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

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16. Abstract

New mineral deposits have recently been discovered in eastern Alaska through application of a hypothesis very similar to one developed in interpretation of Nimbus and ERTS imagery in this investigation, that mineral deposits may be spatially related to a set of crustal linears. The discovery affirms the validity of this hypothesis and provides an additional exploration rationale to the mineral industry. Mosaics of ERTS images have provided additional data on this regional linear set and on other regional fault trends possibly related to mineralized areas.

A regional lineation in lakes near Umiat in northern Alaska, suspected to reflect structures in basement and suggesting areas of possible potential for new petroleum exploration, is found to cover a much larger area than previously suspected east of the Colville River, increasing the area of interest.

Further application of this same imagery exists in that environmental scars to the tundra resulting from previous ground exploration, if of large size, can be recognized and their natural revegetation monitored by use of ERTS imagery.

New geologic data obtained from ERTS images of lowland areas of western northern Alaska facilitates assessing the petroleum potential of this area. Use of the images in field mapping this summer permitted extrapolation of field observations.

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c. Statement and explanation of <u>any</u> problems that are impeding the progress of the investigation:

None.

d. Discussion of the accomplishments during the reporting period and those planned for the next reporting period:

During most of the reporting period the P.I. was involved in preparing for and giving presentations on the results of the investigation. These included:

1. Luncheon address "Worth of ERTS and other satellites in effective development of the environment," given at the Symposium on Environment and Resources of the Alaska Geological Society, Anchorage, September, 1973.
2. Requested presentation of use of ERTS imagery in geology and mineral resource investigation in Alaska to Committee on Polar Research, National Academy of Science, Boulder, Colorado in October, 1973.
3. Oral review of results of investigation SR-180 presented to NASA Geology Panel, Goddard Space Flight Center, October, 1973.
4. Invited address to Northwest Mining Association, Spokane, ERTS applications to Alaskan mineral resources, December, 1973.
5. Presentation of formal papers at Third ERTS Symposium, Washington, D.C., December, 1973:
    a. "Geologic Applications of ERTS Imagery in Alaska"
    b. "Analysis of State of Vehicular Scars on Arctic Tundra, Alaska."

Although the contract was scheduled to terminate formally November 6, 1973, studies have continued beyond that date in fulfillment of the planned investigation for the US/USSR Cooperative Program on Remote Sensing. A preliminary report on those results to date has been prepared and is here included.

A request has been submitted to NASA for the continuation of the investigation beyond its termination date to August 1, 1974, still as an unfunded project but with provision of data.

In the ensuing months, effort will be directed toward further study of the relationship of ERTS linears to subsurface information to refine and augment the preliminary conclusions, and to relate the regional linear system thus far identified to tectonic features of Alaska and to current hypotheses of history of continental development and deformation.

e. Discussion of significant scientific results:

Significant scientific results of the last six months are embodied in the two papers given at the Third ERTS Symposium (see d above) and in the attached report "Preliminary Results of Comparison of Space Image Linears to Subsurface Geology in Alaska," by Ernest H. Lathram and Nairn R. Albert.

f. A listing of published articles, and/or papers, preprints, in-house reports, abstracts of talks, that were released during the reporting period:

Gryc, George, and Lathram, E. H., 1972, Identification of geostructures of continental crust, particularly as they relate to mineral resource evaluation: U.S. Dept. Commerce, Natl. Tech. Inf. Service, NASA-CR-133154, 7 p.

______, 1973, Identification of geostructures of continental crust, particularly as they relate to mineral resource evaluation: U.S. Dept. Commerce, Natl. Tech. Inf. Service, NASA-CR-133881, 10 p.

______, 1973, Identification of geostructures of continental crust, particularly as they relate to mineral resource evaluation: U.S. Dept. Commerce, Natl. Tech. Inf. Service, NASA-CR-133820, 3 p.

Lathram, E. H., 1973, Interpretation of lineaments observed on a 1971 satellite photograph of Alaska and western Canada: Geol. Assoc. Canada, Proc., v. 25, p. 13.

______, 1973, ERTS applications to Alaskan Mineral Resources; Invited talk given at Northwest Mining Association Meeting, Spokane, Washington, December 8, 1973.

______, in press, Geologic applications of ERTS imagery in Alaska, in Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Third: Nat. Aeronaut. Space Admin., Washington, D.C., December, 1973.

______, in press, Analysis of state of vehicular scars on Arctic tundra, Alaska, in Symposium on Significant Results Obtained from Earth Resources Technology Satellite-1, Third: Nat. Aeronaut. Space Admin., Washington, D.C., December, 1973.

g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and/or results as related to a maximum utilization of the ERTS system:

None.

h. A listing of date of any changes in Standing Order Forms:

None.

i. ERTS Image Descriptor forms:

None.

j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDPF during the reporting period:

None.

PRELIMINARY RESULTS OF COMPARISON OF SPACE IMAGE LINEARS TO SUBSURFACE GEOLOGY IN ALASKA

Ernest H. Lathram and Nairn R. Albert

ABSTRACT

Examination of Nimbus images revealed a set of linears that was previously unrecognized in Alaska. ERTS images show these and many other linears clearly. In areas studied to date, a regional system of linears trending north, east, northwest and northeast has been consistently identified. Linears of this system correlate exceptionally well with trends of magnetic and gravity anomalies in the area north and east of Umiat and with trends of magnetic anomalies in the Yukon-Tanana Upland, suggesting that these linears reflect subsurface geologic structure. The convex-north pattern of the major arcuate faults of southern and central Alaska seems due to late movement guided by a northwest- and northeast-trending regmatic set of older crustal flaws. Trends of linears in the shape and orientation of lakes in lowland areas correlate well with the trends of the major system, suggesting that the orientation and shape of the lakes is also due to subsurface structure, rather than wind direction as previously supposed.

INTRODUCTION

Examination of an image of Alaska taken by the Nimbus IV Image Dissecter Camera System revealed the existence of a previously unrecognized orthogonal set of northwest- and northeast-trending linears that may reflect crustal structures (Lathram, 1972). Study of ERTS imagery has been undertaken to identify these and other regional linears, determine their pattern, relate their distribution to subsurface structure, and analyze their significance in terms of various theories of the tectonic history of Alaska, and of continental mobility and crustal deformation in general.

Studies to date have been focused on:

1. A regional determination of the pattern of orientation in lakes in lowland areas of central and northern Alaska.
2. A comparison of prominent linears in the Umiat area (fig. 1) with known surface structures and with seismic, magnetic and gravity data.
3. A determination of the pattern of linears in the Yukon-Tanana Upland and adjacent area (fig. 1) and a comparison of these linears with magnetic data.

This report presents preliminary results of the above, and some tentative conclusions that these results suggest. Study of these and other areas is continuing.

ORIENTATION OF LOWLAND LAKES

A qualitative analysis of the trend of rectilinear shores of lakes in lowland areas of central and northern Alaska, and of alignment of lakes and interlake areas reveals a relatively consistent pattern of north, northwest, northeast and east trends (fig. 2). Estimates of the order of prominence are subjective and no attempt has been made to measure the relative importance of the various trends in terms of numbers of linears or combined lengths of linears.

No single trend is dominant in all areas, and some of the trends vary slightly in azimuth from area to area. In northern Alaska, west of the Ikpikpuk River (approximately 1° W) a dominant northerly trend is expressed by an average N 9° W elongation of lakes (Black, 1969). To the east of this line, an orthogonal easterly linear trend in the lake area is dominant (Lathram, in press). Numerous workers concur that the northerly elongation of lakes is due to erosion at right angles to the prevailing wind direction (Black, 1969). 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.

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. However, the analysis of sparse data on subsurface structure is incomplete.

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

ANALYSIS OF LINEAR TRENDS IN 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.

Lineations Suggesting Geologic Structure

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, recorded on Orbit 44, July 27, 1972 (fig. 3).

The linears are expressed as: (1) straight nearly east-trending alignments of small lakes, of distortions in the shorelines of larger lakes, and of linear areas between groups of lakes; and (2) curvilinear alignments of small lakes, locally enclosing large elliptical areas. A similar easterly linear trend in the lakes near the Sagavanirktok River was noted concurrently by R. L. Detterman (oral commun., 1972) in his examination of a mosaic consisting of a very large number of aerial photographs.

Evidence of Geologic Structure

Study of geological and geophysical data in the area of ERTS-1 image 1004-21395 suggests that the east-trending linears are expressions of concealed geologic structures beneath the Gubik formation.

Although the alignment of some lakes, particularly those at the southern margin of the plain near the Colville River (fig. 3) 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. The geological and geophysical evidence of control by subsurface structure is as follows:

1. Parallel deflections in axial trends of exposed folds. The axes of most folds mapped in Cretaceous rocks exposed in the northern foothills, trend northwest. However, 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 and is parallel, or nearly parallel, to the trend of the straight linears (fig. 4). In some more southerly folds, axial trends change from northwest to west, and back to northwest along the structure, accentuating the suggestion of a divergent structural control parallel to the linears.

2. Seismic data in shallow Cretaceous rocks. Seismic-reflection data are sparse in the area of linears, except for a small detailed study in the western part of the area (fig. 4). Structural contours drawn on a phantom horizon in shallow Cretaceous rocks underlying the eastern part (Woolson and others, 1962) suggest a smooth easterly dip, but are based on seismic profiles more than 20 miles apart. A similar regional dip is indicated by the contours of another phantom horizon under the western part. The more detailed contours of the western area show numerous deflections, however, suggesting small reversals superimposed on the regional dip. The individual profiles of two seismic lines that cross the eastern and western ends of the large elliptical area show comparable repeated dip reversals (U.S. Geological Survey, 1957). Although the seismic lines are too far apart for correlation, they suggest regional, nearly east-trending structures, spread apart on the order of several miles, with flanking dips of 1° - 4°. Most of the seismic data are confined to the upper 4,000 - 6,000 ft of strata.

3. Parallel trends in magnetic anomalies. A contour map of magnetic intensity from Woolson and others (1962, plate 3) shows three areas of magnetic anomalies with differing trends (fig. 5). In the most southerly, area "A", trends of anomalies vary progressively from northwest in the east to north in the center and to northeast in the west. In area "C", in the north, anomalies trend northeast. Between these areas is area "B", in which 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. Par~~e~~allel deflections in gravity contours. The pattern of deflections in contours of an observed gravity map (Woolson and others, 1962, plate 2) in the area also shows a trend parallel to that of the straight linears (fig. 6). The suggested line separating areas "A" and "B" on the magnetic contour map, figure 4, generally lies along deflections in gravity contours or alignments 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.

Extent of Lineated Area

If the linears are controlled by geologic structure, the total extent of the area characterized by linears is significant. It is possible to delineate a northern boundary of the lineated area. This boundary trends east along the southern shore of Teshekpuk Lake (fig. 5) and nearly coincides with the boundary between aeromagnetic anomaly areas "B" and "C" as shown by Brosgé and Tailleur (1971) in this area.

Not only do the linears in the lake area parallel the alignment of magnetic anomalies in the area of image 1004-21395, but also the total area of lineations west of the Colville River, including the area of the image, seems to coincide with an area of distinctive aeromagnetic anomalies.

East of the Colville River, the area of east-trending linears extends to the Canning River. However, published magnetic or gravity data ~~is~~ are not available for this area.

Discussion

The parallelism of deflections in trends of known folds, of alignment 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 4,000 - 6,000 ft of strata, whereas the gravity and magnetic data probably reflect basement character and morphology, at depths ranging from 15,000 to 20,000 ft in this area. The pattern of linears and of local seismic reflectors and regional seismic contours suggests minor regionally linear crenulations superimposed on a broad gentle dome, or the nose of a broad 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 décollement 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 décollement 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 commun., 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.

ANALYSIS OF LINEAR TRENDS IN YUKON-TANANA UPLAND AREA

Setting

The physiographic and geologic setting has been most succinctly stated by Foster and others (1973). "The Yukon-Tanana Upland is a hilly and mountainous region about 30,000 sq mi (77,700 sq km) in area which lies between the Yukon and Tanana Rivers."

"The Yukon-Tanana Upland is primarily a region of complexly deformed metamorphic rocks which have been intruded by Mesozoic batholiths and smaller Mesozoic and Tertiary plutons. However, in the northwestern part of the upland there is a sequence of sedimentary and metasedimentary rocks of Precambrian (or Cambrian) to Tertiary age along with felsic to mafic intrusive bodies. Thus, the upland consists of two different parts--a metamorphic complex in the eastern and central part and the relatively unmetamorphosed northwestern part.

"The southern physiographic boundary of the Yukon-Tanana Upland is the Tanana River. It separates the upland from the Alaska Range and is possibly a structural boundary as well, because, in places in the Tanana valley, there is geomorphologic evidence of faulting. However, metamorphic and granitic rocks similar to those in the upland are present in the Tanana valley and south of it in the Alaska Range, and the most distinct change in lithology is south of the Denali fault system. The Denali fault system separates the metamorphic rocks on the north from mostly unmetamorphosed late Paleozoic and Mesozoic rocks on the south. Little is known about the kind and time of movement along this sector of the Denali fault, but topographic expression and offset of topographic features and rock formations suggest right-lateral movement, possibly mostly in Tertiary time. Fresh local scarps also indicate some Holocene vertical movements.

"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 unmetamorphosed or relatively unmetamorphosed rocks. Right-lateral movement along the Tintina fault zone has been postulated by Roddick (1967, p. 28), largely on the basis of geologic relations in Canada. He estimated that there may have been 40 mi (64 km) of lateral offset in Paleozoic time and an additional 220 mi (354 km) in Mesozoic time. Several faults have been mapped in the northwestern part of the upland, one or more of which may indicate an extension of the Tintina fault zone."

Linears Suggesting Geologic Structure

ERTS images of the Yukon-Tanana Uplands clearly show a multiplicity of linears, many more than had been previously suspected, and of a more consistent and extensive pattern than previously recognized. Analysis of these linears was enhanced by the availability of an outstanding mosaic at 1:1,000,000 scale assembled by the Soil Conservation Service, U.S. Department of Agriculture (fig. 7).

Linears in the Yukon-Tanana Upland and adjacent areas have been divided into two classes--regional linears many hundreds of kilometers long (fig. 8), and short linears 160 km (100 miles) or less in length. Because the trace of many of the regional linears is defined by a mixture of criteria, such as topographic alignments, drainage courses, lines of tonal change and vegetal changes, no attempt was made to quantify the relative importance of their trends. A qualitative analysis of the approximate trends of these linears shows a grouping of vectors around N 80° E, N 55° E, N 35° W and N 55° W. The shorter linears are dominantly indicated by straight drainage trends, and a quantitative analysis of these was made (fig. 10) in which the length of each vector is proportional 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.

Relation of Linears to Magnetic Field

A contour map of the total magnetic intensity of the area (Brosgé 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 major linears to the trends of the magnetic anomalies is striking. 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. Northerly trending linears, although widespread, are limited in length to less than 160 km.
5. A significant alignment 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 on the Nimbus image.
6. Magnetic anomalies do not seem to be disposed in smooth arcuate north-convex curves, parallel to the trend of the Denali fault. Rather, the anomalies tend to be linear and are aligned along two straight intersecting trends, or are irregular in shape, suggesting the presence of both trends and a resulting interference.

Discussion

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

Linears seen in the surrounding lowland lake areas (fig. 2) correlate well with the major linears observed in the Yukon-Tanana Upland (fig. 10), 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 Yukon-Tanana Upland.

The virtual absence, in the area north of the Denali fault, of convex-north arcuate major linears and magnetic anomalies that parallel this fault, suggests that the movements postulated for the fault may have been controlled by buried and presumably older intersecting geologic structures trending northwest and northeast.

CONCLUSIONS

A regional system of northwest-, northeast-, north-, and east-trending major linears can be consistently identified in all the areas studied. These linears correlate well with magnetic and gravity anomalies in the Umiat area, and with magnetic anomalies in the Yukon-Tanana Upland area, suggesting that these linears reflect subsurface structure. Trends of linears reflecting the shape and orientation of lakes in lowland areas of central and northern Alaska correlate well with the trends of the system of major linears. As this system seems to reflect control by subsurface structure, the shape and orientation of the lakes may also be due primarily to subsurface structural control rather than wind direction as previously supposed.

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Woolson, J. R., and others, 1962, Seismic and gravity surveys of Naval Petroleum Reserve No. 4 and adjoining areas, Alaska: U.S. Geol. Survey Prof. Paper 304-A, 25 p.

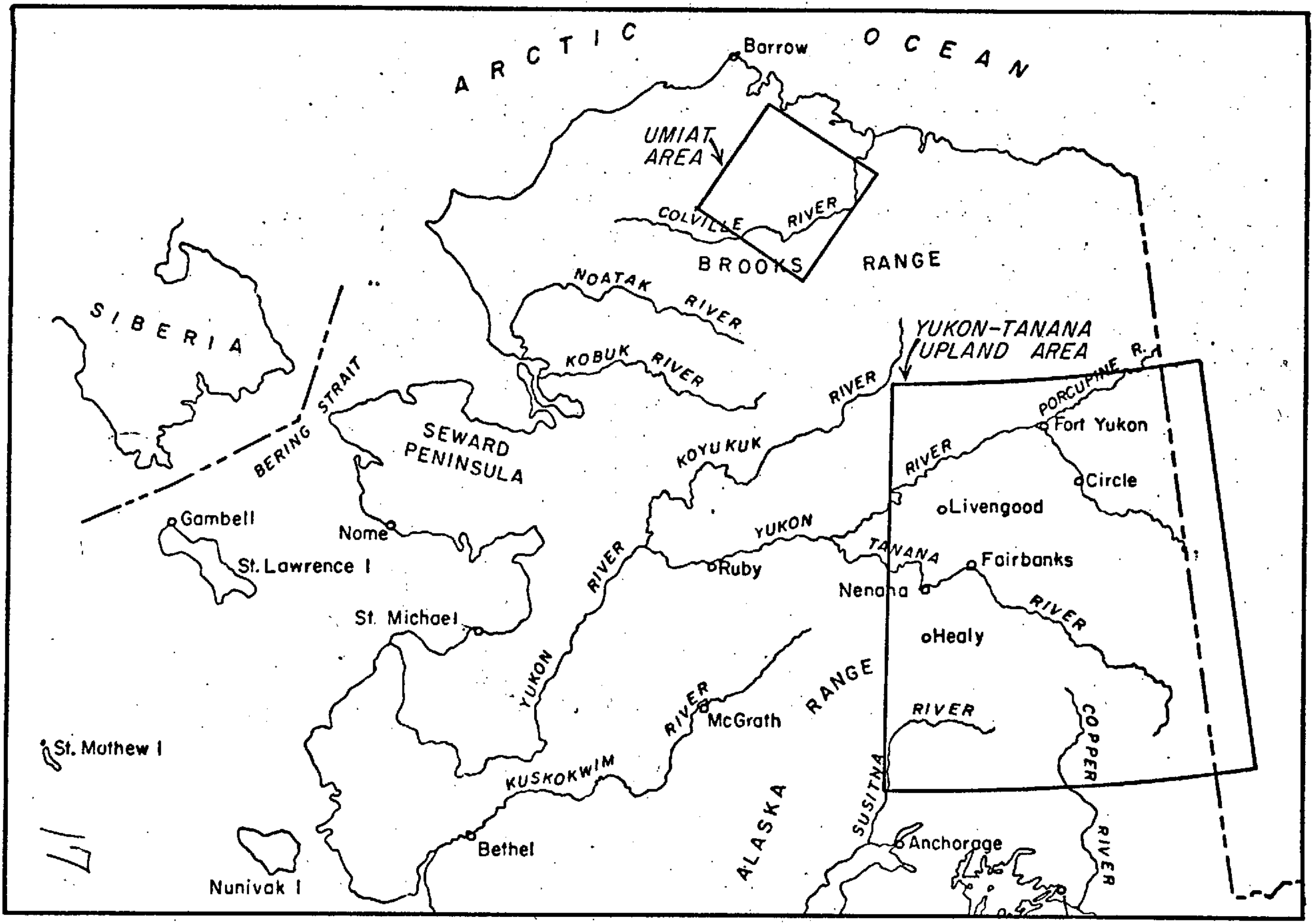


Figure 1. Index map of northern and central Alaska showing location of areas of study.

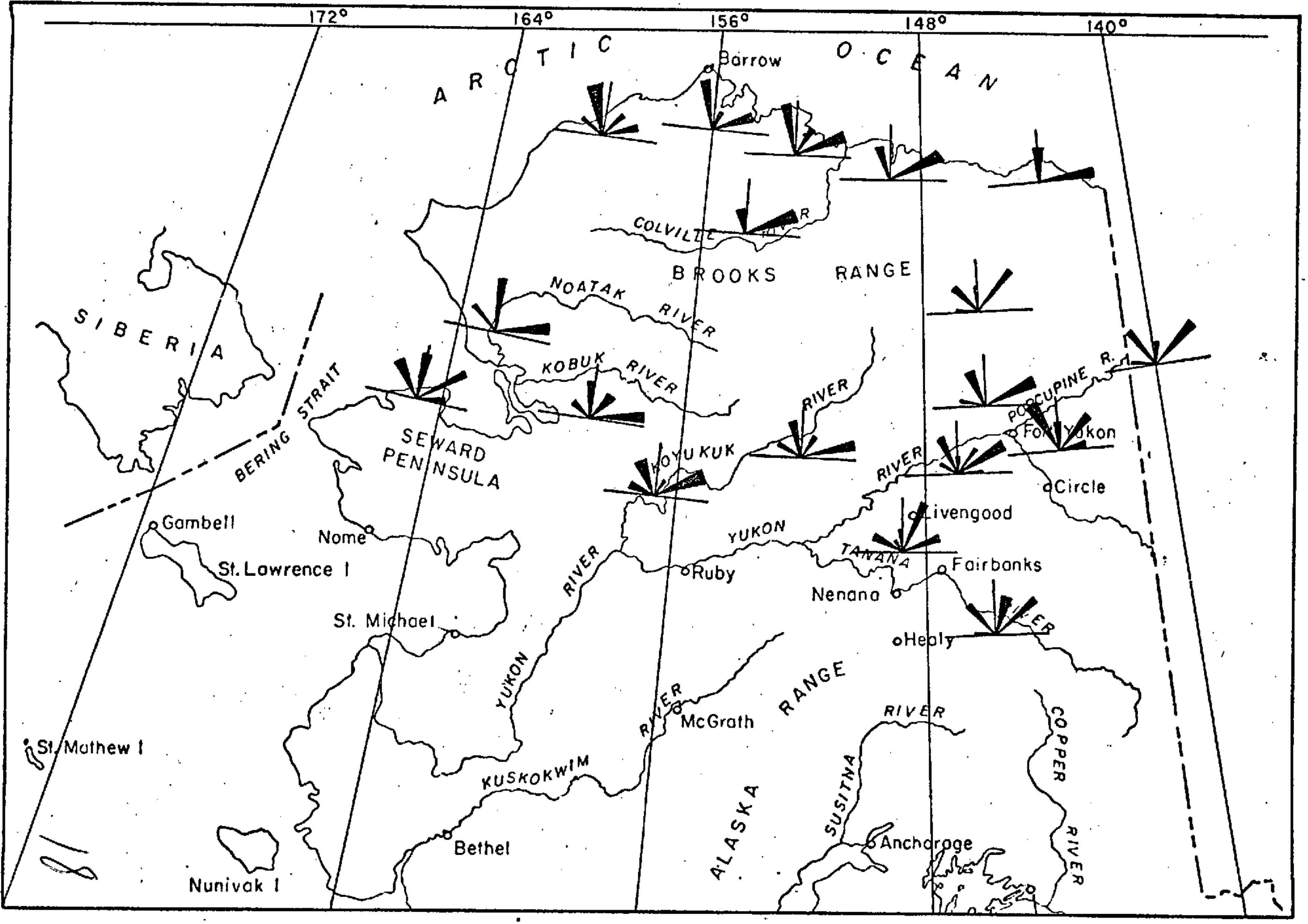


Figure 2. Map qualitatively showing linear trends in shape and alignment of lakes in northern and central Alaska.

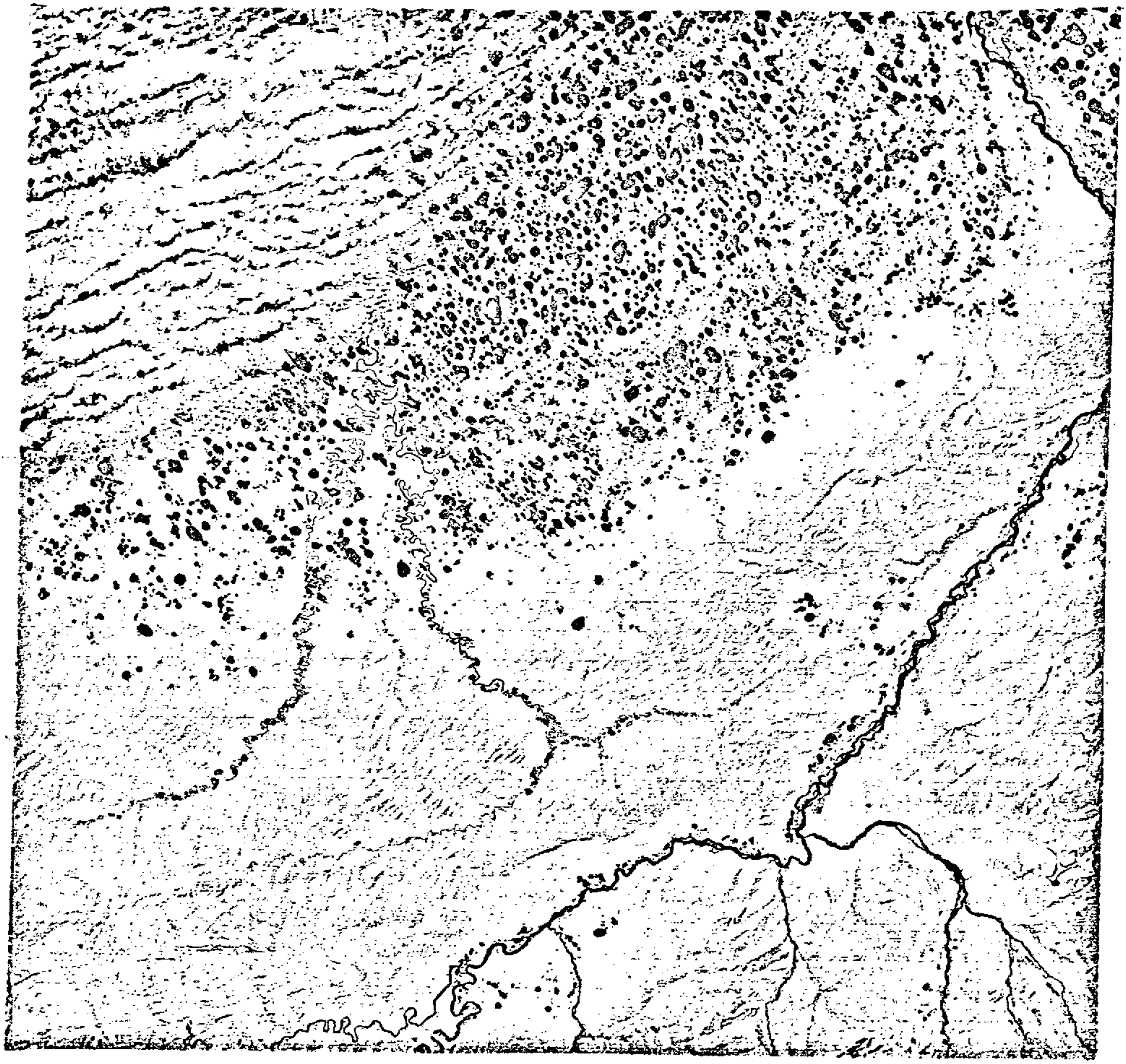


Figure 3. ERTS image (1004-21395) of Umiat area, band 7. Lakes are in black.

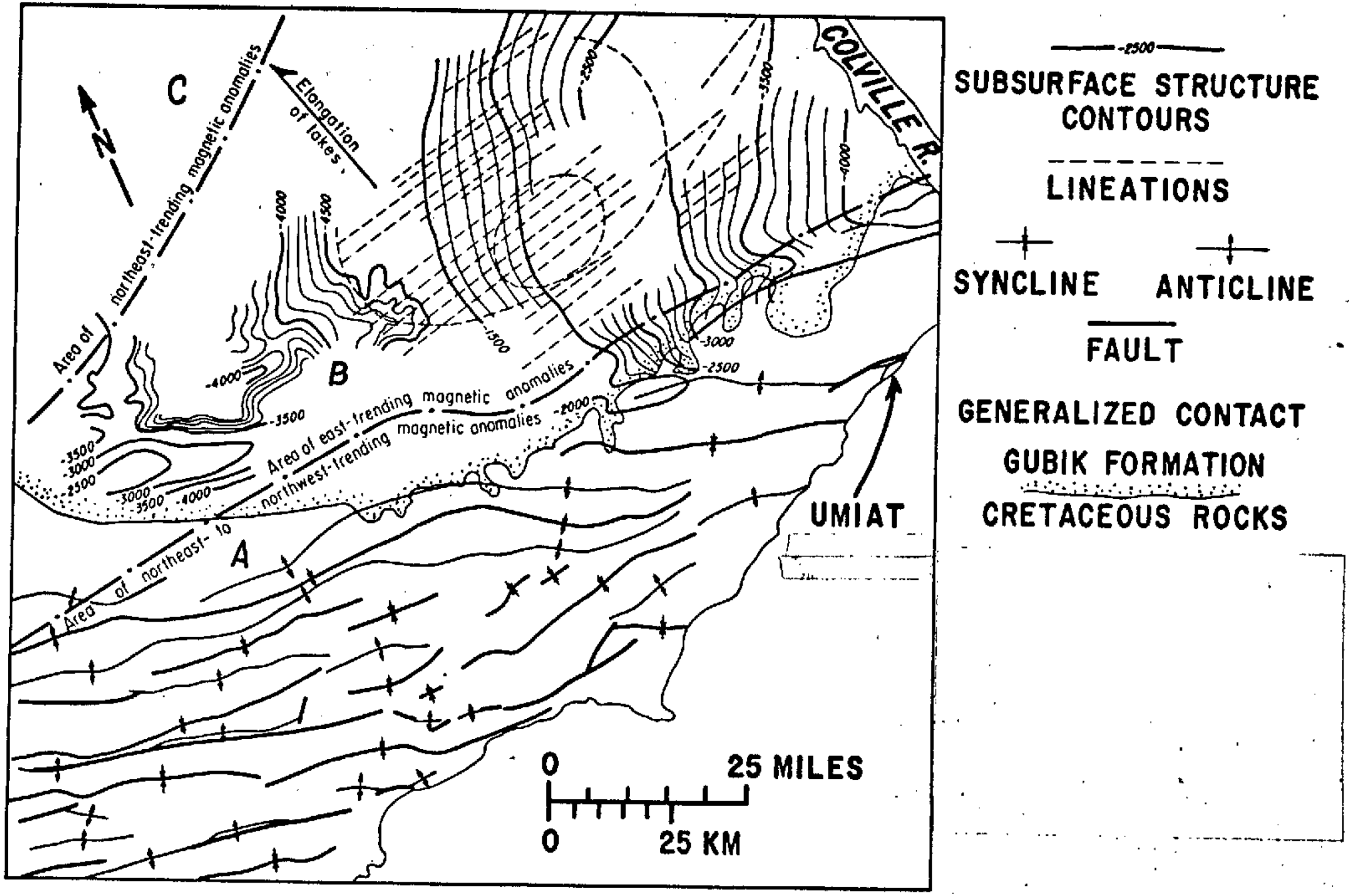


Figure 4. Map showing geologic features in the Umiat area.

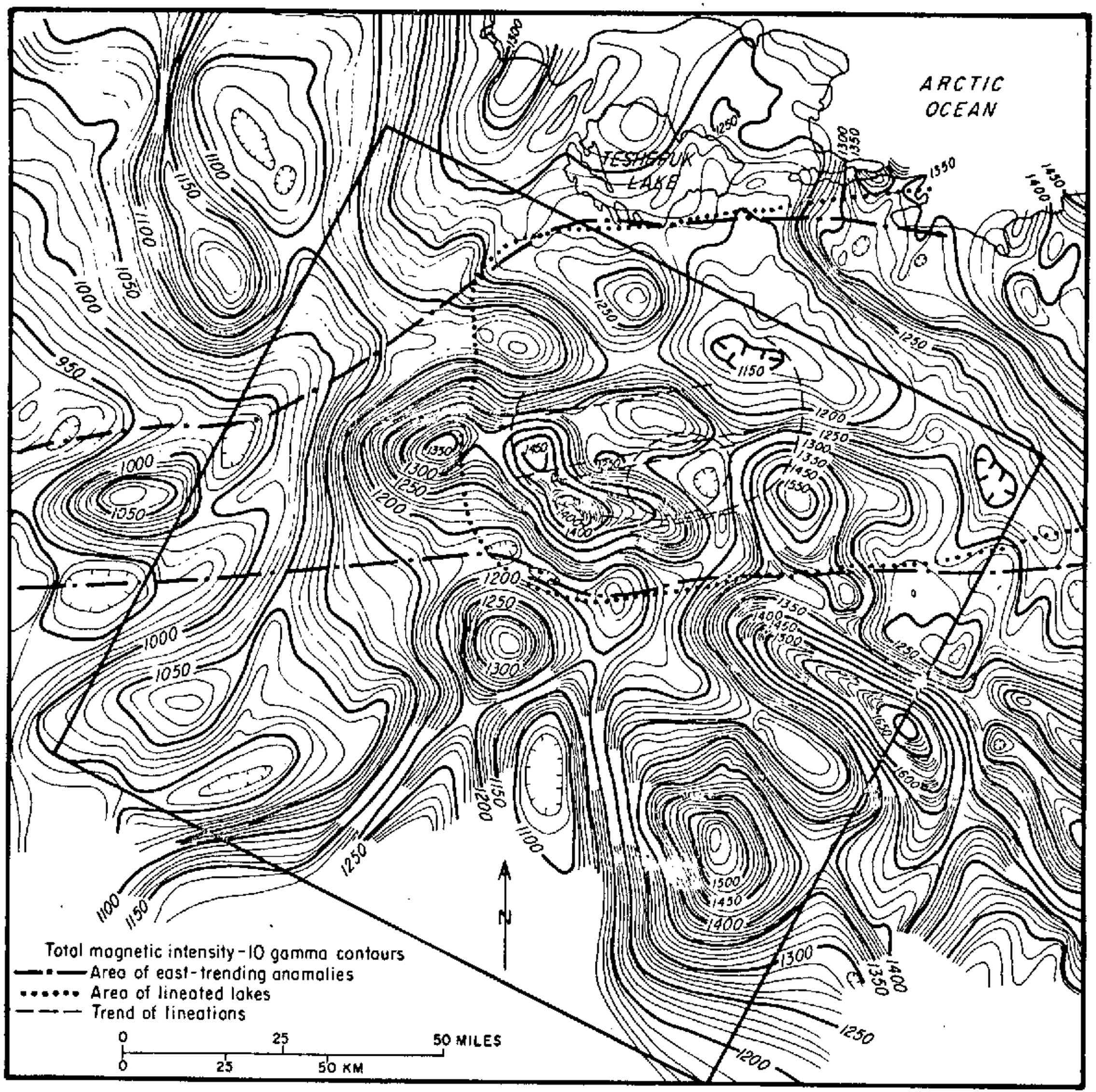


Figure 5. Map showing total magnetic intensity in the Umiat area (after Woolson and others, 1962), area covered by ERTS image, area of east-trending anomalies and lineated area.

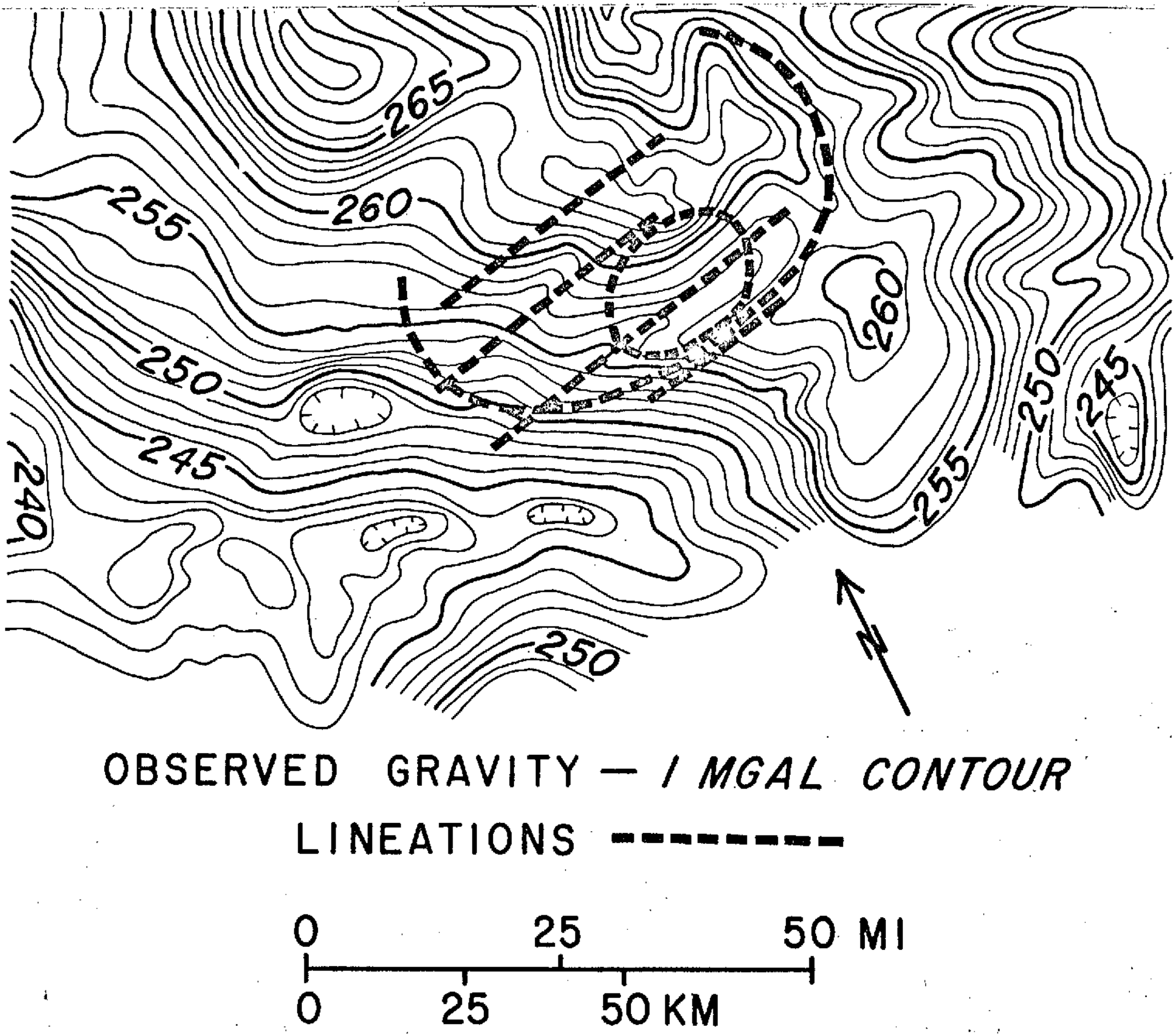
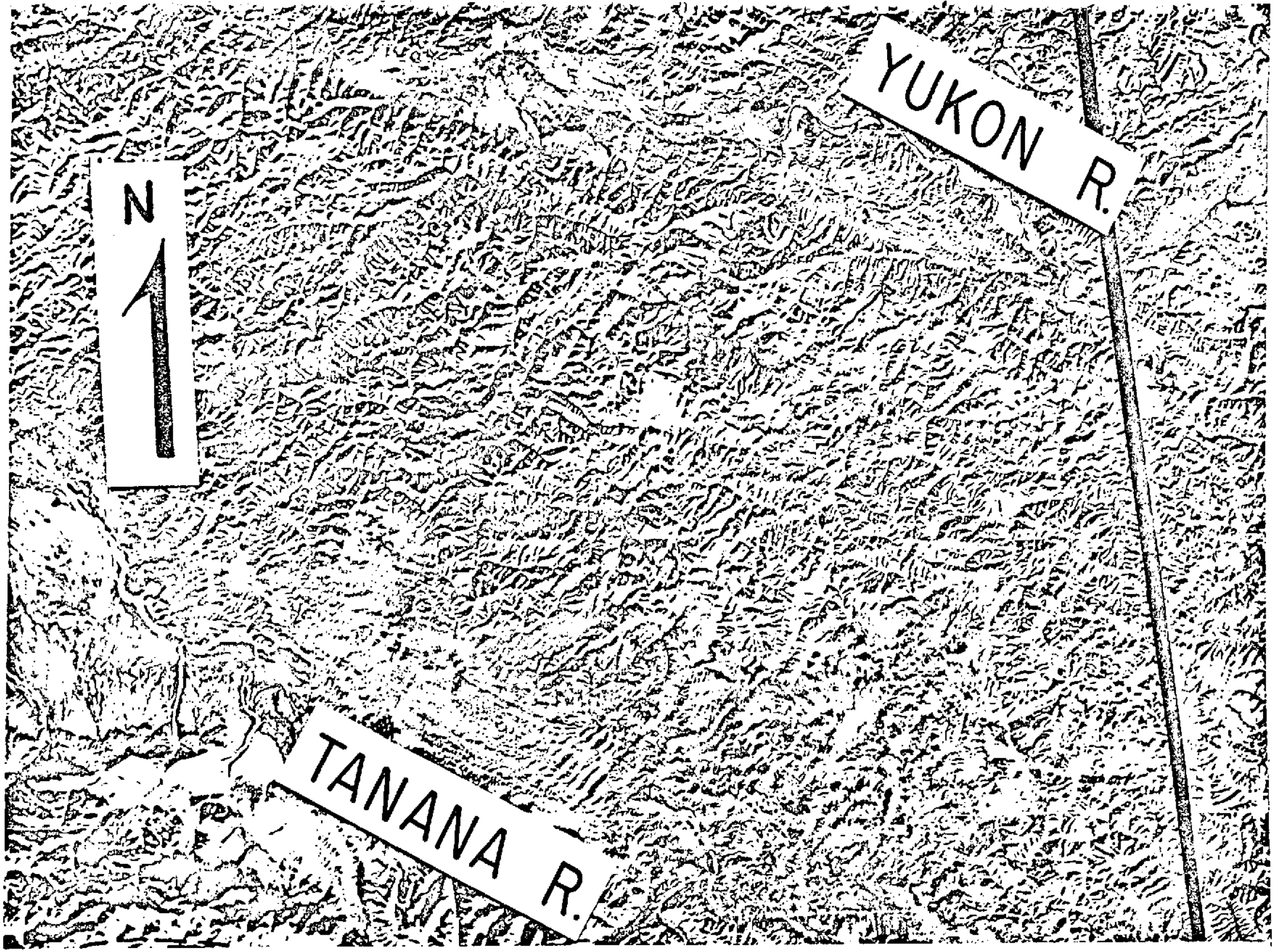


Figure 6. Map showing observed gravity in the Umiat area (after Woolson and others, 1962).



23

Figure 7. ERTS mosaic of Yukon-Tanana Upland area (Mosaic by U.S. Department of Agriculture).

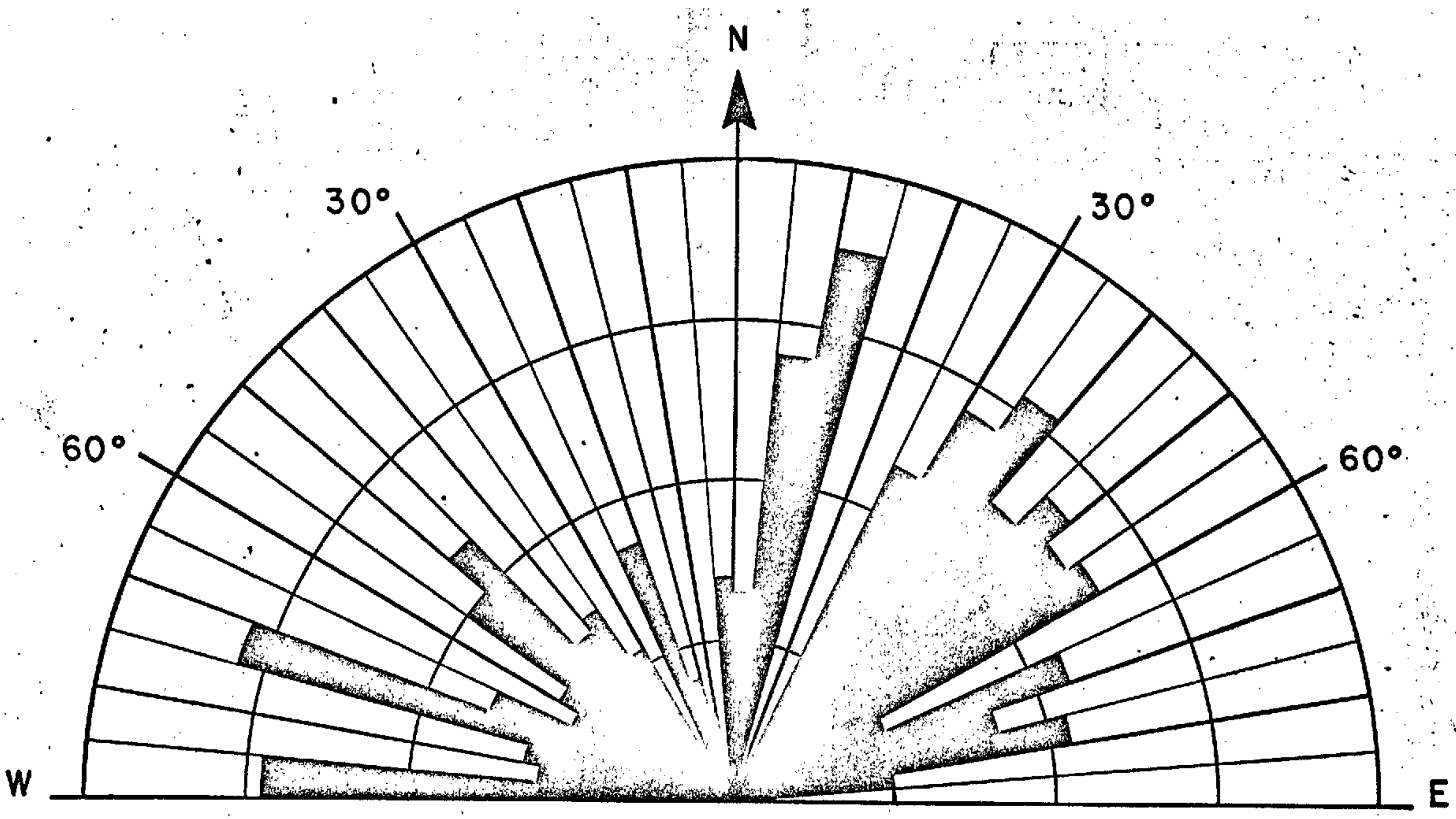


Figure 10. Compass rose showing trends of linears less than 160 km (100 miles) in length in the Yukon-Tanana Upland area. Length of vectors is proportional to the sum of lengths of linears having the same orientation.

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