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GEOLOGICAL SURVEY

COMPUTER-ENHANCED LANDSAT IMAGERY AS A TOOL FOR MINERAL EXPLORATION IN ALASKA

By

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Abstract

Recent work in the Nabesna and McCarthy quadrangles, Alaska, indicates that computer-enhanced LANDSAT imagery shows many of the known mineral deposits and can help in the prediction of potential mineral occurrences. False color, "simulated natural color" and color ratio techniques, were used successfully in conjunction with a black and white, single band photomosaic of Alaska. Computer techniques involved 2 stages of digital image processing: 1) atmospheric and sun elevation corrections, noise removal, computer mosaicking and change of the data format; and 2) image enhancement, involving data manipulation for maximum discrimination of surface materials and structure. Application of a new technique called a "sinusoidal" stretch gave information not available in other products having standard contrast stretches. We identified several orthogonal sets of linears and found parallel linears to be regularly spaced at approximately 30-35 km intervals. The locations of known mineral occurrences correlate well with the linears. Extensions of known faults and possible locations of hidden intrusive bodies were identified. Analysis of numerous areas of anomalous light reflectance showed that most are associated with known mineral occurrences, altered zones or geochemical anomalies, whereas some are not and may represent unexplored altered zones or mineralized areas worthy of future exploration.

INTRODUCTION

Recent work carried out in the Nabesna and McCarthy quadrangles, Alaska, under the Alaskan Mineral Resource Assessment Program (AMRAP) indicates that LANDSAT data can significantly help detect and predict mineral occurrences, when used in conjunction with geologic mapping, geochemical sampling, aeromagnetic and gravimetric data. LANDSAT data can also provide additional geological and structural information relevant to mineral exploration that may not be acquired by other methods.

This report presents the results of LANDSAT data interpretation in the Nabsena quadrangle, Alaska (Albert, 1975) and the preliminary results of similar interpretations in the McCarthy quadrangle, Alaska and their significance to mineral exploration.

Location

The Nabesna and McCarthy quadrangles are located in south-central Alaska (fig. 1). The quadrangles are bounded on the north and south by the 63°N and 61°N latitudes and on the west by 144°W longitude. The eastern boundary is the Alaska-Canada border (141°W longitude).

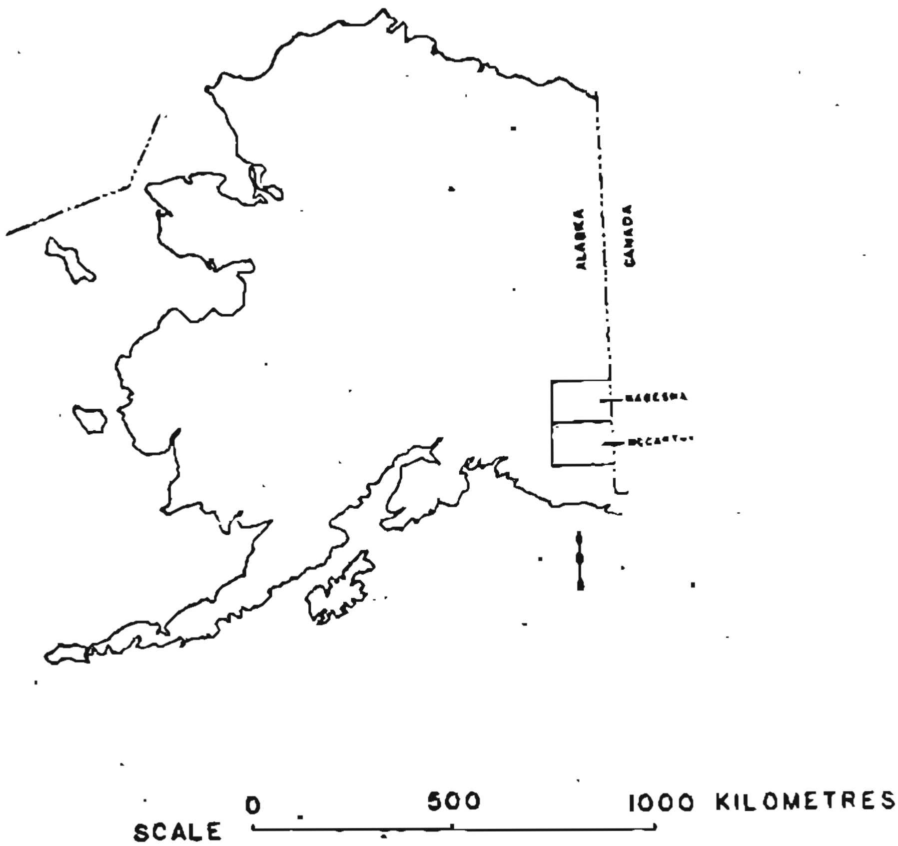


Figure 1. Map of Alaska showing location of the Nabesna and McCarthy quadrangles.

Physiography

Topographic extremes in the area studied range from a low of about 305m (1000') in the western portion of the McCarthy quadrangle to a high of over 5000m (16,400') in the southeastern portion. The area can be divided into 3 types of terrain: 1) plains and lowlands from about 305m (1000') to 1220m (4000'), with heavy to moderate vegetation and few outcrops; 2) low mountains from about 915m (3000') to 1830m (6000'), with heavy to light vegetation and numerous outcrops in the higher elevations, 3) high rugged mountains from about 915m (3000') to over 5000m (16,400'), with moderate to no vegetation, numerous glaciers, heavy snow cover and extensive outcrops.

Temperatures in these quadrangles range from highs of over 38°C (100°F) during the summer to lows of less than -57°C (-70°F) during the winter. Much of the area is underlain by discontinuous permafrost.

Brief Geologic Description

The Nabesna and McCarthy quadrangles are underlain by three general geologic terrains which are separated by the Denali and Border Ranges faults (fig. 2). North of the Denali fault are mainly regionally metamorphosed lower Paleozoic sedimentary and subordinate igneous rocks. South of the Denali fault and north of the Border Ranges fault, there are three assemblages of extensive andesitic volcanic and associated sedimentary and intrusive rocks: Upper Paleozoic, Upper Mesozoic, and Upper Cenozoic. South of the Border Ranges fault are extensive Mesozoic flysch-type sedimentary deposits.

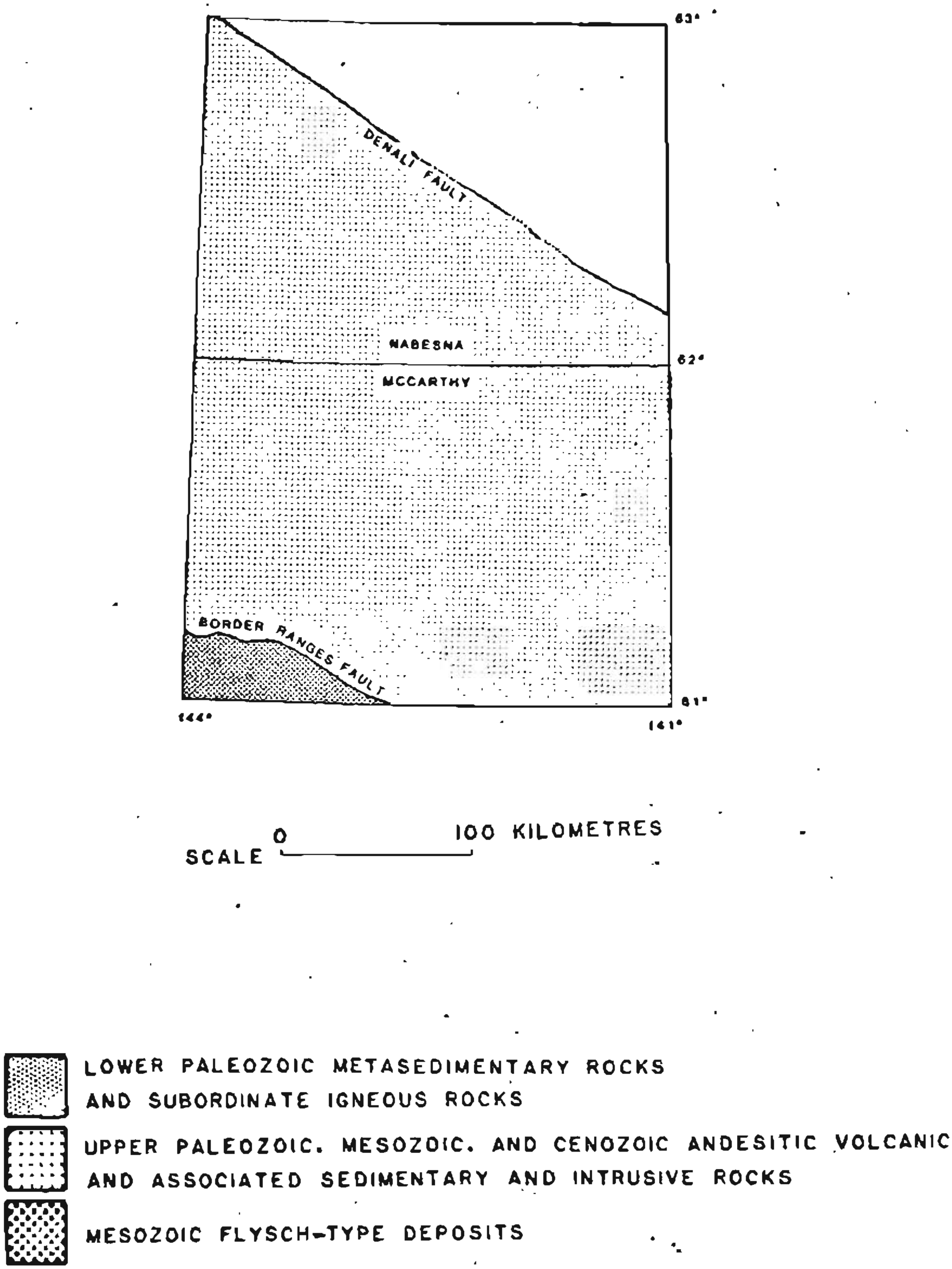


Figure 2. Map of the Nabesna and McCarthy quadrangles showing generalized geologic terrains.

Most mineral production in the Nabesna and McCarthy quadrangles has been in the area between the Denali and Border Ranges faults. These minerals have been chiefly copper, gold and silver (Richter and others, 1975, and MacKevett and Cobb, 1972).

INTERPRETATION OF IMAGERY

The study of 3 kinds of computer-enhanced LANDSAT imagery in conjunction with a single-band, black and white LANDSAT photomosaic of Alaska, resulted in; 1) the identification of linear and circular features and their correlation with known geology, mineral occurrences and geophysical data; and 2) the identification of mineral occurrences and numerous potential targets for future exploration.

Linear Features

One of the types of imagery used in this study was the Alaskan LANDSAT mosaic constructed in 1973 by the Soil Conservation Service, U.S. Department of Agriculture, using band 7 images generated without computer enhancement. Because of the synoptic perspective and low sun-angle of the non-summer images used, the mosaic was most useful for identifying linear and circular features. Additional linear and circular features were identified on the computer filtered imagery discussed later in this paper.

Three nearly othogonal sets of linears were identified in the Nabesna and McCarthy quadrangles (fig. 3). The predominant set trends approximately N43°W and N48°E, while the other sets trend approximately N72°W and N20°E and N87°E and north. Parallel linears trending N43°W, N48°E or N87°E are spaced approximately 30-35 km apart.

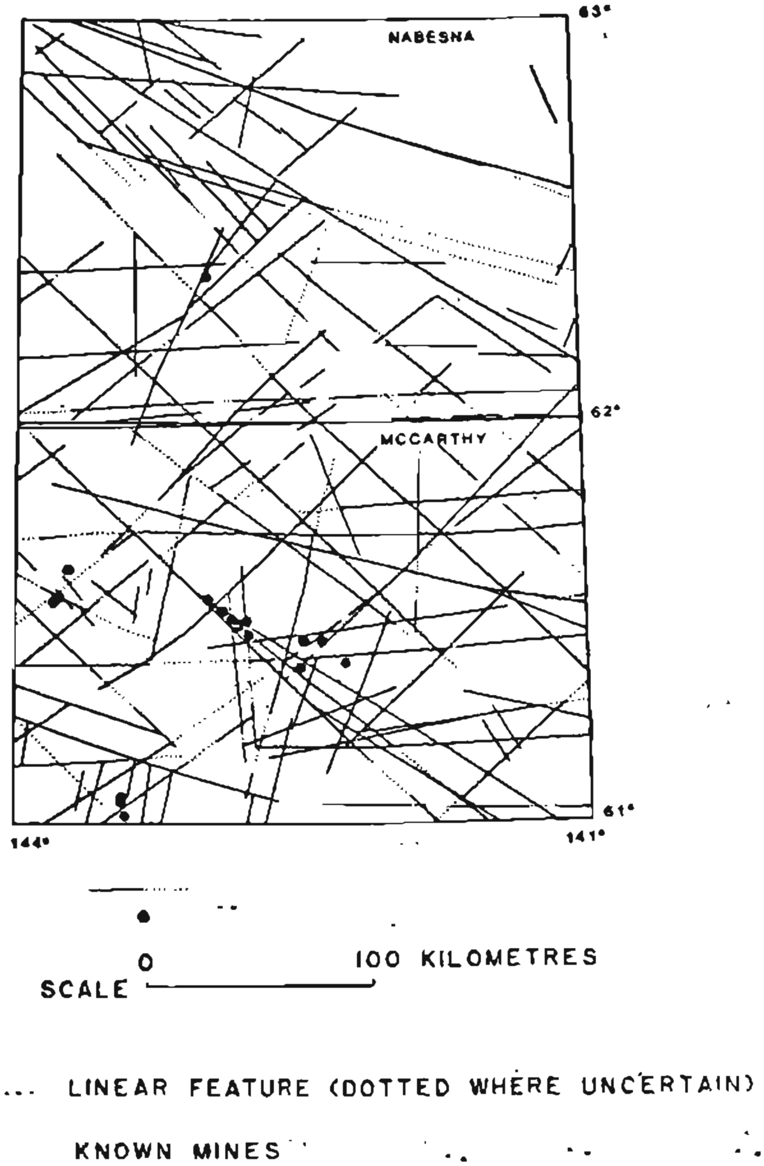
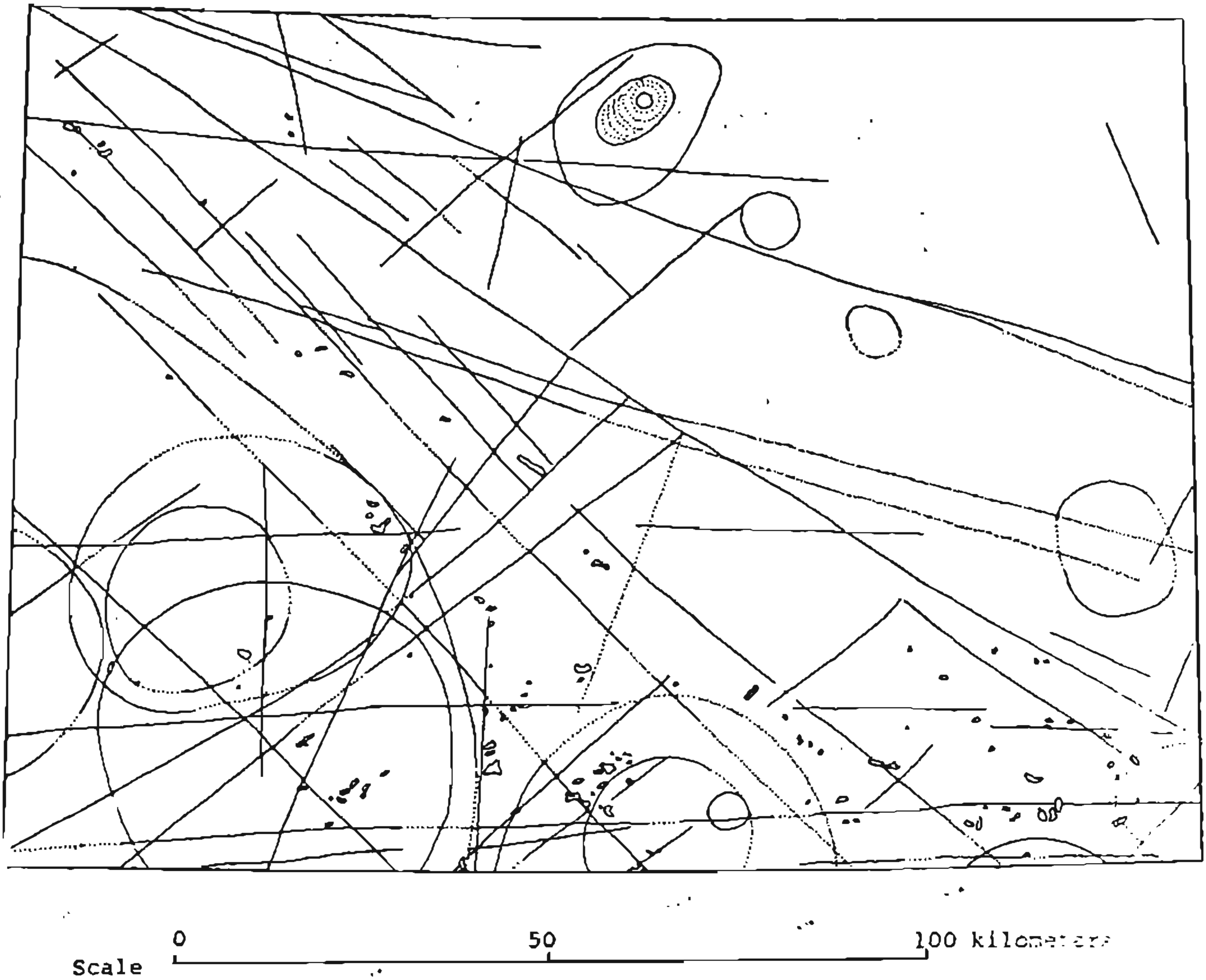


Figure 3. Map of the Nabesna and McCarthy quadrangles showing linear features and mine locations.

East-trending linear features can be seen clearly on LANDSAT imagery (figs. 3 and 4) suggesting the existence of major east-trending concealed structures in the Nabesna quadrangle south of the Denali fault. Aeromagnetic (Griscom, 1975) and gravimetric (Barnes and Morin, 1975) data support the LANDSAT interpretations. These east-trending structures can also be seen in the McCarthy quadrangle (figs. 3 and 5) on LANDSAT imagery and should be substantiated by future aeromagnetic and gravimetric studies.

The correspondence of known mineral occurrences to linear features in the Nabesna and McCarthy quadrangles is very good. There are a total of 257 known mineral occurrences (Richter and others, 1975; MacKevett and Cobb, 1972; MacKevett, unpublished), 141 (55%) of which occur within 1 km of linear features. Of these 257 known mineral occurrences, 124 are prospects or mines, 78 (63%) of which occur within 1 km of linear features. Of these 124 prospects or mines, 17 are mines, 14 (82%) of which occur within 1 km of linear features (fig. 3). These correlations suggest a strong relationship between linear features and the more significant mineral occurrences.

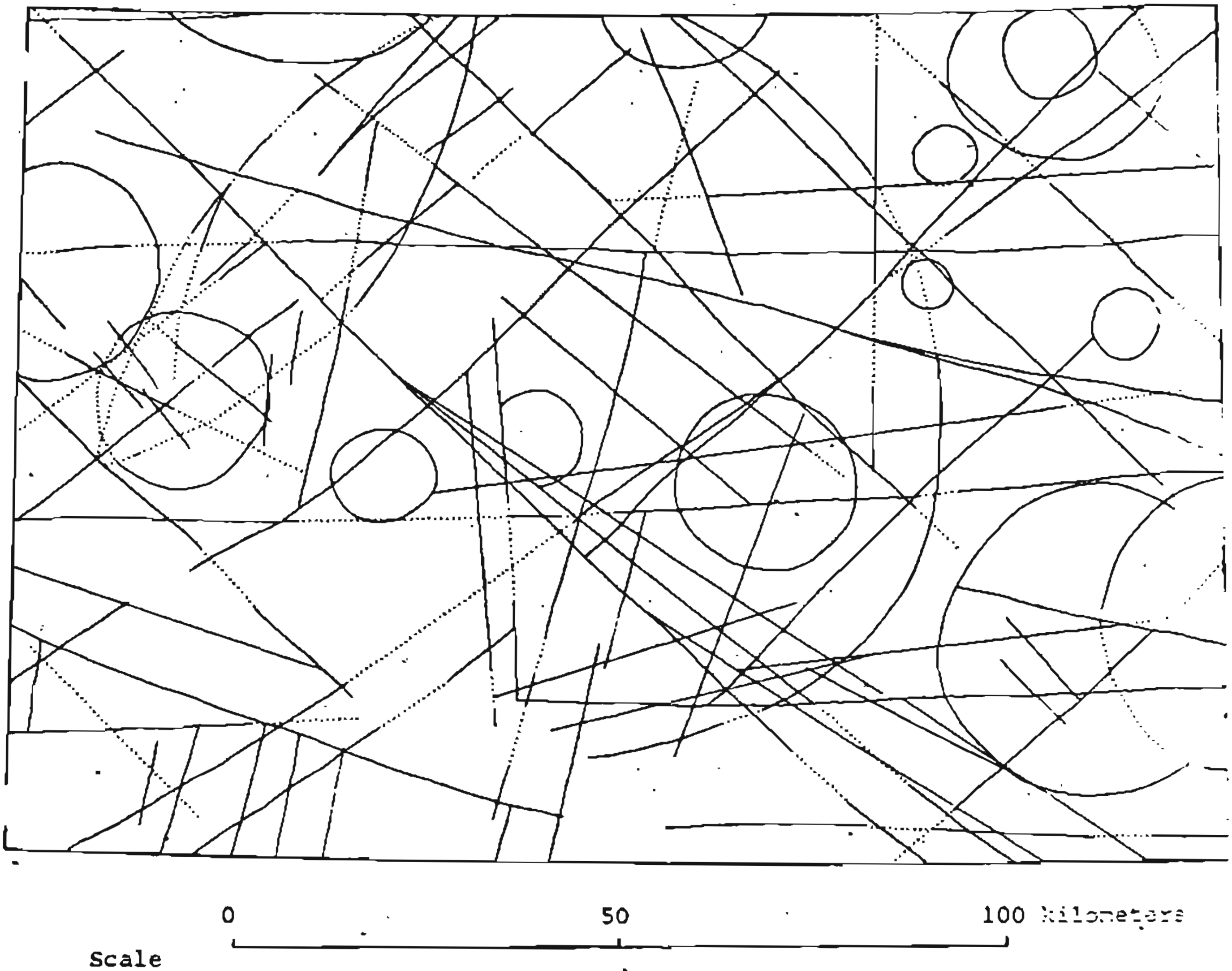
Statistically, the different mineral commodities in the McCarthy quadrangle appear to be related to specific orthogonal linear feature directions (table 1). For example, 34 out of 85 copper prospect and mine deposits, occurring within 1 km of a linear feature, are associated with northwest trending linears. Subordinately, 18 copper deposits are associated with northeast trending linears. This orthogonal relation also appears to be the case for silver, molybdenum, and perhaps antimony



——— .... Linear and circular features (dotted where uncertain)

Color anomaly

Figure 4. Map of the Nabesna quadrangle showing linear and circular features and color anomalies observed on computer-enhanced LANDSAT imagery. From Albert, 1975.



Linear and circular features (dotted where uncertain)

Figure 5. Map of the McCarthy quadrangle showing linear and circular features.

Linear Direction	E	WNW	NW	NNW	N	NNE	NE	ENE
Antimony	-	-	3	-	-	-	-	-
Copper	11	5	34	5	2	6	18	4
Gold	-	-	3	1	-	6	5	2
Molybdenum	-	-	2	1	-	-	-	-
Silver	-	-	9	3	-	-	3	1
Total	11	5	51	10	2	12	26	7

Table 1.--Number of significant mineral occurrences (mines and prospects), in the various linear directions in the McCarthy quadrangle, Alaska.

as well. Gold, on the other hand, occurs primarily near linears with north-northeast and northeast directions and subordinately near linears with northwest trends. Although not shown, chromium, iron, zinc, and nickel also appear to have preferred orthogonal linear direction associations.

Addition of the total number of significant mineral occurrences in each linear direction reveals three groupings: 1) northwest and northeast trending linears to which the most mineral occurrences are related; 2) north-northwest, north-northeast, and east trending linears; 3) west-northwest, east-northeast, and north trending linears to which the fewest mineral occurrences are related. Although the information is preliminary and incomplete, these trends are suggestive of the relationships resulting from the Moody and Hill (1956) model for primary, secondary, and tertiary fault and fold development in regions of wrench-fault tectonics.

Circular Features

Numerous circular features were identified in the Nabesna and McCarthy quadrangles (figs. 4 and 5). North of the Denali fault, these circular features can be correlated with aeromagnetic and geologic data, which suggest that these features may be related to concealed intrusive bodies. Those circular features observed between the Denali and Border Ranges faults, some of which are nearly 200 km in diameter, appear to be related to volcanic activity. The relationship of circular features to mineralization is not yet clear.

Computer-enhanced Imagery

Three types of computer-enhanced LANDSAT imagery were used successfully to locate mineral occurrences in the Nabesna quadrangle; 1) color ratio, 2) standard false color, and 3) simulated natural color. An additional enhancement technique called a "sinusoidal" stretch is being used on imagery of the McCarthy quadrangle. Analysis of these "sinusoidally" stretched images is still in progress, but preliminary observations indicate that they can supply information not available on other types of images.

Digital image processing can be separated into two stages, the preprocessing or "clean-up" stage and the actual image enhancement stage. The output of the clean-up stage is called a data base and is used as input to the different image enhancement techniques.

The preprocessing stage includes noise (striping) removal, haze and sun elevation corrections, and a geometric correction (Chavez, 1975). The final step in the preprocessing stage is to mosaic by computer the different images needed to cover the area of interest. For the 3 degree quadrangles in Alaska, it usually means mosaicking parts of 3 or 4 images together. Four output data base tapes are then generated containing four different LANDSAT bands that cover the entire area of interest.

Several enhancement techniques were used in this study and can be separated into the following types: contrast stretches, color ratios, structural and linear enhancements, simulated natural color, and a "sinusoidal" stretch that maximizes the color variations within an image.

The first type of enhancement, contrast stretch, is a standard false color composite made by using three of the four LANDSAT bands to which linear stretches have been applied. For this study, band 4 was filtered with blue light, band 5 with green, and band 7 with red. The second type of enhancement, color ratios, involves the division of spectral values of one band by those of another band and the application of linear stretches to the subsequent ratios. In the Nabesna quadrangle, the color ratio image was generated by filtering bands 5/4 with red light, 6/4 with green, and 4/5 with blue.

Structural and linear enhancement is generated by the use of a high frequency filter. This filter removes most of the albedo information in order to bring out structural and linear information. In this study, the structural and linear information obtained by this method was added to that observed on the Alaskan photomosaic.

Another type of enhancement is the simulation of natural color (Eliason and others, 1974). In this technique, a pixel (picture element) is classified into one of 3 general categories; vegetation, rocks and soils, and water, using the ratio of band 5 to band 6 after haze removal. Once the pixel has been classified, a different algorithm is used for each category to extrapolate a theoretical value for the blue region of the spectrum. This new band is then used to generate a color composite with colors approximating those that might be seen without atmospheric effects from satellite altitude (fig. 6).

A recently developed enhancement technique is the "sinusoidal" stretch. This stretch is applied to any 3 bands used to generate a

Figure 6. Simulated natural color Landsat image of the Nabesna quadrangle. Image made from mosaic of scene I. D. numbers 1692-20150 and 1692-20152 taken on June 15, 1974.

color composite having maximum color variation (fig. 7). Most dissimilar materials show up as dissimilar colors in the composite, unless the materials have the same spectral response in all 3 bands selected. The sinusoidal stretch extends multiple input spectral reflectivity values over the entire output spectral range. The stretch is sinusoidal so that the color changes are gradual for small differences of gray levels. This new stretch not only enhances large spectral differences within the image, but also very subtle differences not usually enhanced by other methods.

Color anomalies identified on LANDSAT imagery were found to correspond well with known mineral deposits and geochemical anomalies. A color anomaly is considered to be a variation in tone or color observed on the images that differs significantly from the local background color, indicating a reflectivity difference on the ground.

In the Nabesna quadrangle, 120 color anomalies were identified on the standard false color and simulated natural color images. Of these 120 color anomalies, 72 and 69 were identified respectively on the standard false color and simulated natural color images. Twenty-one were identified on both. No color anomalies were identified on the color ratio image.

Of these 120 color anomalies, 39 correspond to known mineral occurrences. Of the 81 that do not, 17 correspond to geochemical anomalies (fig. 8). Of the 64 color anomalies that correspond to neither known mineral occurrences nor geochemical anomalies, 27 were in areas that were not geochemically sampled. Thus, at least 56 (47%)

Figure 7. False color image with sinusoidal stretch of the McCarthy quadrangle. Image made from mosaic of scene I. D. numbers 1350-20223, taken July 8, 1973, and 1709-20090, taken July 2, 1974.

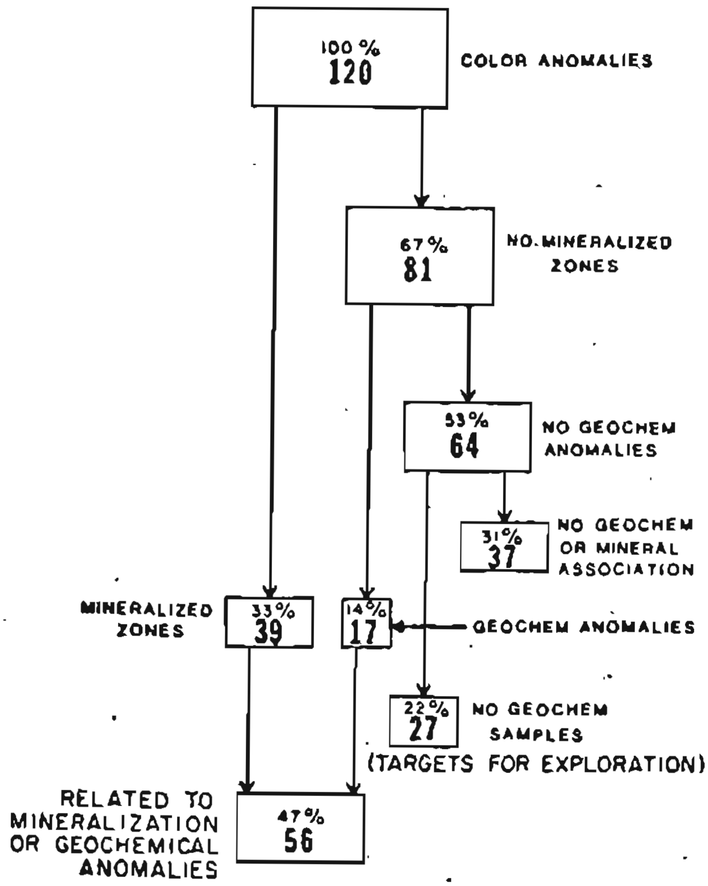


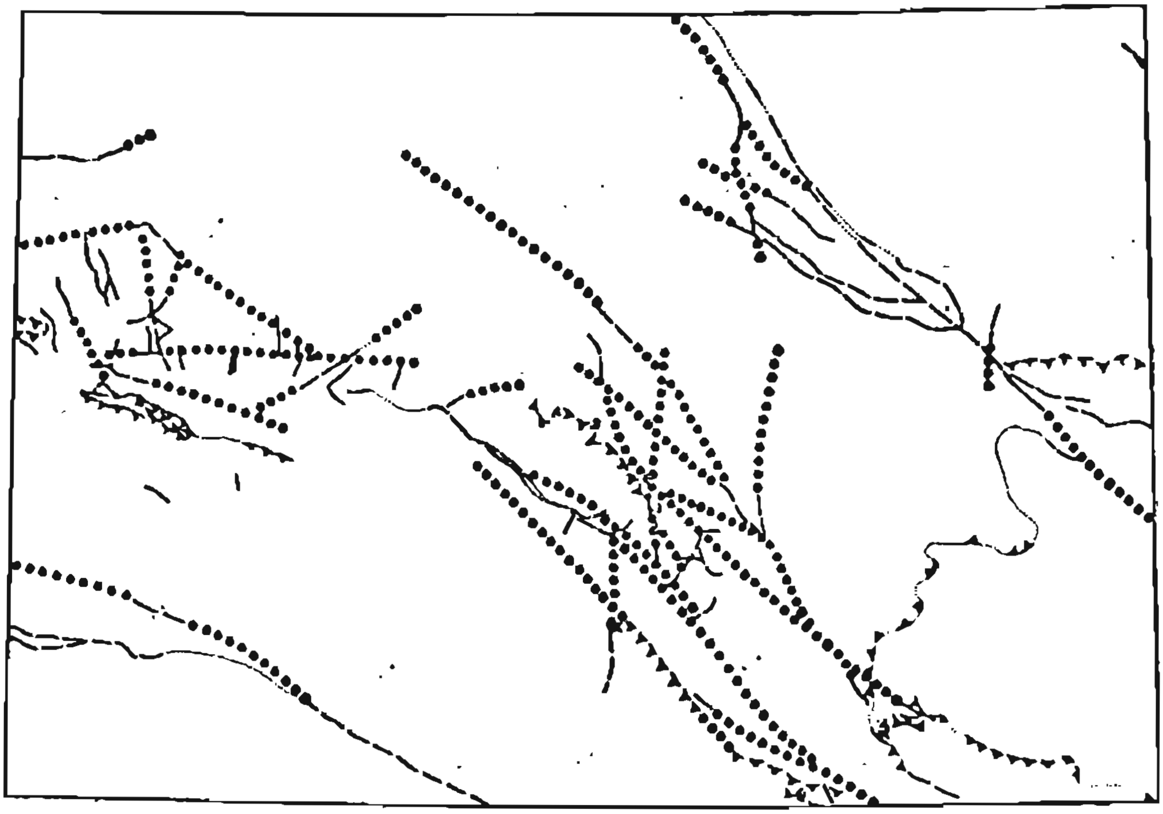
Figure 8. Breakdown of color anomalies seen on computer-enhanced LANDSAT imagery and their association with mineralized areas and geochemical anomalies in the Nabesna quadrangle.

of the color anomalies observed on LANDSAT imagery of the Nabesna quadrangle appear to be related to mineralization. (Many others are thought by Richter [oral comm., 1975] to correspond to unmapped altered zones). In addition, 27 color anomalies may be related to as yet unknown mineral occurrences and should certainly be targets for future exploration.

Studies of computer-enhanced LANDSAT imagery in the McCarthy quadrangle are still in progress. Three types of imagery are being used: 1) simulated natural color; 2) color ratio with bands 5/4 in blue, 6/7 in green, and 7/4 in red; and 3) false color using sinusoidal stretches, with the various bands expressed in different color combinations.

One of the advantages of the sinusoidal stretch is that snow, a major feature in Alaska, does not have to be displayed in white, as it does in standard false color and simulated natural color images (fig. 7). Photographically, the white, snow covered areas tend to "bleed" over into adjacent non-snow areas, reducing reflectivity discrimination of rock, soil, or vegetation differences.

By superimposing mapped faults in the McCarthy quadrangle over a sinusoidally stretched image with bands 5 in green, 6 in blue and 7 in red, it was possible to draw numerous extensions of these faults based on linear and curvilinear features visible in the image (fig. 9). The true nature of these extensions and their relationship to mapped faults is uncertain. However, their actual surficial expressions have not been observed by field geologists (MacKevett, oral comm., 1975) and may



Scale 0 50 100 kilometers

Mapped faults (dotted where uncertain)

Mapped low-angle faults (dotted where uncertain)

Possible extensions of faults

Figure 9. Map of the McCarthy quadrangle showing known faults and their possible extensions as determined by linear and curvilinear features visible in the sinusoidally stretched false color image of the McCarthy quadrangle.

be detectable only by high-altitude imaging systems. Additional data on the existence and nature of these extensions may soon be available upon completion of an aeromagnetic map of the McCarthy quadrangle.

Further studies of the LANDSAT imagery of the McCarthy and other Alaskan quadrangles are in progress and a more thorough evaluation of sinusoidally stretched imagery and its usefulness to mineral exploration will be possible at a later date.

CONCLUSIONS

LANDSAT data have furnished significant geological and structural information to mineral resource appraisal studies of the Nabesna and McCarthy quadrangles, Alaska. When used in conjunction with geological, geophysical and geochemical data, this type of information should be considered an essential tool to any effective regional mineral exploration program.

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