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**Summary/Notes**

A methodology is proposed for international geological correlation studies based on LANDSAT-MSS imagery. Bullard's et al. model of continental fit and compatible structural trends between Northeast Brazil and the West African counterpart. Six extensive lineaments in the Brazilian study area are mapped and discussed according to their regional behavior and relation to the adjacent continental margin. Among the first conclusions, correlations were found between the Sobral Pedro II Lineament and the megafaults that surround the West African craton, and the Pernambuco Lineament with the Ngaurandere Lineament in Cameroon. Ongoing research to complete the methodological stages will include the mapping of the West African structural framework, reconstruction of the pre-drift puzzle, and an analysis of the counterpart correlations.

**Remarks**

STRUCTURAL MAPPING FROM MSI-LANDSAT IMAGERY: A PROPOSED METHODOLOGY FOR
INTERNATIONAL GEOLOGICAL CORRELATION STUDIES

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ABSTRACT

A methodology is proposed for international geological correlation studies based on LANDSAT-MSS imagery, Bullard’s et al. model of continental fit and compatible structural trends between Northeast Brazil and the West African counterpart. Six extensive lineaments in the Brazilian study area are mapped and discussed according to their regional behavior and relation to the adjacent continental margin. Among the first conclusions, correlations were found between the Sobral Pedro II Lineament and the megasutures that surround the West African Craton; and the Pernambuco Lineament with the Maassare Lineament in Cameroon. Ongoing research to complete the methodological stages will include the mapping of the West African structural framework, reconstruction of the pre-drift puzzle and an analysis of the counterpart correlations.

1. INTRODUCTION

Since 1972, the LANDSAT Multispectral Scanner System has been collecting repetitive data over global regions in the visible and near infrared spectral regions.

Global tectonics has shown that the geological evolution of distant regions of the world can be markedly similar. In the general acceptance of continental drift by the scientific community, geological correlations have been made between selective drifted areas. Studies of this type can be supplemented by global LANDSAT scanning and image interpretation.

The Brazil-Africa Geological Correlation Project (Gondwana Project) developed by the Brazilian Institute for Space Research (INPE) intends to test the application of LANDSAT imagery for international correlation studies based on the theory of Continental Drift.

This paper presents the methodological approach that has been followed as well as some results already obtained and some preliminary conclusions.

2. DISCUSSION OF METHODOLOGY

The proposed methodology was based essentially on modern means of global data acquisition, as in the application of satellite technology to the study of continental drift and tectonics.

Orbital patterns of the LANDSAT type permit the collection of multispectral data of the most extreme areas of the planet. Geometric resolution is constant, while radiometric resolution can suffer variations, such as solar illumination with the latitude of the imaged area. In that sense, the study considered areas along roughly the same latitude. We assumed from a radiometric point of view the basic data for correlation to be equivalent, providing for spectral properties related only to natural targets, independent of atmospheric effects and different latitudes.
The areas studied are in regions classically correlated by researchers involved in continental drift. The physiography of the Atlantic Equatorial continental margin appears as pieces of a "jigsaw" puzzle, lending a natural tendency for reconstructing the ancient continent. The similarity between the continental margins of Africa and Brazil was the initial point of Wegener's hypothesis (Wegener, 1915). Ballard, Everett and Smith (1964) proposed a fitting of the two continents based on the depths of the continental edge, considering it as the actual margin of the two continents. The scheme proposed by these authors will be the model used in this study, together with LANDSAT research to discriminate the structural frameworks of the Brazilian northeast and African northwest. The model has been applied to Proterozoic geologic correlations (Almeida, 1980) as well as to tectonic fabric correlations of the continental margins (Carini and Fryman, 1975).

The continental margins adjacent to the South Atlantic are commonly classified as Atlantic type (Weisner, 1974) as opposed to the Pacific type. While the first type adjoins deep oceanic zones of expansion, the margins of the Pacific type are adjacent to zones of coalescence and thrusting plates, as on the western margin of the South American continent. For the method proposed, it is fundamental that the continental margins be of the Atlantic type, whose tectonic processes were less intense than the Pacific type and did not evolve to disfigure the adjoining landward structures.

Following the criteria that the continental margin be of the Atlantic type, that a model for connecting the continents be applicable and that LANDSAT data be available, the visual interpretation of imagery and integration of tectonic and structural data could be pursued.

Proceeding the actual research stage, the larger lineaments, principal structural tenovclides, and different geological sequences of the Brazilian Northeast were mapped. To support the visual interpretation, three geologic profiles were developed: the first, NE, from Natal to Currais Novos (Rio Grande do Norte), the second, NS, from Ceara (Cearà) to Orin (Goiás) and, the third, from Dundo (Ceará) to Santa Bárbara, in a NW direction to Santa Catarina Island. The profiles permitted the lithological and structural characterization of the principal tectonic groups of the Brazilian Northeast.

The stage to follow would be the development of the same interpretative work for the African area, the aim being to restructure the Gondwana segment, using, preferentially, the geometry of the structural map of the Brazilian-African counterparts.

The last stage would be an analysis of continental correlation. Several types of correlations to support the theory of continental drift could be tested, based on LANDSAT images and reconstitution maps.

In summary, the various stages of the proposed methodology can be summarized as follows:

1. Selection of LANDSAT-MS Imagery, channels 5 and 7 at the 1:1,000,000 scale.
2. Collection of available regional geological papers and regional maps from both sides of the Atlantic.
3. Definition of a dependable model for reconstitution of the continents.
4. Recognition of the types of adjacent continental margins.
5. Outline and elaboration of structural and tectonic frameworks of the correlation areas.
6. Integration of the areas following the reconstruction model and principal lineaments into-drift puzzle.
7. Interpretation of the LANDSAT models, a.
8. Analysis of correlation.
3. STRUCTURAL FRAMEWORK OF THE BRAZILIAN NORTHEAST

Visual interpretation of MSS imagery has allowed the mapping of 6 major lineaments striking regionally for hundreds of kilometers (Figure 1). There are other fracture line not so apparent as the Cabaui lineament and Santa Quitéria lineament. For such extensive lineaments, the regional tectonic behavior concerning the Precambrian geological scheme and the physiography of the adjoining continental margin will be described. These major lineaments are often strike-slip in nature but sometimes multiple slips are present (Mello et al., 1978).

Some lineaments are polycyclic and therefore older than 1,800 m.y. as are the Pernambuco and Patos lineaments. Cabaui Lineament otherwise seems to be younger, its volcanism being 20–30 m.y. old (Santos, 1968; Ponte and Asmus, 1976).

3.1 SUBRAL–PEDRO II LINEAMENT

This lineament extends northeasterward over 300 kilometers from the Parnaiba Paleozoic Basin to the Barreirinha Cenozoic basin close to the Atlantic margin. In the Parnaiba Basin, it appears as a normal faulting system following the Upper Valley of Pote River. Inside the Precambrian area, there are post-tectonic granitoids (450 m.y.) intruded along the lineament strike and some alignments of grabens. The enclosures of these grabens are 430 m.y. or Cambro–Ordovician age (Almeida et al., 1967).

At the submerged continental margin, this lineament bounds two different basin architectures. In the west, the basement is deep and dips seaward. In the east, the basement is shallow and dips seaward (Ponte and Asmus, 1978). Thus, the lineament shows some reactivation in Upper Cretaceous. Upper Cretaceous marks the beginning of Wealdienian reactivation of Brazilian Platform (Almeida, 1969).

3.2 NOVA RUSAS (TAUA) LINEAMENT

This lineament is a strike-slip fault extending over 300 kilometers, in a Precambrian domain. The predominant trend is WSW with a final trend following the trend of the Subral–Pedro II Lineament (Figure 1). The south segment is aligned with the Sènador Pompeu Lineament and controls the Coccoi Graben filled with clastics of Cambro–Ordovician age (Almeida et al., 1967). The Northern segment confines locally the eastern border of Parnaiba Basin separating the Paleozoic basin from the granitic zone of Santa Quitéria. (Santa Quitéria Median Massive). The structural trends of Curu–Independência Folded Belt (Bruto Novos, 1975) are clearly aligned with the Nova Rusas Lineament.

3.3 SÉNADOR POMPEU LINEAMENT

This lineament comprises several dextral transcurrent faults trending NE along 300 kilometers, from Coccoi, at Parnaiba Basin border, to the Potiguar Cretaceous Basin in the coast. Several granitoids and metabasites are present along this fault system. Granitoids are elongated to the NE following the lineament trending. Almeida (1967) suggests that granitoids are post-tectonic according to the radiometric ages (430 m.y.), supposing otherwise, the older age for the metabasite (dioritic) bodies. The southwestern segment of the lineament controls the southern fault of the Cocci Graben.

3.4 JAGUARIBE LINEAMENT

This structural feature extends over 400 kilometers from the Parnaiba Basin border to the Potiguar Basin in the coast line.

Three extant faults conform to this lineament between Fortaleza (Ceará State) and Orós (Ceará State), (Figure 1). These faults trend NNE, from Orós to the coastline, the lineament is formed by two faults: one is the Dina fault that trends NNW, the other is the Jaguaribe fault that trends WNW. These several faults show multiple slips: strike-slip and thrust slips. The prominent definition

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of this lineament, which abruptly changes the trend from SW to ENE, is followed by all structural alignments between Patos Lineament and Jaguaribe Lineament. This deflection can be seen in the elongated forms of the granitoids, in contorted grabens, in the migmatite foliation and in the metasedimentary bending. The lineament was reactivated in Upper Cretaceous although confined to the western border of the Araripe Cretaceous Basin—a relevant feature related to the Northern Brazilian Continental Margin. Ponte and Assunção (1978) described some horizontal displacement in the block faulted system of the continental shelves caused by the reactivation of the Jaguaribe Lineament.

3.5 PATOS LINEAMENT AND PERNAMBUCO LINEAMENT

These lineaments are the most remarkable elements from the northeastern structural framework. They are confined to a wide zone of EW structural trending, known as the transversal belt of the Brazilian Platform. These broad lineaments can be drawn out over much of 500 kilometers from the Pernambuco Basin to the continental border.

The Patos Lineament has a final deflection to NE while the Pernambuco Lineament follows a strict EW trend. Both lineaments bound relevant tectonic elements of the Brazilian Northeast. The Patos Lineament limits the Rio Piranhas Median Massif (older than 1,500 m.y.) from the Piancó Alto Brígida folded belt (younger than 1,000 m.y.).

The Pernambuco Lineament bounds partially to the Pernambuco-Alagoas Median Massif from the adjoining Upper Proterozoic folded belt (Brito Neves, 1975).

Both lineaments were reactivated in the Early Cretaceous as can be drawn from the images. Patos Lineament confines the northeastern border of Araripe Basin while Pernambuco Lineament confines the northern border of Jatobá Basin.

Some offshore features are aligned with these lineaments. The Parába escarpments are aligned along the 6°40'N parallel, the same latitude as the Patos onshore lineament (Ponte and Assunção, 1978). Significant magnetic anomalies were drawn by Fainstein et al. (1975) offshore of Parába. The Pernambuco Seamounts and the Pernambuco Plateau are aligned with the Pernambuco Lineament. Fainstein et al. (1974) link significant magnetic anomalies with the Pernambuco Plateau. For a time, the alignment of these features were considered only coincidental by Ponte and Assunção (1978). The Cabo Magnetic Province (Cobrinha, 1967) is emplaced closely with the Pernambuco Lineament near Recife. Basic volcanics and alkaline granites are the predominant rocks. According to Sanderson (Almeida et al., 1967), age determinations of Cabo Granite reveal values of 90 m.y. for the event. This suggests that Cabo Granite may be the youngest of the Brazilian Platform. Cobrinha and Bryan (1975), among other authors, suggest a genetic relationship between Cabo Province and Pernambuco Lineament.

IV. FIRST CONCLUSIONS

Although the interpretation of LANDSAT images over Africa has not been developed, some preliminary conclusions can be made based on the reported results and available bibliography of Africa:

1 - The structural frameworks displayed by the Pan-African Cycle in Western Africa (Turcotte, 1968) and by the synchronous event of the Brazilian Cycle in northeastern Brazil, are the most secure parameters in the reconstruction of a paleocontinent, since they were not affected by younger orogenic cycles.

2 - Four extensive fault zones can be correlated according to the proposed model. The Sobral-Pedro II Lineament can be correlated with the NS transcurrent faults that separate the metasediments of the West-African Craton (Almeida, 1966; Bertrand and Caby, 1978). Both lineaments limit orogenic areas partially, conditions post-tectonic granites and associated Cambro-Ordovician grabens. The Pernambuco Lineament can be
correlated with the volcanic line of Cameroon and the Ngauruandere Lineament. The Pernambuco Lineament has a transcurrent character and conditions Cretaceous grabens, recent volcanism and young granites (Cabo Granite). According to Almrida (1966), Corine and Bryan (1975), the Ngauruandere Lineament is also transcurrent, has reactivated during the Cretaceous conditions grabens and is associated with young volcanism (Cameroon volcanism).

3 - The extensive oceanic transforming faults are not secure structural elements for correlations since their tectonic conditioning elements are different on both sides of the Atlantic. Ponte and Assis (1978) point out that the Atlantic fractured zones are tangent to the Brazilian coast and do not affect significantly the physiographic character of the continental margin. In equatorial Africa, on the other hand, they condition the limits of several Cretaceous basins (Togo-Dahomey, Abidjan, and the Ben. Trough) without affecting significantly the extensive African lineaments (Delteil et al., 1976; Corin and Bryan, 1975).

4 - The structural directions of Serido fold belt (NE) (Brito Rovers, 1975) and of Dahomey fold belt (NE) (Cohen, 1966) are compatible when the continents are fitted.

5 - Geochronological data compiled from bibliographical sources show correlations that certify the continuity of the tectonic events between both continents. The Pan-African tectogenesis is correlatable with the Brazilian and the Eburnean tectogenesis with transamazonian (Cohen and Snelling, 1966; Clifford, 1970; Almrida et al. 1973). Two tectonic cycles affected the pre-cambrian rocks between Recife and Fortaleza, likewise, two cycles affected the pre-cambrian rocks between Cameroon and Ghana. The synchronism between events as well as the similarities between the structural tendencies when the pre-drift scheme is sketched indicate that the pre-drift hypothesis is a perfectly verifiable fact.

In that, continental drift is a verifiable fact, and the continental margin is of the Atlantic type, it appears to be feasible to develop studies of international geological correlations with LANDSAT images.

5. ONGOING RESEARCH

Ongoing research will complete the final stage proposed by the methodology. They can be drawn as follows:

1 - To map the structural framework of Western African between Cameroon and Ghana using MSS imagery, channel 5 and 7, 1:1,000,000 scale.
2 - To fit the counterparts based on their structural framework and on Ballard's fitting model.
3 - To fit the LANDSAT mosaics from the continental counterparts.
4 - To analyze the correlation supported by tectonic and lithological data.

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