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Applications of ERTS-1 Imagery to Mapping of Lineaments Favorable to the Localization of Ore Deposits in North Central Nevada

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Abstract

The purpose of this study is to demonstrate the value of ERTS-1 data as a supplement to mineral reconnaissance techniques. Field studies have revealed that the major mining districts in Lander and Eureka counties, Nevada, tend to be aligned in northwest-southeast belts with ore deposits occurring in carbonates which have been exposed by domal windows through the upper plate of the Roberts Mountain thrust.

Analyses of composite color images of ERTS-1 data obtained from a digital image-editing system indicated that many of the ore districts are related to lineaments not previously mapped either by aerial or field studies. These lineaments very likely indicate deep zones of structural weakness along which igneous rocks and related ore-bearing fluids have penetrated. An iso-lineament intersection map prepared from the imagery displays a concentrated band of lineament intersections that coincides with the previously mapped mineral belts. Within that band, a strong correlation exists between areas of intersection concentration and domal windows associated with major districts. Based on this correlation, two major intersection concentration areas which have no known associated ore deposits are interpreted to be buried domal areas and potential exploration targets.

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 program, explorationists now have the opportunity to apply remote sensing techniques to aid reconnaissance exploration compaigns 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 and automatic data processing techniques can be useful in supplying information concerning geologic features that serve as guides to the location of ore deposits. These guides range from the mapping of lineaments which may represent major crustal fractures to the identification of lithologies favorable as host or source rocks, whose presence is recorded only as subtle spectral variations.

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.

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 northwest trending belts (Roberts, 1960 and 1966). The major belts in the area under discussion are the Battle Mountain-Eureka Belt and the Lynn-Railroad Belt (Figures 1 and 3). The Battle Mountain-Eureka belt includes the Battle Mountain, Cortez, Roberts, Lone Mountain and Eureka mining districts. The Lynn-Railroad belt includes the Lynn, Maggie Creek, and Railroad districts.

Geological Setting

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

The oldest rocks in the area are sedimentary and igneous rock of Paleozoic age. These rocks can be divided into four assemblages: a lower Paleozoic eastern miogeosynclinal assemblage composed of limestone and dolomite with some shale and quartzite; a lower Paleozoic siliceous western eugeosynclinal assemblage consisting predominantly of clastic sedimentary rocks, chert, and volcanics; a transitional assemblage, composed of interbedded limestone, clastic, and volcanic rocks; and an overlap assemblage of Mississippian to Permian age clastic rocks (Roberts 1958).

Mesozoic sedimentary rocks consist chiefly of carbonates and clastics. Tertiary sediments are of non-marine origin and consist chiefly 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.

Folding and faulting has continued since Paleozoic time, and the Paleozoic units occur in complex thrust sheets and fault blocks. According to Roberts et al. (1958), thrusting is related to the Late Devonian to Early Pennsylvanian Antler orogeny and 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 intermittantly 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 character of the Basin and Range physiography developed during these latter orogenies.

Ore Deposits

The ore deposits occur mostly in Paleozoic carbonate rocks that are now exposed in windows through the upper plate (Paleozoic eugeosynclinal siliceous assemblage) of the Roberts Mountains thrust (Figure 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 and others, 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 whichigneous rocks and related ore-bearing fluids have penetrated. The northwesterly trends do not parallel any known trends in the Paleozic 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; according to Roberts (1960) the productive intrusives are granites of late Cretaceous or early Tertiary age. 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. In this area of Nevada, the principal ore bodies have been localized in the lowest carbonate unit in the section, usually the oldest carbonate dolomite (e.g. Eldorado Dolomite at Eureka). Presumably the ore-bearing solutions rose from depth along fractures (Roberts, 1960) cutting quartzite and siliceous shale and were in equilibrium with these rocks. When the solutions came in contact with the lowest carbonate unit, reaction followed and precipitation took place.

ERTS-1 Investigations

Mapping of major structural features was performed on color composites of bands 4, 5, and 7. The composites were 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 images 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 analyzed independently by each of the three investigators. The results were compared and a lineament map produced (Figure 6).

A 1/2" grid (3 miles square) was overlain on the lineament map and the number of lineament intersections occurring in each grid square was counted. The number of intersections were then contoured resulting in an iso-lineament intersection map (Figure 7).

Study of Figures 6 and 7 reveal an excellent association of the major ore districts with lineaments and lineament intersections. The lineaments very likely represent fracture zones that extend deep into the earth and may have been present as far back in time as the Precambrian. The northwest trending zone of concentration of intersections as shown on Figure 7 helps explain the northwest trend of ore deposits and windows in north central Nevada. These fracture zones very likely formed the "plumbing system" that permitted igneous magma and accompanying ore solutions to more upward into higher crustal levels. The relationship of this fracturing to igneous activity is well illustrated by the aeromagnetic map (Figure 8). This map displays a prominent 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. Robinson's (1970) detailed analysis of the aeromagnetic anomalies of the area suggested that the elongate doming of the Paleozoic sedimentary rocks associated with the thrust may be related to emplacement of magnetic anomaly source material and implied that this has been a zone of recurring tectonic activity since at least late Paleozoic time. A comparison of Figures 7 and 8 shows an excellent correlation between the iso-lineament belt and the dominant magnetic anomaly zone.

Within the band of concentrated 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 channel ways 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 7 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 is 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 closely with a large window of exposed linestone 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 to which ERTS imagery can be used as an aid to reconnaissance exploration compaigns.

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 delineating 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 analyces 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 over specific areas.

Acknowledgements

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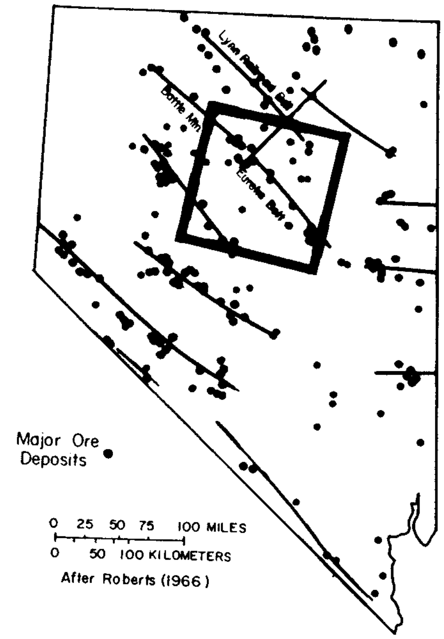

Fig. 1 Index map of Nevada showing outline of area and mineral belts.

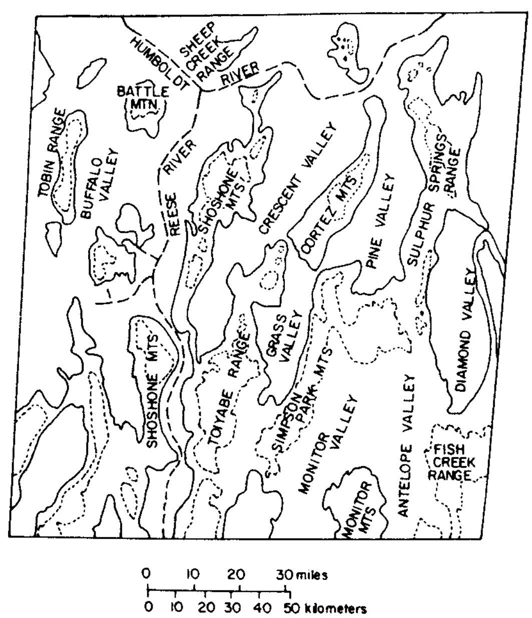

Fig. 2 Map showing major topographic features in north-central Nevada.

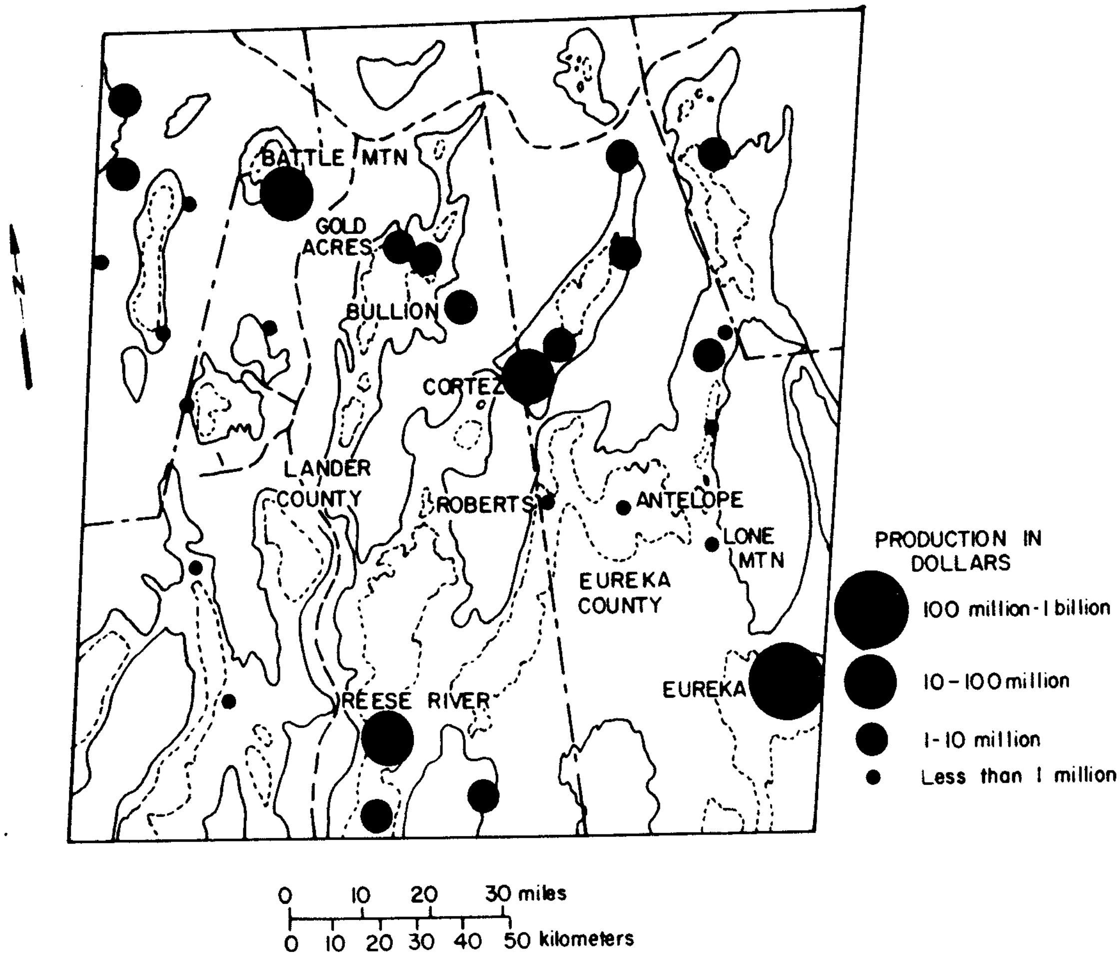

Fig. 3 Map showing major metal mining districts in north-central Nevada (from Nevada Bur. of Mines Map 37).

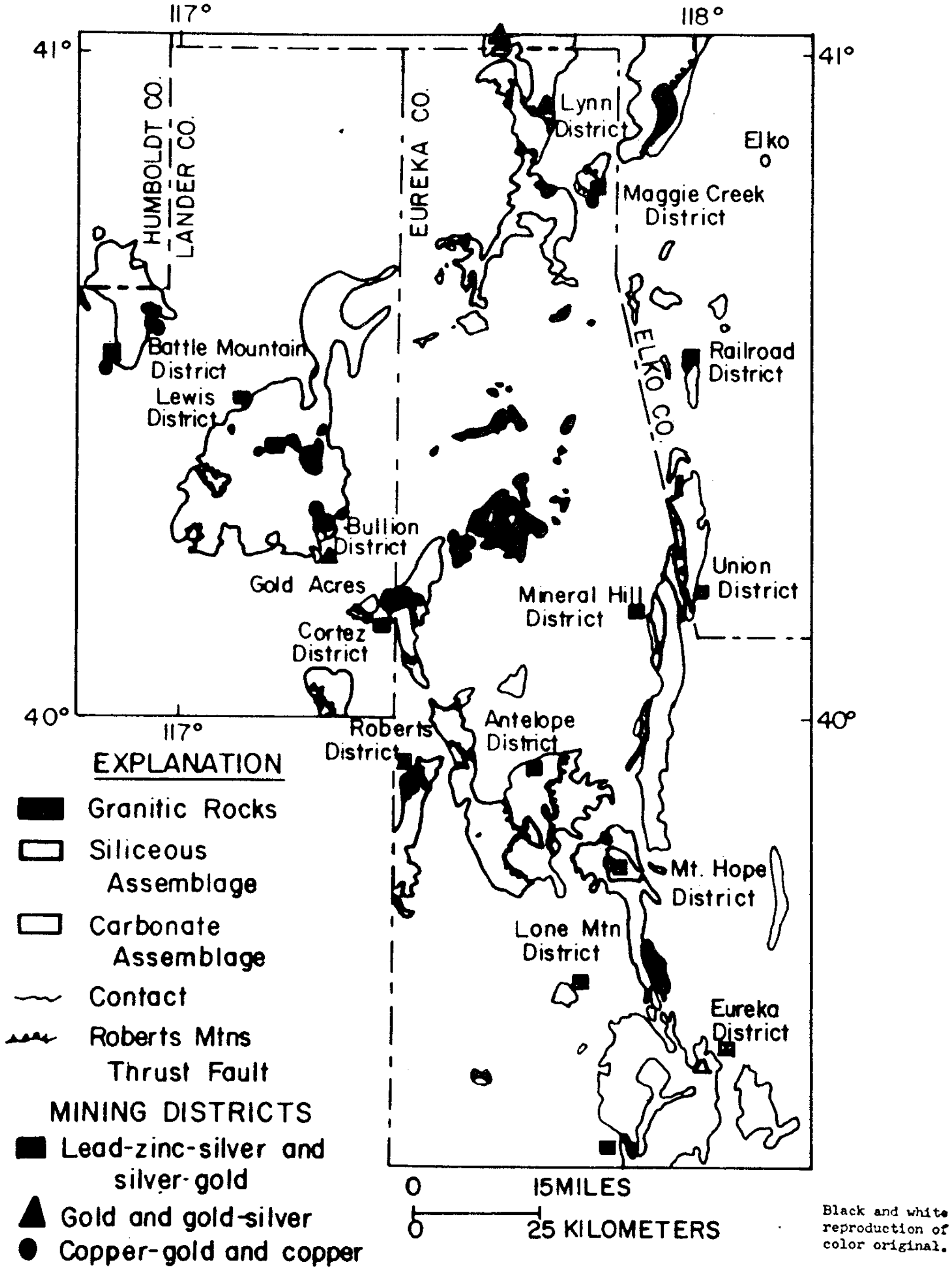

Fig. 4 Generalized geologic map of north-central Nevada showing alinement of mining districts. (After Roberts, 1966)

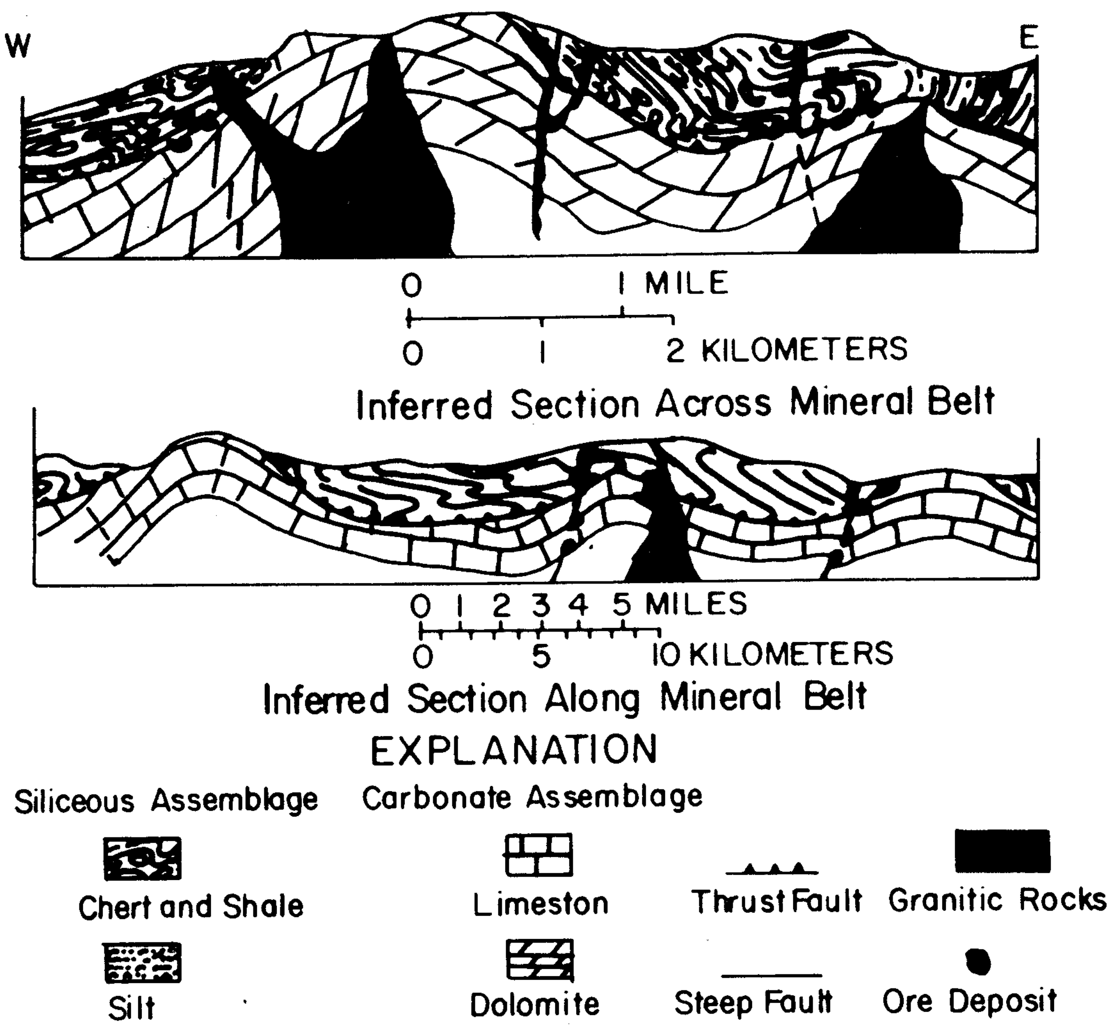

Fig. 5 Inferred sections across and along a mineral belt in north-central Nevada showing possible sites for ore deposition. (After Roberts, 1966).

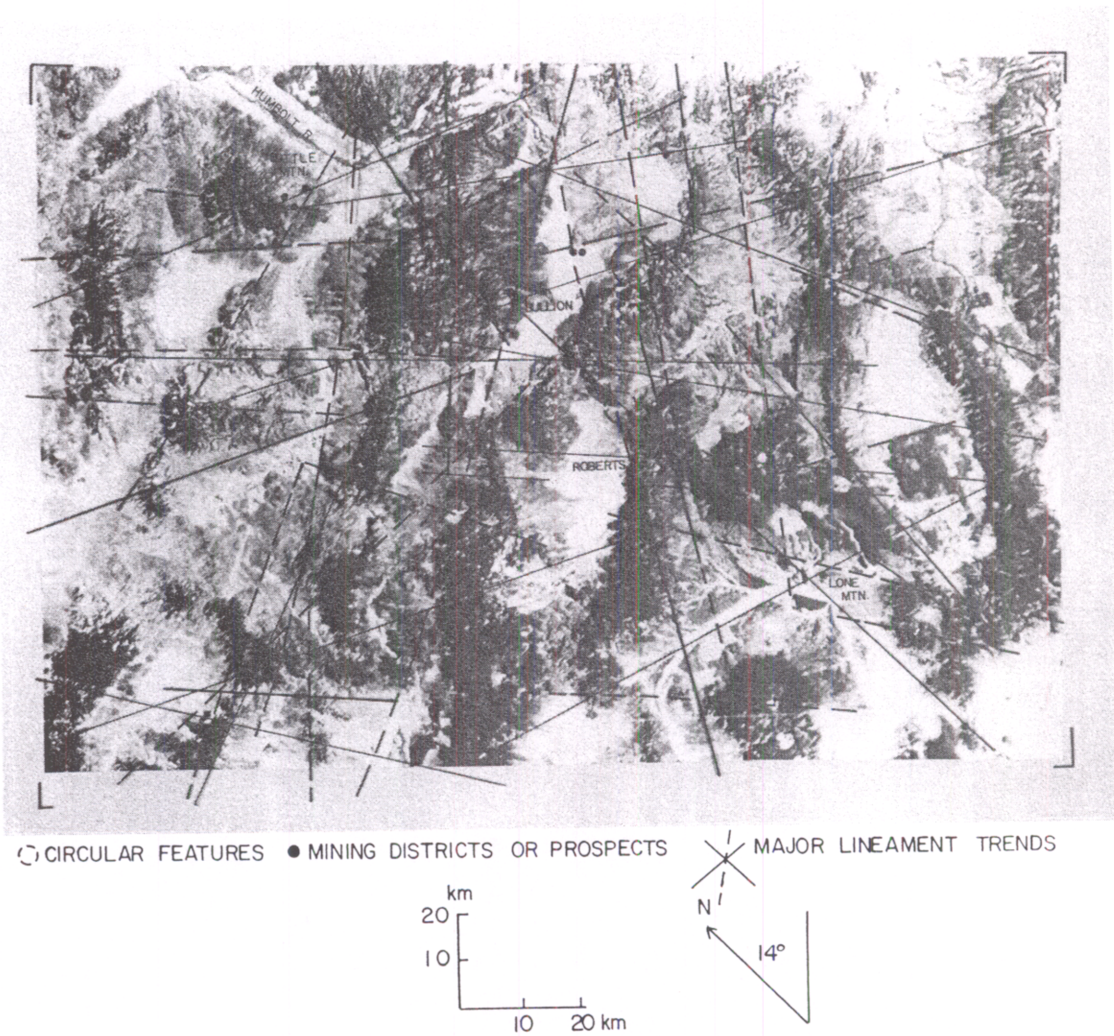

Fig. 6 Observed structural lineaments of north-central Nevada resulting from interpretation of color composites of ERTS frame 101817592.

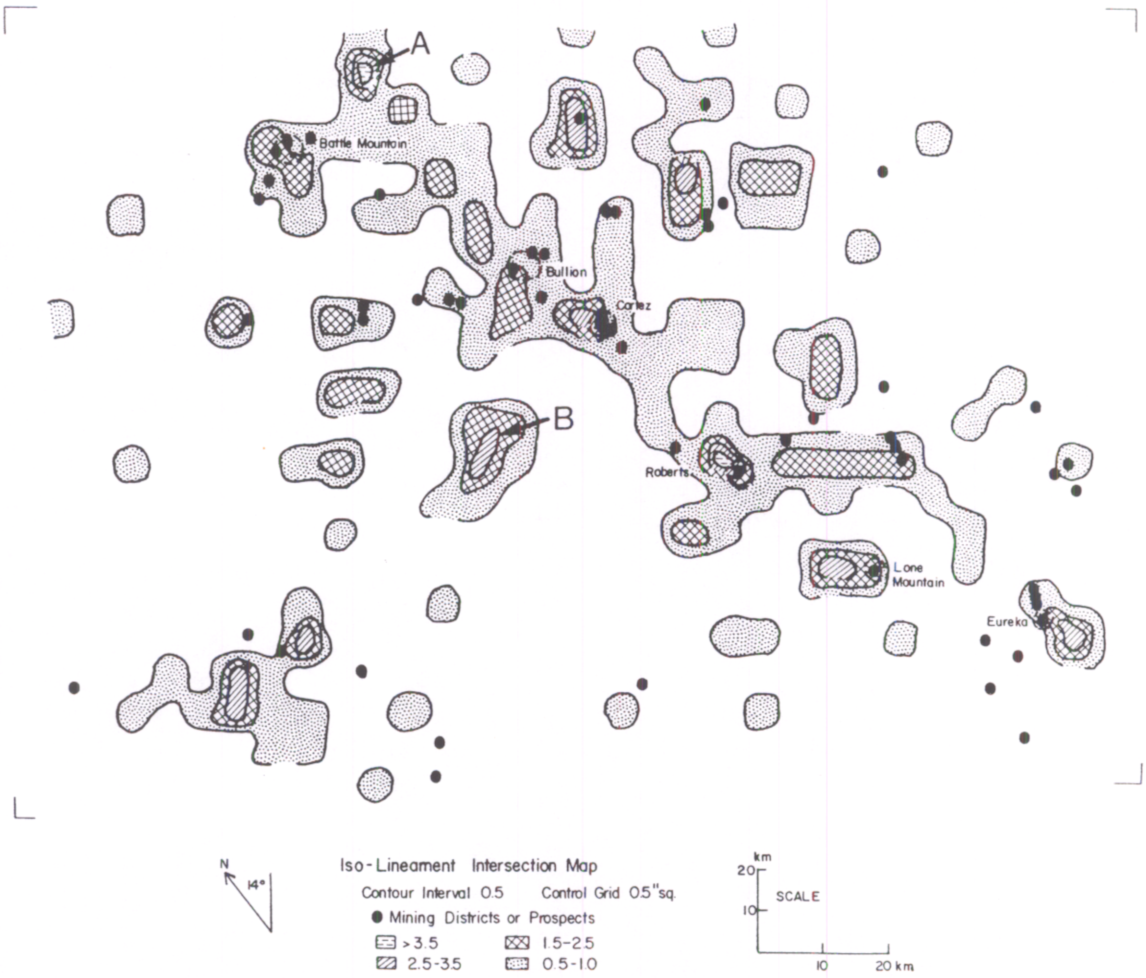

Fig. 7 Iso-lineament intersection map of north-central Nevada showing exploration target areas.

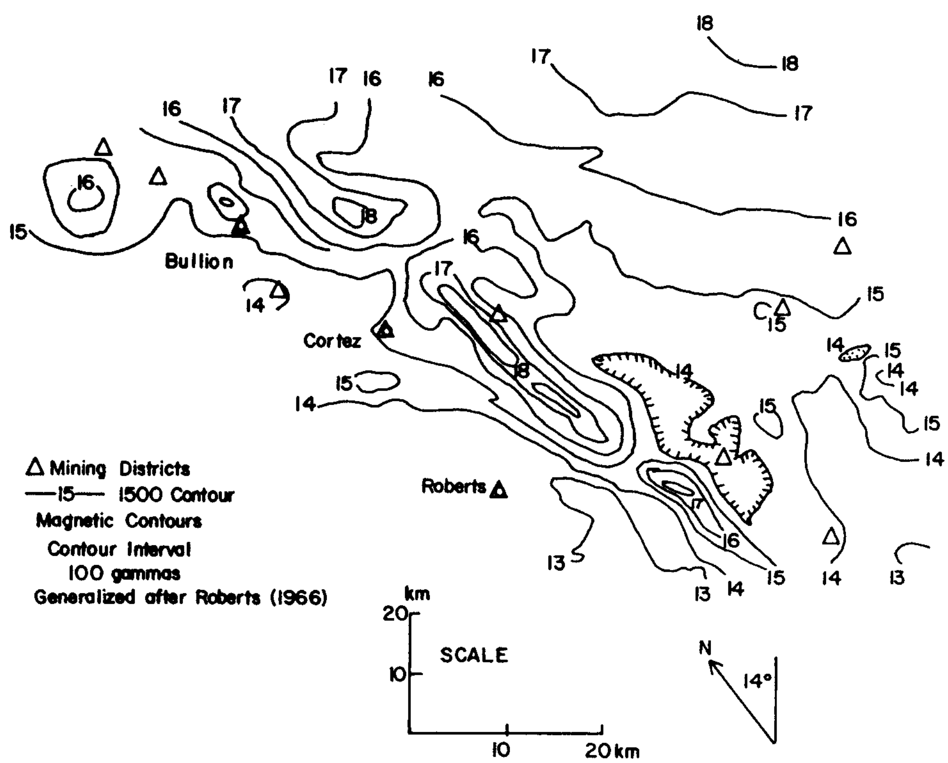

Fig. 8 Aeromagnetic map of north-central Nevada.