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MORPHOTECTONIC ANALYSIS IN THE BARREIRAS GROUP, SOUTH COAST OF STATE OF BAHIA, BASED ON THE SQUARE OVER RADAR IMAGE APPROACH.

CARLOS CÉSAR UCHÔA DE LIMA* GERALDO DA SILVA VILAS BOAS**
* Departamento de Ciências Exatas. UEFS, Km. 03 BR 116 CEP 44031-460, Feira de Santana, Bahia Brasil. email: uchoa@uefs.br.
** LEC – Curso de Pós Graduação em Geologia, CPPG/IGEO/UFBA, Rua Caetano Moura 123, Federação CEP 40210-350, Salvador, Bahia, Brasil. email: gsvboas@pppg.ufba.br.

RESUMO

O presente trabalho aborda um novo método, que analisa a influência da neotectônica na modelagem do relevo, a partir da observação do direcionamento da drenagem presente em blocos estruturais, observados em imagem de radar, na escala 1:250.000. O estudo se desenvolveu na costa sul do Estado da Bahia e demonstrou que o grau de orientação preferencial da rede de drenagem é diferente entre os blocos estruturais estudados. O bloco 01 possui uma direção do sistema de drenagem para nordeste, com um vetor de resultante de N70º, enquanto que, os blocos 02 e 03 mostraram orientações preferenciais para N106º e N129º respectivamente. Essas diferenças na distribuição da rede de drenagem revelam a contribuição da neotectônica durante o Quaternário, na configuração da morfologia do relevo atual. Movimentos tectônicos atuaram sobre o bloco 01 basculando-o para nordeste, alterando a orientação e o padrão de drenagem. O bloco 03 evidenciou um movimento para sudeste a partir desses esforços, enquanto que o bloco 02 indicou pequeno ou nenhum deslocamento. Adicionalmente, o controle estrutural do embasamento foi importante, sendo este evidenciado por anomalias observadas no padrão de drenagem da região estudada, tais como, mudanças abruptas na orientação de drenagem, *offsets* de canais, além da presença de cursos de rios retilíneos que sugerem controles associados aos lineamentos que constituem os falhamentos geológicos da região estudada.

Palavras chaves: neotectônica, blocos estruturais, sistema de drenagem.

ABSTRACT

The present paper deals with a new approach, that analyzes the neotectonic influence in the modelling of the relief, from the observation of the drainage orientation in structural blocks, observed in 1:250,000 radar image. The study was developed in the south coast of the State of Bahia and it demonstrated that the degree of preferential orientation of the drainage net is different among the studied structural blocks. The block 01 possesses a direction of the drainage system to northeast, with a resultant vector of N70º, whereas blocks 02 and 03 showed preferential orientations to N106º and N129º respectively. These differences in the distribution of the drainage net have revealed the neotectonics contribution, during the Quaternary, in the configuration of morphology of the present relief. Tectonic movements acted on the block 01, providing a northeast tilting, altering the orientation

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and the drainage pattern. The block 03 has evidenced a movement for southeast, while the block 02 indicated little or no displacement. Additionally, the structural control of the basement was important. This control is evidenced by anomalies observed in the pattern of drainage of the studied area, such as, abrupt changes in the drainage orientation; offsets of channels, besides the presence of courses of straight rivers that suggest controls associated to the lineaments that constitute the geological faults of the studied area.

Keywords: neotectonics, structural blocks, drainage system

INTRODUCTION

Despite of some differences in conceptual and/or terminological views regarding recent tectonic activity in Brazil, according to Saadi (1993), there is an agreement among the research community, that a fundamental relationship between neotectonics and the configuration of present day morphology should be considered, irrespective of the age of the studied features, which could be as old as 10^7 years.

Hasui (1990) used the term *resurgent tectonics*, for the Tertiary-Quaternary reactivation of Pre-Cambrian fault structures in Brazil, relating Neotectonic activity to the drift of the South American continent and consequent opening of South Atlantic, since the beginning of the Mid Tertiary. As markers of those events, Hasui (1990) proposed the beginning of the deposition of the Barreiras Group, the last sedimentary package deposited in the coastal basins and also the Mid Miocene end of magmatism in Brazilian territory, dated at about 12 Ma in northeast of Brazil. The aforementioned conceptual conflicts reflect the growing number of researchers who became interested with neotectonic issues in Brazil, especially those who concentrate efforts in study of the Barreiras Group (Bezerra 1999, Bezerra & Vita Finzi 2001, Lima 2002).

The depositional history of this Group spanned from Miocene to Pleistocene times (Suguio et al. 1986, Arai 1997), with the basin fill being, in general, composed by poorly consolidated (unconsolidated), fine grained to cobble sized sediments and interpreted as resulting from deposition associated with mass flows and fluvial processes (Bigarella 1975). This work aimed to evaluate the effects of neotectonics on the sedimentation of the Barreiras Group in the coastal zone of State of Bahia, Brazil, using a new methodology, here denominated the method of the small squares over images, described below. This method rescues old techniques, rereading and give them new approaches.

AREA SELECTION

The studied area is located in the south coast of the State of Bahia, and it is limited to the north by the João de Tiba River, whose mouth is located at the city of Santa Cruz of Cabrália, and to the south by the Caraíva River (Fig. 1). This area was selected for the following reasons:

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1. The whole area is blanked by the same sedimentary unit, the Barreiras Group, being therefore, considered homogeneous in terms of lithology;
2. At the employed working scale, throughout this area, there is a dense network of streams/water bodies;
3. The area is plane, with little or no deformed sediments; maximum topographical unevenness in the order of 40m and well defined fluvial valleys, limited by cliffs.
4. The whole area can be segmented into three structural blocks, separated by fluvial valleys (structural lows) (Fig. 2). To the east, the blocks are bound to the ocean by coastal cliffs;
5. The whole area is part of a single 1:250.000 radar image, which facilitates the integrated view of all blocks.

PREVIOUS RESEARCH

Since 50' decade researchers were interested in studies based on images, as aerial photographs. Blanchet (1957) identified rock fracture systems in aerial photographs, both in areas of exposed sedimentary cover and crystalline basement. However, knowledge about tectonics in that time was not clear for this author, and, according to him, such fracture systems were resultant from the action of "...external stresses, which have been active throughout geologic time and which continue to act upon the crust today...". Kupsch & Wild (1958), using photo mosaics, identified several lineament trends in Pleistocene glacial sediments in the area of Avonlea (Saskatchewan, USA) and considered them as being external expressions of faults active during Pleistocene and probably even during the Recent. The identified lineaments were related to the distribution of the topographic relief, streams adjustments, as well as to the alignment of elongate closed basins, of the vegetation and of the soil- moisture differences. Lattman & Nickelsen (1958) worked with aerial photographs in the scale of 1:20,000, drawing what they denominated of fracture trace that varied in length from 0.2 to 0.75 miles and were distinguished by the alignments of the vegetation, tonality of different soil types and trends in segments of currents.

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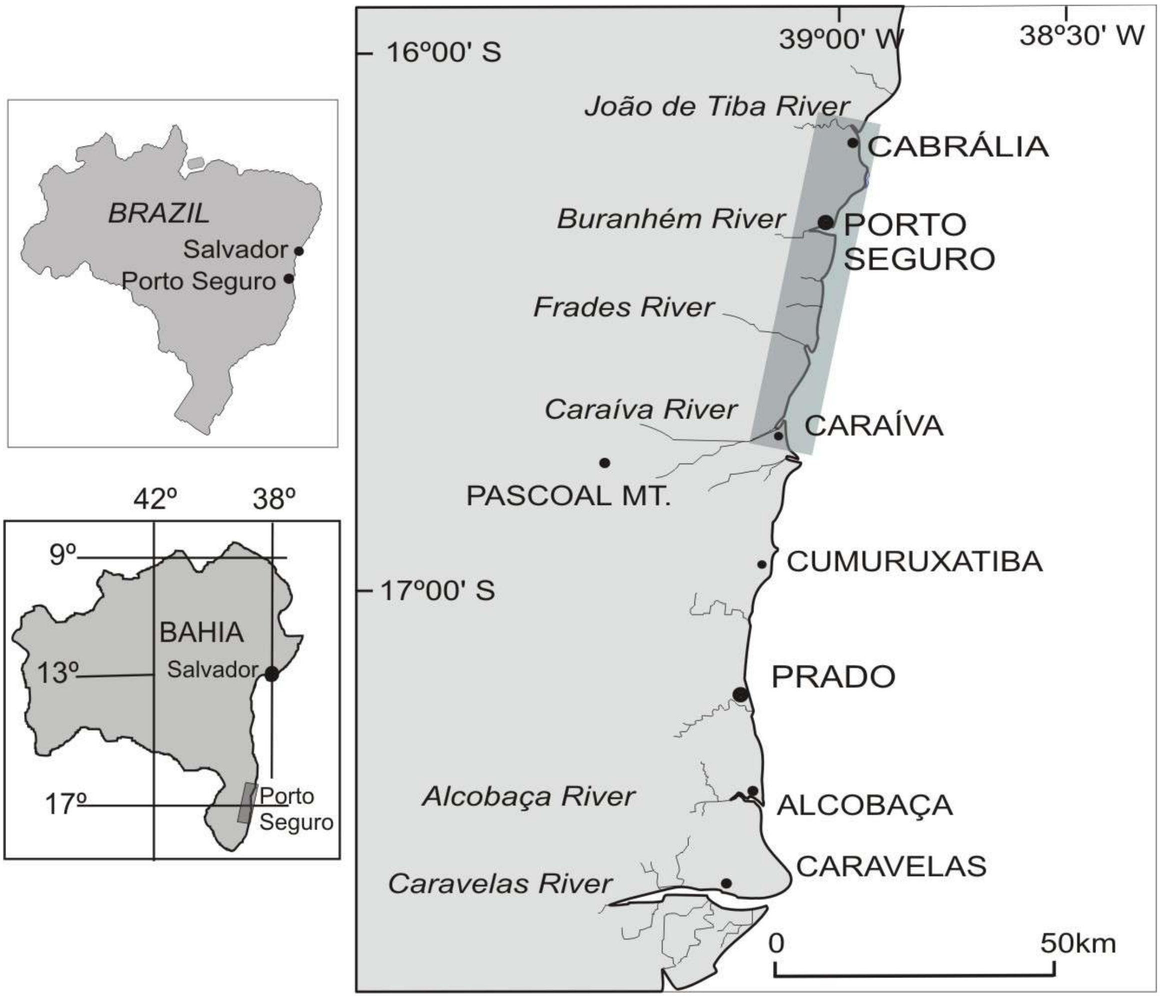

Figure 1 – Situation and localization map of the studied area. Structural blocks studied are between Cabrália and Caraíva.

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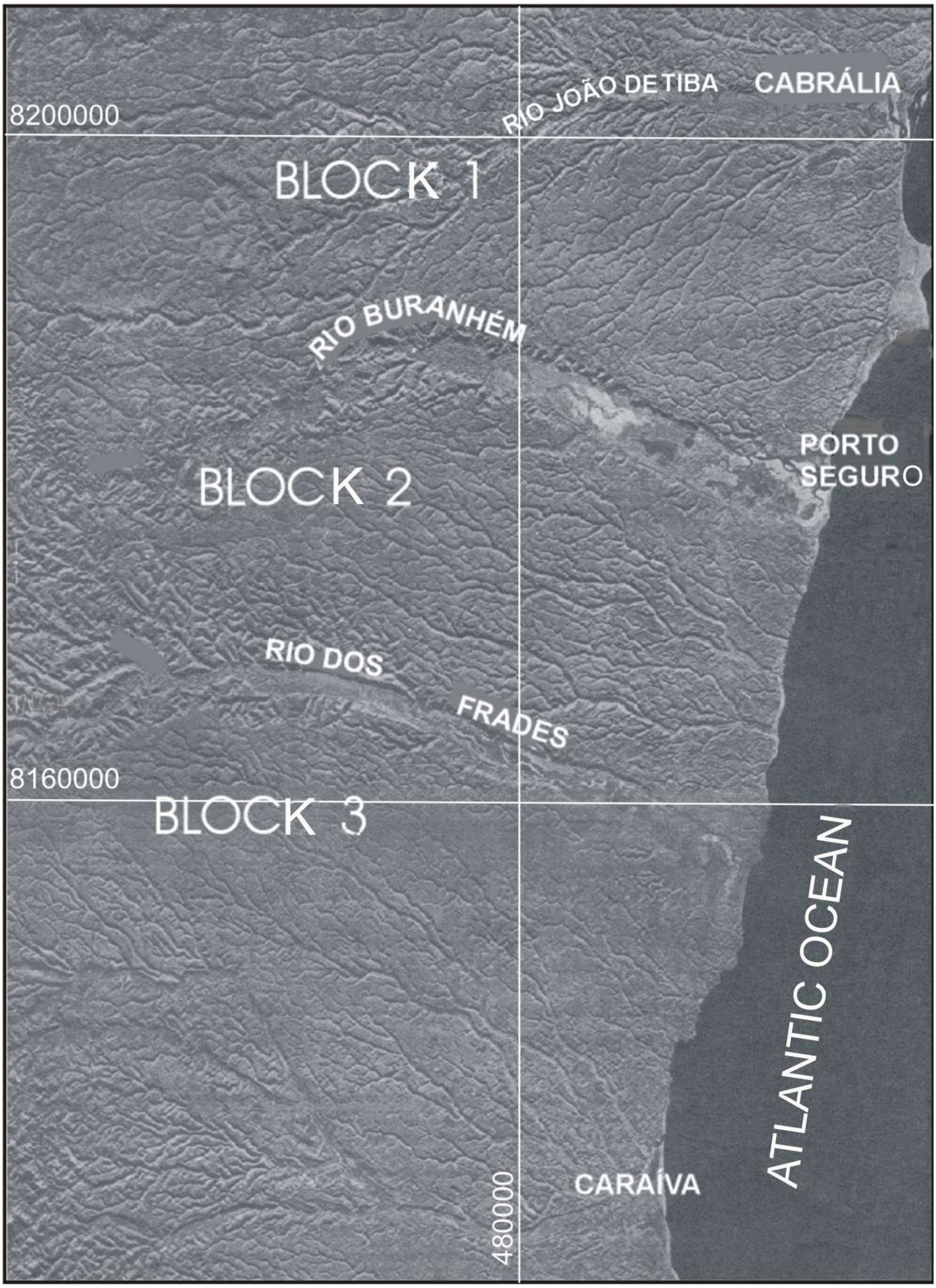

Figure 2 – Radar image of the three studied structural blocks.

The application of drainage analysis from aerial photographs to the identification of structural features has been employed since the 60' (Howard 1967, Ponte 1969). This method becomes particularly important to help fieldwork in the perception of geological and topographical controls, such as areas lithologically homogeneous, with a smooth relief. However, in order to accomplish such analyses, it is necessary that the scale of the used images is adequate to the drainage density observed in the studied area. Ponte (1969) used photo-geomorphological interpretation as a tool in the identification of the structural framework of the Sergipe-Alagoas Basin in the Northeast of Brazil. Based on the obtained results, Ponte (1969) suggested that tectonic forces, including minor epeirogenic tilting, acted after the deposition of the sediments of the basin, reactivated pre-existing geological structures and affected the morphology of the upper layers.
Recently, Lima et al (2002) identified from Landsat TM image, a fault system that constitutes the limit of the "V" shaped São Francisco Coastal Plain in Sergipe/Alagoas Basin. Bittencourt et al (1982) cited these faults as product of reactivation of Precambrian faults, during Pleistocene.

THE METHOD

For the present work, the square over radar image approach method was employed for the evaluation of neotectonic activity. The method is based on the analysis of the drainage patterns and anomalies of river currents using images of the studied area. Image used in this work were obtained from RADAM BRASIL Project. The whole area is subdivided in small squares (Fig. 3), within which the orientation of the drainage is observed and the domain of the main currents highlighted. The small squares are drawn in a transparent overlay with one on of sides of the squares parallel to the true north, to facilitate measurements of drainage directions. The overlay is then fixed onto the radar image with an adhesive tape to avoid errors. Two corners of the overlay were kept unattached so that measurements in areas underneath the sidelines of the drawn squares could be made. The direction of the main drainage were measured with a standard compass and systematically recorded and logged separately for posterior interpretation.

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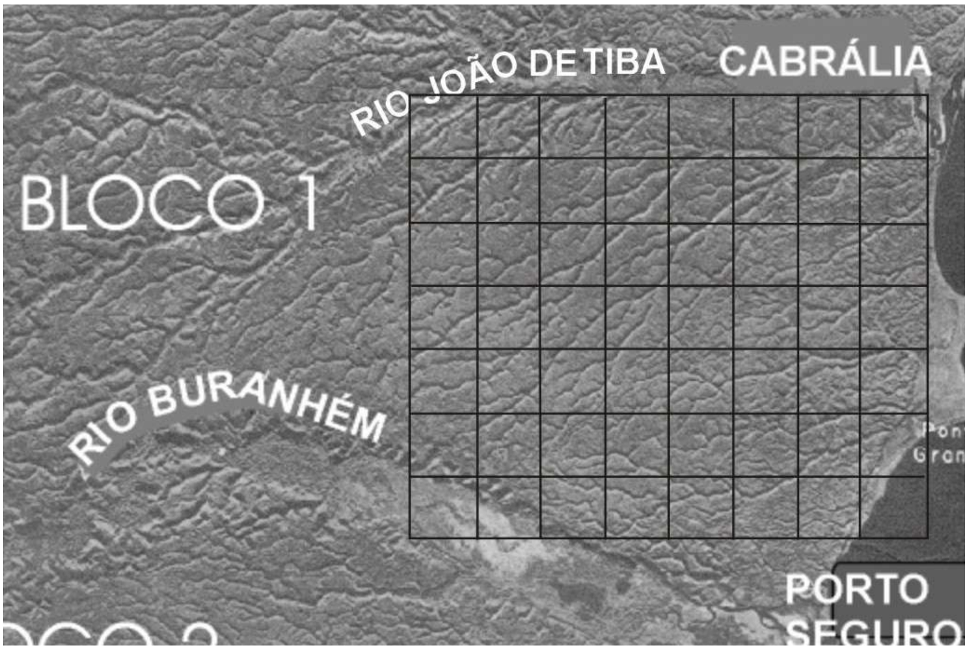

Figure 3- Example of a small square over radar image. Squares in this figure are only illustrative and do not correspond the true size used in this work.

In the studied area, the analysis was carried out separately for each one of the aforementioned structural blocks. Each analyzed square was carefully indicated with a dot in black ink to avoid repetition of the measurements. The chosen working scale was 1:250.000, so that each traced square of 1 cm^2 represented an analyzed area of 6.25 km^2. This scale enabled the evaluation of river current trends, drainage patterns and also anomalies in one single image. The definition of which were the main drainages inserted in each square was based on their dimensions, and hierarchy of the observed channels. After the measurements were recorded, rose diagrams (histograms) (Nemec 1988) were prepared for each individual block and the mean and magnitude vectors were calculated (Curray 1956) and indicated for best visualization of current directions.

RESULTS

The block 01, situated between João of Tiba and Buranhém rivers, exhibited only one domain of drainage trends. For this area, 143 measurements were taken, covering an area of about 356km^2, and showed a predominance of current directions towards Northeast. Plotting of the measurements on a rose diagram, as proposed by Nemec (1988), clearly shows this preferred NE trend (Fig. 4a). The resultant vector, according to the method proposed by Curray (1956), is directed towards N70º, with a magnitude vector of 92%, confirming the preferential orientation of the currents. Some drainage anomalies were observed, represented mainly by abrupt changes in the direction of the currents. One of those observations involved a major offset in the segment of the course of the current. Such deviation was associated with a fault structure trending approximately

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N135º and with a length of about 0,8cm, which, for the scale of work, corresponds to a fault length of about 1,8km. The observed offset length was of approximately 0,5mm, equivalent to about 125m.

The block 02, located between the Buranhém and Frades rivers, showed a dominant E-SE drainage trend, markedly distinct from the Block 01 described above. 148 current direction measurements were taken in this block, which has an area of approximately $513km^2$. Using the method of the rose diagrams, dominant paleocurrents directions trending between N90º and N120º were observed (Fig. 4b). The resultant mean vector had a trend of N106º, with a magnitude vector of 92%, indicating an excellent preferred orientation in the analyzed river currents.

The block 3 exhibited a particularity with respect to the two other blocks. Two domains of drainage trends were identified. The first one comprises current directions down to the mid course of the rivers and, the other, from this point to the mouth of them. In both cases, the general current trend is towards SE. In the first domain, measured directions yielded a mean vector trending N126º, whereas in the latter the obtained mean vector has a trend of N132º. The resultant mean vector for a total of 114 measurements, over an area of about 588 km^2, is directed towards N129º. The larger domain of the drainages was between N 120º and N150º (Fig.4c) while the magnitude vector was of 95%, also showing an excellent degree of preferred orientation of the measured currents.

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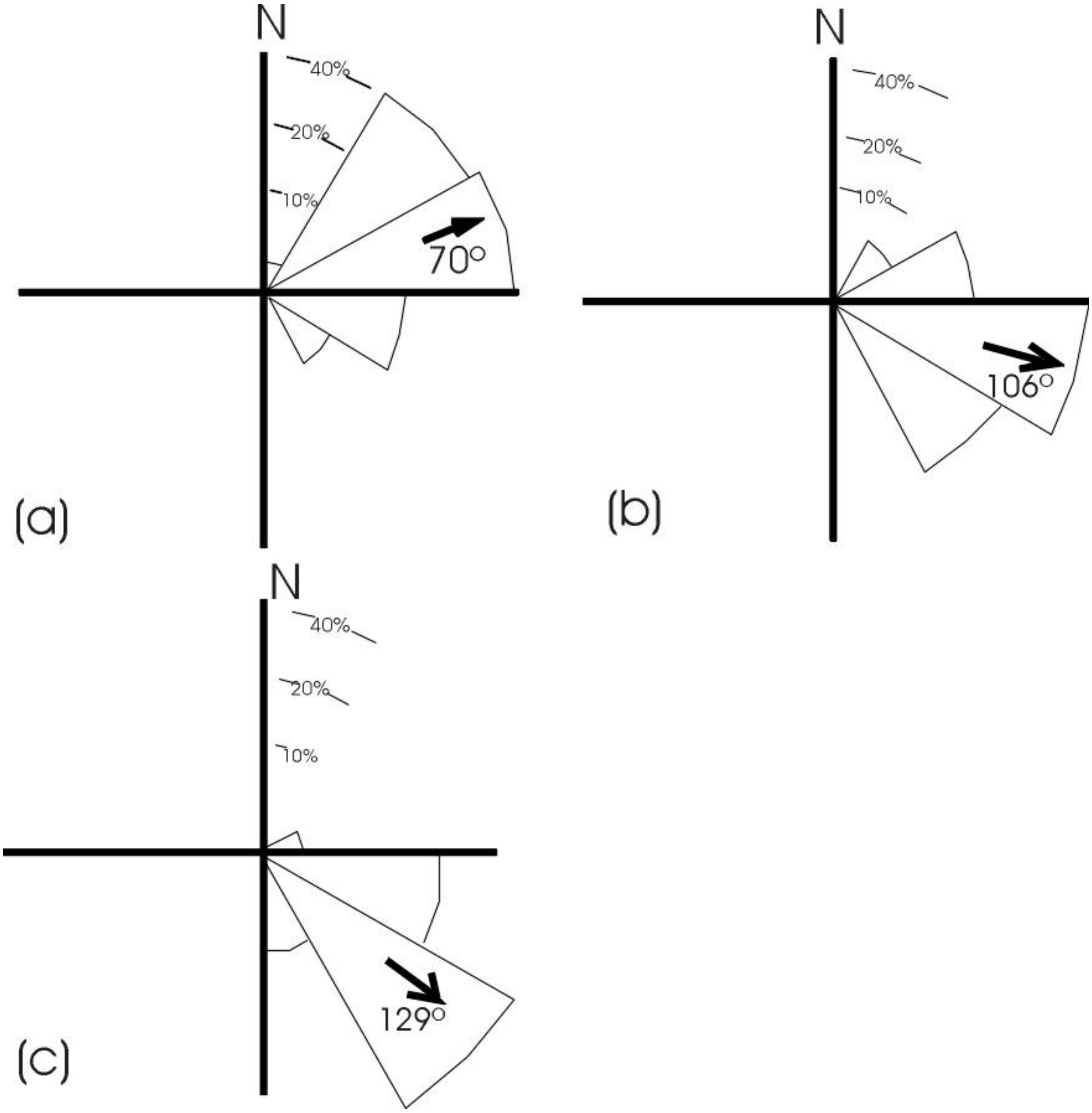

Figure 4 – Histograms and mean vectors of drainage systems in: (a) block 1; (b) block 2; and (c) block 3. Results presented here show the difference of preferred orientation of drainage system in each block.

DISCUSSION

Due to the lithological homogeneity of the studied area, a dendritic drainage pattern should normally be expected (Howard 1967). With respect to the block 01, although most of the tributary currents indeed develop such pattern, larger currents tend to become parallel. This pattern may have been superimposed, on an earlier developed overall dendritic pattern, by later rigid block tilting. The smaller drainages in this block develop a sub-trellis pattern (directed from SE to NW), and this is probably due to the

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fracture system found in the area. Those fractures are also recorded in basement rocks exposed to the west of the studied area, being however of larger magnitudes. The drainage offset observed in block 01 is an evidence of later faulting, in this case with a sinistral kinematics, after the deposition of the Barreiras Group, supporting the operation of neotectonic activity in that region.

In contrast to blocks 01 and 03, the main rivers of block 02 end directly on the sea, showing a natural gradient of the currents towards the ocean. For this reason, block 2 may have experienced little or no rigid movement. Even so, some drainage anomalies were observed and related to fracture systems, indicating a strong structural control imposed on some segments of the rivers. As with the block 01, those fracture-related drainage anomalies also have a NW-SE trend, but in this case, the length of river segments oriented according to the fracture system is generally larger, suggesting that the structural control (fracture-related) for the block 2, was stronger than the one imposed by neotectonic activity.

Block 03 shows drainages directed to SE, with the main streams ending at the Caraíva River valley. This pattern, as with block 01 suggests the influence of tilting. However, the tilting pattern is distinct, as block 01 experienced an accentuated inclination towards NE. Furthermore, the occurrence of two drainage trend domains in block 03 indicates that the movements in this block have not occurred in a homogeneous way, with a greater degree of tilting occurring at the lower course of the rivers. One of the largest tributaries of the Caraíva River exhibits a straight, NW-SE directed course direction and clearly runs along a fault zone with the same trend of observed structural lineaments in the basement to the west of the studied area, showing that, in some cases, the structural control is greater than the neotectonic control.

ADVANTAGES OF THE METHOD

The main advantage of the method is perhaps the fact that it establishes a statistical sequence of measurements of the currents, similar to the methodology used for paleocurrent analysis from structures recorded in fieldwork on sedimentary rocks. This method enabled a clearer visualization of possible structural modifications imposed within the studied blocks.

Another advantage of the method, at least in the employed working scale, was that it permitted the investigation of small parts of the whole drainage system and therefore allowed detailed observation. Had the system been analyzed as a whole, some important details would have been missed. An example of this is the offset drainage pattern observed in millimeter scale on the image, which would have been very difficult to identify and record if the area had been investigated by a traditional method. Finally, the quantification of the results and the mathematical verification of theoretical results were particularly important, as they yielded a mean vector for the paleocurrent directions, which before were just visually observed.

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CONCLUSIONS

Silva & Tricart (1980) were probably the first ones to use aerial photographs and radar images to investigate the effects of neotectonics along the southern coast of Bahia. According to these authors, evidences of this neotectonic activity in the area include: the SE-directed tilting of the uppermost part of the Barreiras Group, the orientation of the drainage valleys parallel to Pre-Cambrian fault structures, and for the anomalies verified in drainage patterns.

Mendes et al. (1987), first drew attention to block tilting in the area north of the Buranhém River, between the cities of Porto Seguro and Santa Cruz of Cabrália, here denominated block 01. However the authors have not reported other movements involving other blocks.

Some conclusions drawn from the method used in this research improve the understanding and further highlight the effects of neotectonics in the studied area. It was verified that:

1 - ratifying the observation reported by Mendes et al. (1987), the block limited by the João of Tiba and Buranhém rivers experienced a NE-directed tilting, leading to the discharge of the main streams in the area into the João de Tiba River, although minor streams to the east directly discharged into the sea.

2 - Block 02 has not experienced significant movement from Pleistocene to the Recent, so that river traces kept their original trends, ending at the sea, along an approximate SE direction. Still, a strong structural control is evident by the abrupt deflections in the traces of some of the main currents, followed by straight river courses controlled by a fault with a NW-SE orientation.

3 – The contrast in the orientation of drainage patterns, between blocks 02 and 03, also indicates a significant movement of the latter, resulting in a shift of current directions towards SE. Such movements (SE-directed tilting) in block 03 are clearly evidenced by a river trace deflection of about 23° with respect to the streams of block 02.

4 – Similar to what has been observed by Ponte (1969), in his studies of the Sergipe-Alagoas Basin, subparallel drainage patterns also occur in the south coast of Bahia, along gentle slopes resulting from block tilting and with some angularity associated to structurally (basement) controlled sub-dendritic patterns.

These conclusions led us to believe that fault reactivation occurred during Pleistocene, with enough magnitude to promote block tilting. As a consequence, river traces in the region were redirected, modifying the drainage pattern, which, from the lithological homogeneity of the sediments and from the morphologic characteristics of the landform, should have developed dendritic, instead of the observed sub-parallel patterns.

The main movements occurred along fault structures that are oriented parallel to the valleys of the main rivers separating the studied blocks, with these valleys behaving as structural lows. Additionally, NW-SE oriented faults occur as indicated by offsets in drainage courses and by the development sub-trellis patterns in several tributaries. In Block 03, the trace of one of the largest tributaries of the Caraíva River has this same NW-SE trend, being clearly constrained within a fault zone.

NE-SW oriented fractures are observed in block 01 and they were also observed by Lima & Villas Boas (1999) at outcrop scale. In addition, Lima (2002) developed a carefully study of neotectonic joints and have concluded that the stress responsible for originate them are also oriented NW-SE.

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