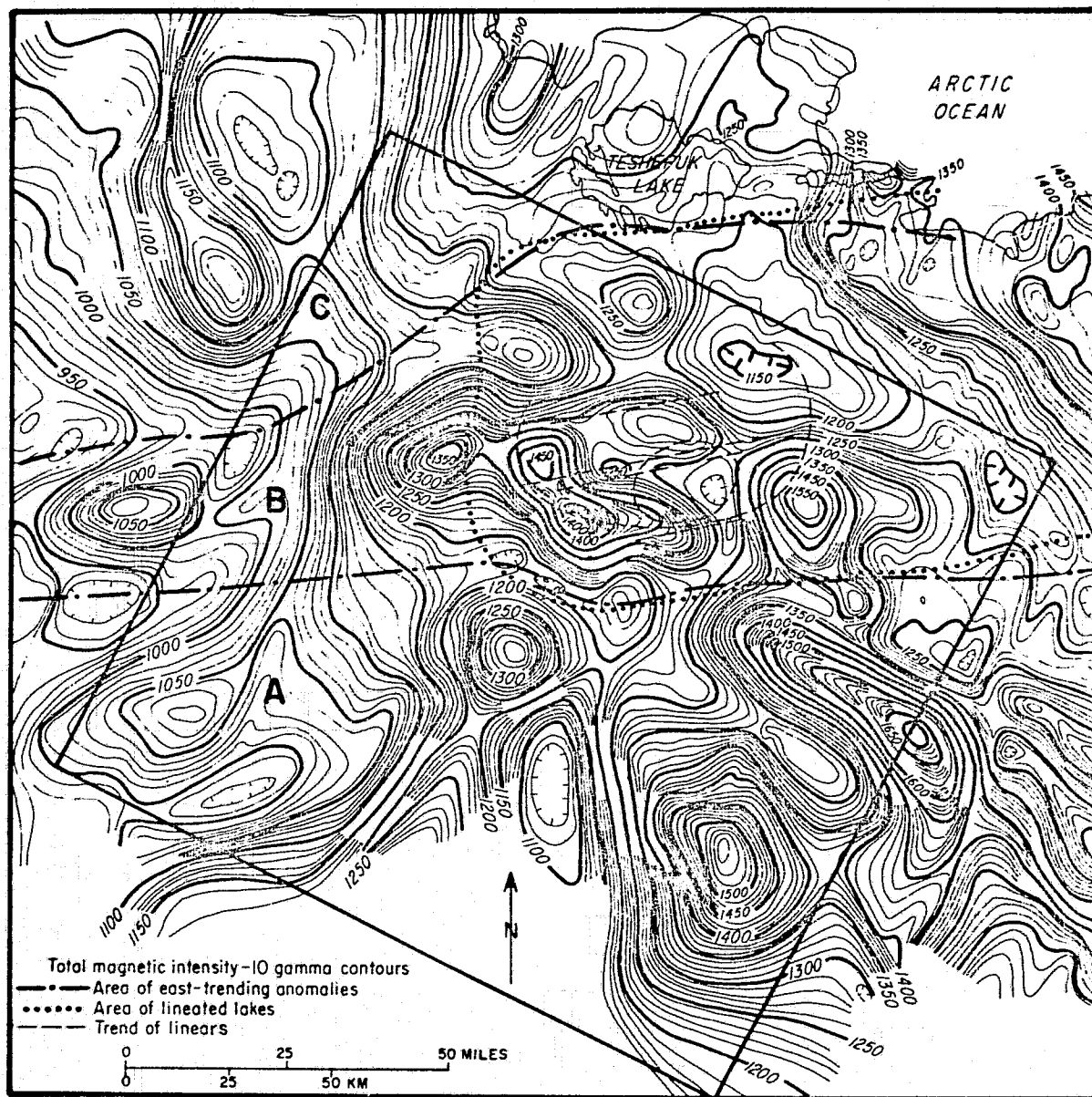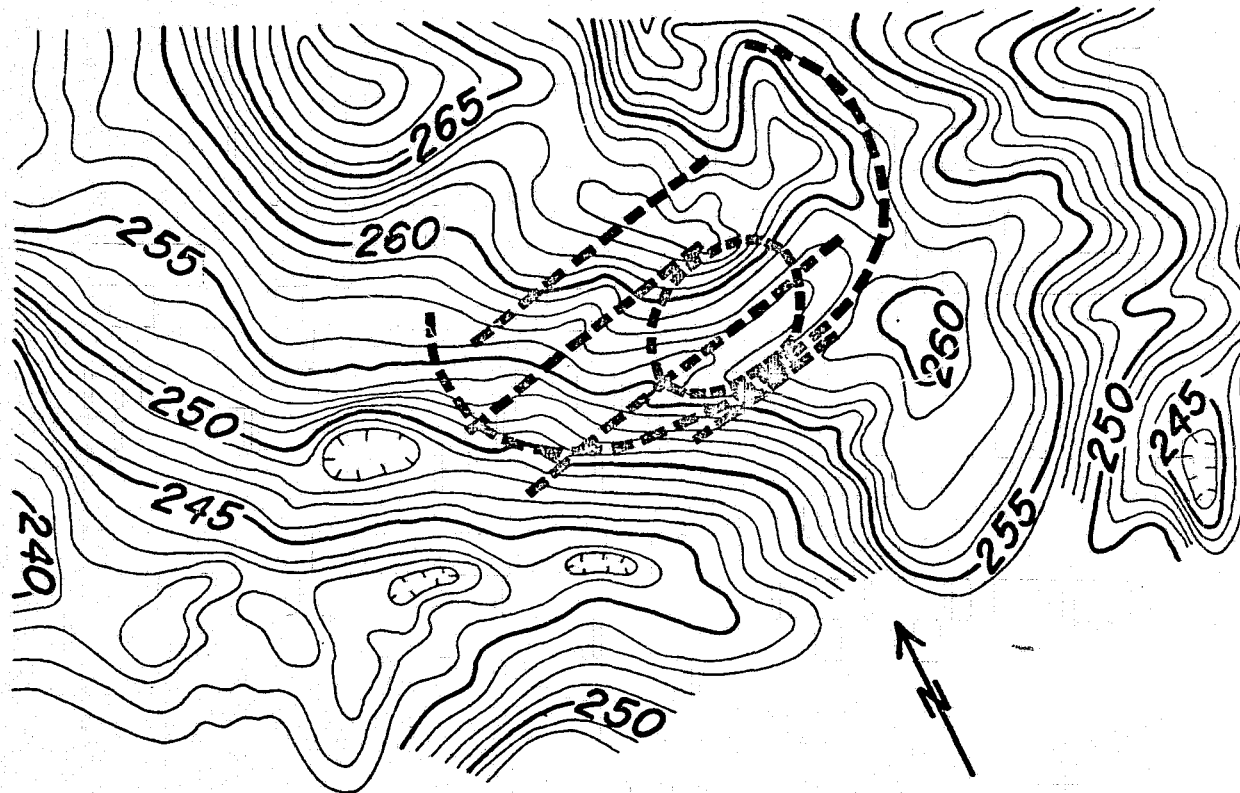Figure 6. Map showing total magnetic intensity in the
          Umiat area (after Woolson and others, 1962),
          area covered by ERTS image, area of east-
          trending anomalies and liniated area.

OBSERVED GRAVITY — *1 MGAL CONTOUR*

LINEARS ▬ ▬ ▬ ▬ ▬ ▬

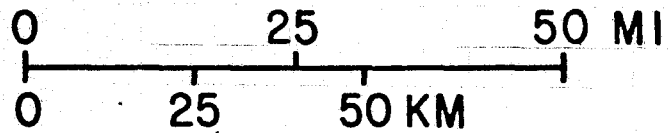0   25   50 MI

0   25   50 KM

Figure 7. Map showing observed gravity in the Umiat area (after Woolson and others, 1962)

anticline. The apparent relationship of both straight and curved linears to gravity and magnetic features, and of the total area of linears to an area of distinctive aeromagnetic anomalies, suggests that these geologic structures reflect the character of the basement.

Folds in the foothills to the south are known to be underlain by one or more decollement surfaces, and therefore surface structures in that area cannot be considered indicative of structure at depth. However, the structures in the Arctic Coastal Plain lie north of the probable maximum northern extent of decollement surfaces (Brosgé and Tailleur, 1971) and could persist to great depths.

Brosgé and Tailleur also point out that folding stresses were continuous during Early and Late Cretaceous time, resulting in the continuous growth of folds involving beds of this age. Fold stresses have continued since then, into Quaternary time, as folded latest Cretaceous and Tertiary strata and warped glacial terraces indicate (R. L. Detterman, oral comm., 1972). It is reasonable to assume that the structures reflected by the linears may be folds that have grown continuously during and after deposition. They may, therefore, be accentuated at depth, and persist to basement.

The apparent coincidence in changes in both the magnetic and gravity fields along the line separating areas "A: and "B" (figs. 4 and 5) suggests a fundamental change in basement character and morphology, just as the linear, seismic, and geologic differences between foothills and plain suggest a fundamental change in the structural regimen in the overlying strata. The significance of the coincidence of the larger elliptical area and specific magnetic and gravity anomalies is unclear.

LINEAR DOMAIN IN YUKON-TANANA UPLAND AREA

The Yukon-Tanana Upland is a hilly and mountainous region about 77,700 km^2 (30,000 mi^2) in area which lies between the Yukon and Tanana Rivers. It is primarily a region of complexly deformed metamorphic rocks which have been intruded by Mesozoic batholiths and smaller Mesozoic and Tertiary plutons, bordered in the northwest by a sequence of sedimentary and metasedimentary rocks of Precambrian (or Cambrian) to Tertiary age along with felsic to mafic intrusive bodies.

The Upland is bounded on the south by the Tanana River, possibly the trace of a structural boundary. Metamorphic and granitic rocks similar to those in the Upland occur south of the Tanana River in the Alaska Range, and north of the Denali fault, which is believed to have experienced right-lateral movement in Tertiary time. The Upland is bounded on the north by the Tintina fault zone and the Yukon Flats. Like the Denali fault system, in most places in Alaska the Tintina separates metamorphic rocks from relatively unmetamorphosed rocks. Right-lateral movement of as much as 418 km (260 mi) along the Tintina fault zone has been postulated by Roddick (1967, p. 28). (Most of the above discussion was taken from Foster and others, 1973).

ERTS images of the Yukon-Tanana Upland clearly show a multiplicity of linears, many more than had been previously suspected, and of a more consistent and extensive pattern than previously recognized (fig. 8).

Linears in the Yukon-Tanana Upland and adjacent areas can be divided into two classes--regional linears over 160 kilometers in length (100 miles) (fig. 9), and short linears 160 kilometers or less in length (fig. 10). The trace of many of the regional linears is defined by a mixture of criteria, such as topographic alinements, drainage courses, and lines of tonal change and vegetal changes, whereas the shorter linears are dominantly indicated by straight drainage trends. A quantitative analysis of the linears was made (fig. 3B, C) in which the ordinate of the Cartesian diagram is equal to the combined lengths of all observed linears having that trend. The shorter linears show a more random distribution than the regional ones, but a gross pattern of similar orientations is suggested.

A contour map of the total magnetic intensity of the area (Brosge and others, 1970; Alaska Division of Geological Survey, 1971) was compiled to the same scale and projection as the ERTS mosaic and the regional linears, with north-trending shorter linears added, were superimposed (fig. 11). The correlation of the trends of regional linears to the trends of the magnetic anomalies is apparent. The following observations can be made:

1. Trends in both major linears and magnetic anomalies show strong preferred orientations in a northwest direction.

2. Many magnetic anomalies seem to owe their shape to combinations of north, northwest, northeast, and east trends.

3. Several major linears seem to separate areas having anomalies of differing trends, and several seem to cross anomalies formed of more than one trend, at or near the intersection of these trends.

4. A northerly trend is prominent in low magnetic anomalies, presumably reflecting the trend of concealed bodies largely composed of sediments. However, as the flight lines parallel this trend, differences in flight elevation may have enhanced the trend. The fact that northerly trending linears, although widespread, are limited in length to less than 160 km (100 miles) lends support to this possibility.

5. A significant alinement of magnetic lows trends about N. 35° W. from the Yukon River at the eastern margin of the area, and seems to occupy the position shown by such a linear (W on fig. 12) on the Nimbus image.
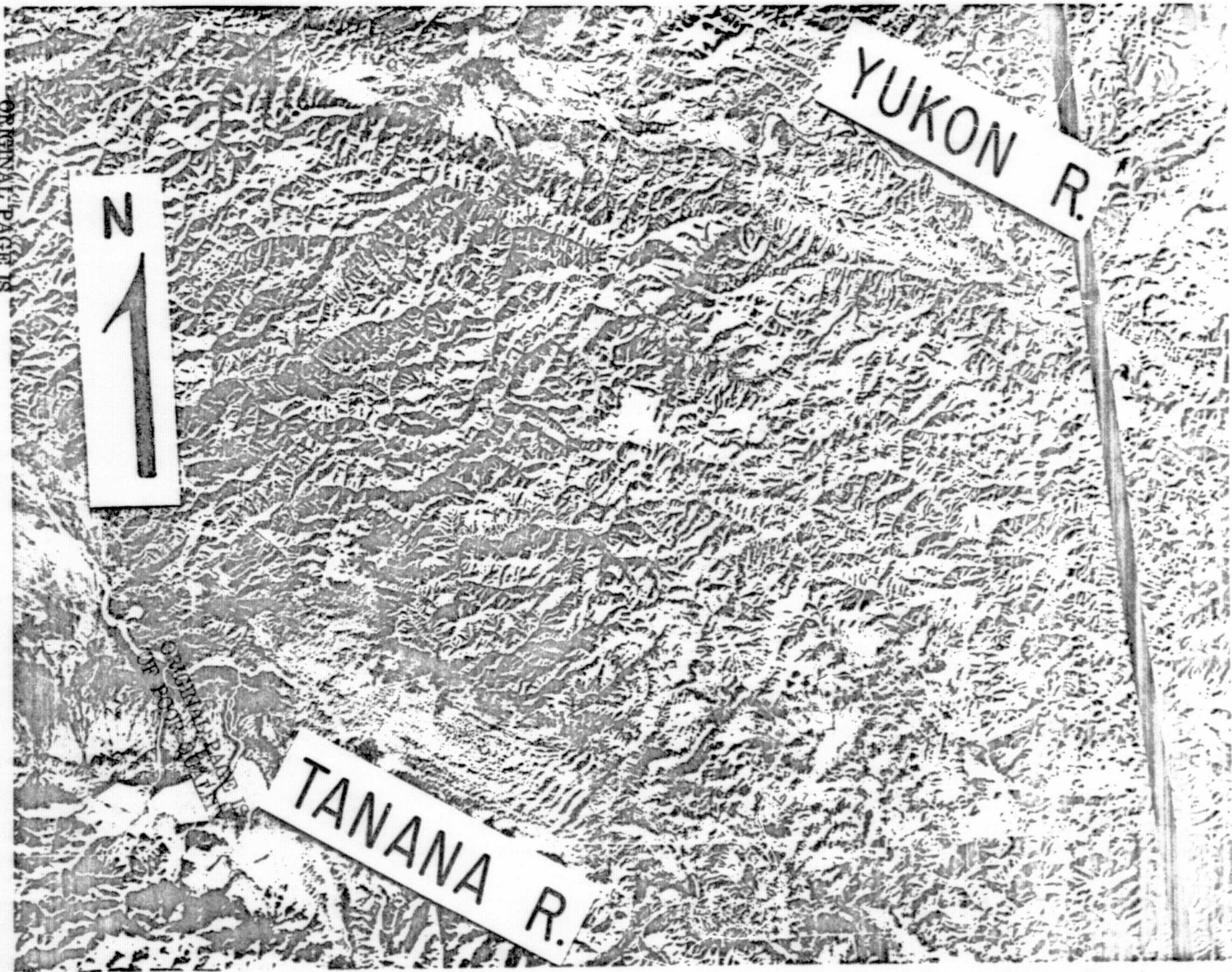
Figure 8. ERTS mosaic of Yukon-Tanana Upland area (Mosaic by U.S. Department of Agriculture).
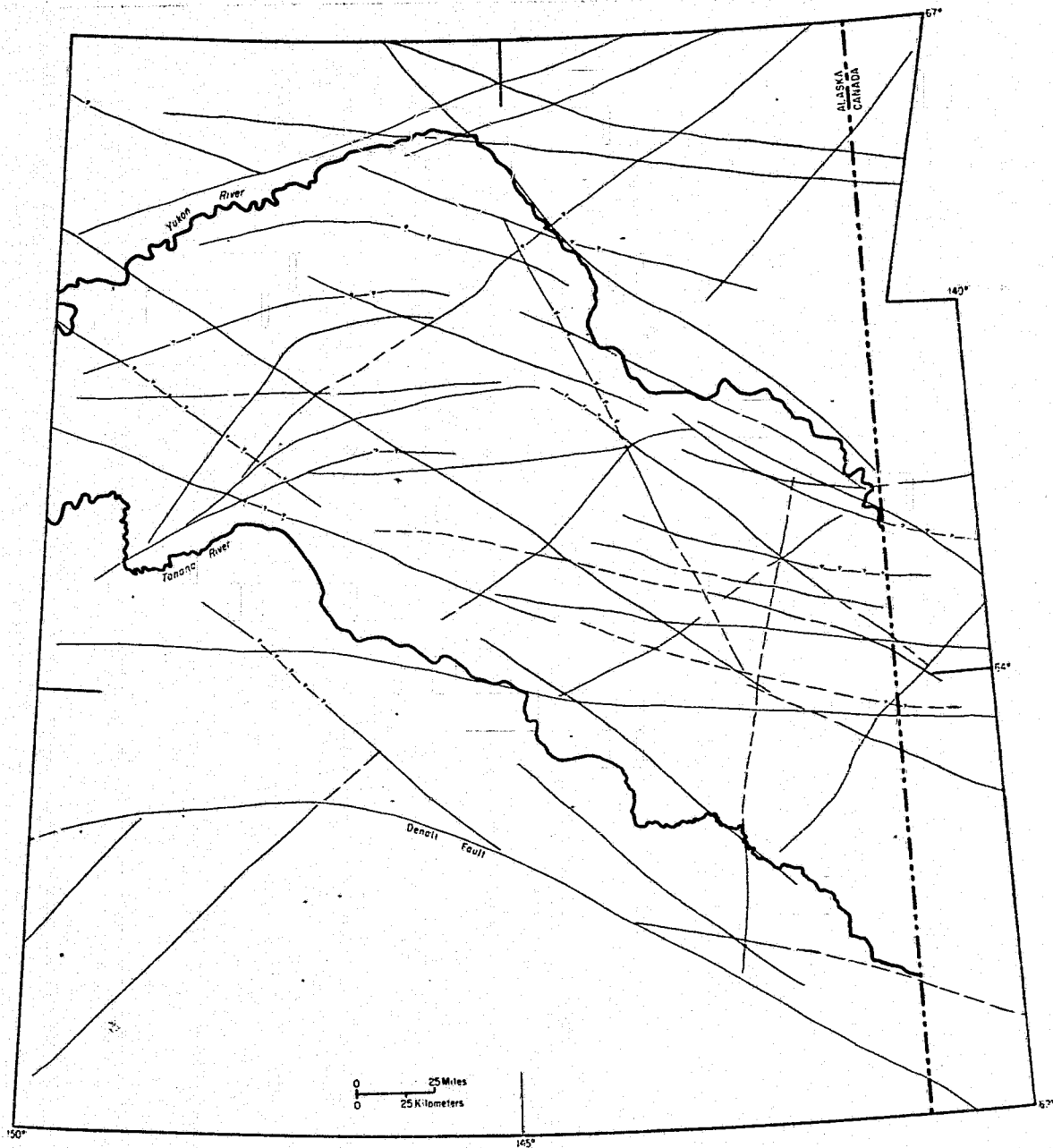
Figure 9. Map showing linears greater than 160 km (100 miles) in length in the
Yukon-Tanana Upland area.
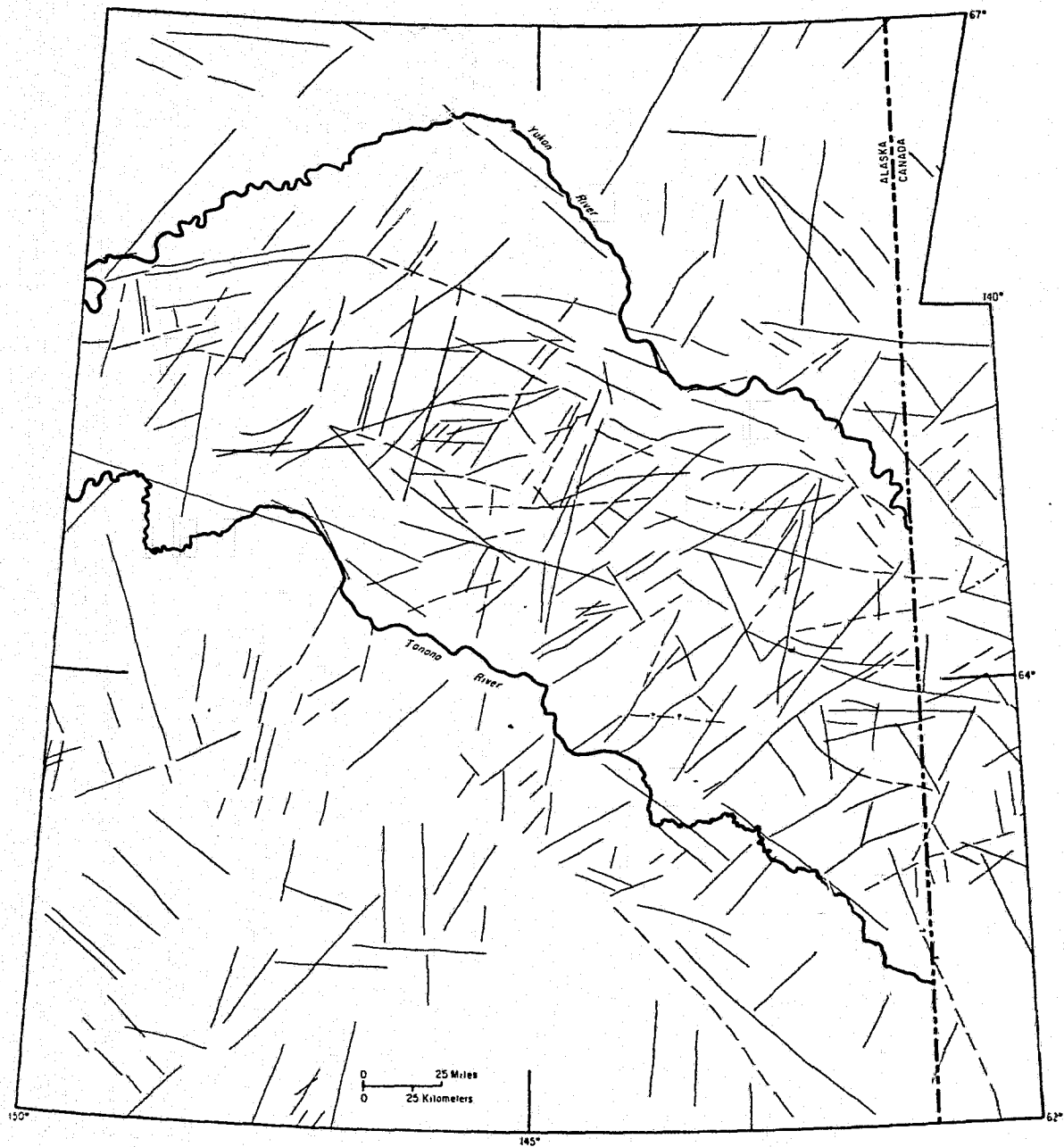
Figure 10. Map showing linears less than 160 km (100 miles) in length in the Yukon-Tanana Upland area.

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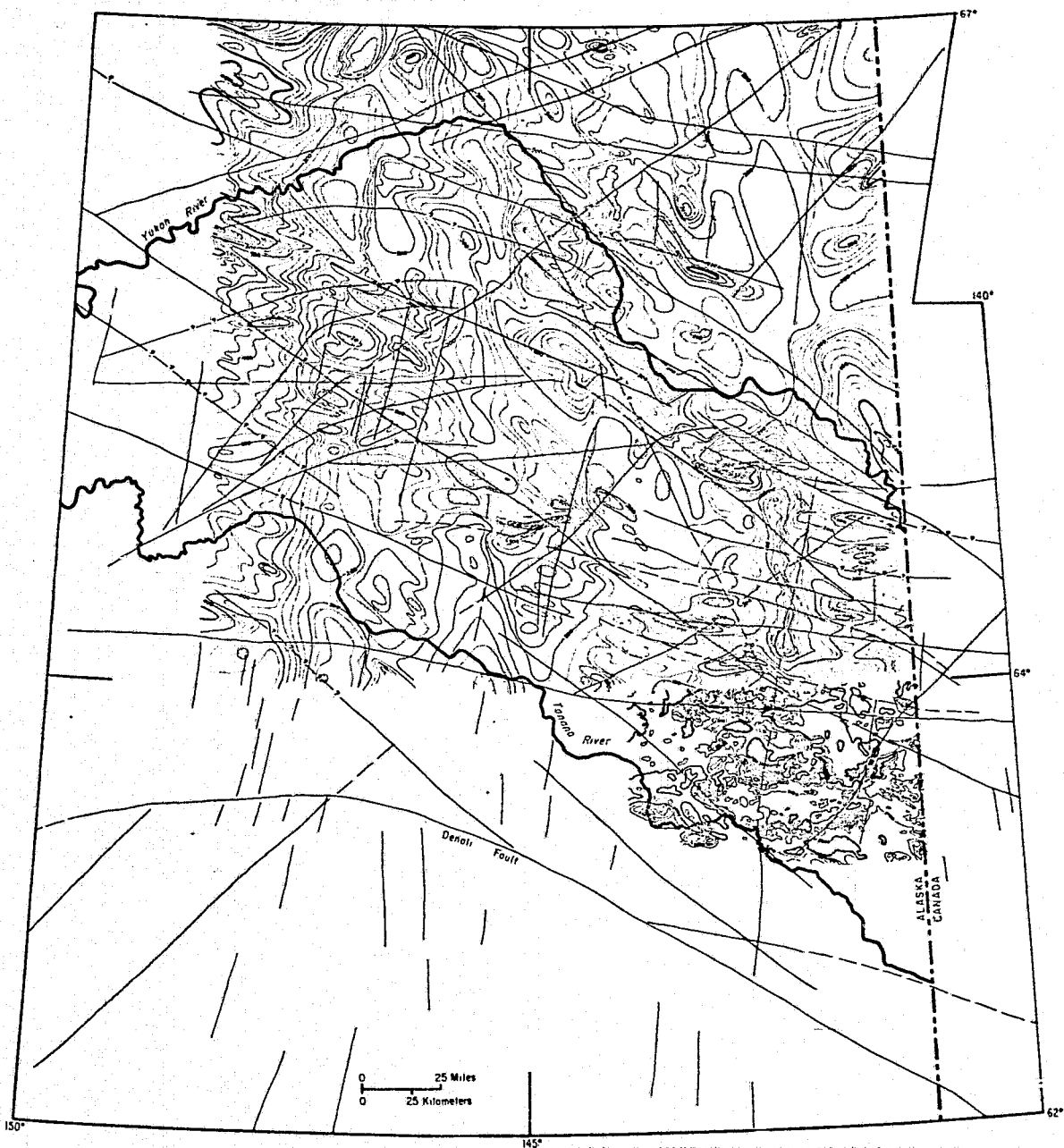
Figure 11. Map showing relationship of major linears to trends of magnetic
anomalies in the Yukon Tanana Upland area (magnetic data after
Brosgé and others, 1970 and Alaska Division of Geological Survey, 1971).
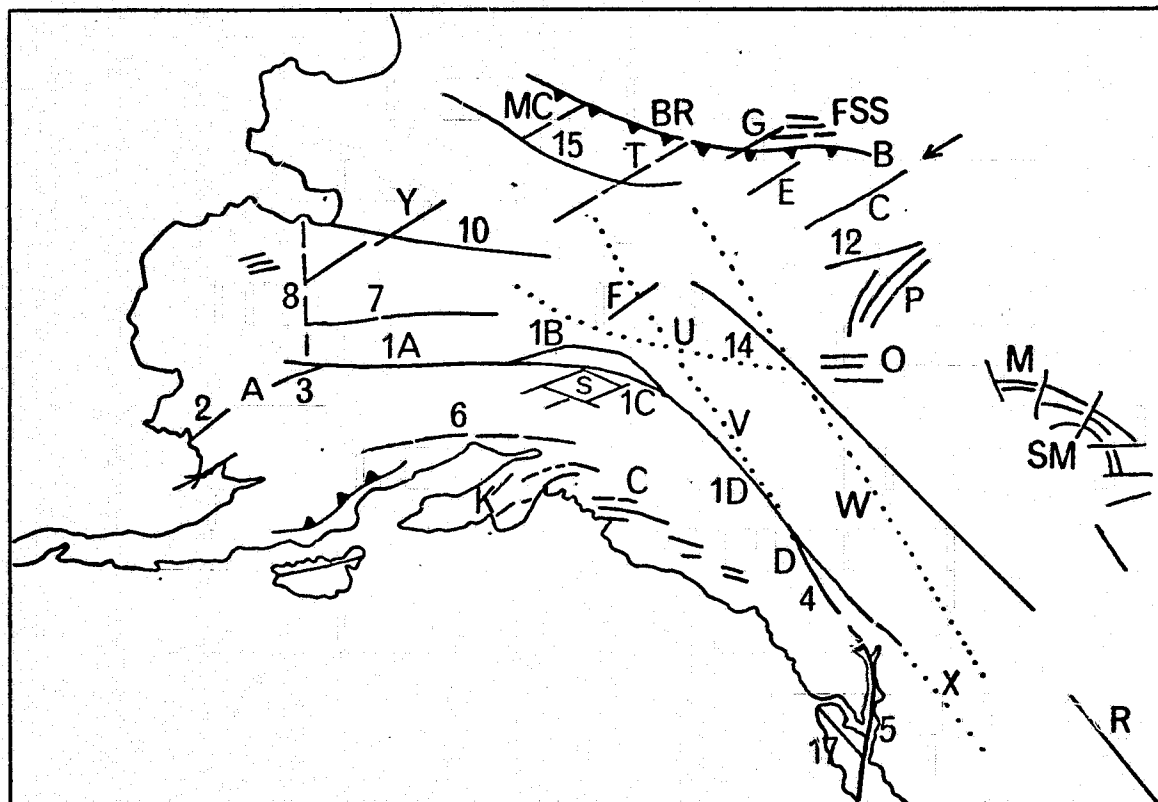
Figure 12. Linears observed on Nimbus IV images and discussed in text. See text for explanation of symbols. (Known or suspected great faults after Grantz, 1966).

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6. Magnetic anomalies do not seem to be disposed in smooth arcuate
    north-convex curves, parallel to the arcuate part of the trace
    of the Denali fault. Rather, the anomalies tend to be linear
    and are alined along straight intersecting trends, or are irregu-
    lar in shape, suggesting the presence of both trends and a
    resulting interference.

The correlation of major linears in the Yukon-Tanana Upland with aero-
magnetic data suggests that these linears reflect concealed geologic
structures.

The virtual absence, in the area north of the Denali fault, of convex-
north arcuate major linears and magnetic anomalies that parallel the arcuate
part of this fault suggests that the arcuate trace is anomalous. It may
be a much younger feature than those reflected by the magnetic anomalies,
and may have resulted from a young rotational movement trailing along an
old northwest-trending fault and then an old southwest-trending fault,
bridging between them in the area of their intersection in the manner
suggested by Grantz (1966).

PATTERN OF GIANT LINEARS IN ALASKA

Examination of images of Alaska taken by the Nimbus IV Image Dissector
Camera System revealed the existence of linears that coincide with the
position of many known or suspected great strike-slip faults (Grantz, 1966)
and structural trends in mountain belts as well as a previously unrecog-
nized orthogonal set of northwest- and northeast-trending linears (Lathram,
1972).

Linears on Nimbus images coincide with major strike-slip faults as
follows (fig. 12): Kobuk Trench (15), the Kaltag (10) and Yukon Flats
(12) faults, the Tintina Trench (14), the Aniak-Thompson Creek (8),
Iditarod-Nixon Fork (7), Togiak-Tikchik (2), and Holitna (3) faults, and
Denali fault system (1A, B, C) (including the Shakwak fault (1D)), the
Castle Mountain (6), Chatham Strait (5) and Peril Strait (17) faults, and
the northern end of the Rocky Mountain Trench (R). The Duke depression
(D) and Chilkat River fault (4) seem indicated by a single short linear.
Linears on Nimbus images coincide with the following structural trends in
mountain belts (fig. 12): the northern thrust front of the Brooks Range
(BR), the faults that bound the Franklin, Sadlerochit and Shublik Mountains
(FSS), arcuate fold and thrust structures in the Porcupine (P), Ogilvie (O),
MacKenzie (M) and Selwyn (SM) Mountains, and arcuate fold trends in the
Chugach (C) and Kenai (K) Mountains. These linears also appear on the
ERTS-1 mosaic.

Other linears, for whose position knowledge of structural control is
scant or as yet nonexistent, also appear on the Nimbus images (fig. 12).
One (V) suggests that the Denali fault system (1A, B, C, D), rather than
being deflected southward to join with the Chatham Strait fault (5; Grantz,
1966; King, 1969), passes north of the Chatham Strait fault and continues

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southeastward (X), east of the Coast Range in British Columbia on strike
with Campbell's (1972) northwestward extension of the Fraser-Yalakom
fault system. The existence of this linear is supported by the ERTS-1
mosaic as far southeastward as the latitude of Ketchikan. If these
fault systems connect, the Denali-Yalakom-Fraser and the Tintina-Rocky
Mountain fault systems would form parallel structures that traverse the
Cordillera from the latitude of Fairbanks to that of Vancouver, a distance
of over 2500 km (Lathram and Gryc, 1973). Another linear, interpreted
on the Nimbus images as following the straight northeast-trending segment
of the Yukon River (Y) and traversing the Brooks Range along the Makpik-
Cula Creek transcurrent fault (MC; Lathram, 1972) is seen on the ERTS
mosaic to traverse the Brooks Range farther to the east in the vicinity
of Walker Lake and to reach nearly to the mouth of the Anaktuvuk River
(A, fig. 13). A series of aeromagnetic profiles across this linear
between latitudes 64° N. and 66° N. shows a sharp magnetic high along the
linear flanked by belts of relatively smooth magnetic response (Dempsey
and others, 1957). Eastward in the Brooks Range a faint linear of
northeast strike on the Nimbus images (T, fig. 12) has not been recognized
on the ERTS mosaic but the quality of the mosaic is poor in this area.
A parallel linear (G, fig. 12) on Nimbus images along the western boundary
of the Franklin, Sadlerochit and Shublik Mountains is also apparent on
the ERTS mosaic. Many previous workers have noted that in the north-
eastern Brooks Range, Paleozoic and older strata are exposed only east
of this linear; to the west the older strata are covered by deposits of
the Mesozoic Colville geosyncline. Linears along the East Fork of the
Chandalar River (E), and the northeastern part of the Yukon-Porcupine
lineament (C), short linears along the upper Susitna River (S), one (F)
northwest of Fairbanks, and one along the Togiak-Tikchik fault (2) all
also reflect this trend. An east-trending linear (U) occurs south of
Fairbanks. Two southeast-trending linears (V and W) bracket the Yukon-
Tanana Upland in the northwest and, if extended southeasterly with no
change in strike, would pass east of the Coast Range batholithic complex
in the southeast. These linears are expressed on the ERTS mosaic as
broad discontinuous linear zones. They may bracket a continuous belt of
dominantly crystalline rocks in the Yukon-Tanana Upland which was up-
lifted and/or tilted in late Tertiary and Holocene time (Foster, 1969).
As mentioned previously, linear W seems to reflect a northwest-trending
alinement of magnetic lows in the Yukon-Tanana Upland area. These linears
may also reflect faults in Precambrian basement along which transcurrent
or vertical movement has taken place. A more faint linear (indicated by
arrows) extends from the Yukon-Porcupine Lineament (C) southwestward en-
tirely across Alaska. This linear passes northwest of Fairbanks, north-
west of the front of the western Alaska Range and southeast of the Ahklun
Mountains (A), dividing Alaska in two parts. As there are no indications
of a through-going fault in Mesozoic and younger rocks along this linear,
this feature, if it exists, is an old one, largely concealed by the
younger strata. Along this linear a narrow belt, characterized litho-
logically by a thin shelf facies representing continuous deposition from
Cambrian through Silurian time and possibly separating differing facies
to the northwest and southeast, has been noted in the Coleen River area

(Brosgé and Reiser, 1969), and in the area from Fairbanks southwest to
the lower Kuskokwim River area (Churkin, 1973). Rather than a fault, this
linear may reflect an old hinge line, possibly a segment of an outer car-
bonate platform (Brosgé and Dutro, 1973), which exerted varying control
over post-early Paleozoic sedimentation. Extended northeasterly through
Canada, the linear would roughly coincide with the trend of Paleozoic
shelves and depositional troughs in the Canadian Arctic Archipelago
(Thorsteinsson and Tozer, 1960). It would also parallel but lie north-
west of the Aklavik Arch, a 1400 km (880 miles) long "persistent composite
structural feature comprising a system of uplifts, depressions and faults",
trending northeast from the Alaska border to the Beaufort Sea, which
similarly exercised control over mid-Paleozoic and younger sedimentation
and may be a "major link between the structure and stratigraphy of the
northern mainland and the Arctic Archipelago" (Norris, 1973, p. 38-39).
Although several shorter linears are visible along this line on the ERTS
mosaic, this giant linear seems less apparent on ERTS imagery than on
Nimbus imagery.

The ERTS mosaic also shows giant linears in Alaska that are not
apparent on the Nimbus images. These and the Nimbus linears seem to form
a pattern of parallel systems in Alaska, some orthogonal to others, with
well-defined trends (fig. 13). Analysis of their geologic significance
is incomplete. Linear A, at its eastern end, coincides with a fault
boundary between Paleozoic and Mesozoic strata (King, 1969), and, where
it crosses the Alaska Range north of Mt. Spurr, coincides with the north-
eastern boundary of belts of both Jurassic intrusive bodies described by
Reed and Lanphere (1973) and of Recent volcanoes, which trend southwest
along the Alaska Peninsula. Linear B, at both east and west extremities,
parallels structures in exposed Precambrian or possible Precambrian rocks
(King, 1969). Linear C, which seems a logical continuation of Nimbus
linear V (fig. 12), coincides with a significant change in structural
style and trend in Mesozoic rocks, which is interpreted to represent the
interference between an older north-directed thrust belt in the Brooks
Range and a slightly younger east-directed thrust belt on Lisburne
Peninsula (Lathram and others, 1973).

A plot of these giant linears (fig. 3A) in which cumulative length
rather than number of linears is used as the ordinate, shows that three
well-defined northeast- and northwest-trending linear systems are present,
which can be considered as three nearly orthogonal sets. A strong east
southeast-trending group is also present, but no orthogonal north-
trending giant linears are apparent on the mosaic.

SIGNIFICANCE OF LINEARS

General Discussion

The congruity of linear trends, geologic structures and geophysical
anomalies in widely separated areas of Alaska suggests that most, if not
all of the linears observed reflect a fundamental control by geologic

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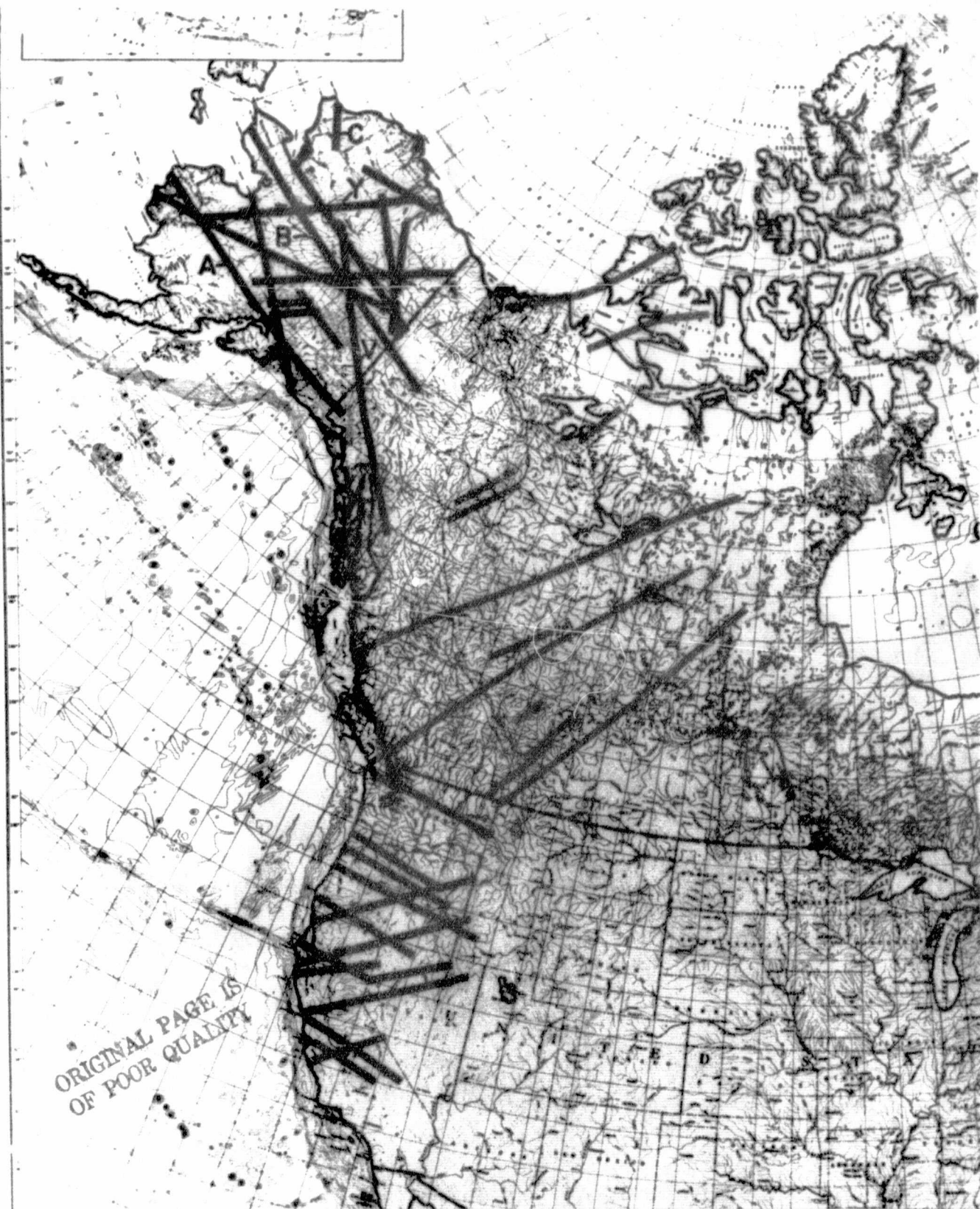
Figure 13. Map of western North America showing pattern of giant linears
in Alaska, trace of selected giant linears observable on ERTS
mosaic of conterminous U.S. west of 114 West longitude, and
trace of Precambrian structures concealed beneath Phanerozoic
strata in the Cordillera and Interior Plains of Canada.

phenomena. Many of the linears can be directly related to exposed geologic structures, as some in the Yukon-Tanana Upland area, and those that mark the trace of the known or suspected great faults. Many of the linears, although expressed in undeformed surficial materials, can be related to buried structures by inference from geologic and geophysical data, if regional relationships are sufficiently well known, as those in the Umiat area. Other linears reflect trends in geophysical data but not in exposed geologic structures, as is the case for many of the long linears of the Yukon-Tanana Upland area and some of the giant linears recognized; the nature of the controlling structures cannot be clearly determined because knowledge of subsurface geologic conditions is lacking. Still others, particularly most of the giant linears, cannot yet be related to geologic or geophysical features, although their parallelism and similarity to better understood linears suggests that relationships to geologic structures will eventually be found. It is evident that determination of the verity or significance of a space image linear cannot rely solely on examination of exposed geologic conditions (traditional "ground-truth"); study of subsurface geologic and geophysical data, paleogeologic reconstructions and the tectonic framework is necessary to assess the validity and significance of many linears.

Space image linears in Alaska vary in length from 10 km to over 1000 km. In general, they may be grouped into three size ranges--10 to about 200 km, about 200 to 1000 km, and >1000 km (roughly 10 to 100 miles, 100 to 600 miles, and >600 miles). The frequency of linears varies, the greatest number being in the 10 to 200 km range, the smallest in the >1000 km range. The linears also vary widely in trend (fig. 3) and include giant curved linears. Well-defined sets of linears are apparent in the giant linear group and in the short oriented lake linears, but only one orthogonal set (N. 62° W. and N. 28° E.) is common to both. Linears of less than 1000 km length in the Yukon-Tanana Upland area display a greater variation in compass trends, those shorter than 200 km exhibiting the largest variation.

These considerations suggest that the shortest and most sharply defined linears, those that clearly express surface geologic structures, may not represent fundamental regional tectonic patterns. Rather, they may simply reflect local variations in structural response of differing rock materials developed during the most recent tectonic episode or combinations of structural response to successive tectonic episodes. Maps and plots of such linears commonly mask the pattern of long linears, as younger tectonic movements mask older ones. The longer, and commonly more obscure linears that are not relatable to surface geologic structures, but are relatable to subsurface structure or geophysics stem from older, more fundamental geologic features, and may therefore be more significant in terms of resource evaluation and tectonic analysis. In this context, it is useful to consider the abundant short linears as "tectonic noise", which must be filtered out by observation from a more synoptic viewpoint in order to achieve regionally significant concepts.

Significance in Mineral Resource Evaluation

Preliminary attempts have been made to analyse the significance of space image linears in exploration for new metallic mineral (Lathram and Gryc, 1973) and fossil fuel (Fischer and Lathram, 1973) sources. In neither case have new deposits been discovered yet by direct application of these analyses; however, both present new hypotheses which enhance exploration potential.

Metallic Minerals

In previous years, regional metallogenic studies have employed a stabilistic tectonic model, in which most epigenetic deposits are related to the geosynclinal cycle, with its specific types and stages of igneous intrusion. In Alaska, these studies have all resulted in a pattern of arcuate belts of mineralization which generally follow the north-convex arcuate distribution of lithologic belts (fig. 14A). Recently, a mobilistic, or plate tectonic model has been applied to metallogenic analyses (Mitchell and Garson, 1972; and others). The distribution of ore deposits in the Canadian (Sutherland-Brown and others, 1971) and Alaskan (Berg and Cobb, 1967) Cordillera could be consonant with the plate tectonic model although the fit is not exact (Lathram and Gryc, 1973). The plate-tectonic model, however, yields the same general pattern of mineralized belts as does the stabilistic model (fig. 14A).

Comparison of the northeast- and northwest-trending sets of giant linears (possible crustal structures), shown on the space images, with the distribution of mineral deposits and known major structures yields some interesting relations (fig. 14B). Sutherland-Brown and his associates noted the close association between porphyry molybdenum and mercury deposits, and strong northwest-trending fault systems. Their maps show that most of the porphyry copper and molybdenum, and nearly all the tin, tungsten, and mercury occurrences are within a belt bounded by the northwest-trending Tintina-Rocky Mountain and parallel Denali-Yalakom-Fraser fault systems. They also note that the development of mineralized regions seems related to major crustal zones or fractures trending southwestward across the Cordillera from the Precambrian shield (fig. 13, 14B). These include a structural trend from southeastern British Columbia to Hudson Bay, from Howe Sound to Lake Athabasca, and from the Skeena Arch to Great Slave Lake. Reference to Douglas (1970, fig. VIII-2) shows a basement structure on trend between the Stikine Arch mineralized area and Precambrian structures south of Great Bear Lake. In Alaska, by analogy, the mineralized region of massive sulfides in the Prince William Sound and upper Copper River areas and of porphyry coppers in the Nabesna area forms a broad northeast-trending belt possibly related to the Minto Arch on the Shield (fig. 14B). The belt of metalliferous deposits in the western Alaska Range follows a comparable northeast trend. Mercury deposits, suggested by many to be fault controlled, together with most tin and tungsten deposits, occupy a northeast-trending belt between the Bristol Bay-Mackenzie Bay linear and extensions of a linear along the lower Yukon

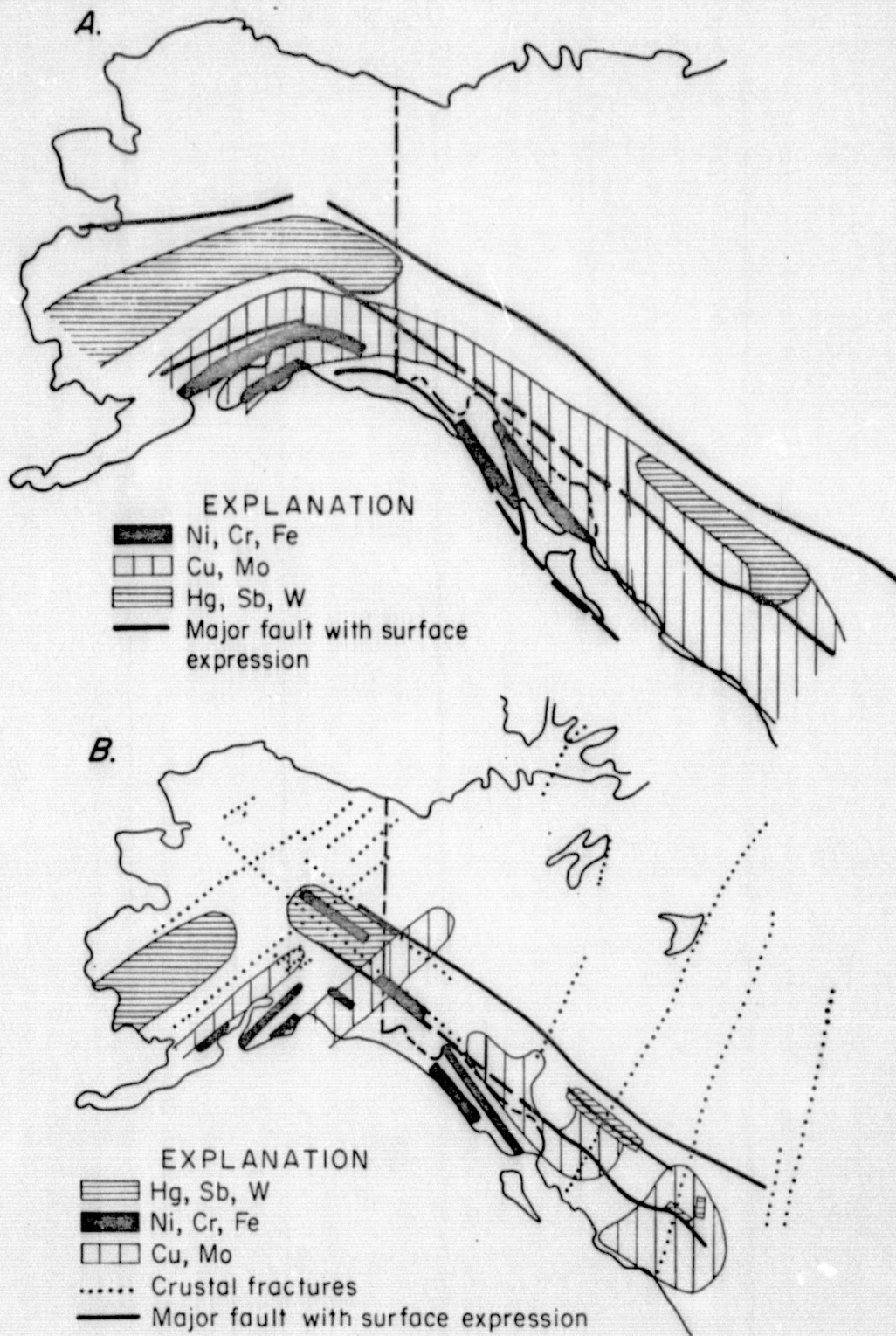Figure 14.--Areas of Alaska and western Canada considered favorable for location of deposits of selected metals based on extrapolation of geologic conditions at known occurrences. A) Conventional concept guided by north-convex arcuate distribution of lithologic belts. B) Postulated alternative assuming that linears seen on Nimbus IV and ERTS images are crustal fractures and have influenced mineralization.

River. This belt intersects the northwest-trending Canadian belt of similar deposits in the Fairbanks area.

Hence, whereas the conventional metallogenic hypothesis (fig. 14A) assumes that areas favorable for occurrence of various types of ore deposits describe arcuate belts through southern and central Alaska, the new hypothesis postulates that favorable areas form belts parallel to major northwest- and northeast-trending fractures, and deposits will be more abundant where such fractures cross. For example, using the conventional concept one would expect to find porphyry copper-molybdenum deposits in an arcuate belt south of the Denali fault, whereas according to the new hypothesis (fig. 14B) such deposits could be found in two northeast-trending belts that could extend northeast of the Denali fault.

Following the ERTS-1 Symposium of March 1973, at which the new hypothesis was discussed (Lathram and others, 1973), word was received that the hypothesis had been substantiated (E. R. Chipp, written commun., 1973). In 1970 and 1971, independent mineral exploration utilizing the intersections of northeast- and northwest-trending fracture systems as a guide resulted in the discovery of a number of porphyry copper-molybdenum deposits in the area northeast of the Denali fault.

These deposits were not found directly by use of space imagery. However, their discovery in an area and in a geologic setting predictable by an hypothesis developed through interpretation of linears on space imagery tends to substantiate the value of these linears as indicators of subsurface (possibly crustal) geologic structure and the hypothesis as a guide in mineral exploration in Alaska.

Fossil Fuel Resources

As previously noted, the area of lineated lakes near Umiat extends eastward to the Canning River. In the Umiat area geologic and geophysical evidence suggest that the east-trending linears and the curvi-linears reflect buried structures. These may be structures in shallow strata as well as in deeper basement rocks.

Several medium-sized oil fields have been developed in shallow Cretaceous strata at Umiat and to the east between Umiat and the Canning River. The zones of sandstone facies favorable for petroleum accumulation in mid-Cretaceous strata trend northwest, and are underlain by a great thickness of shale. The occurrence of seismic reflectors only in the upper 1200 to 1800 m (4000 to 6000 ft) of strata underlying the western part of the lineated area suggests a similar situation. These sandstones, however, should be younger than those at Umiat, and may lie within another zone of favorable facies. If the folds have grown during deposition, the sandstones may have been more winnowed and hence may be more porous and permeable on the crests of the folds, adding to the potential for petroleum or gas accumulation.

In addition, large oil fields have been discovered in the lineated area near Prudhoe Bay, at or near basement. If the linears reflect structures in the basement, conditions may exist at greater depths that are favorable for petroleum accumulation in structural conditions and in facies of Mississippian to Triassic strata similar to those at Prudhoe Bay. At Prudhoe Bay, petroliferous horizons occur along a zone where these strata lap onto older basement rocks. The postulated position of this zone trends southwesterly through the entire lineated area (Brosgé and Tailleur, 1971).

If the linears reflect basement structures, they indicate geologic features considered by Brosgé and Dutro (1973) to be as old as Devonian and possibly older. The correspondence of the linears with geologic, geophysical and paleogeologic data substantiates their value as indicators of potential plays for petroleum exploration and as guides to old tectonic features.

Significance in Tectonic Analysis

Preliminary analysis of space image linears in northern and central Alaska indicates that many reflect subsurface geologic structures of varying ages, some quite old. Linears near Umiat may reflect structures as old as Devonian, those in the Koyukuk River area structures of early Mesozoic or possibly mid to late Paleozoic age, and those in the Yukon-Tanana Upland area structures possibly older than Paleozoic as they correlate with magnetic anomalies beneath a Precambrian (?) and/or Paleozoic terrane.

The correlation of geology, geophysics and possibly metallogenic terranes with giant linears, coupled with the existence of definite sets having nearly orthogonal trends suggests that these linears indicate more fundamental structures than do shorter linears. It is significant that the trends of the giant linears correspond closely with the trends of Precambrian, early and late Paleozoic, and Mesozoic orogenic belts in northern and central Alaska (Lathram, 1973; Brosgé and Dutro, 1973). Grantz (1966, p. 72-73) suggested that a conjugate system of faults or lineaments may lie within the crust of Alaska, disguised by Mesozoic and Cenozoic formations and deformations, along which large blocks have moved differentially. Analysis of the tectonic framework of northern and central Alaska suggested a similar conclusion (Churkin, 1973; Lathram, 1973). Grantz also suggested that the present bending of the great surface faults in the state could result from selective trailing of suitably situated older faults or other structures by younger strike slip movements. The coincidence of the trends of giant linears with the trend of major straight parts of these now arcuate faults, the straight extension of some giant linears beyond the points where arcuate bending is noted in the great faults, and the lack of correlation between aeromagnetic anomalies and the curve of the Denali fault in the Yukon-Tanana Upland area all suggest Grantz' conjecture was correct, and that the giant linears mark the sites of such major, old crustal fractures or structures.

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Lathram (1972), in an earlier discussion, suggested that these giant linears may reflect the global "regmatic shear pattern" of Moody and Hill (1956), Katterfel'd and Charushin (1970), and others. The present analysis shows not one but several northwest and northeast nearly orthogonal sets of linears are present. This suggests that whereas the linears do reflect older, possibly crustal structures, and may be related to the global "regmatic shear pattern", the relationship is not a simple one.

Preliminary and admittedly cursory analysis of the ERTS mosaic of the western conterminous states revealed a number of giant linears in this part of the Cordillera (fig. 13). These linears are similar to those in Alaska, and have trends near the azimuth of both the Alaskan linears and the partially concealed structures of Precambrian age (Sikabonyi and Rodgers, 1959; Haites, 1960) that transect the Cordillera in Alberta, British Columbia and the Yukon Territory. They are also similar in trend to the linears described by Thomas (1974) in Montana, Wyoming and Colorado, which he believes are basement weakness zones along which transcurrent movement has occurred. One of the giant linears in California is discussed by Antonnen and others (in press). Although the ERTS images of Canada have not been examined in this study, many of the concealed structures there are marked by physiographic linears (Haites, 1960) which would appear on ERTS imagery.

The occurrence of giant linears of similar nature and trend throughout the North American Cordillera suggest that they reflect fundamental crustal structures that are not peculiar to Alaska. It is noteworthy that many of these structures traverse both postulated continental and oceanic crustal areas, transecting the supposed boundaries with little or no deviation. Examples are linear Y (fig. 13) which crosses the supposed Permian-Triassic oceanic crustal area of the Yukon-Koyukuk volcanic province (Hamilton, 1970), several of the concealed structures in Canada which cross the presumed Permian-Triassic oceanic crustal area of central British Columbia (Monger and others, 1972) and the linear in California discussed by Antonnen and others (this volume), which crosses the assumed Mesozoic oceanic crust underlying the Great Valley of California (Bailey and others, 1970). If these linears do reflect very old or crustal structures, these structures have apparently been unperturbed by plate tectonic movements. Clearly, an understanding of the origin and age of these linears is significant to the development of tectonic hypotheses, and will provide insight into the tectonic history of specific continental areas.

CONCLUSION

Preliminary analysis of space images of Alaska has revealed a large number of linears varying in size and in azimuthal trend. Linears less than 200 km (about 100 miles) in length are most numerous, most varied in trend, and most closely related to surface exposures of geologic structures reflecting the most recent tectonic event. Giant linears, over 1000 km (about 600 miles) in length, are of two types--straight,

somewhat obscure ones which reflect old, deep structures whose identity is commonly concealed by later tectonic phenomena, and curved ones which reflect relatively young strike slip movements on faults which trailed along suitably situated old crustal structures that are nearly orthogonal in trend. The nature of the giant linears is important in understanding the tectonic history of Alaska, and of the North American Cordillera, and in developing viable tectonic hypotheses that explain features of the formational and deformational history of continental blocks that accord poorly with modern plate tectonic concepts. The nature of giant linears, and of shorter ones, is also important in analysing subsurface geologic structures which may have controlled the localization of mineral and mineral fuel deposits.

B. ENHANCEMENT OF GEOLOGIC MAPPING

ERTS images are being used to complete a revised 1:1,000,000-scale regional map of northern Alaska. For example, in the earlier compilation (Lathram, 1965), the lowland area of the Ipewik and Kukpuk Rivers is largely devoid of structural data (fig. 15). Despite several seasons of exploration by private companies, and by the U.S. Geological Survey, the ubiquitous tundra cover and paucity of outcrops along the shallow streams and rivers prevented recognition of the distribution of structural elements in this area. Interpretation of conventional aerial photographs revealed little additional data. ERTS images 1009-22090, 1046-22143 and 1046-22145, however, displayed a startlingly clear and detailed representation of the area (Lathram, and others, 1973) (fig. 16). The new compilation of this area (fig. 17), although as yet unedited, shows clearly the complexity of structure revealed by the ERTS image, and the pronounced difference between the structural pattern in this area and that in the area of strata of comparable age to the north and east. This change in structural complexity may be due to oroclinal bending around an axis trending northeast through the lowlands (Tailleur and Brosgé, 1970) or, more probably, to the superimposition of a western and younger belt of east-directed thrust faults upon an eastern and older belt of north-directed thrust faults (Grantz and others, 1970). Recognition of the structural complexity, and determination of its cause, are critically important in determining the potential for petroleum accumulations at depth in the area.

Enlargements of ERTS images to a scale of 1:250,000 are also being used in medium-scale geologic mapping. In the Kukpuk-Ipewik Rivers area of northern Alaska, compilation of known geology on the ERTS images has permitted extrapolation of data into unmapped areas, and has resulted in the recognition of structural and stratigraphic anomalies that suggest new interpretations of the geology (Tailleur, in Gryc and Lathram, 1973). In field mapping in 1973, W. P. Brosgé, I. L. Tailleur, and others successfully used ERTS images to determine the location of lithologic contacts between successive field stations (Tailleur, oral commun. 1973). G. Plafker, R. L. Detterman, and others employed ERTS images in field studies of the

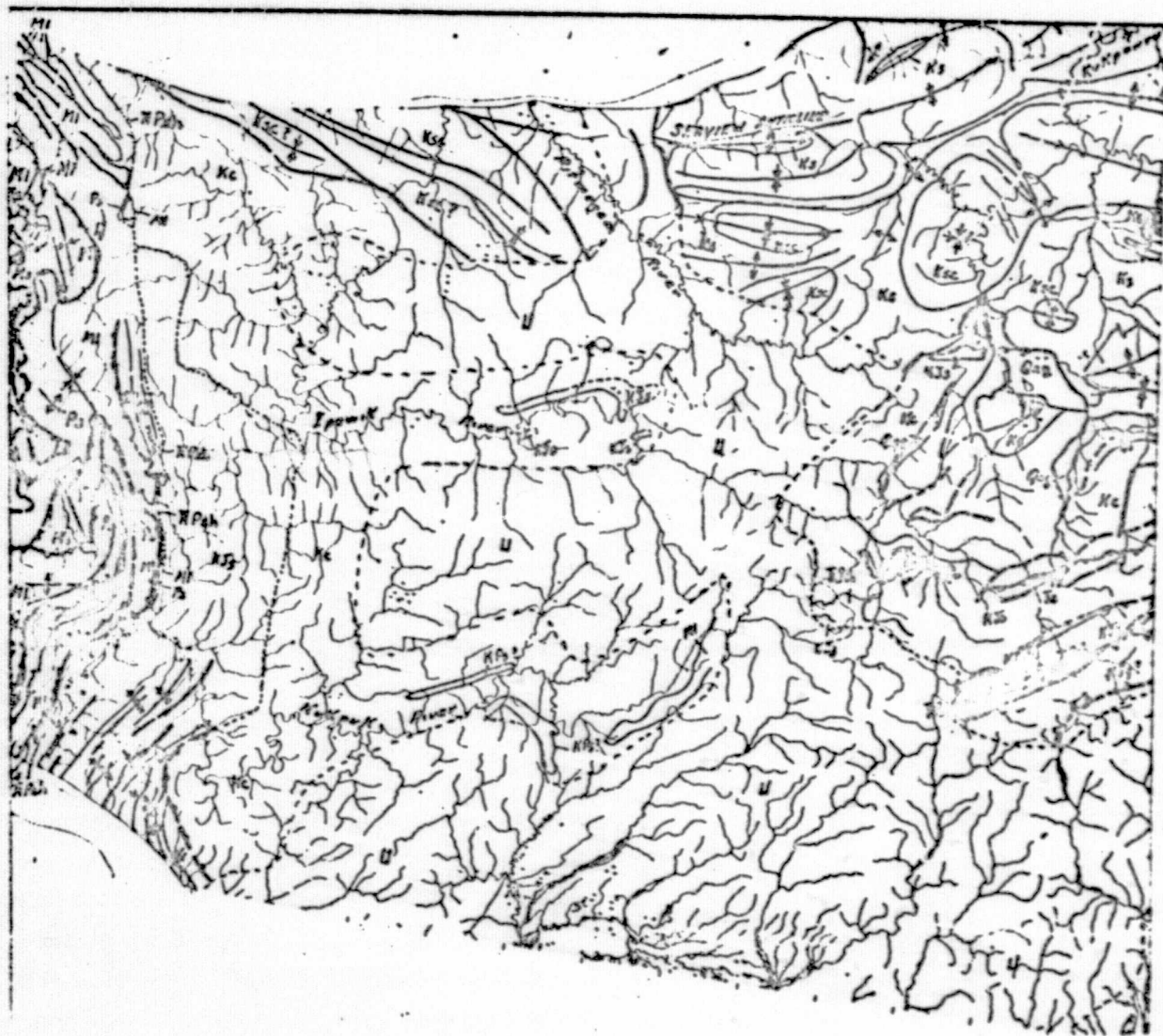Figure 15.   Part of regional geologic map compilation prepared in 1965 showing paucity of data in lowland of Ipewik and Kukpuk Rivers.
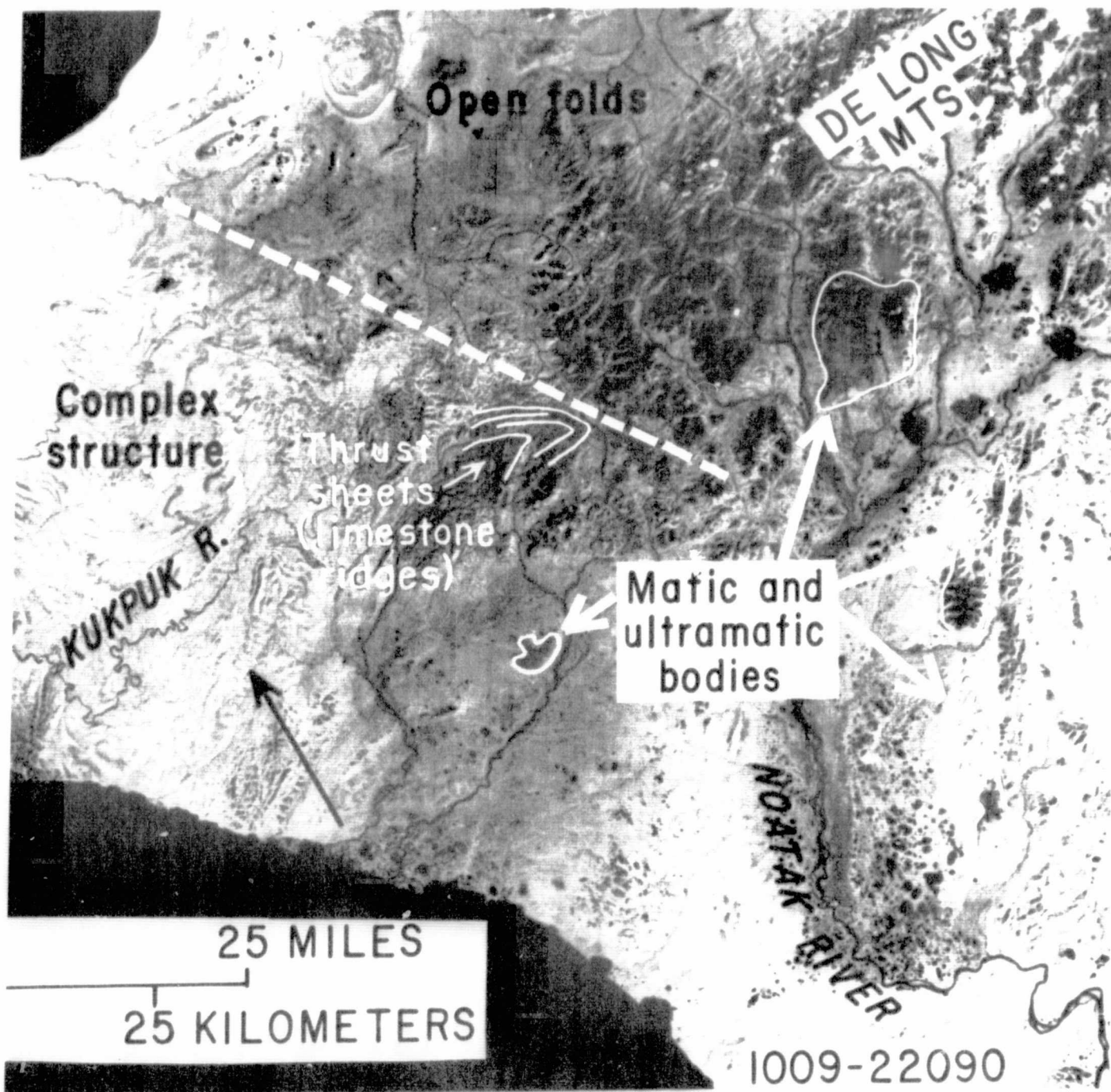
Figure 16. ERTS-1 image (Band 7) showing differing structures and the
aspect of some known lithologic types in the western De Long
Mountains.

Figure 17. Part of revised regional geologic map compilation prepared in 1973 showing additional structural data obtained from ERTS images.

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location and continuity of major faults in southern Alaska, as a part of the U.S. Geological Survey's Earthquake Hazards Reduction Program. The images were particularly useful in mapping in the snow field areas bordering the Gulf of Alaska. Not only is the location of field observations more easy and accurate in the ERTS image (fig. 18) than on the most recent topographic map (fig. 19), but the distribution of perennial snow is more true on the near real-time image than on the more than ten year-old map (G. Plafker, oral commun., 1973).

W. W. Patton, Jr., on the basis of previous field mapping, interprets the Kobuk Trench to be the northern margin of a broad west-trending fault zone bounded on the north and south by strike-slip faults. He reports that preliminary examination of image 1072-21180 provides new data in support of that interpretation. Within the fault zone in the area, the west-trending Alatna Hills are composed of apparently structurally homogeneous Cretaceous sedimentary rocks. On the ERTS image, however, these rocks are seen to be cut by numerous, closely spaced northeast-trending linears that terminate at the north and south margins of the fault zone (fig. 20). These appear to be complementary fractures that would be expected to develop as a result of the differential movement between strike-slip faults.

The southeastward continuation of a fault that has been mapped in the vicinity of Dan Creek (McCarthy B-4 and B-5 quadrangles, Alaska) shows up as a lineament on ERTS image 1043-20163 that can be traced for more than 50 miles southeastward to beyond the Alaska-Canada boundary. The lineament probably reflects a major fault that is significant in understanding the complicated tectonics of the Wrangell Mountains-Saint Elias Mountains complex. From a study of the ERTS image, low-level vertical photography, and limited fieldwork in the largely unmapped region, E. M. MacKevett, Jr., speculates that the eastern part of the fault may mark the southern boundary of a mid-Paleozoic metamorphic terrane that constitutes the westernmost known extent of the Alexander terrane of Berg, Jones, and Richter (1972) and correlates with the Kaskawulsh Group in Canada.

ERTS images are also being used operationally in the Alaska Mineral Resource Appraisal program, a multidiscipline effort of geologic mapping, geophysical, geochemical, and remote sensing studies to evaluate the mineral resource potential of selected quadrangles in Alaska. The images are being used not only to aid mapping, and to determine by computer analysis the distributions of lithologies and altered zones, but also as base maps for the compilation of reports.

C. ENVIRONMENTAL ANALYSIS OF VEHICULAR SCARS ON ARCTIC TUNDRA

Introduction

Umiat, Alaska was the hub of intense vehicular activity during the exploration of Naval Petroleum Reserve No. 4 in the period 1945 to 1952. It has since been used, though less intensively, by private industry as a staging area for petroleum exploration of sites outside the reserve.
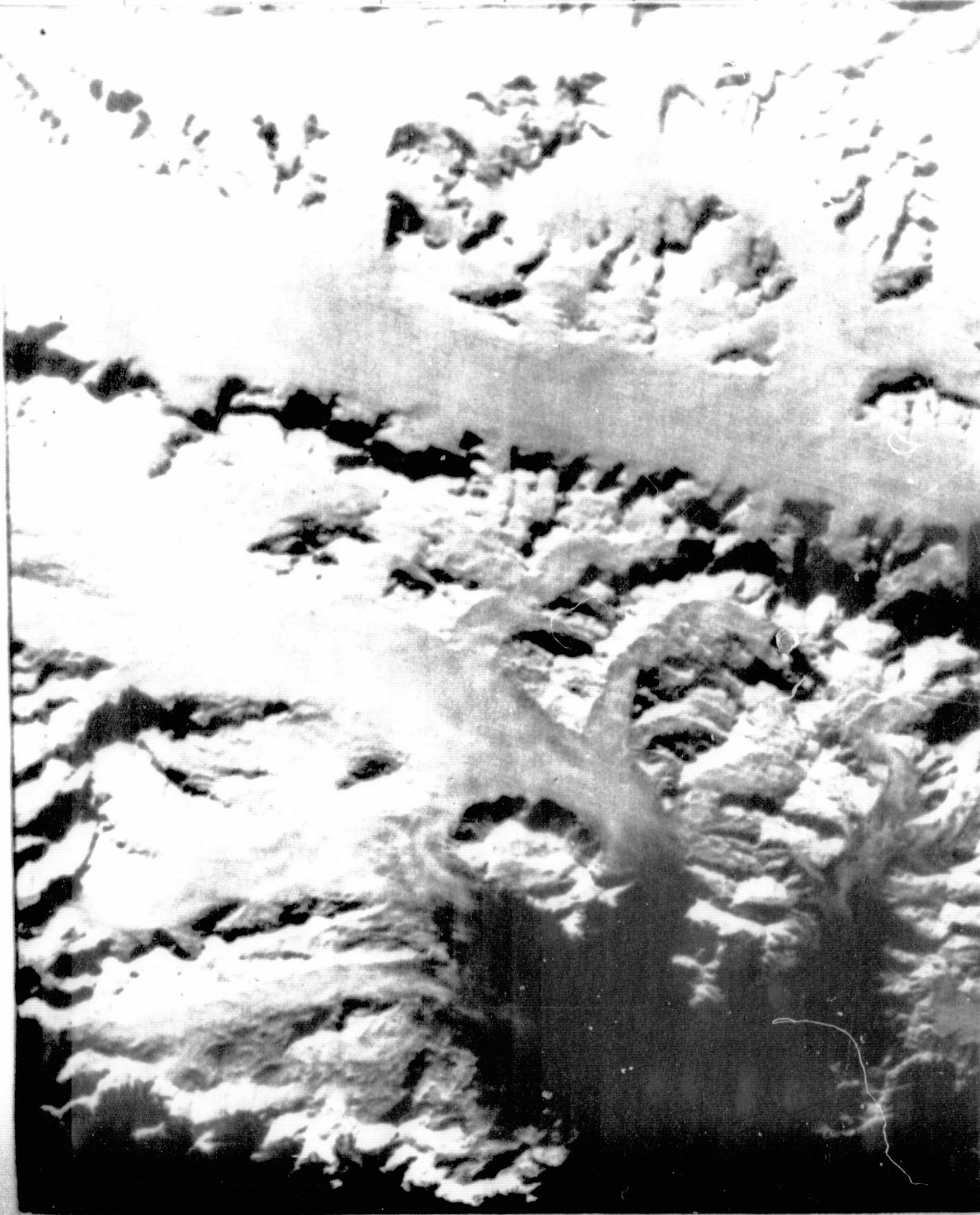
Figure 18. Part of ERTS image of Bering Glacier area, approximate scale 1:250,000.
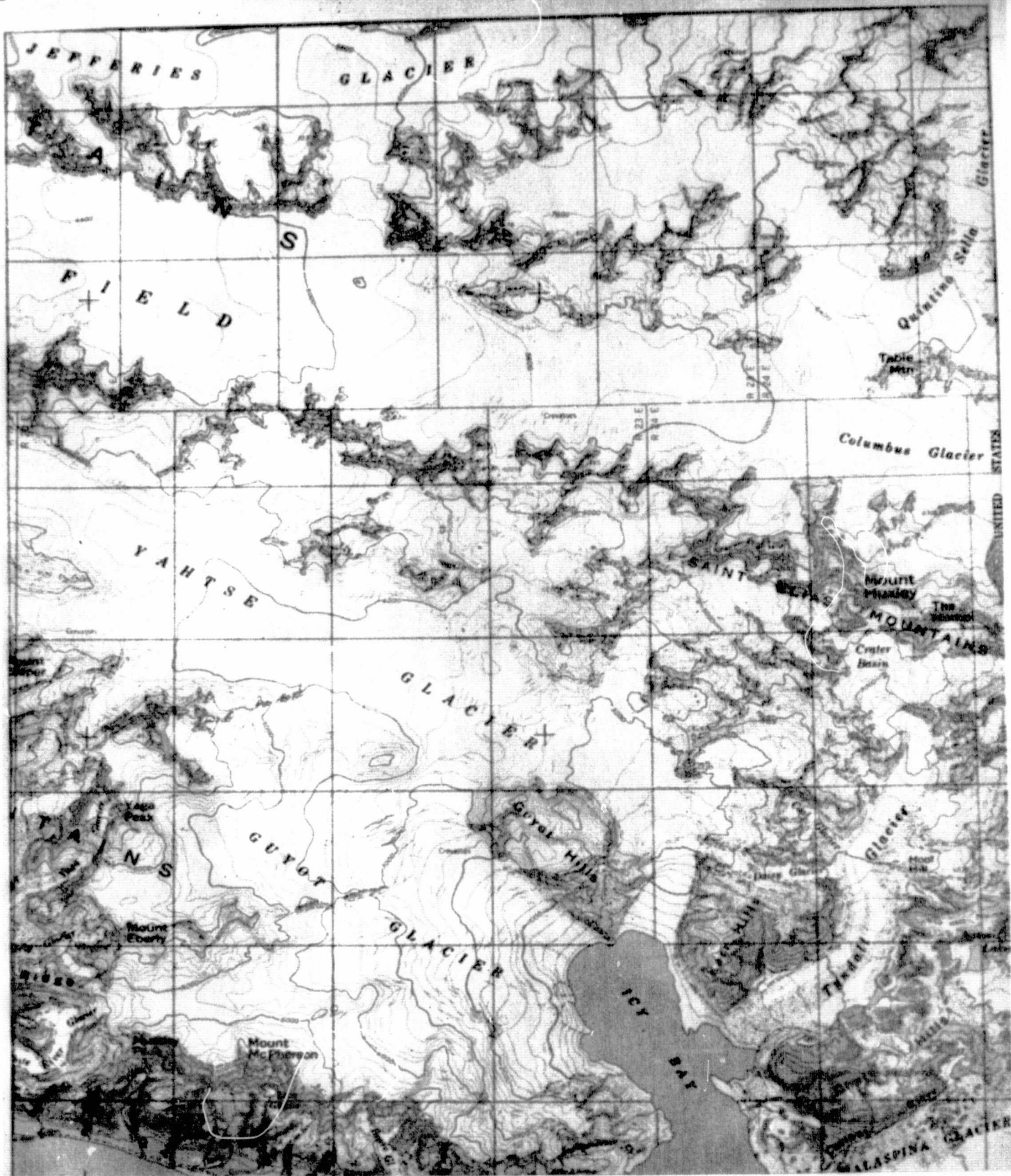
Figure 19. Part of standard topographic map of Bering Glacier area, scale
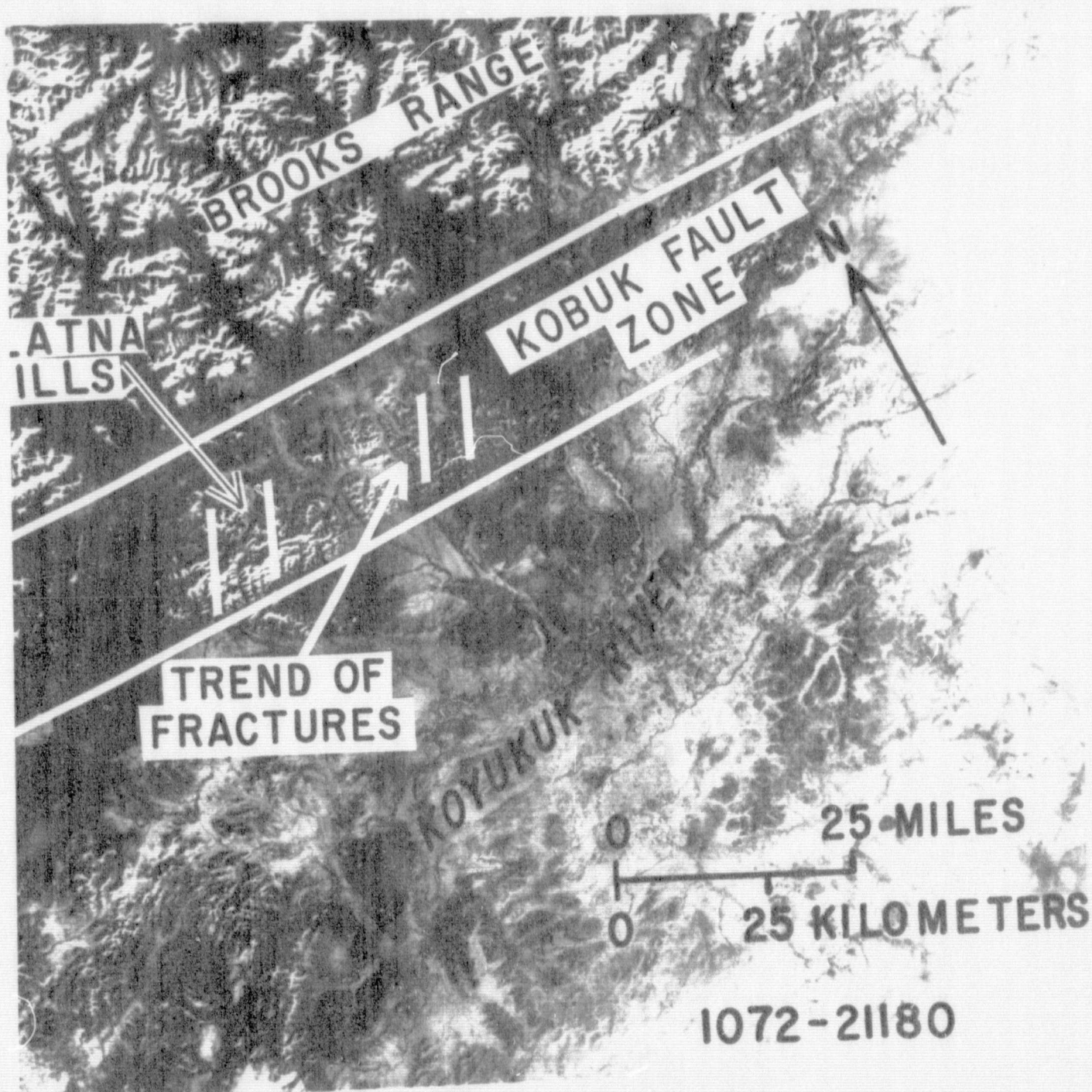1:250,000, showing stylized representation of nunataks.

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Figure 20. ERTS-1 image (Band 5) showing closely-spaced fractures in
Kobuk fault zone.

Much concern has been expressed over the permanency of scars to the tundra resulting from damage to insulating vegetation and disturbance of the underlying permafrost brought on by such vehicular traffic. The more extreme conjectures purport that such scars will never heal and will spread unchecked.

DISCUSSION

Preliminary examination of ERTS-1 image 1004-21395 (taken in 1972), which covers the area around Umiat (fig. 21), revealed no trace of scars resulting from this activity (W. A. Fischer, in Lathram and others, 1973, p. 38). Because ERTS sensors lack the resolving power (>20 meters) required to recognize features as narrow as these tracks were originally, Fischer observed "This does not mean that the scars are gone, for I am confident they are not wholly healed and could be observed on the ground or from a low-flying plane, but it does mean that they are not spreading like cancer, as some purport, over the northern tundra." Subsequent study of this image under the microscope at enlargements up to 1:80,000 revealed that a scar on the ridge north of Umiat can be identified on Band 5 (reflected red light) images of the area.

During the summer of 1973, Robert L. Detterman, Geologist, U. S. Geological Survey, accompanied by John Koranda, Botanist, Lawrence Livermore Laboratory, made a one-day review of the status of the scars in this area. The area surrounding Umiat, in the eastern part of image 1004-21395, and to the east beyond its borders was examined from the air and on the ground. Weather prevented observations in the western part of the image area and was generally poor, with a ceiling of 100 feet and visibility of one-fourth mile, which also reduced the quality of illustrative photography. Comments herein that refer to the surface state of scars are based on the observations of Detterman and Koranda.

During the planning, a report of a similar field study by the Bureau of Land Management in 1969 (Hok, 1969) was utilized, and it was possible to revisit areas previously studied for comparison and recognition of changes that had occurred over the intervening 4 years.

All scars observed in the Umiat area are being revegetated at varying rates depending on the nature, degree and age of the disturbance or are approaching a stable state. At all places where sites studied by Hok were reexamined, revegetation had proceeded further in the intervening 4 years.

The extent of scarring depends, as Hok found, on the season of occurrence, substrate (particularly with respect to water content, i.e., ice-wedge occurrence), degree of vegetation removal, and slope. Trails made by small tracked vehicles such as weasels and bombardiers have left little trace. LVT trails are most intensely scarred. Cat-tracks, with little or no blading, and used only in winter, do not cause extensive scars.
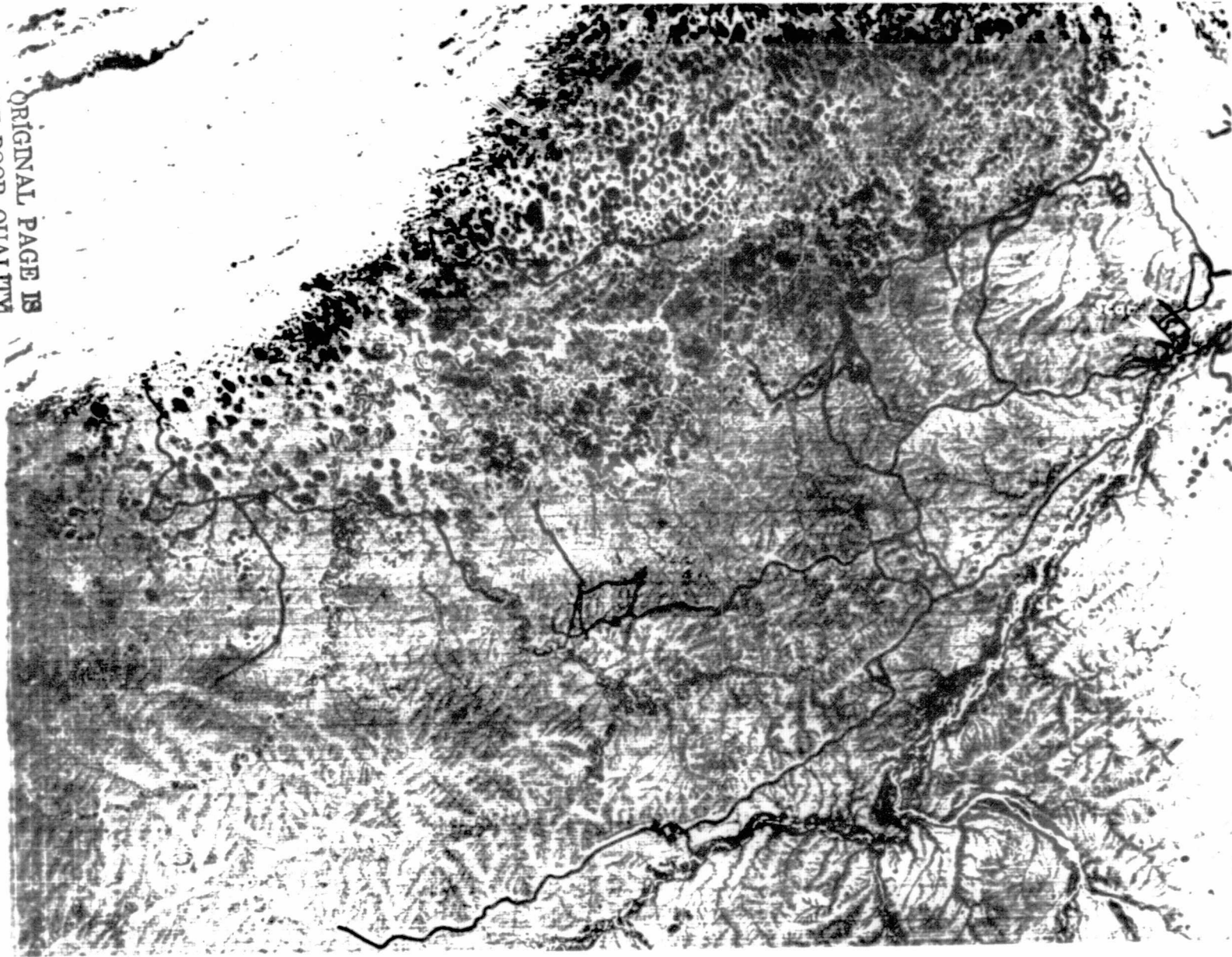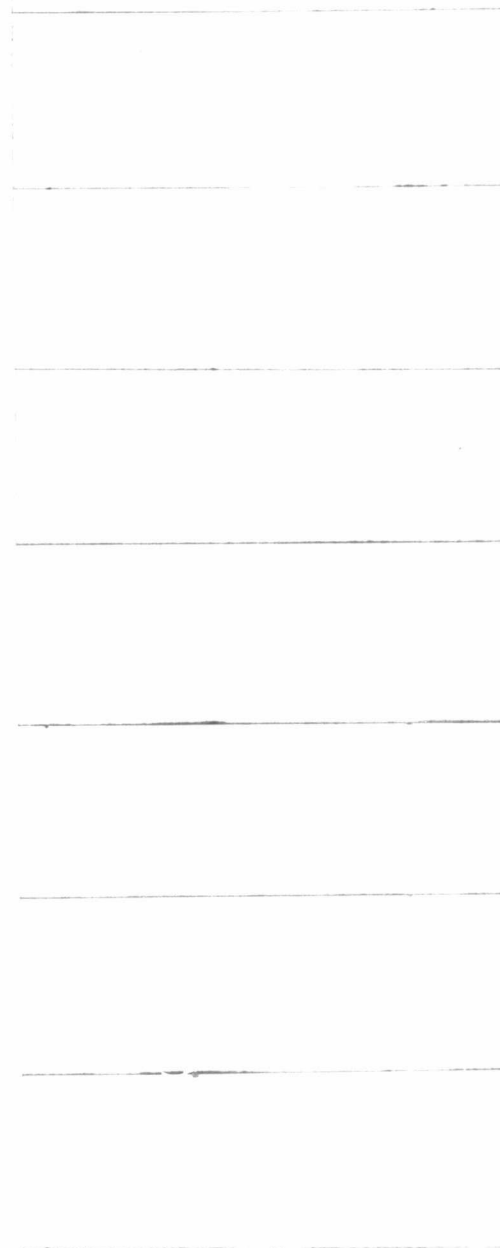
Figure 21. Known trails in the Umiat area. Arrow shows location of scar
visible on band 5 image of ERTS-1 scene 1004-21395.

The scars presently visible from the air will remain visible from the air for a few years after the physical effects of the disturbance have been healed (fig. 22). The principal indicator of trails is the presence of grasses in the tracks that are not present in surrounding terranes, giving the tracks a greener appearance. Old trails are difficult to see on the ground at present and in 5 to 10 years will probably not be visible on the ground (fig. 23).

On lightly bladed trails in which only the tops of the tussocks were removed, while the rhizomes were left intact, growth is resuming in the original tussocks, and they will attain their original size in 4 to 5 years.

Trails crossing ice-rich lowlands that have been heavily bladed are assuming the appearance of the beaded stream prevalent in the tundra, a linear vegetated depression with irregularly spaced water-filled potholes up to 6 feet where an ice wedge was exposed (fig. 24). The beaded lakes will probably enlarge to the size of the ice wedges exposed, but interlake parts of the trails are not becoming wider, and the trails are approaching a stable state.

Although vegetal damage along trails in ice-poor soils is slightly wider than the original vehicle track, this damage is not propagating, i.e., the trails are not becoming wider.

Hok noted one site near the Colorado Oil and Gas Company Gubik test well, where a bladed trail made since 1960 crossed a 10° slope in ice-poor silt. Reexamination in 1973 shows increased revegetation of the main scar (fig. 25, compare with Hok, 1969, photographs 29 and 32), increased revegetation of part of the silted area at the foot of the slope (Hok, 1969, photograph 30), and little active siltation at present, indicating a reduction and early cessation of active erosion.

The most striking example of scarring, which Hok apparently did not visit, occurs on the ridge north of Umiat. Here a heavily used cat trail, bladed bare of vegetation, leads up a 10° slope to the site of several drill holes. Not only was the trail bladed, but it was also used summer and winter during the 1945 to 1952 period and crosses the exposed area of a bentonitic shale formation. The trail has spread to a depression on the slope about 150 ft wide and up to 15 ft deep (fig. 26). This is the scar noted on Band 5 ERTS images of the Umiat area. Here, revegetation is proceeding, with felt-leaf willow, equisetum, and a grass (stipa) not noted elsewhere, indicating the onset of healing, although much more slowly than elsewhere.

Study of images of the area to the south and east where exploration activity has occurred since 1960 indicates that younger scars may be more apparent on ERTS images than the older scars in the Umiat area. To date these studies have all been visual inspection of imagery. No attempt has been made to employ computer enhancement techniques to identify less severe scars or changes in scars.

Figure 22. Old trails on hills near Umiat.

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Figure 23.   Old trail in ice-poor soil near Umiat seen from ground.
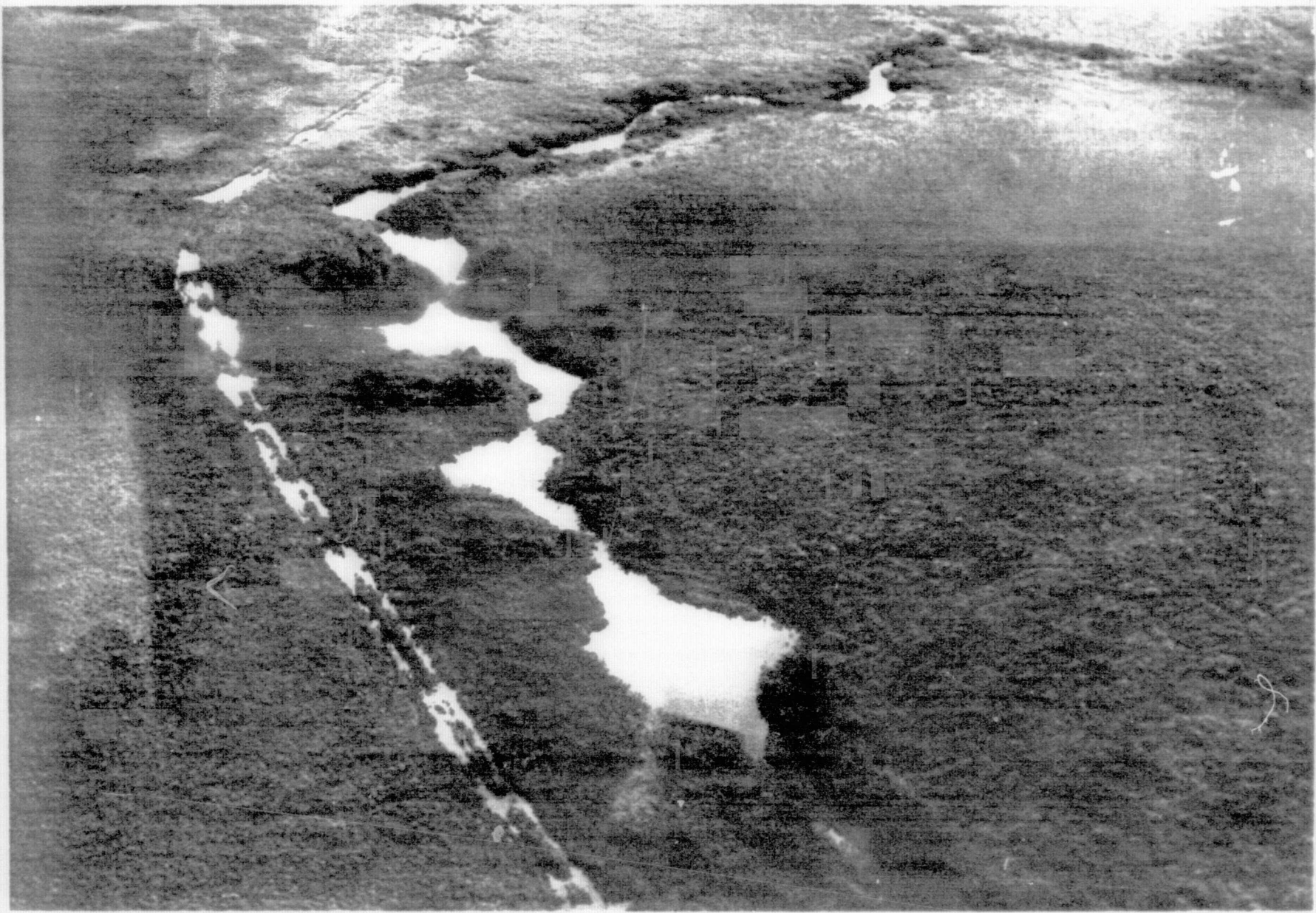
Figure 24. Trail across ice-rich lowlands assuming appearance of beaded stream on right.

42

Figure 25.   Scar formed by more recent activity than 1952.

43

Figure 26.   Severe scar on ridge north of Umiat.

CONCLUSIONS

The recognition of the scar north of Umiat on ERTS images indicates that if scars are large enough, or if they spread sufficiently to be resolved by ERTS sensors they can be recognized by use of ERTS data. Preliminary results of study of other images suggest that ERTS imagery can be used to identify young severe scars and monitor their healing.

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APPENDIX I

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