GL02888-7 of 7 Geophysics

RELATIONS BETWEEN ERTS LINEAMENTS, AEROMAGNETIC ANOMALIES AND GEOLOGICAL STRUCTURES IN NORTH-CENTRAL NEVADA

Don W. Levandowski
Ted V. Jennings
W. Terry Lehman

Department of Geosciences
and Laboratory for Applications
of Remote Sensing
Purdue University
West Lafayette, Indiana 47907

ABSTRACT

Analyses of composite color images of ERTS - 1 data for an area covering the major portions of Eureka and Lander Counties, Nevada, reveal a number of lineaments not previously mapped either by aerial or field studies. An iso-lineament intersection map prepared from the imagery displays a northwest concentrated band of lineament intersection density that corresponds with a northwest alignment of domes of Paleozoic sedimentary rocks associated with the Roberts Mountains thrust fault. Within the band, a strong correlation exists between areas of intersection concentration and domal windows associated with major areas of mineralization and igneous intrusives. The band also coincides closely with a prominent north-northwest trending zone of aeromagnetic anomalies.

Stress analyses of the ERTS lineaments, aeromagnetic linears, and domal structures suggest that the doming of Paleozoic sedimentary rocks associated with the thrust may be related to the emplacement of magnetic anomaly source material along zones of weakness related to a deep-seated fracture zone trending in a northwest direction. Further, it is suggested that the preferred areas of igneous activity are related to weakness zones developed at deep-seated fracture zone intersections.

INTRODUCTION

The need to discover new resources is forcing the mineral industry to inventory and renew exploration in known producing regions as well as undertake exploration of remote, relatively unsurveyed regions of the earth. Obviously there is a need to develop reconnaissance exploration techniques which enable large areas (amounting to hundreds of thousands of square miles) to be scanned at a low cost per unit area in order to select and reliably identify regions of highly promising ore potential within these broad areas. Then higher cost detailed prospecting techniques such as airborne and ground geophysical and geochemical techniques could be focused in these high priority regions. With the advent of the Earth Resources Technology Satellite (ERTS) program, explorationists now have the opportunity to apply remote sensing techniques to aid reconnaissance exploration campaigns by providing a rapid means to recognize, delineate, and map structural and lithologic conditions favorable for mineral occurrences.

The purpose of this study, which concerns one of the older and more important mining areas in Nevada, is to illustrate the extent to which ERTS imagery can be useful in supplying information conerning geologic features that serve as guides to the location of ore deposits. Emphasis is placed on the mapping of major lineaments and domal features.

LOCATION AND TOPOGRAPHY

The area selected for study (Figure 1) is that portion of north central Nevada covered by ERTS Frame No. 101817592 (10 August 1972). This area contains major portions of Lander and Eureka Counties as well as minor portions of Churchill, Elko, Pershing, Humboldt, and White Pine Counties.

The dominant topographic features of the area are generally north-trending ranges and intervening valleys, typical of the Nevada Basin and Range physiographic province (Figure 2). Several of the high points of the ranges are over 10,000 feet above sea level and 9000-foot peaks are common. Average relief of the ranges is about 4000 feet. The elevations of the valley floors range from 4500 to over 6000 feet above sea level. The ranges are flanked locally by narrow pediments which pass laterally into fans that extend down into the adjacent valleys.

The present topography is the result of normal faulting and erosion during late Tertiary and Quaternary time. Displacements of several thousand feet have been determined on the normal, generally north-trending faults or fault zones that separate the valleys from the ranges.

MINING DISTRICTS

The principal mining districts of the area are shown in Figure 3 which also shows the relative productivity of each district. Of the major districts in the area, many have produced over $10,000,000 and one of them, the Eureka district, has produced over $100,000,000 in ore values. The principal metallic constituents produced in the area have been gold, silver, lead, zinc and copper.

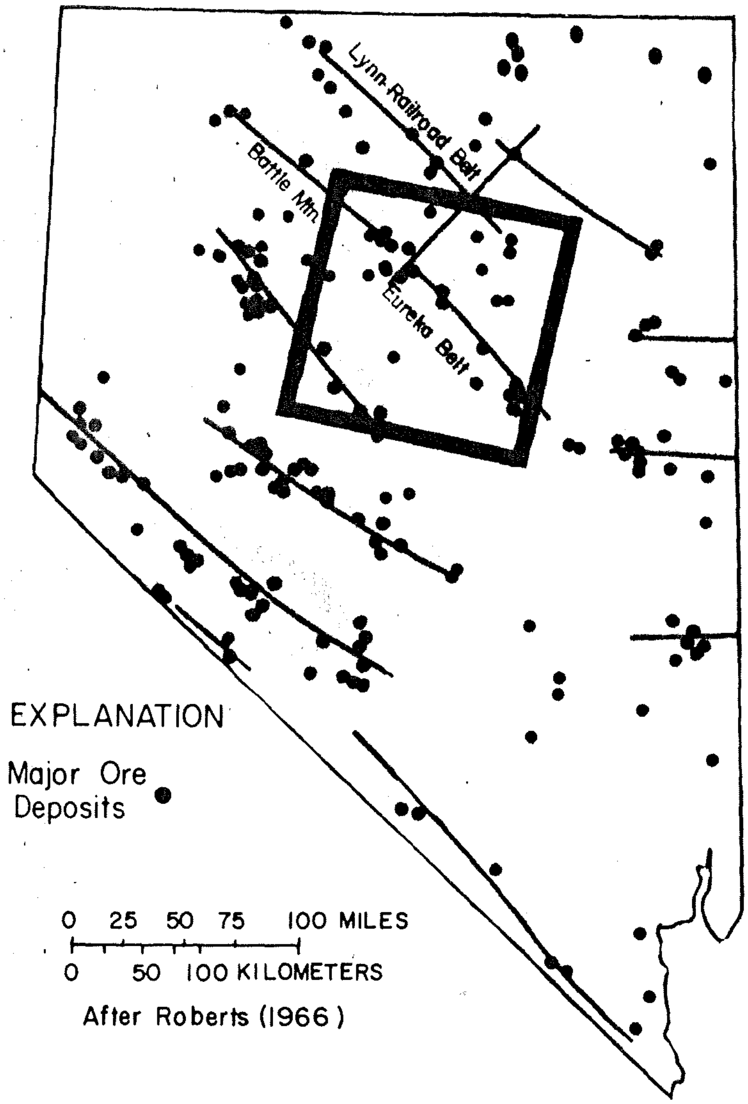

Figure 1. Index map of Nevada showing outline of area and mineral belts.

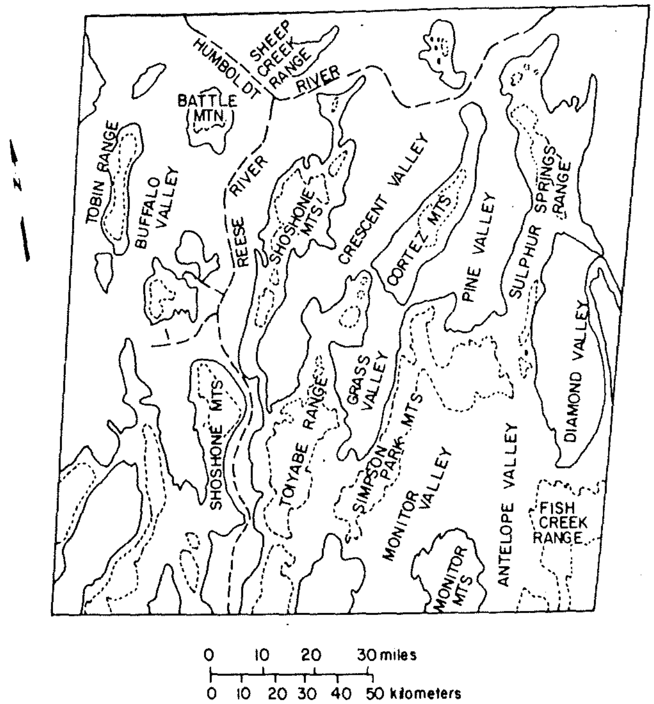

Figure 2. Map showing major topographic features in north-central Nevada.

Intensive field studies during the 1960's by geologists of the U.S. Geological Survey, Nevada Bureau of Mines and various mining companies have revealed that major mining districts in Nevada are aligned in north-west trending belts (Roberts, 1960 and 1966). The major belt in the area under discussion is the Battle Mountain-Eureka Belt (Figure 1 and 3) which includes the Battle Mountain, Cortez, Roberts, Lone Mountain, and Eureka mining districts.

GEOLOGICAL SETTING

Recent geological studies in the area have been reported by Roberts (1960), Gilluly and Gates (1965), Gilluly and Masursky (1965), Muffler (1964), and Roberts et al. (1967). A generalized geological map is shown in Figure 4.

The oldest rocks in the area are sedimentary and igneous rocks of Paleozoic age. These rocks can be divided into two major assemblages: a lower Paleozoic eastern miogeosynclinal assemblage composed of limestone and dolomite with some shale and quartzite; and a lower Paleozoic siliceous western eugeosynclinal assemblage consisting predominantly of clastic sedimentary rocks, cherts, and volcanics (Roberts et al., 1958).

Mesozoic sedimentary rocks consist chiefly of carbonates and clastics. Tertiary sediments are of non-marine origin and consist of sandstone and tuffs. Post-Paleozoic intrusives of intermediate to granitic composition are exposed in the ranges, and Tertiary and Quaternary volcanics are widespread over the area.

The Paleozoic units occur in complex thrust sheets and fault blocks. According to Roberts et al. (1958), thrusting related to the Late Devonian to Early Pennsylvanian Antler orogeny occurred along a regional thrust plane, designated the Roberts Mountain thrust fault, that brought the western eugeosynclinal clastic rocks over and into fault contact with the eastern miogeosynclinal carbonate rocks of correlative age. Orogenic activity continued intermittently during Late Pennsylvanian and Permian time and culminated in the Late Permian Sonoma orogeny.

Erosion of the Antler and Sonoma orogenic belts during the Triassic period was followed by Jurassic and Early Cretaceous volcanism and intrusive activity. Additional folding and thrusting are indicated to have recurred at this time (Roberts, 1960). Continued folding and normal faulting took place during Late Cretaceous and early Tertiary time.

Cenozoic Basin and Range orogenic activity was characterized by extensive high-angle faulting and volcanism. Early Basin and Range structures that formed during Oligocene and Miocene time trend generally east-west in contrast to later structures which trend north to northeast. The general charac-

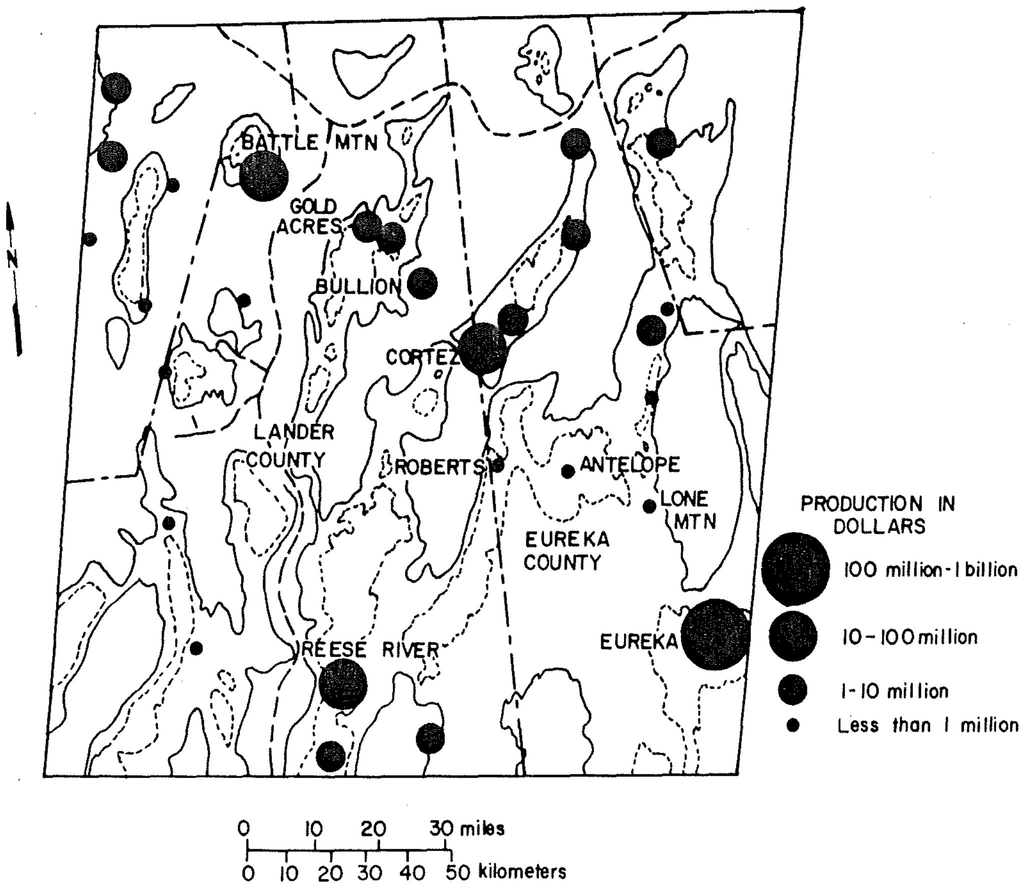

Figure 3. Map showing major metal mining districts in north-central Nevada (from Nevada Bureau of Mines Map 37).

ter of the Basin and Range physiography developed during these latter orogenies.

ORE DEPOSITS

The ore deposits occur mostly in Paleozoic carbonate rocks that are exposed in windows through the upper plate (Paleozoic eugeosynclinal siliceous assemblage) of the Roberts Mountains thrust (Figures 4 and 5). The windows are the result of erosion of upper-plate rocks near local areas of doming. The doming occurred during or shortly after thrusting (Roberts, 1960, Roberts et al, 1967) and was later accentuated during the emplacement of igneous bodies of late Cretaceous to early Tertiary time. The alignment of these windows according to Roberts (1960) indicates that they are controlled by major zones of structural weakness along which igneous rocks and related ore-bearing fluids have penetrated. The northwesterly trends do not parallel any known trends in the Paleozoic and, according to Roberts, were likely inherited from Precambrian structural trends.

The ore bodies lie parallel to the thrust plane, near vertical faults, or replace carbonate rocks along bedding (Figure 5). The rocks of the upper plate close to the thrust are also locally mineralized, especially near intrusive bodies.

Thus the area displays the three major factors that control ore deposits: genetic, structural, and lithologic. All occur together in and around the domal windows. Figure 4 shows that many of the windows contain intrusive bodies of granite of late Cretaceous or early Tertiary age that served as the source of mineralizing solutions. The structural controls are provided by the doming and the faulting associated with the thrusting and the doming. The lithologic control is primarily the presence of carbonate rock.

ERTS - 1 INVESTIGATIONS

Mapping of major structural features was performed on a color composite of bands 4, 5, and 7. The composite was made by displaying the gray level of each ERTS band, 4, 5, 7, respectively, on a digital display unit of a computer. The display of each band was photographed with an appropriate filter, thereby reconstituting a color composite from the separate gray level images.

Analysis of the composite color image reveals structural features not readily identifiable at larger scales of observation. For example, a number of regional lineaments are present on the image that have never been reported in the literature. These linears appear as tonal discontinuities in contrast to their surroundings, as alignments or breaks in topographic features, or as subtle vegetation alignments. They occur in bedrock areas and can often be traced across the alluvium-filled valleys.

To facilitate objective mapping of the lineaments, 8" x 10" color prints, each covering 1/4 of the ERTS frame, were

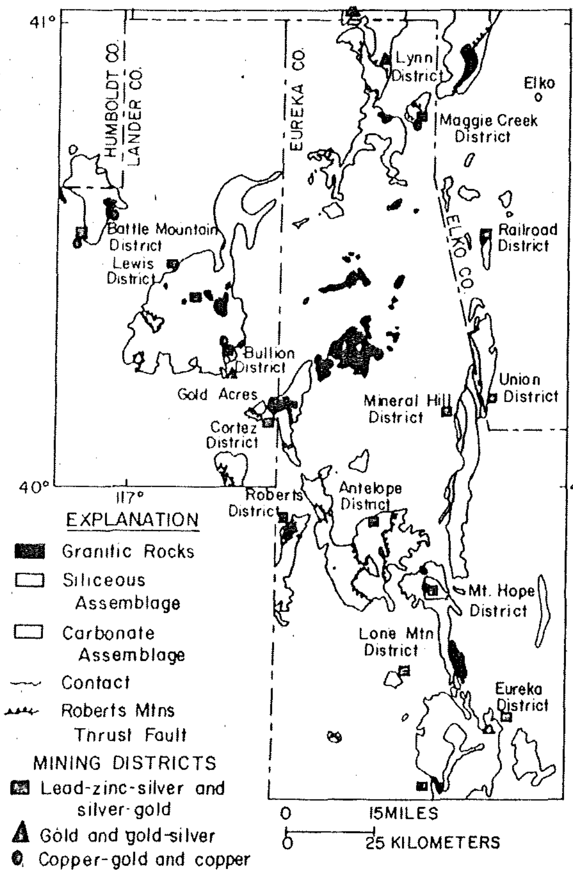

Figure 4. Generalized geologic map of north-central Nevada showing alignment of mining districts.

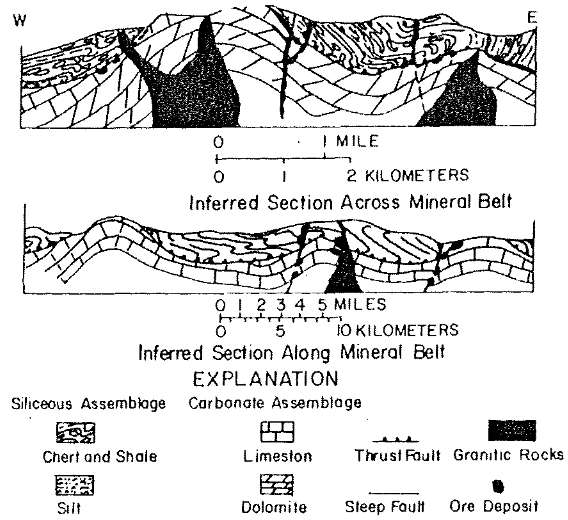

Figure 5. Inferred sections across and along a mineral belt in north-central Nevada showing possible sites for ore deposition.

analyzed independently by each of the investigators. The results were compared and a lineament map produced (Figure 6).

AEROMAGNETIC LINEARS

In order to interpret the geological significance of the ERTS lineaments, an examination was made of the aeromagnetic map (Philbin et al., 1963) of a portion of the area and the high angle faults as mapped on published geological maps.

The aeromagnetic map (Figure 7) displays a dominant north-northwest trending zone of magnetic anomalies, located along the alignment of windows through the Roberts Mountain thrust and attributed by Roberts (1966) to a swarm of diabase dikes.

Lineation mapping (Figure 8) of the aeromagnetic map was performed using the method described by Affleck (1963). Straight lines are drawn along closed highs and lows as well as along open noses and flexures in contour lines. The lengths and azimuths of all linears were tabulated for subsequent preparation of a histogram plot showing percent of total line lengths in 5° azimuth plots (Figure 9). Using a 5% cutoff, three principal maxima can be seen: N25°W, N3°E, and N13°E.

The most prominent is the well developed maxima centered at N3°E, a direction very well developed in terms of Cenozoic structural grain throughout the Basin and Range province of Nevada. It very likely represents the effect of near surface geological structure on the magnetic field.

The next best developed maxima, N25°W, represents the almost continuous magnetic maxima of high amplitude and is clearly associated with the trend of the Battle Mountain-Eureka mineral belt.

HIGH ANGLE FAULTS

Figure 10 is a map of the high angle faults as derived from published geologic maps of the area (Gilluly and Masursky, 1965; Roberts et al., 1967). Individual faults within the study area are frequently curvilinear in map view and the fault pattern within parts of the area is nearly rhomboid.

Aximuths of 185 faults were tabulated, length weighted, and summarized as a histogram (Figure 11). This histogram shows maxima greater than 5% centered at N32°W, N 18°W, N3°E, and N50°E. With the exception of the strong N50°E direction, this plot is very similar in overall character to the magnetic linear histogram.

ERTS LINEAMENTS

The ERTS lineaments as depicted in Figure 6 were replotted on a topographic base of 1:250,000 scale (Figure 12). With one exception, all lineaments occurred as straight line segments. One northeast trending feature was curvilinear but was divided into three straight line segments for plotting and analysis. Lineaments of all strike directions trend through one another without termination and with little or no observable offset.

The histogram plot (Figure 13) of these length weighted lineaments in general has four major groupings of trends: N55°- 80°W, N20° - 25°W, N to N 35°E, and N 73°E with maxima greater than 5% centered on N70°W, N25°W, N8°E, N23°E, N35°E, and N73°E. None of these are

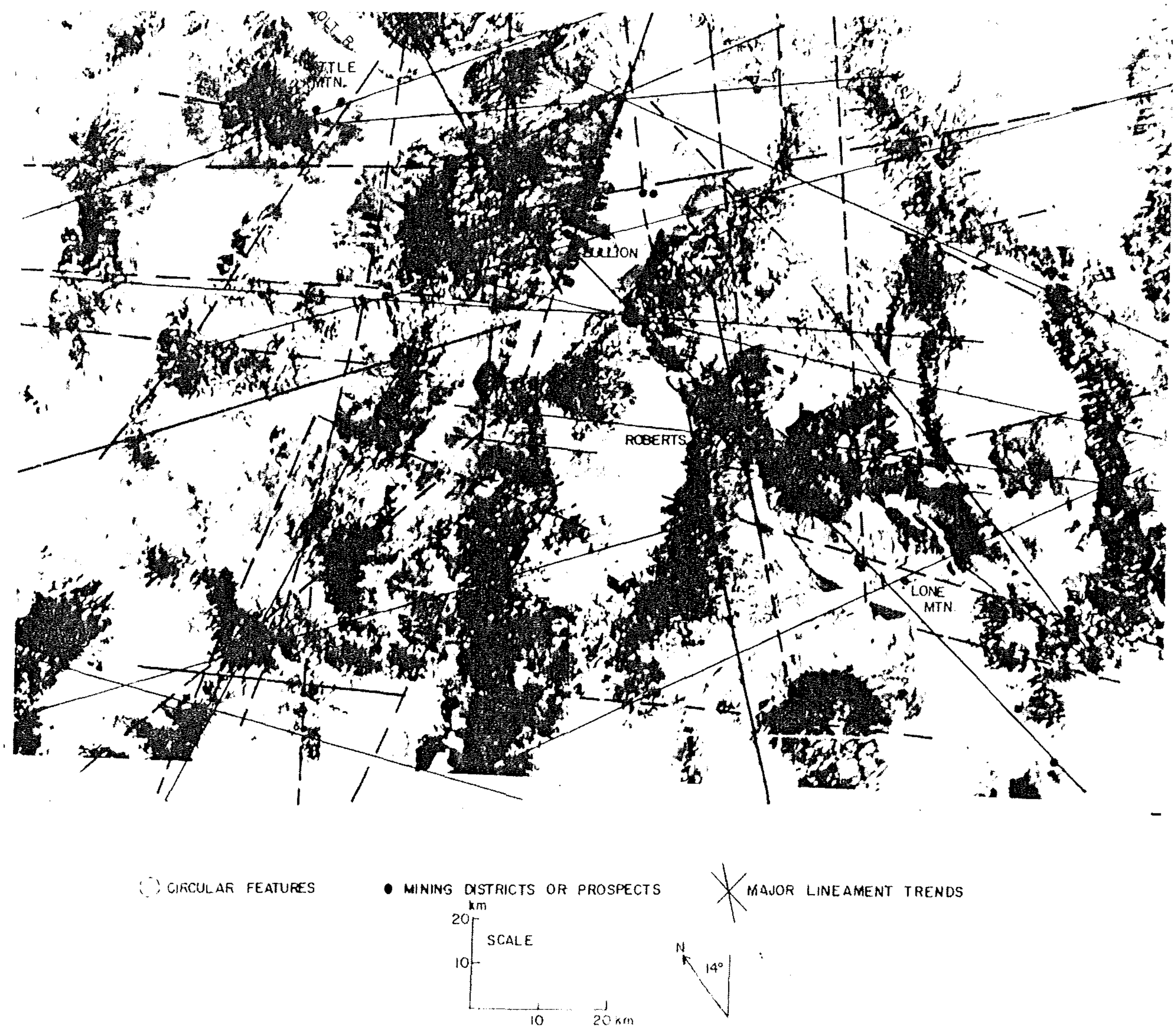

Figure 6. Observed structural lineaments of north-central Nevada resulting from interpretation of color composite of ERTS frame 101817592.

appreciably more well developed than the others. This is in marked contrast to the results from the magnetic linears and high angle faults.

TECTONIC ANALYSES

The marked coincidence of ERTS lineaments, magnetic linears, and high angle faults (Figure 14) in a NNE direction is consistent with the predominant trend of Cenozoic faulting within the Basin-Range Province of Nevada. This trend is commonly believed to fall within a model of extension in an E-W to WNW-ESE direction. The inception of Basin-Range normal faulting has been dated at 15-17 m.y. (Noble, 1972) and thus suggests that the NNE lineament sets were active in Cenozoic time. This does not preclude the possibility of this trend being active during or inherited from an earlier episode of deformation.

The N25°W lineament coincides almost exactly with the trend established by the magnetic linears and by an alignment of domal windows through the Roberts Mountains thrust fault. Although not directly coincident, the N18°W and N32°W peaks on the high angle fault plot are suggestive of the same general direction of deformation. Robinson (1970) suggested that elongate doming of the Paleozoic sedimentary rocks associated with the thrust may be related to emplacement of magmatic anomaly source material and a zone of recurring tectonic activity since late Paleozoic time. He also interpreted this NNW trending zone as a potential primary shear zone which may have had a secondary influence on azimuths of high angle faults and dikes. This interpretation is compat-

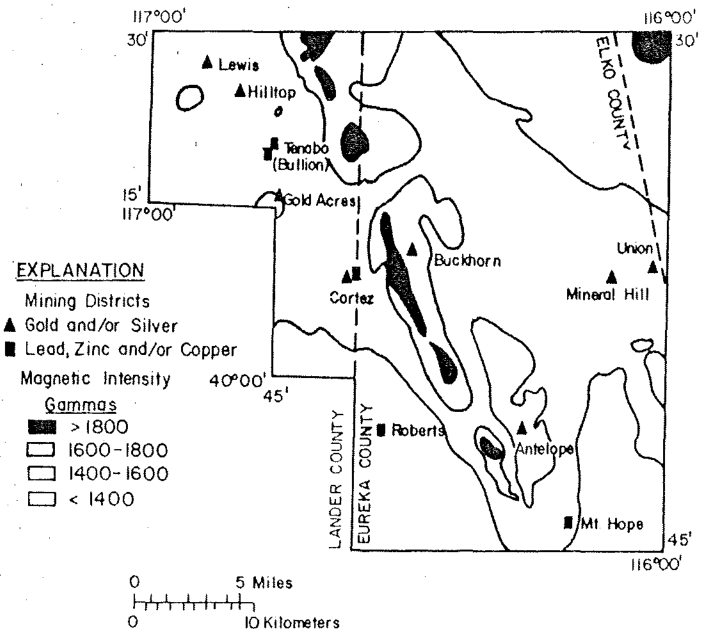

Figure 7. Aeromagnetic map of north-central Nevada.

ible with a simple shear model with extension in the E-W to WNW-ESE direction and if true could push the timing of deformation along the NNE direction back at least to the Paleozoic.

The lineament clusters centered on N70°W and N73°E are more difficult to interpret in terms of a model and in terms of age. If we assume a spreading model for the Basin-Range Province to coincide with extension in an E-W to WNW-ESE direction, the pattern could be roughly analogous to the near orthogonal pattern formed by oceanic ridges and transform faults, with the NNE direction parallel and the generally E-W lineaments perpendicular to the axis of spreading. On the other hand, these directions might well represent preexisting weakness zones which became active during the Basin-Range Cenozoic deformation.

Another alternative explanation is that the ERTS lineaments form two approximately orthogonal pair sets: N25°W-N73°E and N8°E-N78°W. The age and origin of the pair set formation is as yet unknown but the association of Late Paleozoic doming along the N25°W trend indicates a pre-Late Paleozoic origin, probably Precambrian age. Because the lineaments of all strike directions seem to trend through one another without usually terminating and with little or no observable offset, it is hypothesized that fractures represented by the lineaments must have formed originally by vertical movement. The fractures could have been reactivated at numerous times subsequent to their formation, both in Precambrian time and in Phanerozoic time.

During Cenozoic time, differential reactivation of these pair sets took place with discernible movement taking place along the NNE direction due to major extension in an E-W to WNW-ESE direction. This would explain the preferential direction as shown by the aeromagnetic linears and the directions of the Cenozoic high angle faulting.

If the two sets of lineament pair sets do indeed represent deep fractures in the earth's crust then the intersections of the two sets were zones of maximum breakage along which magmas were emplaced. The emplacement of magmas very likely resulted in the doming of the overlying sediments with the igneous centers simultaneously releasing hydrothermal fluids resulting in the remarkable association of ore deposits and domal areas with areas of lineament intersections.

RELATIONS BETWEEN LINEAMENTS, DOMING AND MINERALIZATION

A grid consisting of three-mile squares was laid over the lineament map (Figure 6) and the number of lineament intersections occurring in each grid square was counted. The number of intersections was then contoured resulting in an iso-lineament intersection map (Figure 15).

Study of Figure 15 reveals a pronounced association of major ore districts with zones of maximum lineament intersection development.

The northwest trending zone of concentration of intersections in Figure 15 correlates well with the dominant magnetic anomaly zone and also helps to explain the northwest zone of ore deposits and windows in north-central Nevada. Within the band of concentration of lineament intersections a strong correlation exists between areas of intense intersection concentration and domal windows associated with major mining districts. This association of domal areas and areas of intense lineament intersection implies that the domal areas are associated with zones of local weakness that in turn provided channelways for intrusive magmas. The fact that many domes have intrusive igneous rocks associated with them supports this hypothesis.

EXPLORATION TARGETS

Areas of maximum density of intersections not associated with mapped windows in the thrust plate may indicate domal features below the thrust plate and may represent potential targets for exploration. Two areas on Figure 15 are of particular interest: area A north of the Humboldt River in the southwestern end of the Sheep Creek Range, Lander County, and area B in the northern part of the Toiyabe Range.

Geological data are sparse for both areas. However, geochemical and geophysical anomalies are present in the area of concentration of intersections in the Sheep Creek Range. A detailed geochemical investigation by Gott and Zablocki (1968) revealed that anomalous concentrations of several metals were found throughout Paleozoic cherts and quartzites exposed in the area. They state that these metals - zinc, arsenic, mercury, silver, lead, copper, gold, molybdenum, antimony, tungsten, and tellurium - occur in such great concentrations as to suggest that they constitute a dispersion halo around or over a concealed mineral deposit, possibly located along or below the thrust plane suspected to be present in the area or associated with a buried intrusive mass.

Geophysical investigations (Gott and Zablocki, 1968) reveal that a magnetic anomaly occurs close to the geochemical anomalies. Gravity and electrical resistivity measurements suggest that the magnetic anomaly is due to a shallow, unexposed intrusive mass.

The area of maximum density of lineament intersections in the northern part of the Toiyabe Range appears to coincide

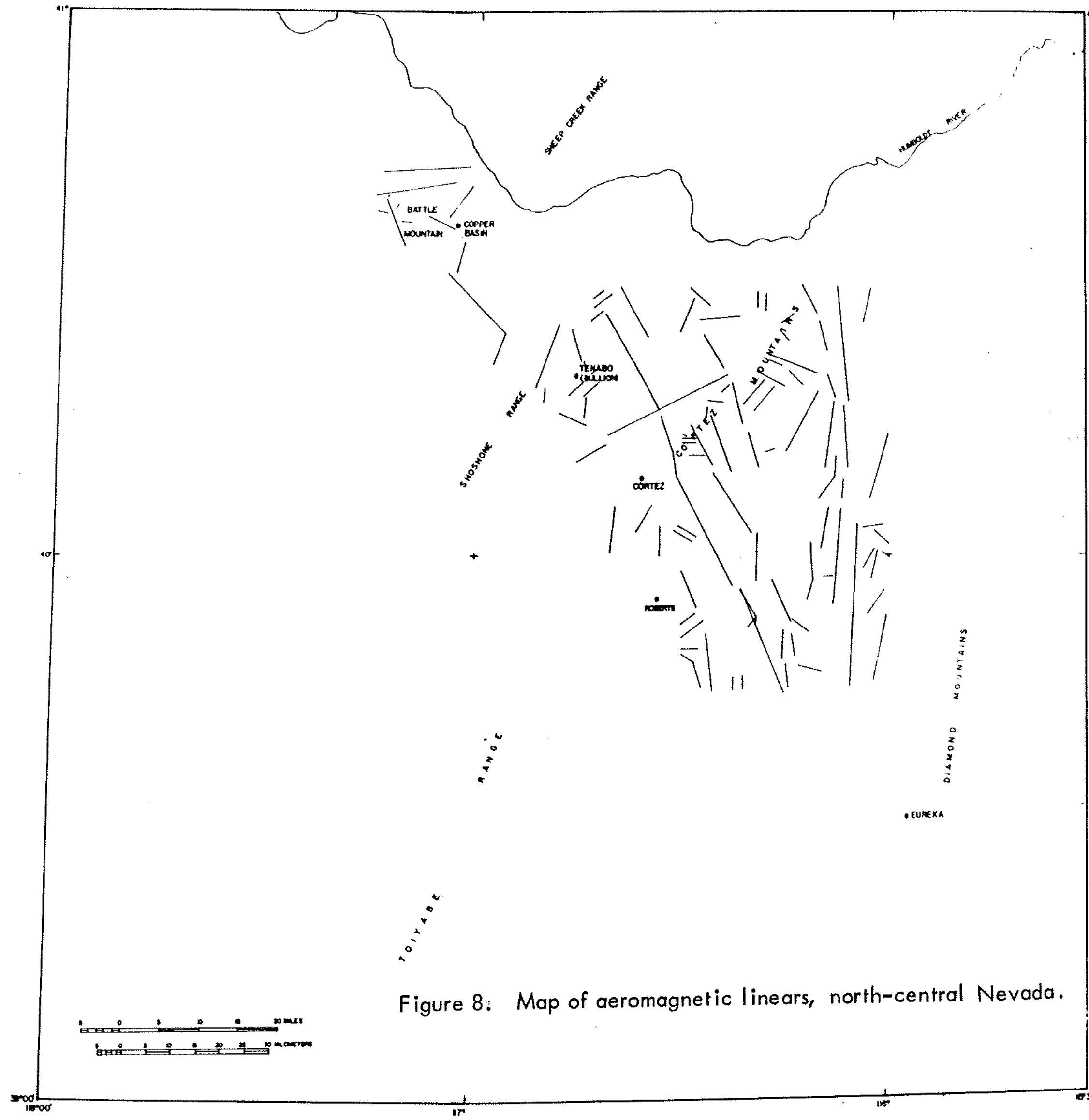

Figure 8: Map of aeromagnetic linears, north-central Nevada.

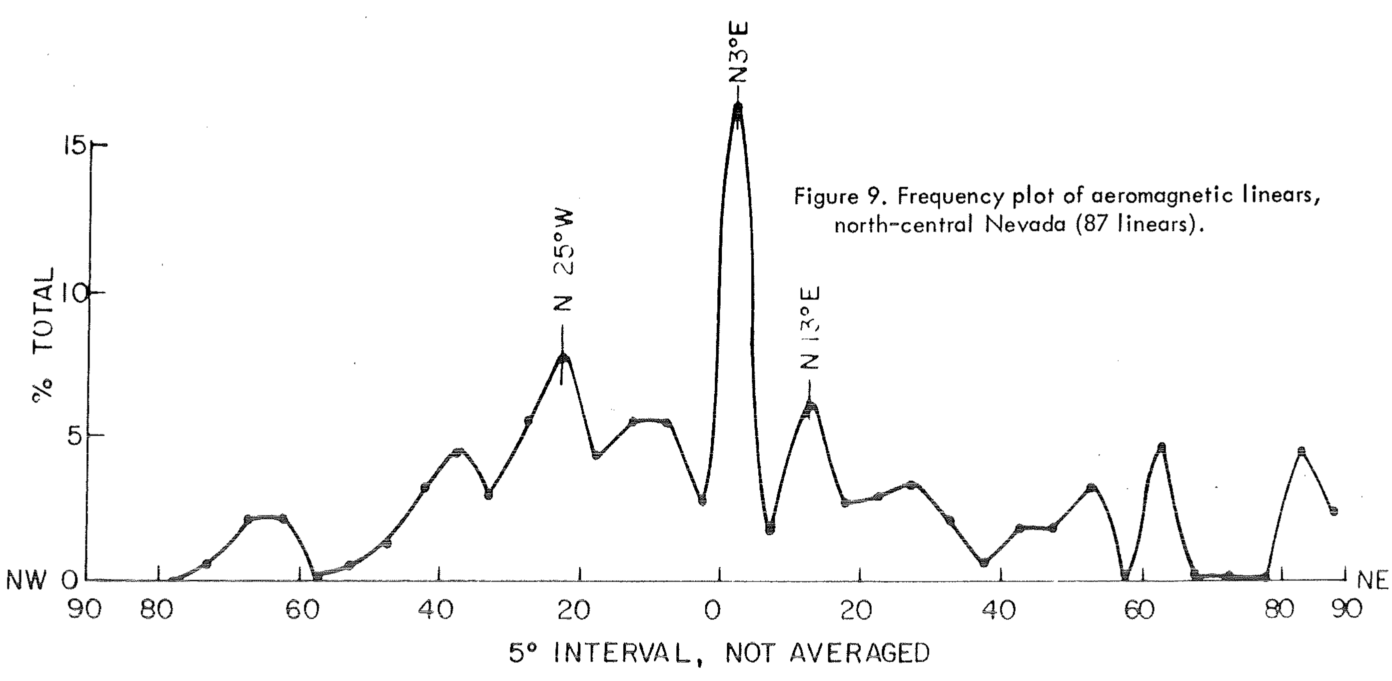

Figure 9. Frequency plot of aeromagnetic linears, north-central Nevada (87 linears).

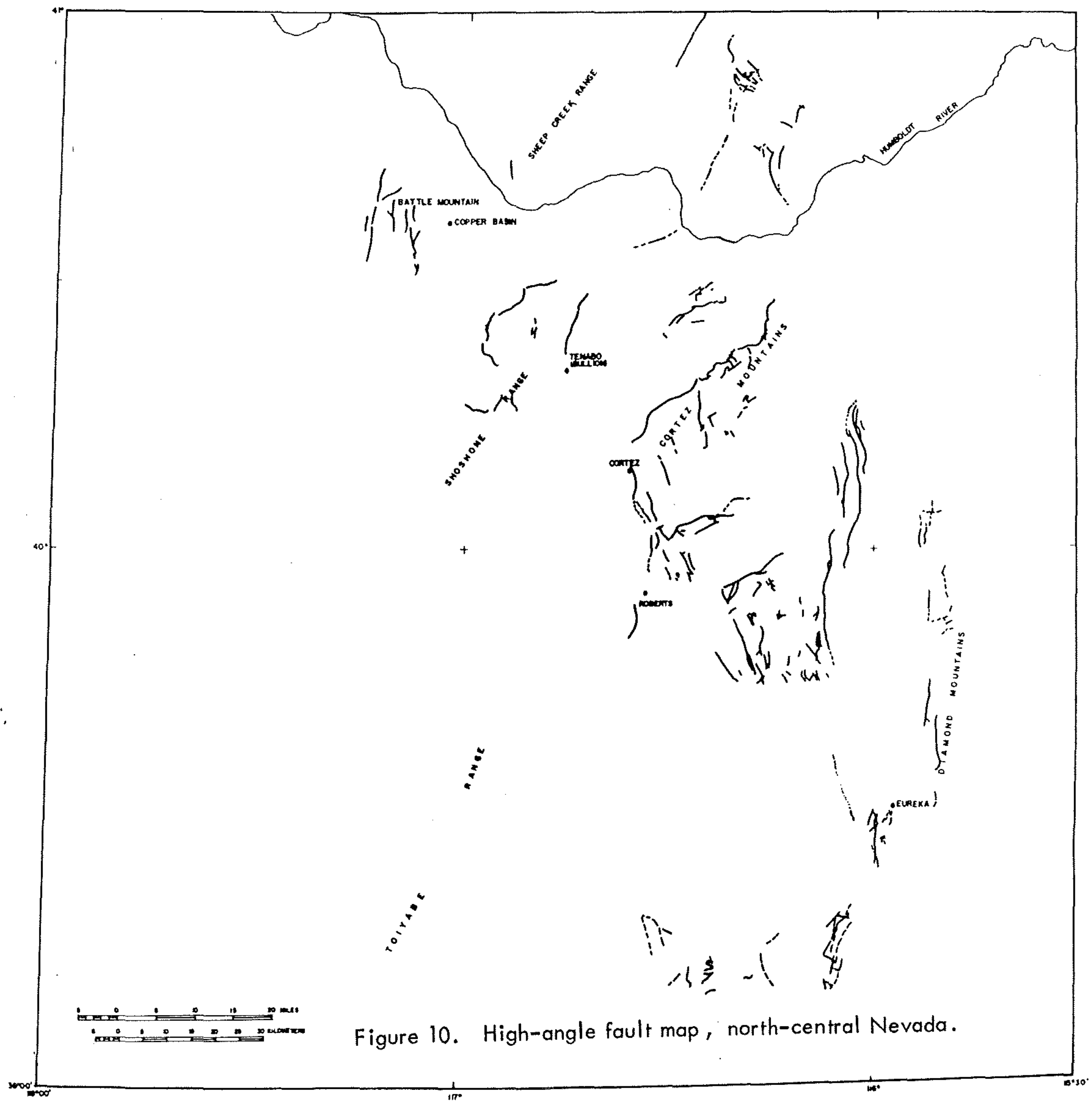

Figure 10. High-angle fault map, north-central Nevada.

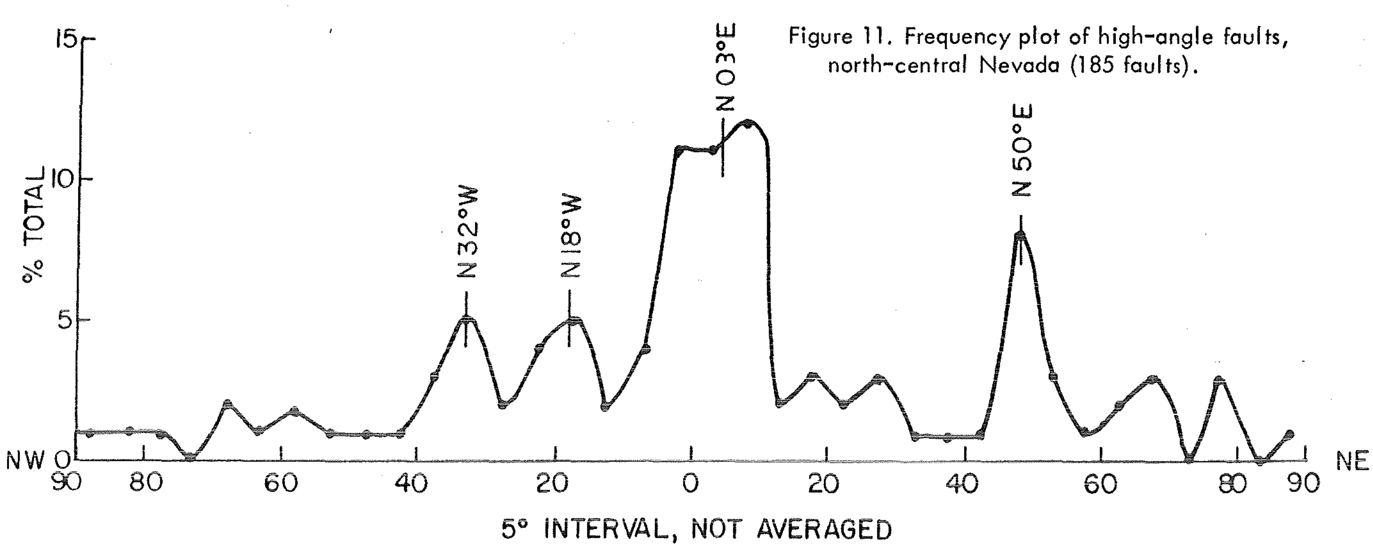

Figure 11. Frequency plot of high-angle faults, north-central Nevada (185 faults).

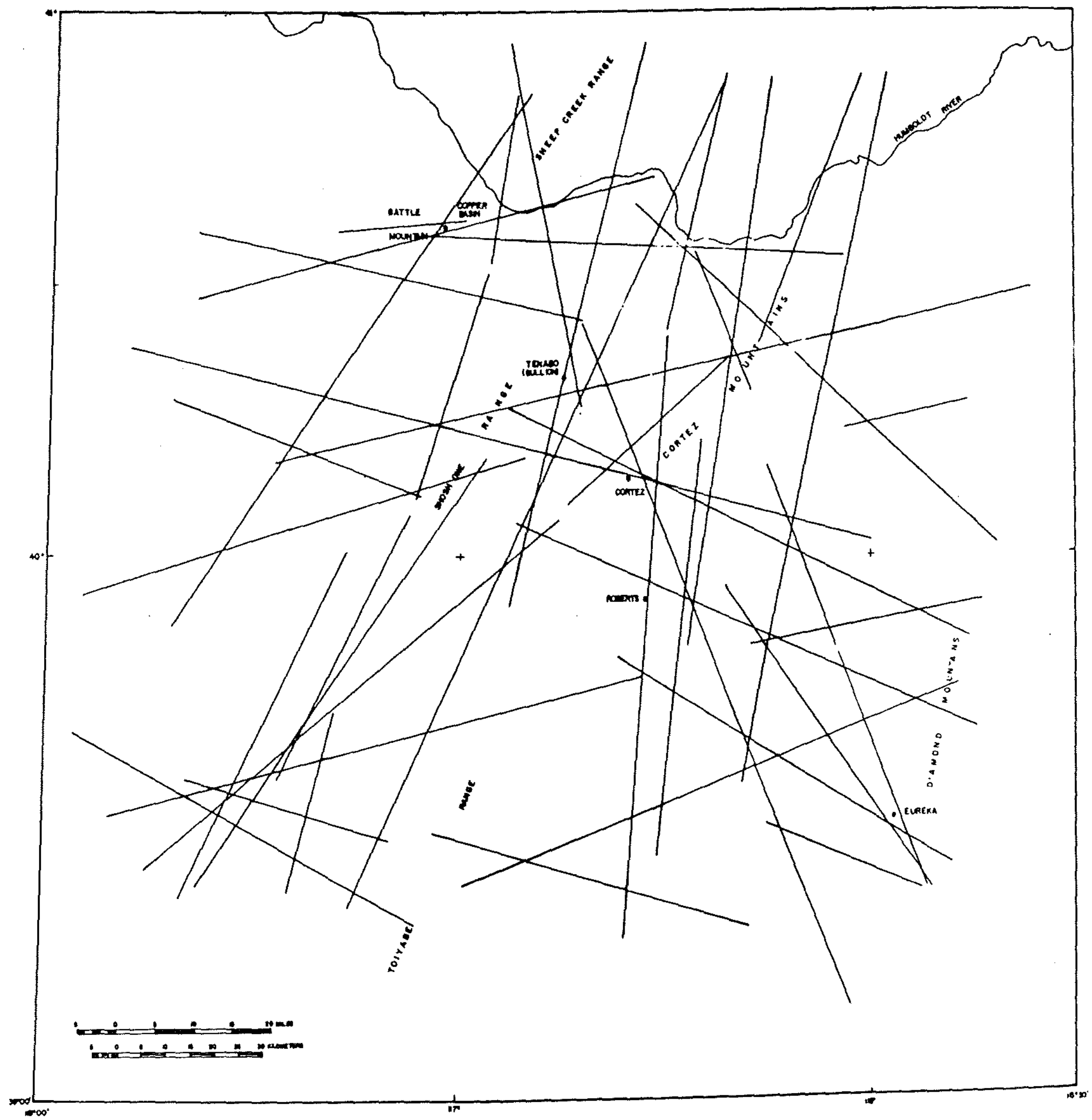

Figure 12. ERTS lineament map, north-central Nevada.

closely with a large window of exposed limestone that is bounded by a warped surface of the Roberts fault which swings with centrifugal dips about the exposure (Gilluly and Masursky, 1965). Consequently, it is suggested that this area is very likely a domal feature that should be investigated by a geochemical survey and detailed field mapping.

CONCLUSIONS

As set forth in the introduction, the primary objective of this study was to illustrate the effectiveness with which ERTS imagery can be used as an aid to reconnaissance exploration campaigns.

The achieved results indicate that at least for the Basin and Range physiographic province, the synoptic view of the ERTS imagery provides a tool for mapping previously unrecognized lineaments which will result in a better understanding of the tectonic framework of the area. In addition, analyses of the lineaments can aid in interpreting the distribution trends of regional geochemical anomalies and assist in determining the geological significance of geophysical anomalies. However, in the particular area under study, the lineament analyses are most significant in pointing up the relationship between domal features and lineament intersections with which the major mining districts are associated and consequently may serve as a valuable tool in directing mineral exploration efforts of specific areas.

ACKNOWLEDGMENT

Partial support of this study was provided by NASA Grant NGL 15-005-112.

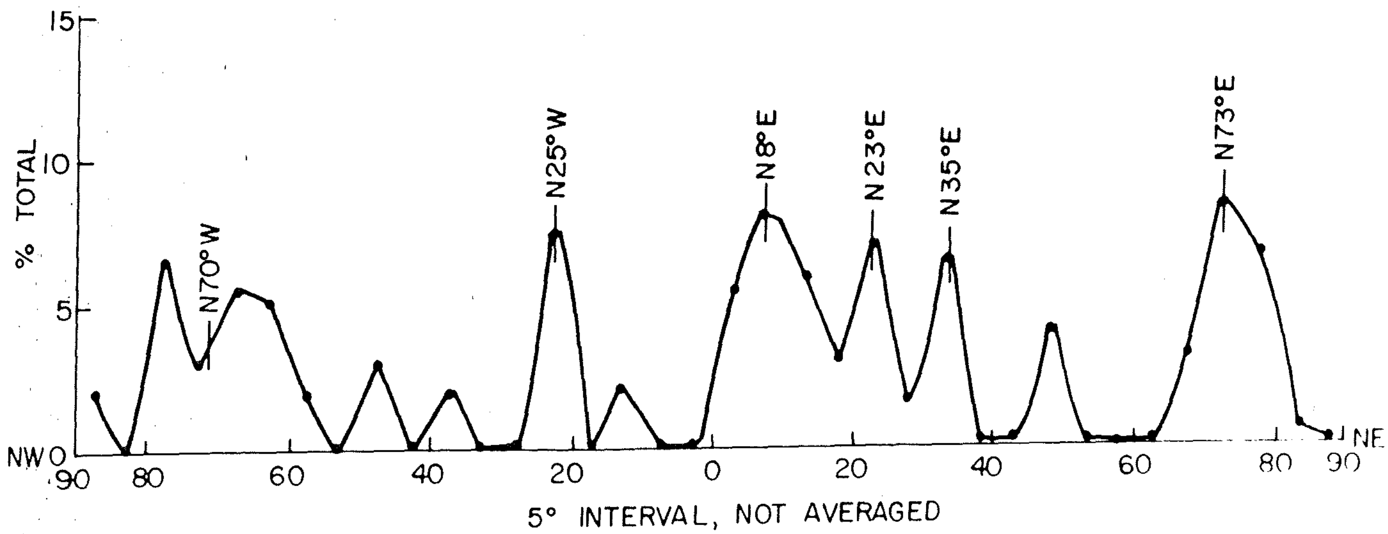

Figure 13. Frequency plot of ERTS lineaments, north-central Nevada (42 lineaments).

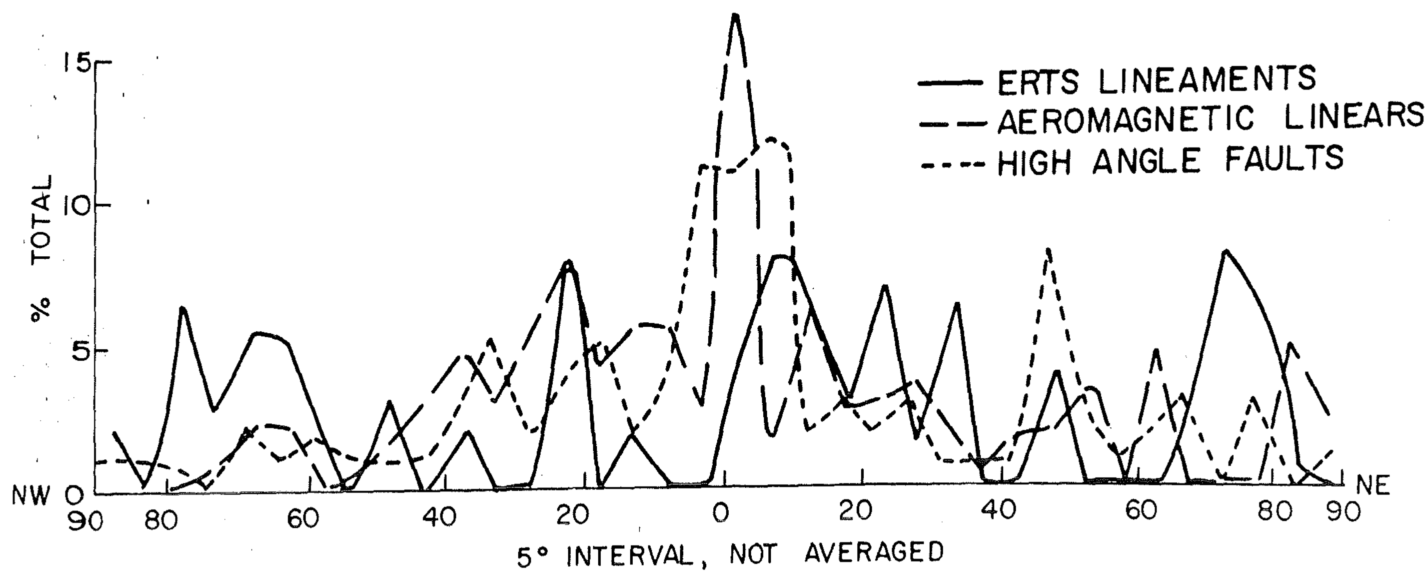

Figure 14. Composite frequency plot showing relation between aeromagnetic linears, high-angle faults, and ERTS lineaments, north-central Nevada.

REFERENCES

Affleck, J., 1963, MAGNETIC ANOMALY TREND AND SPACING PATTERNS: Geophysics, v.28, p. 379-395.

Gilluly, J., and Gates, O., 1965, TECTONIC AND IGNEOUS GEOLOGY OF THE NORTHERN SHOSHONE RANGE, NEVADA: U.S. Geol. Survey Prof. Paper 465, 153 p.

Gilluly, J., and Masursky, H., 1965, GEOLOGY OF THE CORTEZ QUADRANGLE, NEVADA: U.S. Geol. Survey Bull. 1175, 117 p.

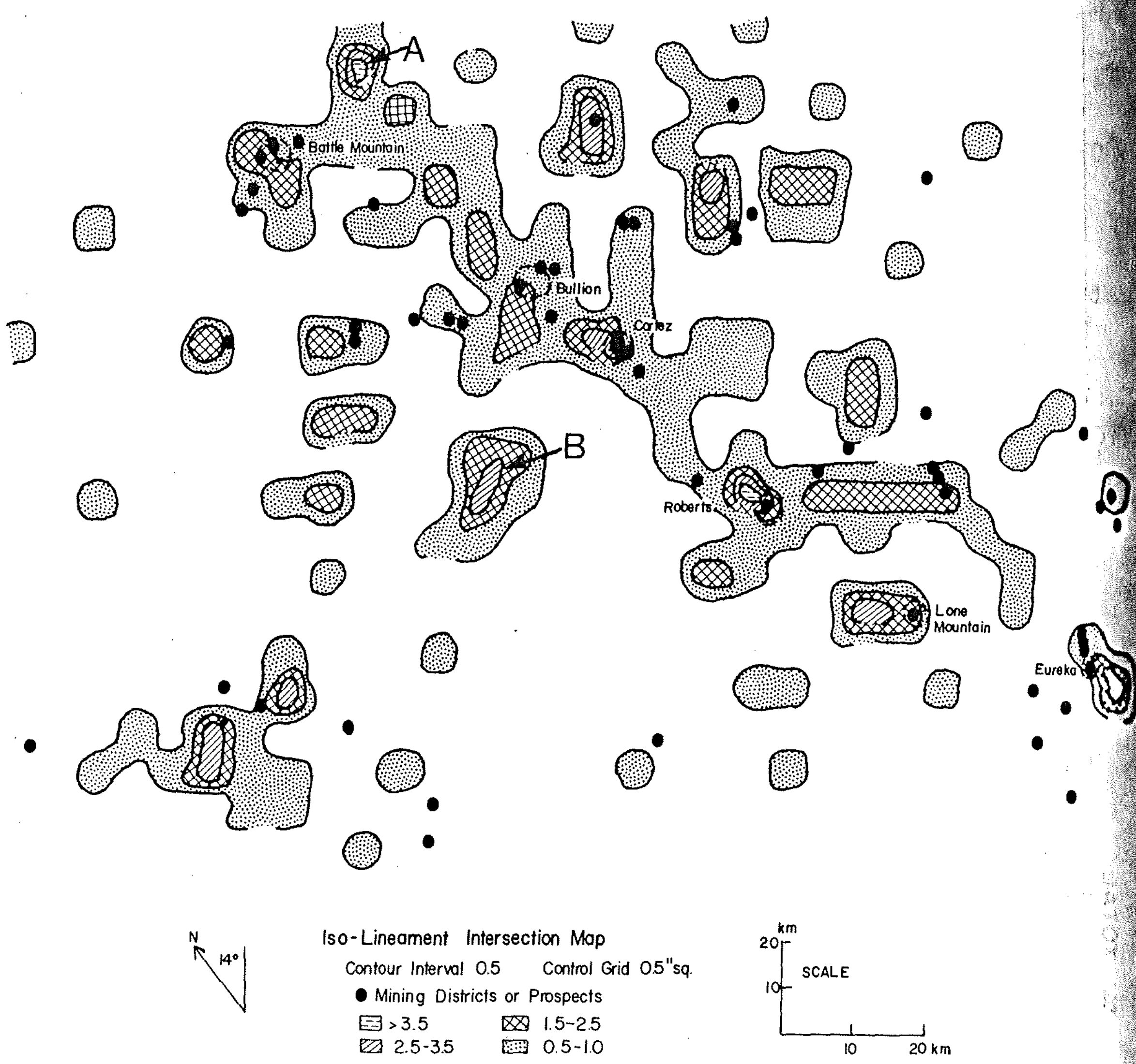

Figure 15. Iso-lineament intersection map of north-central Nevada showing exploration target areas.

Gott, G.B., and Zablocki, C.J., 1968, GEOCHEMICAL AND GEOPHYSICAL ANOMALIES IN THE WESTERN PART OF THE SHEEP CREEK RANGE, LANDER COUNTY, NEVADA: U.S. Geol. Survey Circular 595, 17 p.

Muffler, L.J.P., 1964, GEOLOGY OF THE FRENCHIE CREEK QUADRANGLE, NORTH-CENTRAL NEVADA: U.S. Geol. Survey Bull. 1179, 99 p.

Noble, D.C., 1972, SOME OBSERVATIONS ON THE CENOZOIC VOLCANO-TECTONICS EVOLUTION OF THE GREAT BASIN, WESTERN UNITED STATES: Earth and Planetary Sci. Letters, v. 17, p. 142-150.

Philbin, P.W., Meuschke, J.L., and McCaslin, W.E., 1963, AEROMAGNETIC MAP OF THE ROBERTS MOUNTAINS AREA, CENTRAL NEVADA: U.S. Geol. Survey Open-File Rept. (one map in 2 parts).

Roberts, R.J., 1960, ALIGNMENT OF MINING DISTRICTS IN NORTH-CENTRAL NEVADA, in SHORT PAPERS IN THE GEOLOGICAL SCIENCES: U. S. Geol. Survey Prof. Paper 400-B, p. B17-B19.

__________, 1966, METALLOGENIC PROVINCES AND MINERAL BELTS IN NEVADA, in PAPERS PRESENTED AT AIME PACIFIC SOUTHWEST MINERAL INDUSTRY CONFERENCE, SPARKS, NEVADA, May 5-7, 1965: Nevada Bur. Mines Rept. 13, Pt. A, p. 47-72.

Roberts, R.J., Hotz, P.E., Gilluly, J., and Ferguson, H.G., 1958, PALEOZOIC ROCKS IN NORTH-CENTRAL NEVADA: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2813-2857.

Roberts, R.J., Montgomery, K.M., and Lehner, R.E., 1967, GEOLOGY AND MINERAL RESOURCES OF EUREKA COUNTY, NEVADA: Nevada Bur. Mines Bull. 64, 152 p.

Robinson, E.S., 1970, RELATIONS BETWEEN GEOLOGICAL STRUCTURE AND AEROMAGNETIC ANOMALIES IN CENTRAL NEVADA: Geol. Soc. of Amer. Bull., v. 81, p. 2045-2060.