AN INTERPRETATION

OF THE

TOLITA AND TORO AREA HELICOPTER MAGNETIC SURVEY

MARICUNGA BELT, CHILE

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ABSTRACT

A high resolution helicopter-borne aeromagnetic survey was flown over the Tolita and Toro prospects in the Maricunga Belt, Chile. The purpose of the survey was to delineate structure and to map the magnetic characteristics of the prospects.

The original data provided by the survey contractor was first decorrugated, spectrally analysed to remove random noise and then Reduced to the Pole using a minimal amplitude correction factor. The First Vertical Integral and Derivative were calculated together with a modified Analytic Signal termed the First Total Derivative. These products were used to produce an interpretation overlay.

The results show that both the Tolita and Toro prospects are associated with negative magnetic anomalies and that they fall into separate and different magnetic domains. An apparently regional scale NNE-SSW discontinuity bisects the Tolita domain and terminates the Tolita magnetic anomaly on the west. Other major magnetic discontinuities and undifferentiated linears occur in NW-SE, N-S and E-W directions.

It is concluded that the negative magnetic signatures are more likely to be associated with 'hypothermal' remanently magnetised magnetite rather than with 'epithermal' magnetite depletion. Three of the structural directions NNE-SSW, NW-SE and E-W could be associated with 'open' faulting and may constitute major controls of the mineralisation. A more synergistic interpretation of the magnetic and geological data is required and spectral IP should be carried out on the ground in order to refine the magnetic target areas and facilitate more effective drilling.

CONTENTS

LIST OF PLANS

The following 1 : 20 000 scale plans from the Tolita helicopter magnetic survey accompany this report:

1. INTRODUCTION

The purpose of the helicopter-borne magnetic survey was to map structure and in addition to map variations in lithology and alteration zones.

The scope of this report has been to employ Fast Fourier Transform techniques to remove 'noise' from the data supplied by Geodatos and to calculate a meaningful Reduction to Pole with various derivatives and an integral, in order to produce an interpretation overlay of the data. Highly prospective localised areas have been identified together with recommendations for further work.

2. MINERALISATION

It is now relatively well established that copper porphyry systems containing gold are associated with I -type, single mica granitoids having a felsic to intermediate composition. (Guilbert and Park, 1986; Hunt, 1991.) Such 'granites' are characterised inter alia by their magnetite content and their higher magnetisation than say the ilmenite bearing S-type granites. (Chapell and White, 1974; Sillitoe, 1979 and 1992.) Thus, potentially gold bearing porphyry systems could give distinctive magnetic signatures depending on the magnetic contrast between porphyry and country rocks.

However, in reality the hydrothermal alteration associated with economic porphyry systems considerably modifies the magnetic picture. Table 1 modified from Eamons (1936) and Guilbert and Park (1986) gives the I-type paragenesis with associated ore mineralisation and wall-rock alteration. Gold may be seen to occur both in the 'hypothermal' Zone 2

TABLE 1

TYPICAL I-TYPE HYDROTHERMAL PARAGENESIS AND WALL-ROCK ALTERATION

ZONE	ALTERATION MINERALS	ORE MINERALS	ECONOMIC ELEMENTS
9	Chalcedony, quartz, barite, fluorite	Cinnabar	Hg
8	Quartz	Stibnite	Sb
7	Quartz, chalcedony, amethyst, sericite	Acanthite, native gold, antimony minerals, tellurides, selenides	Au, Ag
6	Quartz, calcite, dolomite, siderite, clay minerals	Silver arsenic-antimony sulphosalts, pyrite, rhodonite	Ag, Mn, (Fe)
5	Quartz	Rhodochrosite, rhodonite, galena, sphalerite, pyrite, chalcopyrite	Pb
4	Ca-Fe-Mn carbonates, quartz, pyropylite, topaz, alunite, kaolinite	Sphalerite, galena, chalcopyrite, tennanite-tetrahedrite	Zn
3	Quartz, sericite, clay minerals, propylite	Tennanite-tetrahedrite, chalcopyrite, pyrite	Cu
2	Quartz, sericite	Chalcopyrite, pyrite, pyrrhotite, Tennantite-bornite-chalcocite, enargite	Cu, Ag, Au
1	Quartz	Scheelite, pyrite, molybdenite,	Mo, W

and the 'epithermal' Zone 7. (The author's zone numbers, not those of Eamons.)

From the geophysics angle the zone is extremely important because the originally deep-seated Zone 2 is commonly associated with an increase in magnetite whereas the originally shallow Zone 7 is almost always the antithesis, being depleted in magnetite. At Tolita the presence of high-temperature, Zone 1 molybdenite (W. Smith, pers. com.) would appear to indicate 'hypothermal' activity, with Zone 2 gold and a concomitant increase in magnetite with its geophysical implications. It is worth mentioning that although arsenic minerals are arguably most abundant in epithermal zones, as shown in Table 1, arsenic is well known to occur throughout the paragenetic sequence at virtually all temperatures. (Although, arsenic anomalies at Tolita are probably not diagnostic in terms of zoning, it cannot be definitely ruled out that a later, epithermal event has not only brought in the gold but also destroyed the magnetite.)

3. STRUCTURAL IMPLICATIONS

In any mineralised district involving hydrothermal activity, structure is generally of prime importance. At a regional scale, the Maricunga Belt is characterised by its relatively great length compared to its diminished width, seemingly indicating excessive compression with, however, complementary extension. Figure 1 shows an idealised strain ellipse of the belt with the permissible complementary structures which can arise. Not all structures will be developed to the same degree and clearly Figure 1 does not include features older, or younger, than the Maricunga Belt.

The most important factors when considering the structural features shown in the strain ellipse are that normal faults tend to be open, and

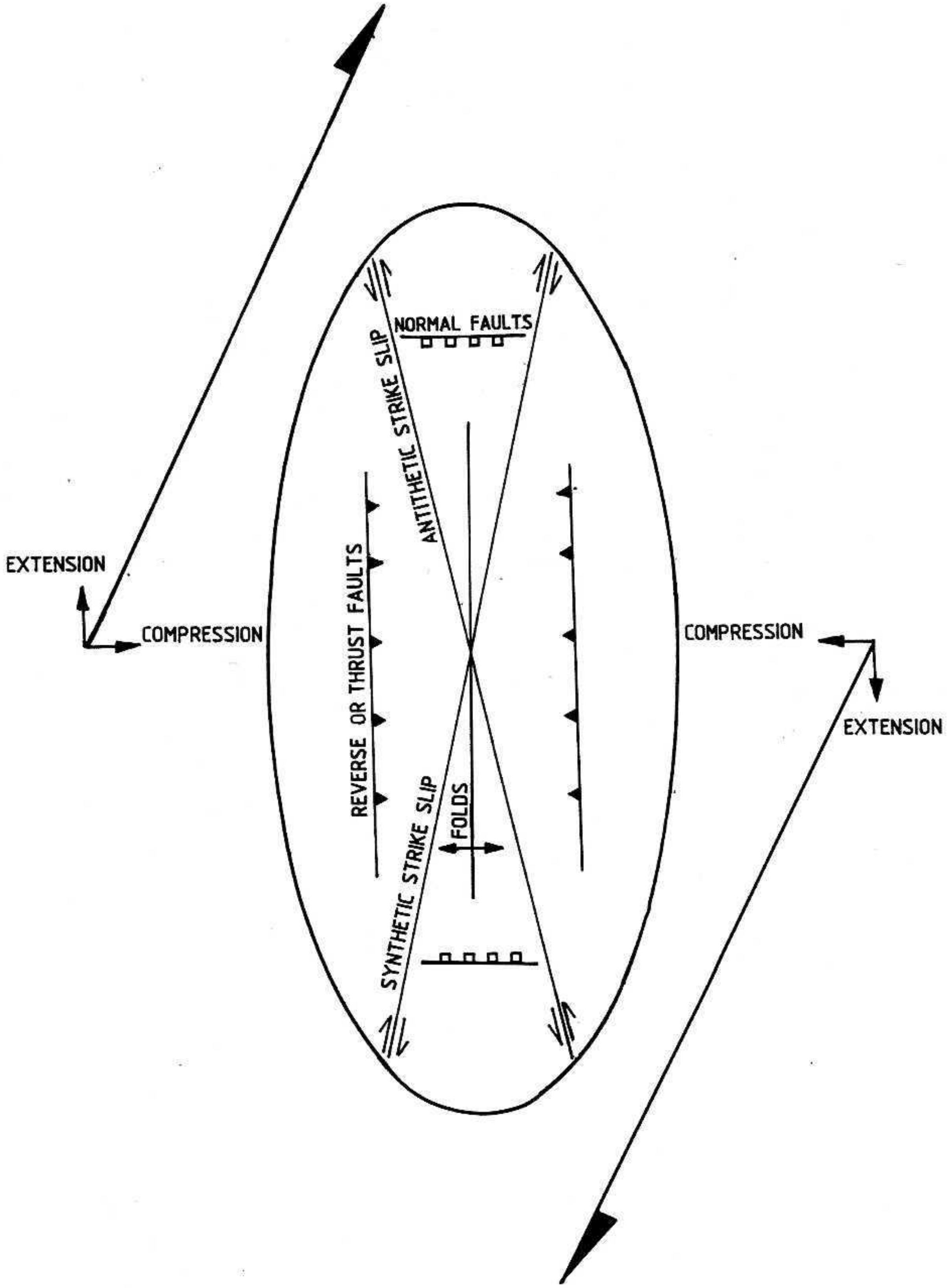

Figure 1: IDEALISED STRAIN ELLIPSE OF MARICUNGA BELT.

reverse or thrust faults closed, while commonly only one of the strike-slip faults will be open.

Hence, allowing for minor variations in the direction of the belt as a whole, those structures likely to control mineralisation will be the E-W trending normal faults, plus one of either the sinistral NNW-SSE *or* the dextral NNE-SSW strike-slip faults.

4. OVERVIEW OF DATA ACQUISITION AND BASIC COMPILATION

The survey was flown by Geodatos between 31 October and 3 November 1996. An Aerospatiale Lama helicopter was employed carrying a Scintrax caesium vapour magnetometer and GPS navigation. Very little information has been provided by Geodatos in their operations report. (Geodatos, 1996.)

The survey was flown with N-S flight lines 100m apart and with E-W tie lines 1 km apart. The mean terrain clearance was 50 m. Examination of the flight path recovery (Geodatos, 1996, Mapa 1) shows that many lines are out of specification, some touching, others too far apart. Some flight lines and at least one tie line are too short. Clearly, greater quality control of the flying would be required in future surveys.

The raw data were edited and compiled by Geodatos in GEOSOFT OASIS. A questionable technique was applied in that although the data were tie-line leveled, thus effectively removing diurnal magnetic effects, the base-station magnetometer readings were also directly subtracted. This has resulted in negative residual magnetic values because the base station magnetometer was reading several hundred nanotesla less than the survey magnetometer. Much more preferable would have been tie-line leveling and the removal of an 'IGRF'. The results of the basic compilations may be seen in Geodatos (1996, Mapa 1). Several rather severe 'pulls' may be seen throughout the map indicative of either navigation errors along line or else poor leveling in general. Again, quality control is required at this stage as well as in the actual flying.

Owing to the nature of the basic compilation of the raw data the Reduction to Pole (Mapa 2) and the First Vertical Derivative (Mapa 3) are extremely noisy, especially the latter. Both Reduction to Pole and First Vertical Derivatives are described in Section 6.

5. FURTHER DATA PROCESSING

5.1 DECORRUGATION

In order to improve the basic Residual Magnetic Intensity supplied by Geodatos the technique commonly referred to as decorrugation was used on the data. The process is conducted in the frequency-domain utilizing the Fast Fourier Transform (FFT).

Decorrugation as performed in Geosoft is a combination of directional, cosine filtering and Butterworth high-pass filtering. The essence of the technique is to remove short wavelength anomalies, that is noise, along the flight-lines, thereby removing 'pulls' and 'herringboning'. The process is equivalent to the contractors' 'microleveling' but the data remains in grid format rather than being returned to line data. A description of the process is given in Geosoft (1994).

Because of the somewhat severe flight-line problem in the data supplied a fairly severe decorrugation was applied. This has resulted in a smoother, but nonetheless more coherent, representation of the basic data which following Geodatos has been termed the Residual Magnetic Intensity, as shown on Plan 1 of this report.

The salient features of the Residual Magnetic Field are as follows:

- The discontinuous, positive signatures in the southwestern portion of the area associated with an ESE-WNW trend.

- A continuous elongate positive feature in the northern portion showing a distinct dislocation or jog.

- Pronounced negative features in the northwestern and roughly central areas including the Tolita area.

- North-south features to the eastern side of the area which are also associated with negative signatures, including the Toro area.

It should be remembered that the Residual Magnetic field produces dipolar anomalies which are displaced from the positions of their true sources. For this reason Reduction to Pole was carried out as described below.

5.2 REDUCTION TO POLE

In order to simplify the dipolar nature of the magnetic anomalies Reduction to Pole was performed. In Reduction to Pole the field is recreated as if it were at one of the Earth's poles where the inducing field is vertical.

The technique, though named differently at the time, was first introduced by Baranov (1957). The data shown on Plan 2 were the result of spectrally analysing the decorrugated data, identifying and removing random noise and finally applying the Reduction to Pole operator as given by Geosoft (1994). The inclination used was 26°S with a declination of zero As can be seen the removal of the random noise has left the Reduction to Pole data considerably smoother than the original Residual Magnetic Intensity data.

The Reduction to Pole map (Plan 2) still gives the broad overall picture of the magnetic environment but without the distortion displayed by the Residual Magnetic Intensity. The main advantage is that anomalies occur over the causative bodies, provided that any remnant magnetisation is anti-parallel to the Earth's present field.

It is extremely important to realise that Reduction to Pole at inclinations less than about 30° tend to become unstable in a north-south direction. The problem stems from an inherent amplitude factor in the filter operator which provides an amplitude correction. At low magnetic inclinations minimal north-south variations become grossly exaggerated at the expense of the true trends. This may be seen on the Geodatos Plana 2 Reduced to Pole results where the main circular and east-west magnetic lows have been drawn out into north-south features. In view of this the Reduced to Pole data shown on Plan 2 of this report were recalculated, using a minimised amplitude correction, and thereby preserving the original trends.

The most significant feature of the Reduced to Pole data shown on Plan 2 is the considerable shift of anomalies to the south. This is especially evident in the negative anomalies in the western and central portions of the area. It should be noted that during the Reduction to Pole process a first-order polynomial trend is removed from the data so that background levels between the Residual Magnetic Intensity and the Reduced to Pole data are different. In fact the Plan 2 Reduction to Pole results are more 'residual' than those of Plan 1, and thus more applicable to mineral exploration. Once the background has been 'normalised' in the Reduction to Pole process the true nature of the negative anomalies associated with both Tolita and Toro become more apparent, notwithstanding the smoother data.

Clearly, a pronounced WNW-ESE trend is associated with the local Tolita area, extending to the west, while a further alignment of strong NNW-SSE negative anomalies extends from Tolita to the north. Tolita itself appears to be closely associated with the smallest and southernmost of these strong negative anomalies.

Toro is associated with a much weaker negative anomaly, trending E-W, in an area where N-S trends are more conspicuous. A well resolved, circular negative anomaly occurs about two kilometres south of Toro, with somewhat similar characteristics to those of Tolita.

5.3 FIRST VERTICAL INTEGRAL

The First Vertical Integral, of the Reduced to Pole data, gives the overall, **regional** magnetic picture of the survey area. As its name implies it is the first integration of the magnetic field with respect to the vertical direction. The calculation is similar to, but not the same as, the pseudo-gravity technique. It was calculated in the frequency domain using Geosoft's (1994) operator.

The main use of the First Vertical Integral is to outline broad magnetic domains which reflect differing geological/exploration domains. Thus, the results of Plan 3 show very broad positive and negative zones together with regional trends and regional scale discontinuities.

The Tolita area is associated with a major negative group of anomalies essentially trending ENE-WSW. It is adjoined to even stronger negative anomalies to the NW, displaced by a regional scale NNE-SSW discontinuity.

The Toro area is also associated with a relatively low series of anomalies, but much less so than the Tolita anomalies. The trend of the Toro domain is more E-W than that of Tolita, bisected by a strong N-S feature

5.4 FIRST VERTICAL DERIVATIVE

As its name implies the First Vertical Derivative is the first differentiation of the Reduced to Pole data, in the vertical direction. It is the opposite of the First Vertical Integral, highlighting short wavelength anomalies and is analogous to the vertical gradient of the Reduced to Pole results. Anomalies still occur directly over their sources but resolution is greatly improved. The process was again carried out in the frequency domain using the standard operator given by Geosoft (1994). The First Vertical Derivative is often useful in mapping near surface structure since the zero-contour approximately defines magnetic boundaries which often correlate with faults or contacts. By the same token individual geological units become well resolved.

The First Vertical Derivative results shown on Plan 4 emphasise the complexity of the area in general. The Tolita anomaly is clearly more complex than portrayed by the straight Reduced to Pole anomaly and it is associated locally with a whole series of differently trending discontinuities.

The Toro anomaly is well resolved too and similarly associated with a complex array of magnetic discontinuities.

5.5 MAGNITUDE OF FIRST TOTAL DERIVATIVE

The Magnitude of the First Total Derivative is the vector equivalent of the Analytic Signal of Roest et al (1992). Unlike the scalar Analytic Signal the First Total Derivative preserves directional information and therefore contains considerably more information than the Analytic Signal (Webb, 1997).

Its main property is that it maps the edges of magnetic bodies, i.e. faults and contacts, rather than the bodies themselves. It is also independent of the Reduction to Pole process and therefore does not require the inclination and declination of the Earth's inducing field. Importantly it is not adversely affected by remnant magnetisation.

As may be seen from Plan 5 there appears to be greater resolution of results than in the First Vertical Derivative data shown on Plan 4. Since horizontal derivatives are used in its calculation certain trends not seen in the First Vertical Derivative also become apparent.

The Tolita area is well resolved as is the Toro area. Both positive and negative anomalies in the data represent contacts and faults and since the results are independent of remanent magnetisation structural features may be considered to be more accurately located than in the preceding processes based on Reduction to Pole.

6. INTERPRETATION

The interpretation shown on Plan 6 should be used in conjunction with a 1:20 000 scale geological/geochemical map and the relevant satellite information.

The interpretation map shows the following:

- Magnetic target areas representing lithologic units and/or alteration zones. These are taken from the First Vertical Derivative and labeled A, B, C etc. on the Interpretation map.

- Magnetic domains taken from the First Vertical Integral. The Tolita and Toro domains are highlighted on the interpretation map.

- An interpreted regional scale dextral strike-slip fault, bisecting and displacing the Tolita domain and terminating the Tolita prospect. This feature is taken from the First Vertical Integral.

- Major magnetic discontinuities and undifferentiated magnetic linears taken from the Magnitude of the First Total Derivative.

6.1 REGIONAL MAGNETIC DOMAINS

In order to view the magnetic domains clearly the Interpretation overlay should be overlain over Plan 3, the First Vertical Integral of the Reduction to Pole.

There are five magnetic domains within the survey area, two of which appear to be especially important from an exploration point of view. The domains constitute broad magnetic zones, both positive and negative, made up of a combination of both laterally extensive groups of rocks and deep seated material, i.e. they reflect regional packages of rocks. Commonly, economic mineralisation will be confined to specific domains and each domain generally will have a unique geochemical signature.

The domains of immediate interest in the survey area are highlighted on the Interpretation overlay. The western, or Tolita domain, shows up strongly negative on the First Vertical Integral. The eastern, or Toro domain, is also negative but much less so than the Tolita domain.

Therefore, it is apparent that there is at least some difference between the Tolita and Toro environments.

The Tolita domain actually comprises two sub-domains divided and offset by a regional scale discontinuity described below. The eastern sub-domain, which contains the Tolita prospect, is less negative than the western sub-domain which tends to exhibit more of a N-S trend than the E-W to ENE-WSW trend of the eastern sub-domain.

6.2 INTERPRETED REGIONAL DEXTRAL STRIKE-SLIP FAULT

This feature is again best seen by overlaying the Interpretation overlay over Plan 3, the First Vertical Integral.

The major discontinuity dividing the two halves of the Tolita domain described above appears to indicate a displacement of two to three kilometres in a dextral, i.e. right-lateral sense. The direction of the interpreted fault is NNE-SSW which is in keeping with the synthetic strike-slip direction predicted by the strain ellipse in Figure 1.

The discontinuity appears to form the western boundary of the Tolita mineralisation and if the evidence is to be believed it could be a major control of the mineralisation, either as a conduit, or by faulting out the western part of the deposit, depending on age relations.

6.3 MAJOR MAGNETIC DISCONTINUITIES AND UNDIFFERENTIATED MAGNETIC LINEARS

Both of these magnetic features are best observed by overlaying the Interpretation overlay on the Magnitude of the First Total Derivative (Plan 5) and the First Vertical Derivative (Plan 4).

Perhaps the most prominent of these features are the roughly N-S major magnetic discontinuities in the eastern part of the survey area. These parallel the main direction of the Maricunga Belt. Although with local variations in the axis of the main belt, these major discontinuities could represent antithetic sinistral strike-slip faults it is more likely that they represent the reverse faults or thrusts depicted in Figure 1. Both reverse faults and thrusts are normally, but not always, 'closed' features which do not control mineralisation.

The second set of major discontinuities trend NW-SE. These are more in keeping with the antithetic strike-slip direction and these features could be an extremely important control on mineralisation.

Of the undifferentiated linears, which could be just as or even more significant than the major discontinuities, the chief trend is E-W.
This is the predicted direction of normal faults shown in the strain ellipse of Figure 1. Since normal faults are commonly 'open' this could again be an important directional control on mineralisation.

6.4 MAGNETIC TARGETS

Seven, first-pass target areas have been identified: those in the Tolita area labeled A, B, C and D, and those in the Toro area X, Y, Z. Target A is actually the Tolita prospect area and Target X the Toro prospect area. All are characterised by negative magnetic expressions. It should be noted that all the negative magnetic signatures associated with the targets are expected to result from remanently magnetised magnetite rather than from an absence of magnetite as in magnetite depletion. This tends to tilt the scales towards a 'hypothermal' rather than 'epithermal' depositional setting.

6.4.1 TARGET AREA A

This is the Tolita target area. The complex negative magnetic signature appears to be bounded on the west by the interpreted regional, dextral strike-slip fault and it is also associated with major NW-SE discontinuities and E-W linears. Hence the exploration setting is complex. If the NW-SE discontinuities are the antithetic sinistral strike slip faults depicted in Figure 1 then any, or all, of the three directions associated with the Tolita mineralisation may be important, since all three have the potential of being hydrothermal conduits.

6.4.2 TARGET AREA B

This target area has a slightly stronger negative magnetic response than Tolita itself. Its main interest is that if the interpreted dextral strike-slip fault has displaced the western Tolita magnetic sub-domain to the north, then Target B could be a faulted out portion of the Tolita deposit, providing the dextral fault post dates mineralisation. If the interpreted dextral fault is contemporaneous with mineralisation then any other alteration/mineralisation, or magnetic targets, along its length could also be important. It should be noted that a major NW-SE discontinuity as well as E-W linears are also associated with Target B.

6.4.3 TARGET AREAS C AND D

Both these target areas are spatially associated with the interpreted dextral strike-slip fault and similar comments to the above apply.

6.4.4 TARGET AREAS X, Y AND Z

These targets occur in the Toro magnetic domain. Target X is associated with the mineralised Toro area. The predominant trends in the vicinity of Toro are again NNE-SSW and E-W, but rather than the NW-SE seen at Tolita, the third direction at Toro is N-S. Apart from Toro, the next best target appears to be Target Z about two kilometres due south of Toro.

7. CONCLUSIONS

It is concluded that:

- Both the Tolita and Toro mineralised areas are associated with a negative magnetic signature, suggestive of remanent magnetisation and a 'hypothermal' association.

- The Tolita deposit lies on the eastern flank of an interpreted regional scale NNE-SSW dextral strike-slip fault.

- The Tolita deposit is also associated with fairly major NW-SE magnetic discontinuities as well as E-W magnetic linears

- Any of these three directions NNE-SSW, NW-SE and E-W could be 'open' structures which have had a major control on the emplacement of the mineralisation at Tolita.

- The Toro prospect is also associated with NNE-SSW and E-W linears but unlike Tolita the third prominent direction is N-S and not NW-SE.

- The Tolita and Toro mineralisation occurs in separate and differing magnetic domains that also contain other negative magnetic target areas which merit additional reconnaissance.

- The helicopter aeromagnetic survey has **defined target areas** rather than **directly detected deposits**. Therefore, another geophysical method like Induced Polarisation should be used to directly detect sulphides within the target areas.

8. RECOMMENDATIONS

It is recommended that:

- All available geological, geochemical and satellite data be correlated, at the same scale, with this initial magnetic interpretation. This should be done by the present author together with the geological staff on site, in order to produce a more synergistic final interpretation.

- Consideration be given to conducting Spectral IP at Tolita and Toro to explore the sulphide potential of these sites prior to drilling and to attempt to distinguish between differing sulphides.

- If at all possible the other targets outlined in the Tolita and Toro domains be reconnoitred.

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