CHARACTERIZATION OF DIFFERENT LINEAMENTS TYPES FROM TM-5 LANDSAT IMAGES AND THEIR APPLICATION TO CONTROL OF GOLD-QUARTZ VEINS IN THE PORTO NACIONAL (TO) REGION, BRAZIL

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ABSTRACT

The lineament analysis technique was developed since the usage of aerial photographs in geology. From the advent of satellite image use, this technique received a new dimension for interpretation, since the satellite images favour the overlook of a given area. However, the method used to extract and to interpret the lineaments patterns remains the same; the current usage is based on the extraction of lineaments as much as possible, in order to build up a pleasant arrangement. No regards are made to distinguish different types of lineaments. This paper is based on the experience got in lineament study for gold-quartz veins control in the Porto Nacional (TO) region, Central Brazil. It aims to emphasize the importance of distinguishing at least two lineament types at the extraction. This method enables the discrimination between ductile and brittle structures and the understanding of the geometric nature of these structures. The observations have shown that it is possible to distinguish between two types of lineaments: a) type 1 and b) type 2. The type 1 lineaments are related to penetrative structures (regional foliations, transcurrent shear zones and granite intrusions) and display rectilinear as well as curvilinear patterns; they develop paired positive and negative geomorphic features and are associated with tonal banding, because of lithological changes. The type 2 lineaments are related to brittle disjunctive structures (joints and faults) and are often rectilinear to slightly curvilinear; they represent negative geomorphic features, characterized by drainage patterns, and are also important features to the control of most of the gold-quartz veins.

1. INTRODUCTION

The Porto Nacional (TO) region has been target for gold research and artisanal minings since the last century. The area has a complex structural framework characterized by a system of sinistral transcurrent shear zone trending N30°E, that are regarded to the Transbrasiliano Lineaments (Schobbenhaus et al., 1975). The shear zones were also place for hydrothermal fluids percolation and show thick quartz veins; the veins are mainly in the subsidiary dilatant faults, distributed in various directions, and are the main source for primary gold.

Recently, the temporal and spatial relationship between the ore and the tectonic structures of the region were discussed by Mesquita *et al.* (1992) and by Strieder *et al.* (1994). The observations presented in these papers demonstrated the importance of make a detailled characterization of the geometric properties of such structures, to evaluate the structural control of the ore occurrences and to select new prospective targets. The first step of this characterization was the visual analysis and interpretation of lineaments from satellite images, since the synoptic vision of the region showed large importance in the obtained results (Cunha, 1996).

2. GEOLOGICAL SETTING OF THE PORTO NACIONAL (TO) REGION

2.1. Lithological Framework

The lithological framework of Porto Nacional (TO) region is constituted by the following lithodemic and lithostratigraphic units: Porto Nacional Complex (**PNC**), Corrego Cachimbo Granite-gneiss Suite (**CCGgS**), Natividade Metassedimentary Suite (**NMS**), Matança Metagranitic Suite (**MMgS**), Ipueiras Granitic Suite (**IGS**), Monte do Carmo Formation (**MCF**), Parnaíba Basin Sedimentary Sequence (**PBSS**) and Cenozoic Deposits (figure 1).

The **PNC** is composed by two principal petrographic lithotypes: a) a mafic rock and b) a quartz-feldspathic rock. The mafic rocks are ortogneisses of dioritic to gabroic composition, with porfiroid texture. The quartz-feldspathic rocks are composed by granodioritic to tonalitic ortogneisses.

The **CCGgS** rocks are very deformed and metamorphosed, presenting a narrow gneissic banding. These rocks can be characterized by fine grained biotite granodiorites to monzogranites in the low strain portions. The higher strain zones has extensive formation of secondary muscovite. This lithologic unit is crosscut by a large quantity of auriferous veins, with varied characteristics and sizes.

The lithologic types that constitute the **NMS** are mainly metaconglomerates, metasandstones, quartzites, conglomeratic quartzites, micaceous quartzites, aluminous schists, tremolite schists and graphitic phyllites. This sequence is locally crosscut by quartz veins, with milimetric to centimetric thicknesses, and intruded by metabasic dikes.

The lithotypes that compose the **MMgS** are metagranitoids (sienogranites to monzogranites) which show magmatic and high temperature tectonic foliations. The primary texture is a coarse

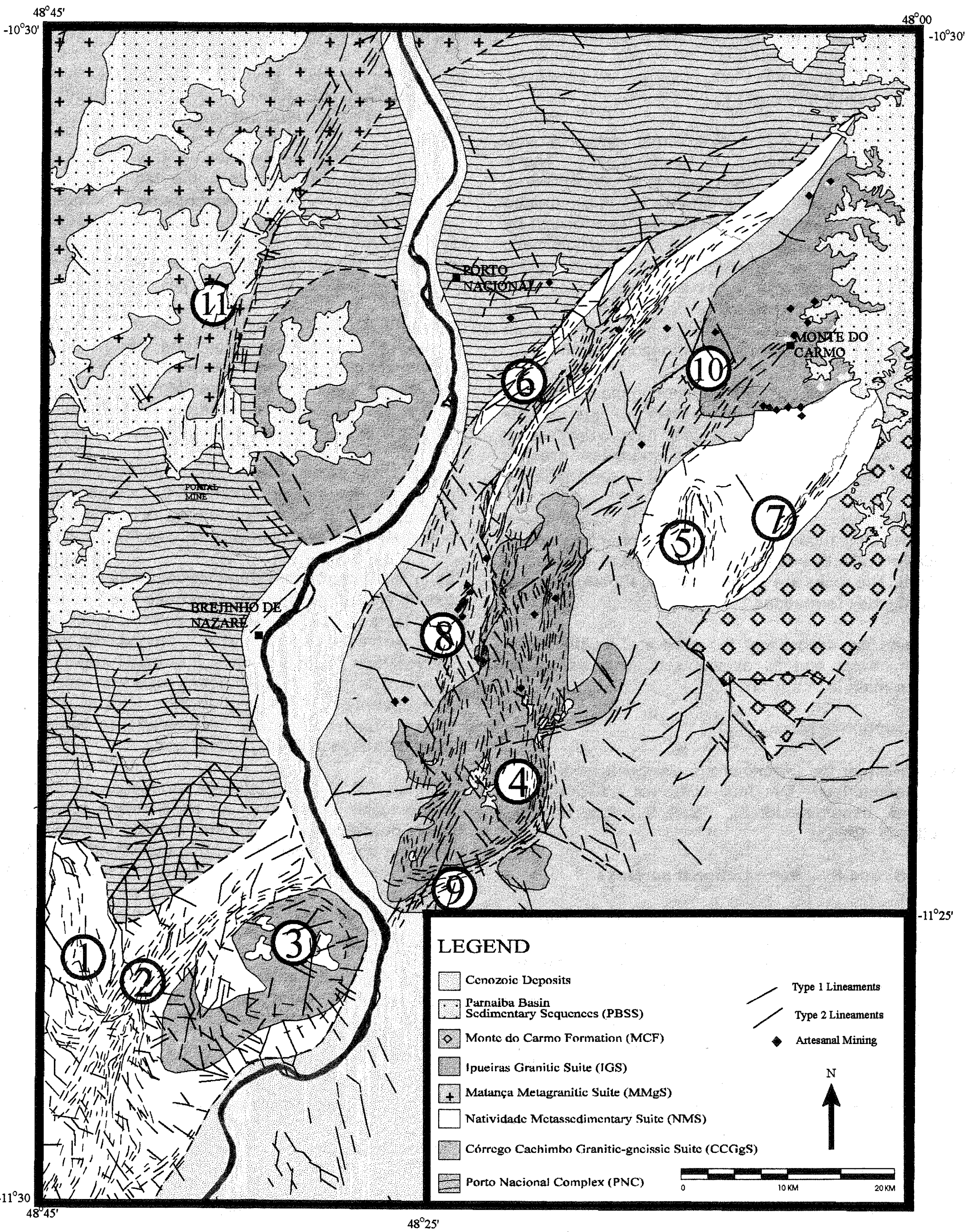

Fig.1 Litological and lineaments map of the Porto Nacional (TO) region.The positions discussed in the text are defined by the white circles (modified from Cunha 1996).

inequigranular one: centimetrical megacrystals and megaporphyroclasts embedded in a medium grained matrix. Associated basic dikes of dioritic composition intrude the metagranites and show features of mechanic mixing of magmas.

The **IGS** is composed by biotite monzogranites and amphibole monzogranites to sienogranites. These lithotypes have two main petrographic facies: a) coarse grained facies and b) medium to fine grained equigranular facies. All of these rocks are crosscut by aplitic and diabase dikes. There are also acidic volcanic rocks, mainly riolites. The **IGS** rocks host many gold-quartz veins of different types and thicknesses. The granitic rocks of the **IGS** are mainly isotropic, but locally may show some evidence of magmatic foliation and ductile and brittle-ductile deformational structures.

The **MCF** is composed by polimitic conglomerates and arcose sandstones, with intercalation of intermediate volcanic rocks. The conglomerates have a framework constituted by pebbles of quartz, quartzites, granites and basic rocks in a matrix composed by sandy shale.

The **PBSS** is mainly composed by sandstones, siltstones and mudstones. The sandstones are fine to medium grained, while the conglomerates are coarse grained. The rocks are regarded to the Pimenteiras and Serra Grande formations.

The cenozoic deposits of the area are constituted by lateritic covers and by alluvial sediments associated with the main drainage lines.

2.2. Structural geology

The structural framework of the Porto Nacional region is characterized by four different deformational surfaces, denominated: S_n, S_{n+1}, S_{n+2}/S_{m+2} and S_{n+3} (Gottardo, 1996).

2.2.1. S_n and S_{n+1} deformational surfaces

The S_n is registered by a regular gneissic banding, characterized by the alternation of mafic bands and felsic bands. The gneissic banding is variably transposed by folds (F_{n+1}) and boudins; the axial plane foliation (S_{n+1}) is an anastomosed structure present in the **PNC**, **CCGgS** and **NMS**. In the **NMS**, S_n is a transposed schistosity, still preserved in micro and meso lithons. The spatial and geometric relations between S_n and S_{n+1} in the **PNC**, **CCGgS** and **NMS** show that both surfaces were paralleled during D_{n+1} deformational event.

2.2.2. S_{n+2}/S_{m+2} deformational surface

The transcurrent to oblique shear zones crosscutting the Porto Nacional region are the main feature regarded to the S_{m+2} deformational surface at large scale. These shear zones are ductile to brittle-ductile and trend N30°E. They extend more than 100 km and show thicknesses from 10 to more than 1000 m. The nucleation and the movement in these shear zones changed the spatial disposal of the previous S_n and S_{n+1} in the **PNC**, **CCGgS** and **NMS**; the structures resulting from this superposition are complexes and may be characterized as follows:
a) the main mesoscopic feature is a mylonitic foliation (S_{m+2}) trending NE, which is strongly anastomosed. There are also isoclinal small scale folds, rootless folds made upon the gneissic banding;

b) the S_{m+2} mylonitic foliation is very heterogeneous: ortomylonites are present in the high strain zones, disposing a highly anastomosed pattern; there are also phyllonites in zones of high fluid pressure. Sometimes, ortomylonite and phyllonite textured zones are alternated to compound a coarse banding. There are central-type gold-quartz veins in this S_{m+2} shear zones;

c) in the **CCGgS**, there are brittle subsidiary shear zones of variable orientation and thicknesses; their movement direction were recovered by slickensides and associated steps and grooves. Most of these shear zones are dilational structures, which control the emplacement of gold-quartz veins;

d) the shear zones gave origin to *en echelon* or large open folds developed upon the **PNC**, **CCGgS** and **NMS**; these folds have axial plane cleavage or foliation (S_{n+2}) and show saddle reefs quartz veins in the hinge zone;

e) in the **MMgS**, the shear structure is a composite foliation (S_{c+2}) made up by magmatic flow features and solid-state strain features. The deformational features are derived from dynamic recrystallization and reorientation of megacrystals, that transformed them in porphyroclasts with asymmetric recrystallization tails. The deformational features include high strain shear zones (S_{m+2}) of variable thicknesses, to where S_{c+2} foliation merge in a S/C relation (*s.s.*);

f) in the **IGS**, the S_{m+2} foliation is observed as discrete, brittle-ductile shear zones or as cleavage zones. The brittle-ductile shear zones are variable in thicknesses and display S/C relation (*s.l.*) to the previous $S_n//S_{n+1}$. These shear zones form extensional strike-slip duplexes and pinnate synthetic ramifications. The relative movement direction is sinistral and was characterized mainly by slickensides and their grooves and steps;
All of these structures ($S_n//S_{n+1}$ and S_{n+2}) are truncated by low angle NE cleavage and minor faults. They show regular planes, spaced from 1 to 10 m, which were regarded as S_{n+3} structure.

3. METODOLOGY

3.1. Revision of the concepts of lineaments

The name lineament was introduced by Hobbs (1904) to characterize any linear feature in the ground. From the advent of aerial photograph and, later, satellite images in geology, there was an increasingly interest in defining and analysing linear features of the Earth. Then, some names were introduced as synonymous to lineament. O'Leary *et al.* (1976) concluded that lineament is the most suitable term to describe these linear features. The lineaments may be simple or composite, and rectilinear or slightly curved. They must differ from the nearby linear patterns, and are the consequence of underground structures. Sabins (1986) also reviewed the application of lineament name in describing linear features, without any genetic implication. Sabins (1986) also discussed several geomorphic and/or tonal features that may give rise to a lineament.

3.2. Typology of lineaments

A look-over at many papers dealing with lineaments showed that lineament extraction is just done in a quantitative sense. This was the point used by Wise (1982) to criticize the methods of lineament extraction summarized in his 32 rules. According to Wise (1982), "it is not the quality of the lines which counts, but rather their number and their potential for compilation into artistically pleasing patterns".

Amaro & Strieder (1994) emphasized that any lineament in images have topographic relief and/or associated tonal features which are due to the underground 3D structure in the Earth's crust. Then, most of them may be considered topographic high (positive lineaments), or topographic lows (negative lineaments), when seen in the lightening direction of the image. The patterns and the nature of the lineaments are different according the association of positive, negative or tonal lineaments. Based in this kind of differences, Amaro & Strieder (1994) proposed to distinguish between two types of lineaments: type 1 and type 2.

3.2.1. Characterization of type 1 lineaments

The **type 1** lineaments are associated to regionally penetrative structures. Such structures develop parallel positive and negative geomorphologic features, distributed in linear or curvilinear patterns. **Type 1** lineaments can be considered composite lineaments, because they are also characterized by a tonal banding related to the lithological component. For the analysis of this kind of lineament, it is important to evaluate parameters such as: density, geometric disposition, azimuthal trend and length. The penetrative ductile structures present the best geomorphological expression of this kind of lineament; however, these lineaments can also characterize sedimentary and/or volcanic layers slightly folded. They represent the differential erosion of penetrative structural features associated to lithology. These lineaments can model structural forms, like folds and shear zones.

3.2.2. Characterization of type 2 lineaments

The **type 2** lineaments are associated to brittle disjunctive structures. They are mainly topographic lows (negative lineaments), which cut across lithological boundaries; this is the case for brittle faults and fracture zones. However, this type of lineaments can also develop associated positive and negative features, sometimes with tonal banding, when regarded to brittle-ductile fault zones. **Type 2** lineaments are often rectilinear to slightly curvilinear features and control drainage pattern. **Type 2** lineaments may be analysed through their spatial distribution pattern, azimuthal trend and length.

4. RESULTS AND DISCUSSION

The discrimination of both types of lineaments were performed in the Porto Nacional (TO) region, through monoscopic analysis of LANDSAT TM-5 paper images (color composition 3-4-5). The images are WRS 222/067 and 222/068, obtained at 24/JUL/1991 (EL 41 and 40, AZ 052 and 051, respectively). According to Moore & Waltz (1983), good lightening elevation to lineaments analysis is from 35° to 45°. July is the driest month in the region, what is also good for lineament extraction.

4.1. Type 1 lineaments analysis

4.1.1 General characteristics: morphology and geometry

The type 1 lineaments in the Porto Nacional region are characterized by rectilinear to curvilinear segments, are fine spaced and have mean length around 1100 m (figure 1). They are associated to positive and negative lineaments parallel to a tonal banding.

Type 1 lineaments occur by three different manner in the SW portion of the area: a) they are part of a regional pattern of rectilinear and curvilinear segments disposed in an open regional fold (**position 1, fig. 1**); 2) they define a rectilinear to slightly curvilinear zone with thickness as much as 3700 m (**position 2**), which obliterate the lineaments of the position 1; c) they define a circular to elliptical pattern centered in **position 3**, which is rimmed by the lineaments of position 2. This circular to elliptical structure were also recognized in **position 4**, where it is rimmed by rectilinear zones of positions 8 and 9.

The regional folded pattern of position 1 is also observed in the central-east portion of the mapped area (**position 5**). The type 1 lineaments of position 2 extend NNE to NE toward the central and NE part of the mapped area, where they define zones of variable thicknesses (**positions 6, 7, 8, 9 e 10**).

In the NW part of the area, the type 1 lineaments are concentrated in another thick zone (4600 m thick) and are longer than in other similar position (**position 11**); this zone extend for than 45 km toward NNE.

In the central part of the area, there are many places where type 1 lineaments could not be precisely defined, since this part correspond to the most eroded one.

4.1.2. Discussion and interpretation

The interpretation of the nature of different type 1 lineaments recognized in the Porto Nacional region was proceeded through field works dealing with structural geology.

Type 1 lineament pattern in the **positions 1** and **5** characterizes regional Fn+2 folds developed upon **NMS** rocks. Then, the lineaments themselves are the geomorphic results of erosion upon $S_n//S_{n+1}$ foliations. The regional F_{n+2} folds are obliterated by shear zones in the **positions 6, 8, 9** and **10**; then, the lineament in these positions are the geomorphic results of erosion upon S_{m+2} foliation. The shear zone in **position 2** extend toward NE and again toward N, and seems to correlate with the shear zone in **position 6**. This structure is named Corrego Manduca Shear Zone.

The type 1 lineaments in **positions 3** and **4** are related to two different granitic intrusions of the **IGS**, which were emplaced in the shear zone system characterized by lineaments recognized in positions 2, 6, 8, 9 and 10.

The type 1 lineaments in **position 7** were recognized to be due to $S_n//S_{n+1}$ foliations and are associated to a fault scarp directed toward W. The main foliations are crosscut by a low angle cleavage (S_{n+3}), possibly related to the low angle faults (back thrusts).

The lineaments in **position 10** rim and crosscut another intrusion of the **IGS**. They were interpreted as ramifications of the main shear zone defined by lineaments in position 9. This structure is named as Monte do Carmo Shear Zone.

The type 1 lineaments in **position 11** define another shear zone, which is located in the east side of the **MMgS** intrusion. This shear zone is named Córrego Matança Shear Zone.

4.2. Type 2 lineaments analysis

4.2.1. General characteristics: morphology and geometry

Type 2 lineaments were mainly identified as rectilinear to slightly curvilinear segments associated with drainage. They are regarded to brittle fracture and/or fault zone, brittle-ductile shear zone, or any other kind of disjunctive discontinuity in the rocks. The water percolation enables the weathering and makes easier the material erosion to give rise the negative lineaments. They develop special regional patterns, where the lineaments intercept each other in different angles (figure 1).

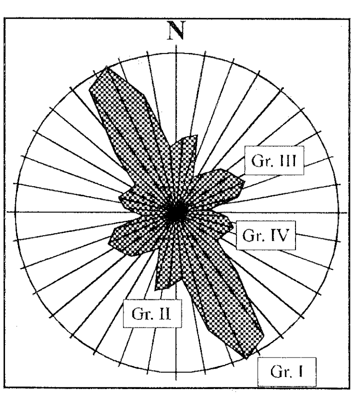

Fig. 2 - Rose diagram of the distribution of type 2 lineaments in the Porto Nacional (TO) region.

The extracted type 2 lineaments were computed through rose diagram; they are disposed into four groups (figure 2). Each group shows mean length varying from 1408 m to 1761 m (table 1).

4.2.2. Discussion and interpretation

The type 2 lineaments can be associated to subsidiary Riedel structures related to the main shear zone system. The kinematic analysis performed in the field data showed that the compressive axis turned anti-clockwise from the NE part of the area to the central portion. In this way, it is not possible to correlate directly the rose diagram groups, that include data of all the area, to single subsidiary Riedel structures.

	Group I	Group II	Group III	Group IV
Azimuthal trend	125° - 175°	175° - 205°	025° - 085°	085° - 125°
Range	50°	30°	60°	40°
Number of measures	450	160	262	160
Mean length	1486 m	1761m	1517m	1408m

Table 1 - Azimuthal distribution of the four groups of type 2 lineaments in the Porto Nacional (TO) region. The computation of mean length for each group was performed by vectorial statistics method (Curray, 1956)

The figure 3 sketches the spatial disposition of subsidiary structures, as they are related to the main shear zones. One can see that, for the northeastern part of the area, the group I of the rose diagram includes R' subsidiary faults, group II possibly comprises R fractures, group III contain P fractures and group IV encompass P' fractures. However, as one follows to the central part of the area, with north-south main shear, R fractures gradually turn to the group I, while P fractures go to the group II, P' fractures turn to the group III and R' fractures go to the group IV. There is not enough structural data in the southwestern part of the area, but the obtained ones points to the same interpretation of the northeastern portion.

5. CONCLUSION

The relations of large, macro and meso-scale structural features to mineral deposits may be investigated through satellite images. However, the location of the ore deposits sites is connected to each type of tectonic setting, since each one show different relations of shear zones, faults, folds, and lithological contacts, which are important to a correct exploration planning (Gupta 1991).

The discrimination of different types of lineaments enabled the recognition of regional folds, shear zones and granitic intrusions (Type 1 lineaments) and also subsidiary fractures zones (Type 2 lineaments). In the Porto Nacional (TO) region, one cannot use a general approximation to locate the gold-quartz veins. The gold-quartz veins can be associated to different trends of type 2 lineaments, considering the schematic model presented in figure 3. The knowledge of the structural control of these gold-quartz veins initiate with a careful interpretation of the lineaments. The best way to investigate and to select target areas with this kind of technique of exploration is to divide specific structural domains.

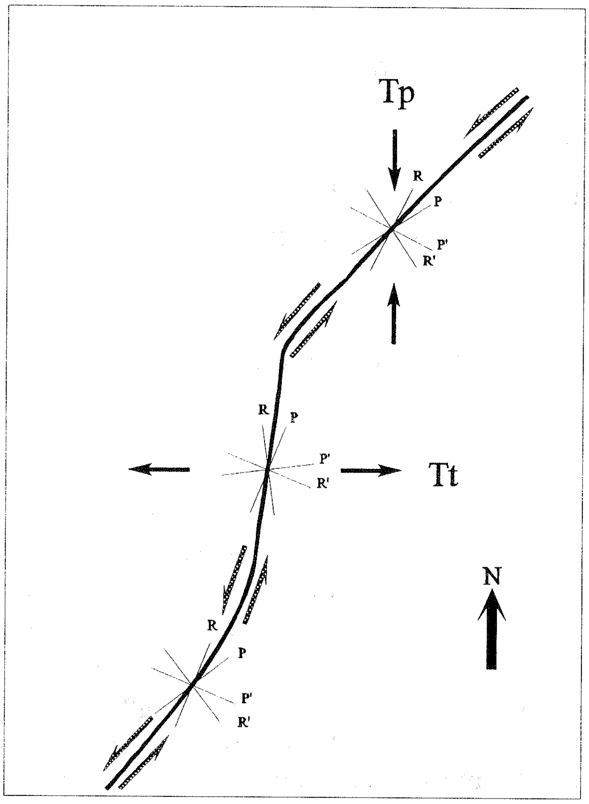

Fig. 3. Schematic model of the geometry and the orientation of subsidiary structures related to the transcurrent shear zones of Porto Nacional region (TO). The symbols Tp and Tt correspond respectively to transpression and transtension zones.

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