ANALYSIS OF SPATIAL DISTRIBUTION OF EPITHERMAL GOLD DEPOSITS IN THE DESEADO MASSIF, SANTA CRUZ PROVINCE

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Keywords: low-sulfidation epithermal deposits; spatial analysis; Fry plots; structural controls; Deseado Massif

INTRODUCTION

The Deseado Massif is located in the southernmost part of the Extra-Andean Patagonia in southern Argentina, approximately between latitudes 46º20'S and 50º00'S and between longitudes 65º30'W and 70º55'W (Fig. 1). It consists of a large non-deformed stable area that had a positive relief through most of its history (Harrington, 1962) and is composed in great part by Upper Jurassic pyroclastic and lava flows of acid to mesosilicic composition. The Deseado Massif can be considered as a differentiated Au-Ag Mesozoic metallogenic province with epithermal mineralizing events related to post volcanic episodes (Schalamuk et al., 2002). Gold deposits in the area are of the low-sulfidation epithermal type and are mainly vein style and therefore, strongly structurally controlled. The deposits seem to have been generated in an environment ruled by generalized extension represented by grabens and half-grabens limited by NNW-SSE trending normal faults produced during Middle and Upper Jurassic. However, the mineralizations could also have partly occurred during transcurrent faulting, which are represented by approximately E-W or ESE-WNW trending fractures, produced immediately after the formation of the grabens.

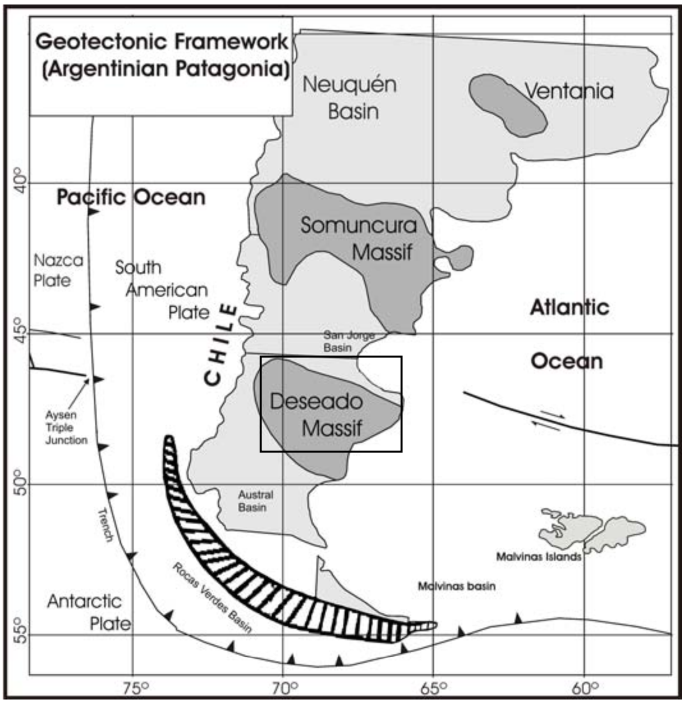

Figure 1: Location of Deseado Massif and study area.

Studies of the structural controls on gold mineralization in the area are scarce and localized in small areas (Marchionni et al., 1999; Mykietiuk et al., 2000; Mykietiuk et al., 2002). While it is generally known that most low-sulfidation epithermal deposits in the area are locally hosted by structures with azimuths that vary from N to W (Schalamuk et al., 2002), some exceptions exist such as Eureka, Rio Pinturas, Laguna Guadalosa and part of La Josefina. The scarcity of knowledge about regional structural controls of gold mineralization in the Deseado Massif precludes development of meaningful predictive models of potentially-mineralized zones.

The study of spatial distributions of mineralization is important in regional-scale exploration, as it can give insights about regional geological controls on mineralization, and therefore can assist in predictive modeling of potentially-mineralized zones. In this paper, we present an intuitive analysis of regional spatial distribution of known gold occurrences to deduce regional geological controls of low-sulfidation epithermal gold mineralizations in the Deseado Massif.

FRY ANALYSIS

A method called Fry analysis was used to analyze the spatial distribution of gold occurrences (Fig. 2) in order to gain insights into their regional structural controls. Fry analysis is a point pattern analysis method that uses separations between all objects of an object distribution (Fry, 1979). Fry plots can be generated by first marking on a paper all points to be used and a series of parallel references. On a tracing paper also with parallel references, a point to be used as origin is marked. Then that point is placed over each one of the points of the first paper, keeping both paper sheets with the same orientation, and each time every remaining point of the first paper are transferred to the second paper. The resultant graph is commonly known as "Fry plot". These plots display the position of each point relative to all other points viewed from a central position. For a number, *n*, of points there are n^2-n translations or spatial relationships (Vearncombe and Vearncombe, 1999).

If there are regular patterns in terms of spacing and orientation of points, the Fry plot will enhance such patterns allowing for an intuitive visual analysis of their spatial controls. The orientations between every two points in a Fry plot can be represented in a rose diagram, which allows further analysis of spatial trends inherent, but not obvious, in the original Fry plot. Regional applications of Fry analysis in mineral exploration involve the use of locations of known deposits to deduce structural directions that control mineralization (Vearncombe and Vearncombe, 1999). It can yield interpretable results even when the

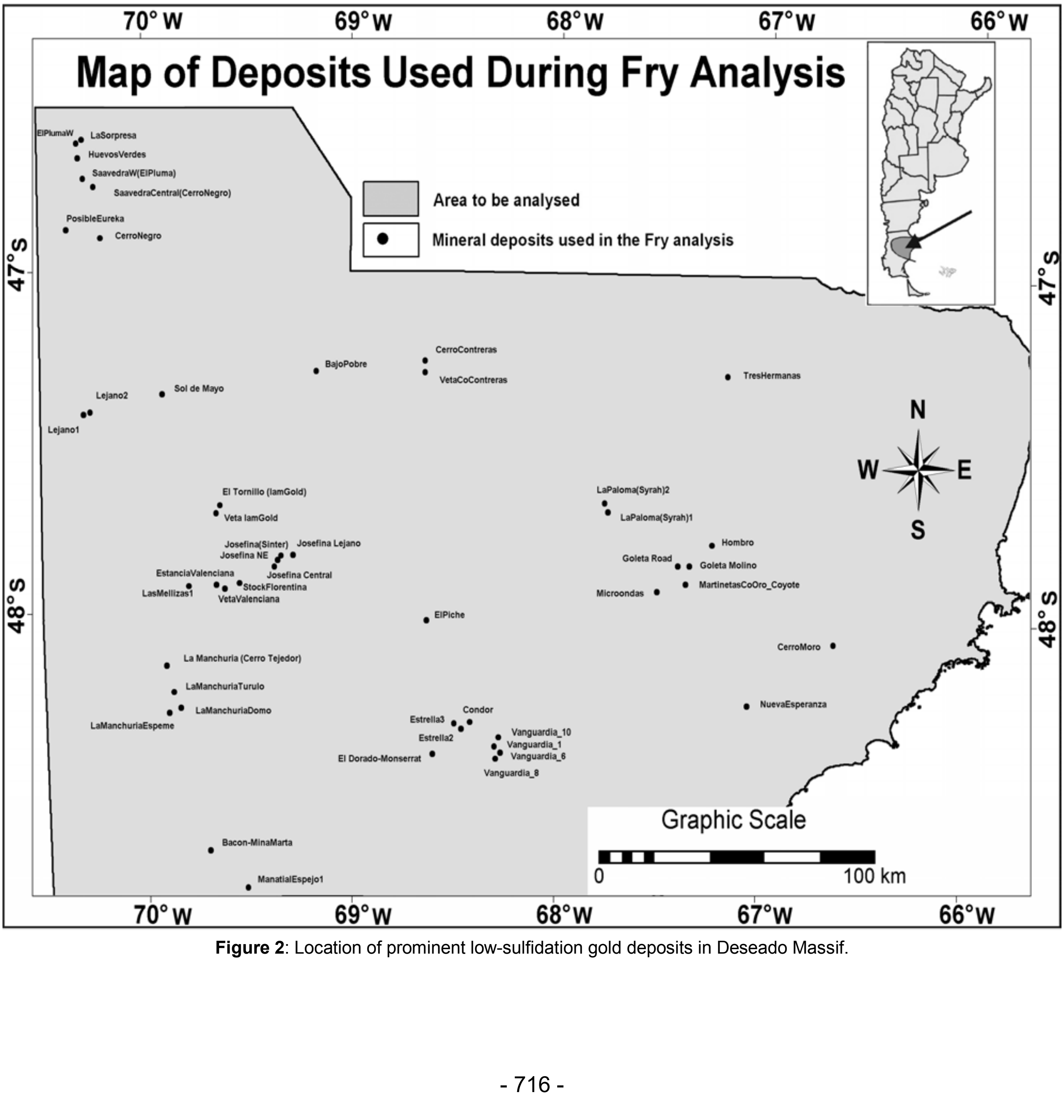

Figure 2: Location of prominent low-sulfidation gold deposits in Deseado Massif.

number of points (mineral occurrences) is small, which is usually the case in poorly explored areas. High frequencies of orientations observed in the Fry plots can reflect orientations of structures that controlled the mineralization.

FRY ANALYSIS OF GOLD OCCURRENCES IN THE STUDY AREA

Fry Analysis was carried out using 48 points, each point representing the approximate location of a prominent low-sulfidation epithermal deposit in the Deseado Massif. Five sets of Fry analysis were made using different sets of deposits in order find out whether their regional structural controls vary spatially. Each of the five sets of Fry analysis were made on the following respective sets of point data: 1) all 48 deposits; 2) deposits hosted in rocks of the Bahía Laura Group (39 deposits); 3) deposits located west of 68ºW longitude (38 deposits); 4) deposits located east of 69ºW longitude (21 deposits); and 5) deposits located in each one of four different sectors of district scale. An overlap 70-km wide containing 11 deposits was intentionally produced between the third and fourth sets of point data to minimize the irregularities in shapes of the sectors that could produce biases in the analysis and mainly to have enough points in each sector to obtain reliable results.

The reason for the analysis of the first set of point data is to infer regional structural controls for all the used deposits in the area without regard to host rock (which is a known lithologic control) and compare this inference with interpretations from the second set of point data, which pertain to deposits hosted by rocks of Bahia Laura Group. The reasons for the analyses of the third and fourth sets of point data (western and eastern sectors) are as follows. In the Deseado Massif, fracturing and volcanism migrated temporally towards the WSW direction (Feraud et al., 1999); probably the associated mineralizing processes migrated temporally towards the same direction. This means that mineralization of the area probably occurred along a few million years (likely around 25 My.) as a continuum of events following the climax of the migrating volcanism. Therefore, different mineralizations were produced in different areas, at different periods and probably under slightly different tectonic regimes and stress directions. In addition, the Deseado Massif is divided in large blocks (grabens, half-grabens and horsts) limited by regional fractures with NNW-SSE trends (Ramos, 2002), which are approximately perpendicular to the mentioned direction of migration. All

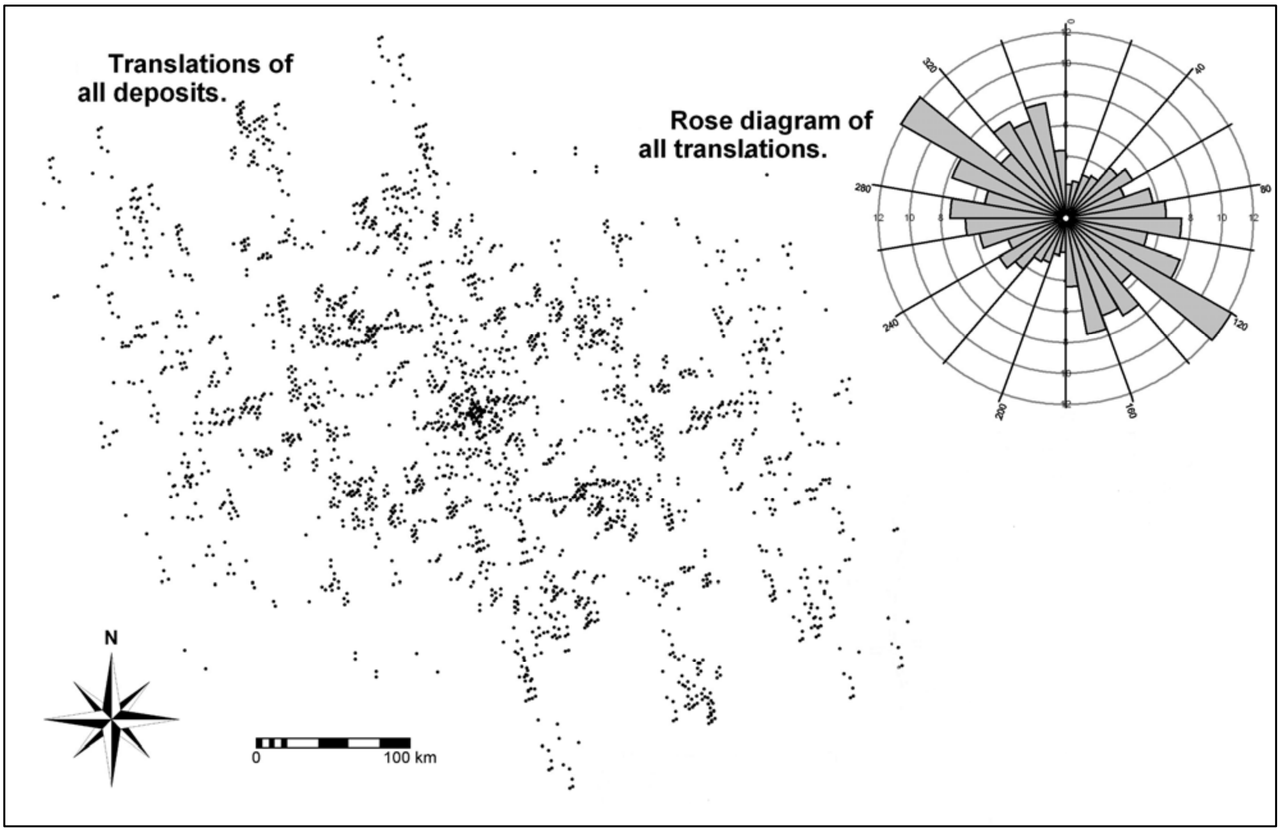

Figure 3: Fry plot and rose diagram of all point translations.

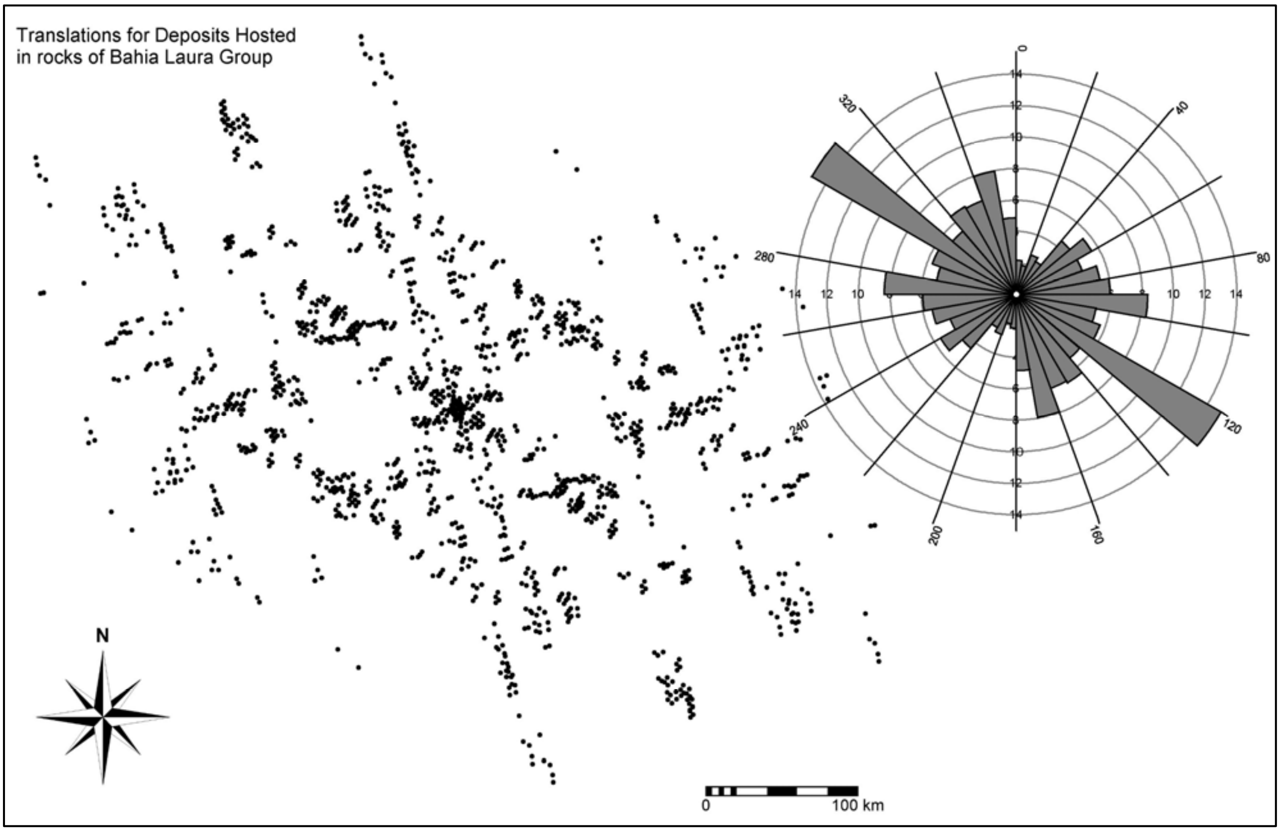

Figure 4: Fry plot and rose diagram of translations of points in Bahia Laura Group.

these circumstances are likely to have produced differences in the mineralizing controls in the eastern and in the western parts of the Deseado Massif along a WSW trend. If such differences existed, they could probably be reflected by Fry plots for deposits in the western part and in the eastern part of the area. Thus, the total population of deposits was divided in two groups depending on their relative E-W position. For the 5th analysis, four sectors of district size containing no more than 10 points each one were analyzed to test if the dominant directions of the regional scale plots were still recognizable in smaller areas and if so, with which relative strength.

The Fry plot and rose diagram of all points is shown in Fig. 3. The predominant direction of the point translations has an azimuth of 120º-130º. Secondary orientations of point translations have azimuths of 160º-170º and 90º-100º, while minor orientations trend 140º-150º and 50º-60º.

The Fry plot and rose diagram of translations of points in the Bahia Laura Group is shown in Fig. 4. The predominant direction of point translations has azimuth of 120º-130º. Secondary orientations of point translations have azimuths of 160º-170º, 90º-100º and 50º-60º. The Fry plot and derivative rose diagram generated for all deposits is similar to the Fry plot and derivative rose diagram for the deposits in the Bahía Laura group. In both of them, the same anomalous directions are present with similar frequencies. The separation by lithological unit had thus no important effect on the patterns determined by the Fry analysis. From this comparison, it is apparent that the mineralizations occurred over the same trends in all mineralized lithologies. The Fry plot and rose diagram of translations of points in the western sector are shown in Fig. 5. There are three strong directions with azimuths of 120º-130º, 140º-150º and 160º-170º, and there are two secondary orientations with azimuths 40º-50º and 90º-100°. The Fry plot and rose diagram of translations of points in the eastern sector are shown in Fig. 6. The predominant orientation has an azimuth of 50º-60º, while secondary directions have azimuths of 80º-90º, 120º-130º and 170º-180º. Fry plot and derivative rose diagram of deposits in the western sector are different from the Fry plot and derivative rose diagram of deposits in the eastern sector. In the western sector, NW-SE trends are strongly predominant; whereas, in the eastern sector, NE-SW directions are predominant. However, in the eastern sector, a NW-SE orientation (120-130º) is still apparent although secondary. Therefore, it is probable that

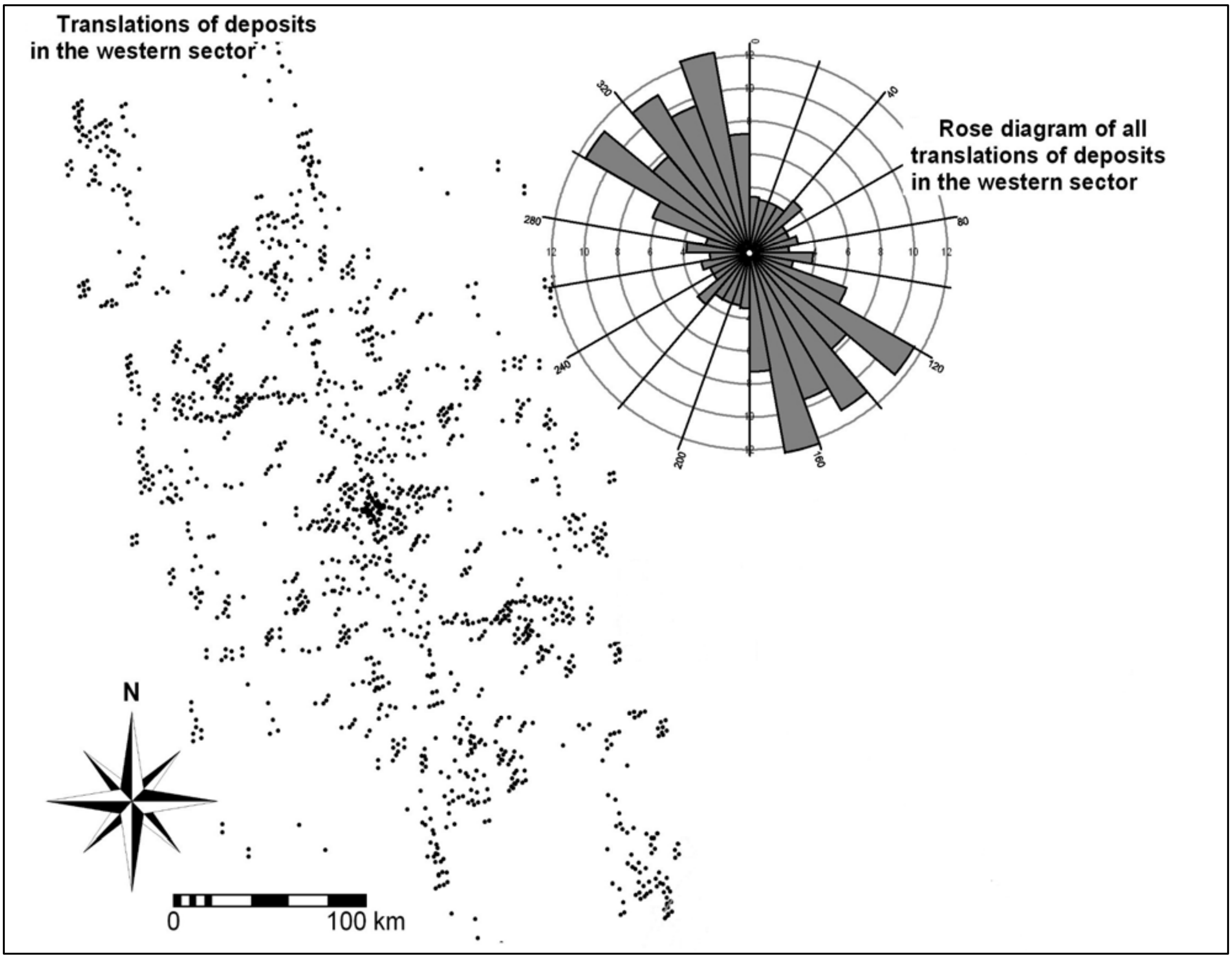

Figure 5: Fry plot and rose diagram of translations of points in western sector.

structures with NW-SE directions provided controls for the mineralization in either the western and eastern sectors, although in the eastern sector controls by NE-SW trending structures were predominant.

The four districts studied in the 5th analysis are (Fig. 7): Cerro Saavedra, in the NW part of the area; Josefina-Esperanza, in the central-west part of the area; Cerro Vanguardia, in the south-central part of the area; and Martinetas-La Paloma, in the NE part of the area. The dominant directions in the directional diagrams are variable, but trends around NW-SE are present and predominant in most of the districts (Fig. 7); in three of the districts, SW-NE trends are also well represented. However, as the number of deposits used in each district is small, results of the 5th analysis are considered suggestive rather than indicative of structural controls.

DISCUSSION AND CONCLUSIONS

The exploratory Fry analysis was useful for intuitive interpretation of the principal regional scale structural controls on mineralization in the area. From the Fry analysis it was inferred that at regional scale most of the deposits are related to NW-SE structural trends with three predominant directions. The orientations 160º-170º and 120º-130º probably have the most significant meaning because they are persistent in every Fry plot in addition to have a geological explanation. On one hand, the orientations 160º-170º probably reflect mineralization along the regional scale fracture zones produced mainly by normal faulting during grabens generation. On the other hand, the orientations 120º-130º probably reflect regional scale structural controls by transcurrent faulting events, represented by approximately E-W or ESE-WSW trending structures, which occurred immediately after the formation of the grabens.

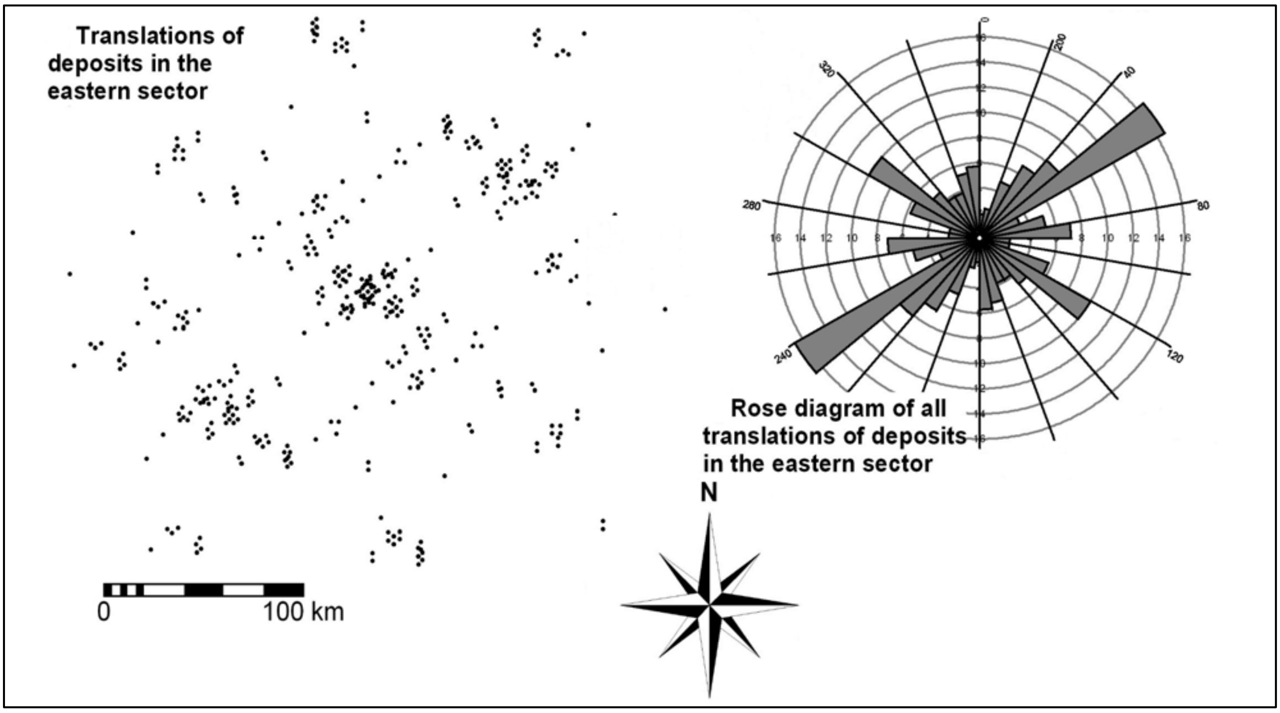

Figure 6 Fry plot and rose diagram of translations of points in eastern sector.

The differences in spatial patterns of the deposits in the western sector and in the eastern sector of the study area probably represent structural controls by different fault/fracture systems. In the western sector, there is apparent stronger control on the spatial distributions by fracture systems with NW trends. In the eastern sector, there is apparent stronger control by fracture systems with NE trends, while the NW trends are weaker controls. For the western area, the main trends indicated by the plots are, in decreasing order of frequency: 160-170º, 120-130º and 140-150º. The first trend (160-170º) probably represents controls on mineralization by NNW trending regional scale fractures, which limit large blocks in the Deseado Massif (showed by Ramos, 2002) (Fig. 7).The second trend (120-130º) corresponds with the range of directions defined for the Bajo Grande system in the Deseado Massif. The third trend (140-150º) corresponds well with general trends of the El Tranquilo system. There are two other observed secondary trends, which could be important because they are observed in the plots generated for all sets of points. One secondary trend, with direction 40-60º, which is prominent in the eastern sector, can be ascribed to the conjugated trends of El Tranquilo system; while the other secondary trend, with directions around 80º-100º, could be associated to some normal faults mentioned by Panza (1994) and Panza and Marin (1998).

The results of the Fry analyses indicate that, at regional-scale, fault/fracture systems are principal controls on spatial distribution of low-sulfidation epithermal deposits in the study area as the Fry plot for deposits in the Bahia Laura Group show no major difference to the Fry plot for all deposits. Thus, lithology is not a major geological control of the epithermal mineralizations in the area. The apparent differences in strengths in structural controls on spatial distribution of low-sulfidation epithermal deposits in the western and eastern sectors may be due to the proposed migration of fracturing, volcanism and mineralization from ENE to WSW in the Deseado Massif and to the changes in the stress directions during the Jurassic. The rose diagrams generated for the eastern and western sectors are suggestive of structural controls on mineralization at regional scale, while the directional diagrams generated for each of the four different districts (Fig. 7) are probably only showing predominant controls on mineralization at local scales.

Although the results of Fry analysis are explainable in association with known regional scale structures in the Deseado Massif, and considering that Fry plots depend on locations of only the already known deposits, the Fry plots could also be partially the artifacts of exploration efforts in the area.

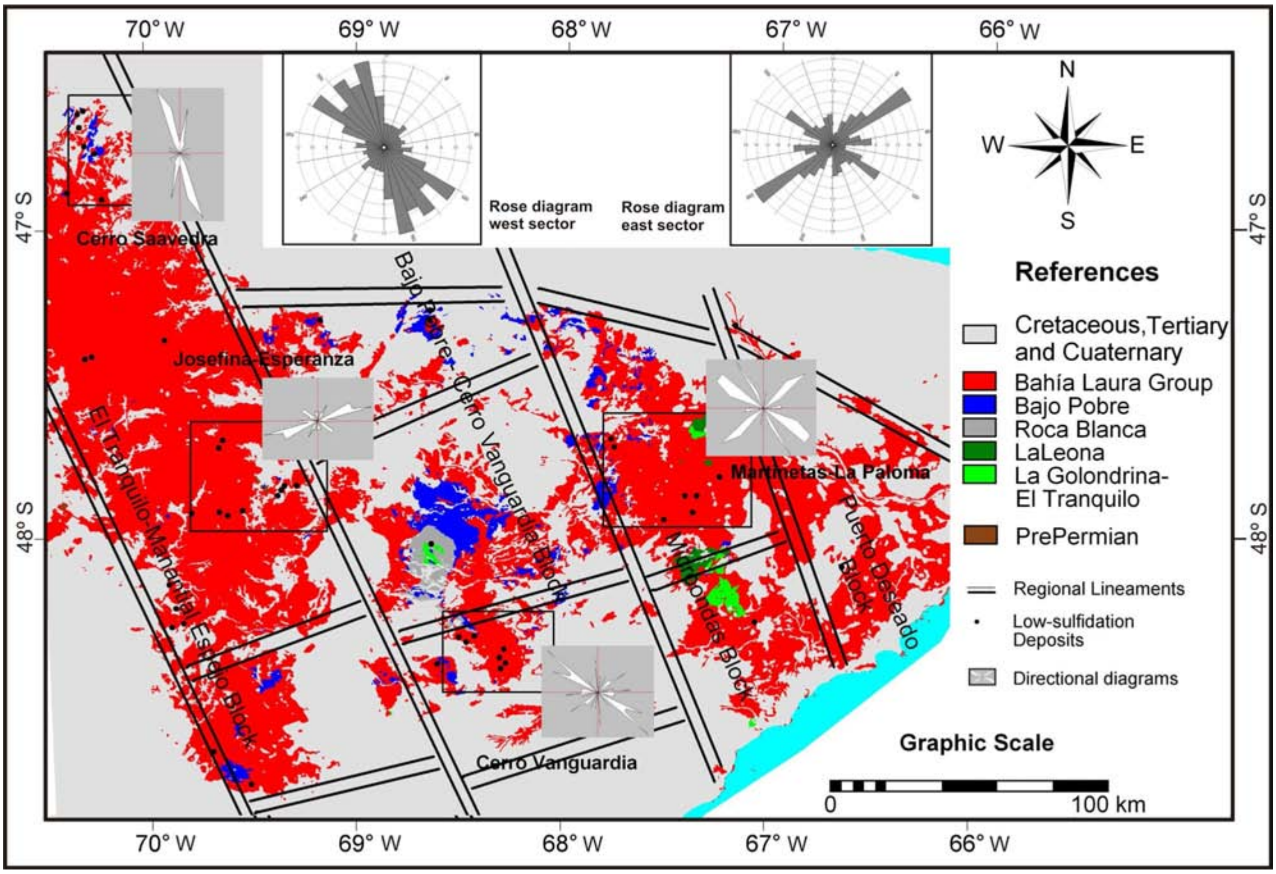

Figure 7: Map of the study area showing lithology, approximate positions of regional-scale structural zones that divide the area into large blocks (Ramos, 2002), rose diagrams for the western and eastern sectors, and directional plots of four district-scale areas called Cerro Saavedra, Josefina-Esperanza, Cerro Vanguardia and Martinetas-La Paloma.

Due to the fact that most of the known deposits are located in the western sector, and that most of the trends recognized in that sector are also recognized in the eastern sector, the structural controls suggested by the Fry plot and rose diagram of the deposits located in the western sector could be useful for predicting presence of undiscovered LSED in the Deseado Massif at regional scale. However, the 40-60º trends, which are highly enhanced in the Fry plot of deposits in the eastern area, suggest that structures with these trends could also be useful in mapping LSED potential in the Deseado Massif at regional scale.

ACKNOWLEDGMENTS

We would like to acknowledge ITC, the Dutch Government and Fomicruz S.E. for providing the necessary support that allowed us to generate this paper.

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