# ON THE ORIGIN AND EVOLUTION OF CIRCULAR FORMS OBSERVED IN REMOTE SENSING IMAGES OF THE RIO DE JANEIRO STATE, BRAZIL*

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**Abstract.** The origin and evolution of circular, semi-circular and stick-like forms identified in a selected area at the southwestern portion of the Rio de Janeiro State, Brazil, is related in this work. Some of these "morphological anomalies" were previously described either as igneous intrusions or as plutonic domes. A Tertiary tectonics of NW-SE compressional stress is known to be responsable for the NE-SW movement of extense blocks. The tangential component of this movement caused the horizontal displacement and partition of pegmatites along the host-rock foliation. Conjugating the NW-SE compressional stress that acted upon the superior crust, with the tangential displacement of blocks situated over the underground, it is possible to suggest a model for the origin of the forms above mentioned. Remote sensing images of a target area were selected to identify the relation of several features with the morphological, structural and drainage anomalies.

## INTRODUCTION

The circular, semi-circular, elliptical and forms alike, are objects of investigation by several authors (Saul, 1978; Poroshin, 1981; Riccomini, 1980; Lima, 1988; Norman, 1984, and others) in different regions around the world.

These forms, of variable dimensions, are present in almost all geological environment. They are usually interpreted as product of meteorite impact or are related to: diapiric plutonic mass movements, generating domes, igneous intrusions in gneiss-migmatitic domains, or just alkaline or carbonatitic

*Presented at the VII Simpósio Brasileiro de Sensoriamento Remoto, Curitiba, PR, Brazil, 10-14 May 1993.

intrusive bodies. In the meantime, some of these forms, localized in the south-western portion of the Rio de Janeiro State, and near to the vicinities of the Serra dos Órgãos Batolith, are of difficult interpretation. Some authors (Liu, 1987), referred to these forms (circular, semi-circular, etc.) as morphological anomalies.

The aim of this work is to propose a model, capable of relating the morphology, drainage pattern and the structural framework of the target area, to the origin and evolution of the circular, semi-circular and stick-like forms. The model comprises an inversion of a prismatic portion of the underground, submitted to a tangential component, generated by the strike-slip faulting, interacting with a lateral tilting and vertical movement over a ramp ("tilt-ramping"). The resultant of the conjugated movements, produced a compression along the foliation, with ascending movement over a ramp as a product of the underground displacement.

## OVERVIEW

Saul (1978), studying different rocks, of various ages, and located in distinct geological environments (Appalachians and Arizona), observed inumerous circular forms, with dimensions ranging from 7 to 700 km, in diameter. The author interpreted these features as related to meteorite impact. Poroshin (1981), after analysing satellite photographs of the Aldan Shield, Eastern Europe, proposed a classification of the ring (circular) structures observed, based mainly on their diameter size. The Global structures outlines ocean basins and continental depressions or rises, and have a diameter of 3,000 km or more. The Gigantic and the Large structures have 400-2,000 km and 60-400 km in diameter respectivally, and are usually associated to orogenic belts. The Small ring structures, less than 60 km in diameter, were subdivided in four main groups: isometric massifs (domes), true ring structures (vulcanoes), circular basins (depressions) and multiple featured (conical, paraboloid, etc.). Norman (1984), admitted that the circular features he analysed worldwide, were formed through the energy generated by meteorite impact.

Riccomini and Amaral (1980), observed circular structures at the Bação Complex southwestern of Minas Gerais State, Brazil, which are evidentiated by the annular drainage pattern. These structures were mentioned before by Herz et al. (1961), but not in later works (Johnson, 1962 and Wallace, 1965, in Riccomini and Amaral op. cit.). Riccomini and Amaral (op.cit.), interpreted these features as structural anomalies, possibly domic, and related them to either a structural rearrangement in the granite-gneissic terrains of the Quadrilátero Ferrífero or to igneous intrusions not exposed yet. Riccomini (1982), based on Salop (1972), defined the circular and elliptical features in the granite-gneissic domain of the Bação Complex, as gneiss domes. Lima (1988), interpreting Side-Looking Radar Images, X-Band

and GEMS of the higher portions of the Mapuera River, northern part of Pará State, Brazil, outlined the main structural lineaments of the region. Over thirty circular structures were observed, and were related to alkaline igneous bodies (Mutum Intrusive Suite).

## PREVIOUS WORKS

There are a few number of publications up to date, dealing with circular and semi-circular forms in the Rio de Janeiro State, Brazil. Liu (1987), combining geomorphological features and lineaments obtained from remote sensing images of the Rio de Janeiro State, suggested the possibility of correlation of these forms with the origin of the Serra do Mar. Using this relation, the cited author admitted that the superior part of the crust, at the southern part of the Rio de Janeiro State, was submitted to a NW-SE compressional stress. At a final stage, the stress originated a conjugated pair of fractures, represented by lineaments parallel, perpendicular or oblique to the stress direction. The author based on the lineaments network, identified circular and semi-circular forms of various sizes. Several of these features are known in the literature: Reis and Valença (1979), Brenner et al. (1980) and Klein et al. (1986). In these works, the forms are referred to as granitic or gneissic domes or alkaline intrusives.

Taking in consideration the concepts of Hills (1963), Badgley (1965) and Dennis (1972), about plutonic emplacement mechanics, Liu (op. cit.) assumed that the circular forms which occur on the Precambriam basement of the Rio de Janeiro State, are domic structures related to diapirism of plutonic masses. The author also mentions that a significant number of these forms are not easily identificable, and suggests they may reflect the presence of ancient basement structures.

Klein et al. (op. cit.), registered horizontal movements in the basement rocks and sedimentary cover of Tertiary continental basins, situated along the Paraíba do Sul rift system, at the northern portion of the Rio de Janeiro State.

## METHODS AND RESULTS

Analysing remote sensing images which cover the Precambriam rocks of the Rio de Janeiro State, it is common to observe inumerous morphological anomalies. In the meantime, the origin of these features are sheldon investigated, thus remaining unknown.

The present work, studying a selected area at the southwestern part of the Rio de Janeiro State (Figure 1), was intended to recognize some of the morphostructural features and their evolution. The data was obtained from the following materials:

- Aerialphotographs in the 1:20,000 scale, from the Cruzeiro do Sul aerophotogametric flight SA-363.
- Satellite images of LANDSAT and RADAR images were used as auxiliatory to the interpretation.

- Geological map of the Piraí Quadrangle, Rio de Janeiro State, in the 1:50,000 scale, published by DRM-RJ.
- Topographic map SF-23-Z-A--VI-1, Piraí (RJ), in the 1:50,000 scale published by IBG-FIBG (1979).

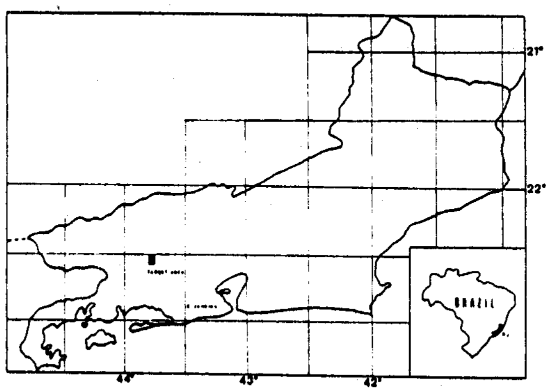

Figure 1: Localization of the target area in the State of Rio de Janeiro, Brazil.

The methodology used to elaborate the study and the maps, consisted of the following steps:

- Geological compilation: using a previous geological map (Grossi Sad et al., 1982 and Castro et al., 1984) containing the target area, a modified and simplified geological map, showing the main rock types and structural features was made.
- Drainage interpretation: it was based in the indentification of superficial drainageways, regardless of whether they were occupied by permanent streams or not. Then a map of the drainage pattern was elaborated.
- Interpretation of the topographical expression: a pictorial representation was made to show the main features of the landscape as well as their relation with the circular, semi-circular and stick-like forms. In the development of the pictorial map, tracing lines were used to sketch the topographic levels of the relief. A stereoscopic pair of aerial-photographs was used to obtain the level lines.
- Interpretation of faults and associated features: these features were individualized using the drainage pattern map, the topographical expression map, aerialphotographs, TM/LANDSAT and RADAR images. A structural framework map was produced.

**GEOLOGICAL CONTEXT**

The main lithological units and structures of the target area, are shown in a regional geologic map at Figure 2. High grade metamorphic rocks of Precambriam age predominates over a large area, with minor occurrence of alkaline dikes of Cretaceous age. The main units are: Serra das Araras Batolith, represented in the selected area by foliated plutonic rocks, dark collored, usually protomilonitized. Granitoids and migmatites with gneissic paleossome are the rock types. The Itaocara Unit is formed largely by banded biotite-gneiss, occasionally migmatized, and with intercalations of quartzite, amphibole-biotite-gneiss and dolomitic marble. In the target area, predominates granite-gneiss, light-gray, fine-grained and in part migmatized, grading to biotite-gneiss migmatized, mylonitic-gneiss and porphiroblastic-gneiss.

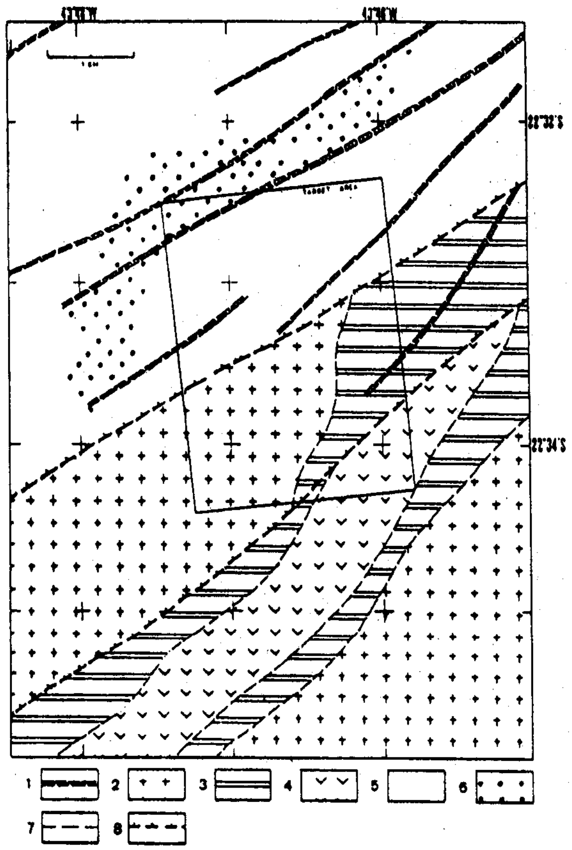

Figure 2: Modified and simplified geological map (from Grossi Sad et al., 1982). (1) Alkaline Dikes. Serra das Araras Batolith: (2) Granitoids; and (3) Migmatites. Itaocara Unit: (4) Granite-Gneiss; (5) Mylonite-Gneiss; and (6) Biotite-Gneiss. (7) Transitional Contact. (8) Reverse Fault.

**MORPHOSTRUCTURAL ANOMALIES**

The term morphostructure defines a presumed structure indentified through analysis and interpretation of the drainage system and relief features. It is characterized by anomalous zones occurring within a general distribution pattern of the drainage and relief elements (Soares et al., 1982).

Analysis of the morphostructures of the target area, was used to obtain information about the circular, semi-circular and stick-like forms. Such technique allows one to obtain, in the surface, the drainage pattern and the topographic expression, both reflecting the structural framework of the basement.

**Drainage Pattern**

Drainage analysis is a useful tool in the photogeology interpretation, specially in areas of low relief (Howard, 1967). Its characteristics can be relationated with the surface features, which are in turn inherited from the litohlogical, stratigraphical and structural framework of the basement. Regions of gneiss-migmatitic domain, as in the studied area, usually display a dendritic drainage pattern.

The drainage pattern of the target area, at a first analysis and considering its regional distribution, could be classified as a basic drainage pattern as described in Zernitz (1932). Meanwhile, local variations were indentified as drainage anomalies, are caused by the intense curvature of the streams and their transition to a modified drainage pattern (Zernitz, 1932). This pattern is similar to the subdendritic, particularly typical of this lithology.

The anomalous variations observed in the drainage, suggests the existence of concentric features in the relief. Considering this relief derivated from high metamorphic grade basement rocks, it can be affirmed, that the drainage pattern mentioned and observed in the Figure 3, is inherent to these rocks.

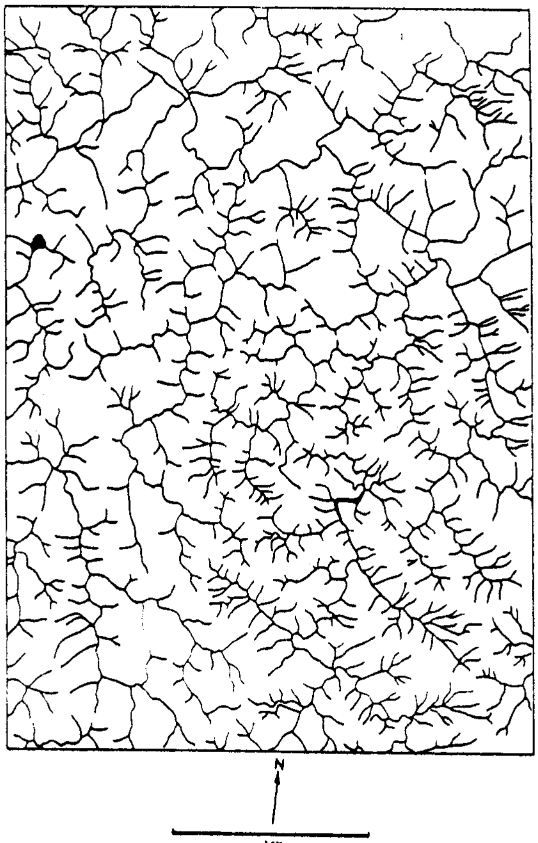


Figure 3: Drainage pattern of the target area.


Figure 4: Pictorical representation of the target area's morphology.

### Topographical Expression

Using this term in reference to a ground surface, Lahee (1970), stated that it is the expression of a particular rock or structural feature. The objective of topographical expression analysis of the target area, was to obtain data about the topographical characteristics of the basement and its conditionants.

The morphostructural anomalies expressed by the topography, consisted basically of a complex arrangement of circular, semi-circular and stick-like forms. The interpretation of aerialphotographs showed that the distribution of these forms actually reflects the structural complexity of the basement (Figure 4).

## STRUCTURAL FRAMEWORK

It was observed that the circular, semi-circular and stick-like forms in the target area, are clearly controlled by curved lineaments (Figure 5). These curved lineaments are related to the development of the regional framework detected in various portions of the Rio de Janeiro State. Dayan and Keller (1990), proposed a classification of these lineaments based on the mechanisms of development, using the nomenclature adopted by Woodcook and Fischer (1986).

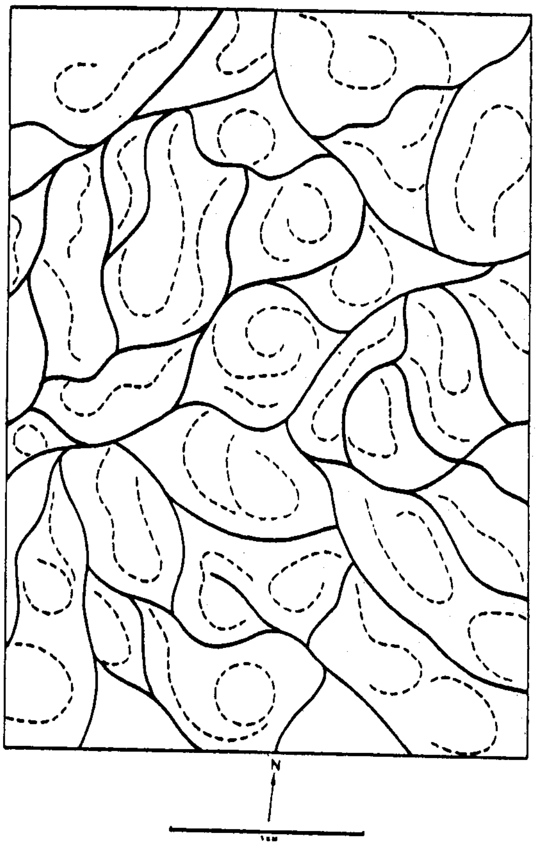


Figure 5: Morphostructural Features: Faults and associated circular, semi-circular and stick-like forms in the target area.

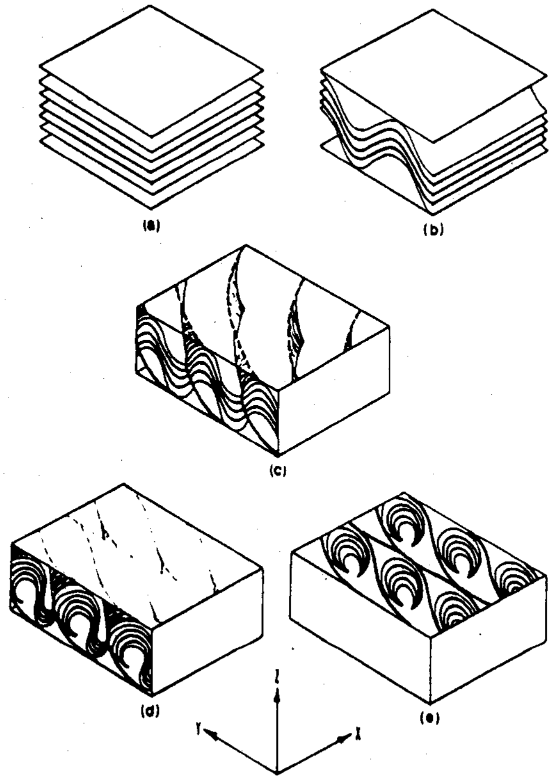


Figure 6: Schematic Sections of the Origin and Evolution of Circular, Semi-circular and Stick-like Forms in the Selected Area: (a) Initial stage, foliation unbended; (b) Effect of the tangential component along the foliation; (c) The tangential component combined with horizontal and vertical movements and tilting of the underground; (d) Evolution of the forms produced in response to the movements in c; (e) Final configuration of the structural framework evolution.

The present work proposes that the forms initially mentioned, are also related to the complex movements of the underground, that combined with tangential movements, caused a continuous bending of the foliation, generating the forms as in the Figure 6.

## FIELD OBSERVATIONS

Some field observations emphasizing the tangential component, were made in certain localities at the Rio de Janeiro State.

The displacement and partition of a caolinized pegmatite dike along the foliation of a metamorphised (high amphibolite facies) ultrabasic body (Figure 7a), was observed in the vicinities of the city of Areal, RJ, (Magalhães, 1985). In the Faraó Valley, Cachoeiras de

Macacu Country, RJ, Castro (1985) noted the verticalization of alkaline dikes, with partial penetration of the host-rock's foliation in them (Figure 7b). This fact is assumed to be caused by the stress increasing in the inferior portions of the block, along with a stress release in the superiors portions, which avoided the penetration of the host-rock's foliation in the superior part of the dike.

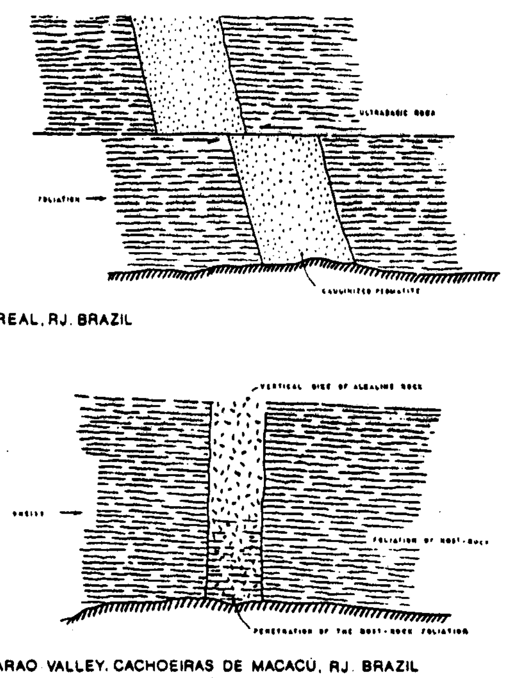


Figure 7: Sketchs of Field Observations: (a) Displacement and partition of a caolinized pegmatite dike along the foliation a metamorphised (high amphibolite facies) ultrabasic body; (b) Verticalization of a alkaline dike, with partial penetration of the host-rock's foliation in it.

## DISCUSSION AND CONCLUSION

Circular, semi-circular and stick-like forms were detected in remote sensing images, which covered the gneissic-migmatitic basement of the southwestern portion of Rio de Janeiro State. These forms are structurally controlled (Figure 5) and outlined by the drainage pattern (Figure 3).

The effect of NW-SE compressional stress, Liu (1987), caused the displacement of the underground blocks, reflecting the basement movimentation, and establishing a lineament pattern, Riccomini et al. (1987), Dayan and Keller (1990), that conditionated the forms above mentioned.

A model is suggested, based on the stress generated during the strike-slip fault movement, Suppe (1985, p.292-293) and Davis (1984, p.314). The stress increasing in the strike-slip fault at depth, caused a stress release at superior portions of the dextral block next to the fault plane. This stress generated a tangential component responsable for the foliation bending. The reversal vertical component combined with the tilting and the block displacement over a ramp ("tilt-ramping"), bended the foliation, producing the circular forms.

The combination of these movements did not result in neither intense deformation with associated metamorphism nor milonitization. The place where these conjugated movements occurred was not deep in the crustal zone, as it is expressed in the model. Mobilization of silica, by fluids liberation, was the only associated event observed. It is rather common to find in the selected area, as well as in many parts of the Rio de Janeiro State, levels of silex standing out in the landscape.

Figure 6, shows a evolutive scheme, represented by dextral prismatic blocks of the underground (a,b,c,d and e), generated by the conjugated movements. In Figure 6a, it is shown the rock's foliation at the strike-slip fault situation. Figure 6b, the tangential component, generated in the strike-slip stress field, produces a bending in the foliation. Figure 6c represents the tangential component combined with the reversal vertical movement and tilting. Figure 6d, shows the evolution of these conjugated movements, from the previous figure. In the Figure 6e, it can be noticed the block inversion by the action of the tangential component, combined with the simultaneous tilt and displacement of the block over a ramp ("tilt-ramping").

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