DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

PRELIMINARY GEOLOGIC INTERPRETATION OF THE HIGH RESOLUTION AEROMAGNETIC MAP OF PART OF THE COCONINO PLATEAU, HUALAPAI INDIAN RESERVATION, ARIZONA

by

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INTRODUCTION

The purpose of this report is to present the preliminary results of an aeromagnetic survey conducted over part of the Coconino Plateau on the Hualapai Indian Reservation. This work is part of an integrated mineral appraisal study sponsored by the Bureau of Indian Affairs (BIA) on the Hualapai Indian Reservation in northwestern Arizona.

Collapse breccia pipes formed in Mississippian to Triassic age rocks are the source of important mineral potential in northern Arizona in recent years. The pipes are thought to have originated in the cavernous Mississippian Redwall Limestone where successive caving of the overlying strata continued upward involving strata as young as the Triassic Chinle Formation (Wenrich, 1985; Krewedl and Carisey, 1986). Uranium mineralization and associated metals (Cu, Ni, Pb, Zn, and Ag) have been recovered from deposits occurring within the brecciated zone.

Many breccia pipes are exposed on the walls of the Grand Canyon and its tributaries, but identifying the pipes on the undissected tree-covered Coconino plateau is more difficult. Characteristic features that can be recognized from the best exposures include the central brecciated zone or throat, extending upward from the Redwall Limestone to at least the Coconino Sandstone. Above the Coconino Sandstone, a collapse cone surrounds the throat involving the Toroweap and younger rocks. The collapse cone nearly always has inward-dipping beds involving rocks of the Kaibab and Toroweap formations. Typical dimensions of the throat may be between 100 to 200 m in diameter and the surrounding cone may be 500 to 1000 m or more in diameter. The attitude of the throat of the pipe is generally vertical, but may plunge in any direction from vertical (Krewedl and Carisey, 1986). Many circular to subcircular features have been recognized on the plateau surfaces both north and south of the Grand Canyon. These circular features may involve one or more of several surface manifestations such as circular depression, vegetation changes, inward dipping beds, circular drainages, and visible alteration of surface rocks (Wenrich, 1985). However, on the eastern part of the Hualapai Reservation dense tree-cover masks potential breccia pipes and limits techniques that are effective in less dense tree-covered areas.

There is a growing body of evidence suggesting a direct spatial relationship of between breccia pipe location and fracture systems which are thought to have controlled cavern development in the Redwall Limestone (Sutphin and Wenrich, 1983, 1985). Presumably, fracture systems in the Redwall Limestone are related to reactivation of previous fault systems present in the underlying crystalline rocks. Preliminary evaluation of regional aeromagnetic data suggested definite patterns of magnetic anomalies thought to be related to magnetic rocks intruded along regional zones of crustal weakness (Flanigan and Long, 1985).

Detailed ground magnetic measurements over one suspected breccia pipe area indicated that the feature can be characterized by a 10 nanotesla (nT) low surrounded by a ring of short-wavelenght magnetic anomalies (Senterfit and others, 1985). The ground magnetic measurements were mathematically continued upward to 100 m in order to determine if the feature might be recognized by a high resolution aeromagnetic survey. The resultant map clearly indicated that in this case the magnetic anomaly associated with the feature could be detected by an airborne survey (Flanigan and Long, 1985). It is not known if the ground test site magnetic anomaly is typical of breccia pipes found elsewhere on the reservation. Considerable detailed electromagnetic (EM) and ground magnetic measurements have been made over areas thought to be breccia pipes. The EM data, particularily the audio-magnetotelluric (AMT) data, are very useful as a exploration tool to delineate these collapse features (Flanigan and others, 1986a, 1986b). The magnetic data from the detailed EM and magnetic surveys showed little consistent magnetic character that could definitely be related to the breccia pipe themselves. Previous aeromagnetic surveys (Sauck and Sumner, 1970; Department of Energy, 1983) covering the eastern tree-covered areas of the Hualapai Reservation were considered to be of insufficient data density to test the aeromagnetic method as a viable exploration tool for breccia pipes.

GEOLOGIC SETTING FOR AEROMAGNETIC SURVEY AREA

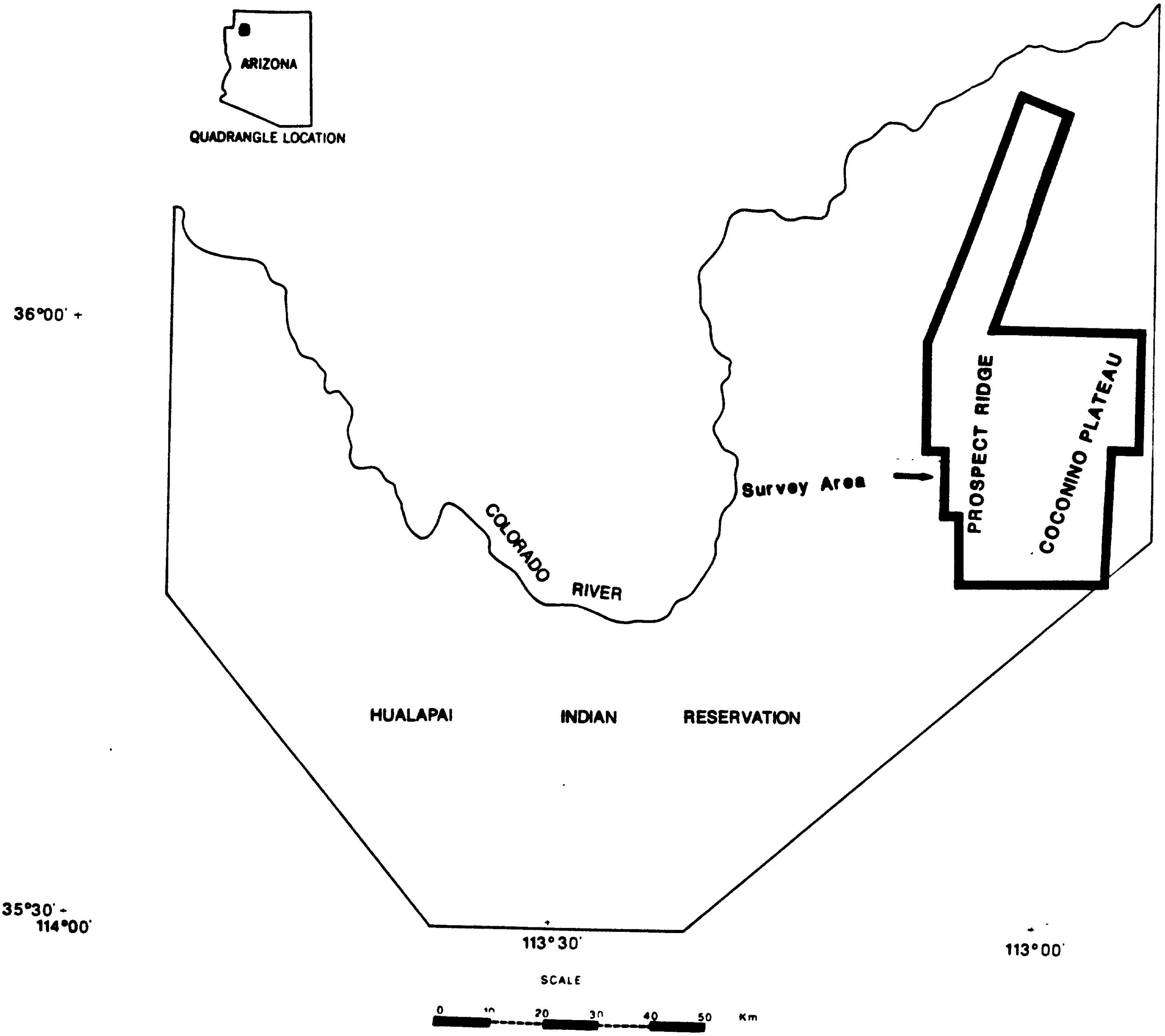
The aeromagnetic survey test area lies over the eastern part of the Hualapai Indian Reservation (fig. 1). This part of the Coconino Plateau is relatively flat, dipping gently to the east. Elevation of the survey area ranges from 2118 m on the west to 1829 m on the east. Paleozoic through Cretaceous sediments were deposited in the area ranging from 2500 m to 4000 m in thickess (Wenrich and others, 1986; Billingsley and others, 1986). Uplift accompanied by widespread erosion occurred as a result of the Late Cretaceous through Eocene Laramide orogeny. The Paleozoic rocks that have been preserved are one kilometer or more thick. Reactivation of basement faulting produced faults and monoclines in the Paleozoic and younger rocks. Post-Laramide faulting reacting to a regional extensional stress regime continues to the present and has left a complex record of tectonic history in the rocks. Large displacement, north-, northeast-, and northwest-trending normal basement faults propagating into the sedimentary section are typical in the survey area and influence the local topography. Permian Kaibab Limestone rocks form the surface of the survey area, and in places are covered by a thin vernier of alluvium.

AEROMAGNETIC SURVEY

Early in 1985 an aeromagnetic survey was flown over about 325 km sq. of the eastern part of the Hualapai reservation (fig. 1). The survey area is mainly tree-covered, extending eastward from Prospect Ridge to the east reservation boundry line. The purpose of this survey was to provide high-quality aeromagneic data that could be used to: 1) delineate regional structures crossing the area, and 2) detect, if possible, magnetic anomalies associated with the collapse features that may be present.

The survey was flown at about 90 m draped above ground level with flight lines spaced 120 m apart. Position control and flight path recovery were obtained by the use of ground-based transponders and on-board electronics to receive and compute aircraft position from the transponder signals. The proton magnetometer cycled every 0.5 second yielding a magnetic reading at average aircraft speeds every 22 m along the flight path. The magnetometer sensitivity for a 0.5 sec. cycling rate is about 0.5 nT.

Standard data processing corrections were applied to the digital data, such as, the removal of diurnal magnetic variations were removed, and positional corrections related to small delays in digital recording. In



re 1 Index map of northwestern Arizona showing the location of the test high-resolution aeromagnetic survey of part of the Coconino Plateau on the Hualapai Indian Reservation.

addition, aircraft heading corrections were made and a reference field related to the actual flight surface was applied to the data set. The resultant residual total-field map is presented on plate 1. For ease of data presentation of these prelimary aeromagnetic maps only the main body of data are presented. The data comprising the north-northeast flight lines on the western side of the survey area will be presented at a later date.

DISCUSSION

The aeromagnetic map (pl. 1) is dominated by a subcircular magnetic anomaly of about 600 nT. The subcircular anomaly forms part of a north-trending belt of anomalies thought to have their sources in basement rocks beneath sedimentary cover rocks (Flanigan and Long, 1985).

In order to assess the value of this magnetic data to delineate geologic features present in the sedimentary rocks it is necessary to evaluate the high-frequency content of the aeromagnetic data. The high-frequency data are first emphasized by filtering the observed data using a bandpass filter allowing data with a wavelength between 0.18 - 1.0 km to pass. The filtered data are then displayed as profiles along the flight line location map (pl. 2). The profiles are plotted using a automatic scaling routine which sets the amplitude of the plot according to the range of magnetic readings along each flight line. Thus, the vertical scale of the data may vary slightly across the map. In general, the highest magnetic anomalies seen on plate 2 are less than 10 nT. It is quite evident that many of the high-frequency anomalies were detected along successive flight lines so that they form anomaly trends whose principal directions are northwest-southeast, north-south and northeast-southwest. Shown also on plate 2 are fault and fracture zones and suspected breccia pipe locations mapped by Wenrich and others (1986) and Billingsley and others (1986). It is evident that many of the linear high-frequency magnetic anomalies are closely correlated to the mapped structures. As one might expect the fracture zones and the magnetic anomalies also follow topographic lows associated with valleys. Fault and valley correlation is not uncommon because most of the valleys are believed to be fault controlled.

The nature of the source of the magnetic lineations is not well understood, although there are several possible magnetic sources for these magnetic anomalies. Detailed magnetic measurements (1 m interval) were made over seven different pipelines crossing the reservation. These pipe lines feed stock watering tanks at places that are widely separated. The pipe lines are iron pipe, two inch or less in diameter laid on the surface of the ground and covered with a foot or more of earth scraped from the adjacent area. The detailed magnetic data show a variety of magnetic anomalies both in amplitude and anomaly shape. Thus, the possibility of the magnetic lineations being related directly to the water pipes seemed feasible. However, no spatial relationship between the magnetic lineations and the pipe locations could be found. Further, detailed ground magnetic measurements over the pipe lines in all cases indicated an anomaly width of about 30 m. At best the airborne magnetic survey would have recorded only one magnetic reading somewhere in that 30 m interval. It seems highly unlikely that the high-frequency magnetic anomalies are associated with the water pipes.

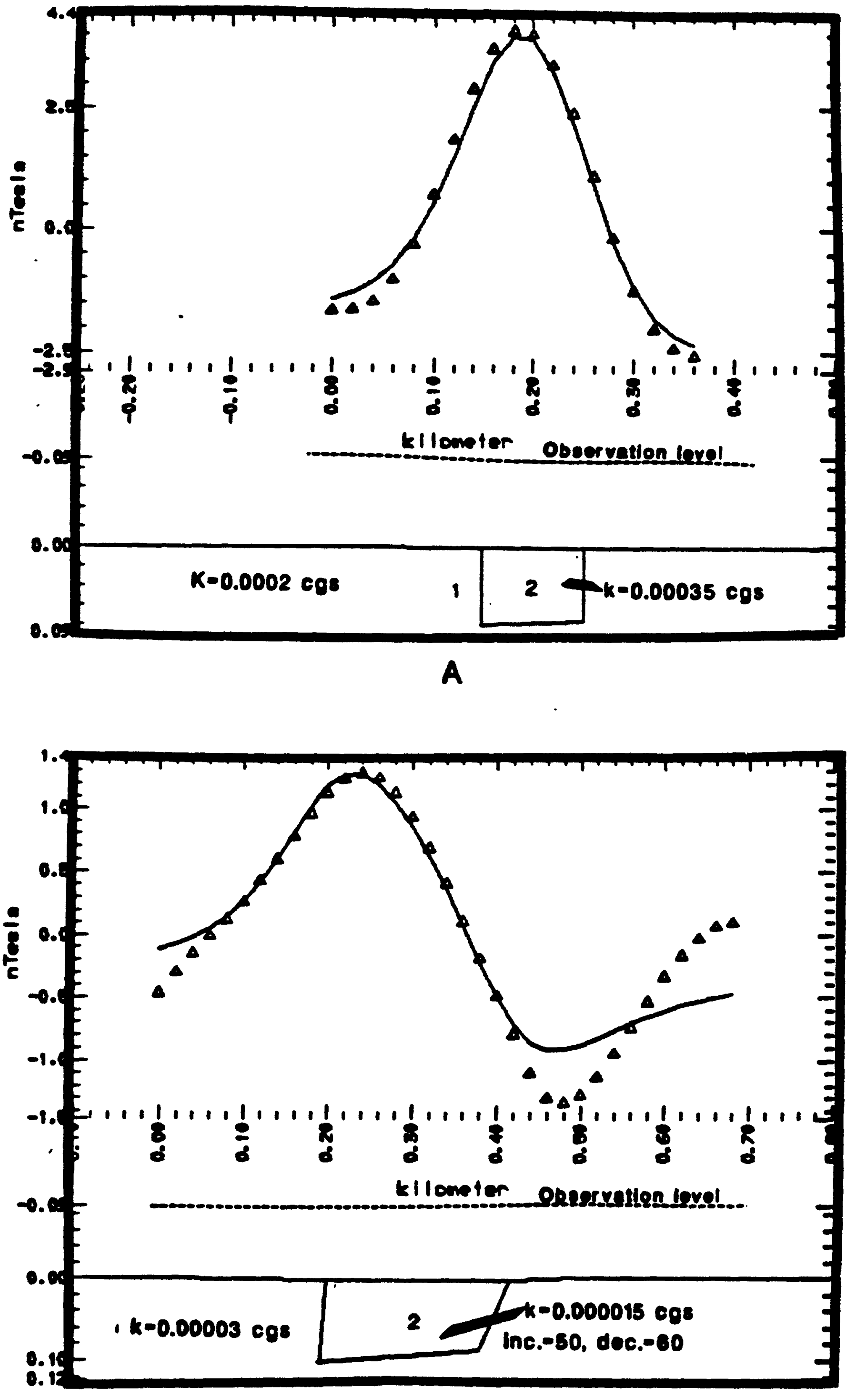
As mentioned earlier, detailed ground magnetic measurements (Senterfit and others, 1985) in the area of a suspected breccia pipe revealed a subcircular ring of magnetic anomalies surrounding the feature. The dipole magnetic anomalies suggest remanent magnetism in rocks oriented differently than the present direction of the Earths' magnetic field. This type of effect might be obtained from a fracture zone (in this case a ring fracture) where blocks of rocks which have a component of remanent magnetism have been rotated by movement within the fracture zone.

Another possible cause for such magnetic anomalies may be related to the accumulation of residual free magnetite within topographic lows. Although the high-frequency anomalies generally follow the valleys they do not everywhere coincide with the indicated drainage channels. This is particularly true of several of the northwest trending features, especially the magnetic lineation which coincides with the Laguna Fault. Here the drainage channel lies about a kilometer to the east of the Laguna Fault and then changes direction normal to the fault.

Several of the high frequency anomalous areas were examined by dragging a magnet through a measured length of the surface soil. Free magnetite is present in the soil but did not appear to be more than found in soils on the slopes adjacent to the valley. These tests cannot be considered conclusive because the content of magnetite in the first few centimeters of soil may not be representative of the entire soil profile.

On close examination of the high-frequency anomalies two anomaly shapes are present: 1) a symmetrical anomaly of about 7 nT in amplitude and 2) a dipole anomaly of about 3 nT in amplitude. These typical anomalies are illustrated on figure 2 by the triangle shaped symbols. The symmetrical shaped anomaly may be modelled (Webring, 1985) as shown in figure 2A by a block of material slightly higher in magnetic susceptibility than the surrounding rock. In the case of the dipole anomaly (fig. 2B) it is necessary to introduce a component of remanent magnetism in order to get a reasonable fit to the observed data.

It seems likely that the sources for the magnetic lineations are either directly associated with faulting as in the case of rotated blocks of rock in the fault zone, or are indirectly related to faulting by the concentration of magnetite in fault controlled valleys. Assuming the magnetic lineations shown on plate 2 are related to fault and fracture zones, several general observations may be made: 1). mapped faults may be extended considerable distances in areas where coherence between the magnetic lineation and the mapped fault is good. 2). Areas where magnetic lineations are present and no fault has been recognized should be reexamined. The most striking example is the strong north-south lineation extending across the east-central part of the map. This magnetic lineation appears to be the extension of National Canyon to the north and suggests National Canyon may be fault controlled much like its' neighbor to the west, Mohawk Canyon. 3). Some north-trending faults, particularly on the eastern side of the map, are not associated with magnetic lineations. One plausible explanation among several is that there has been little or no block rotation associated with movement along this fault. Perhaps the type of stress regime active at the time of faulting may have had a direct bearing on the type of movement along the fault.



re 2 Theoretical models of high-frequency magnetic anomalies. The diamond symbols indicate the shape and amplitude of the observed anomaly; the solid lines indicate the calculated anomaly from the model shown at the lower part of the illustration. The model in figure 2B introduces a component of remanent magnetism to fit the observed anomaly.

The other goal of this test aeromagnetic survey was to determine if there are magnetic anomalies associated directly with the breccia pipes. A close examination of the airborne data in the area of detailed ground magnetic measurements mentioned previously generally confirmed the presence of a magnetic low thought to be related to the suspected breccia pipe. However, other potential breccia pipe areas do not display a unique magnetic anomaly associated with them, either by the limited ground magnetic measurements or by the airborne magnetic data presented here. It appears quite likely that there are no magnetic anomalies associated with the breccia pipes that would provide a reliable exploration tool. It must be remembered however that of the suspected breccia pipes that have been studies with detailed magnetics none have been drilled to confirm the presence of the breccia pipe.

CONCLUSIONS

The high-resolution aeromagnetic residual total-field magnetic map is dominated by a subcircular magnetic anomaly of about 600 nT amplitude. The magnetic source for the anomaly is thought to be igneous rock beneath Paleozoic sedimentary rocks. The high-frequency component of the magnetic data set gives insight into the near-surface magnetic character of the sedimentary rocks. The high-pass filtered data reveal numerous linear magnetic features extending tens of kilometers across the Survey area. These linear magnetic anomalies have a close spatial relationship to both mapped fault structures and topographic lows. Several possible sources for the high-frequency magnetic anomalies were examined in order to understand the nature of the magnetic sources for these anomalies. Iron pipe water lines are not believed to be a source of the linear magnetic anomalies. Residual magnetite concentrated in valley bottoms may be the source of the anomalies. Initial ground checks to confirm the presence of magnetite in topographic lows was considered inconclusive and requires further study in order to be definitive. Another possible magnetic source for the linear high-frequency magnetic anomalies is thought to involve blocks of rocks containing a component of remanent magnetism which have been rotated in a fault zone so that the resultant magnetic anomaly is strongly influenced by the direction of the remanent magnetic inclination and declination. Theoretical models suggest that either of the later two potential magnetic sources may be reasonable.

If the low-amplitude linear magnetic anomalies are associated with regional fault patterns then it is evident that mapped faults may be extended in some areas and new faults mapped in other places.

No spatial relationship of the magnetic lineations and breccia pipe location can be positively identified from these data. Nor can any unique magnetic signature be associated directly with breccia pipes.

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