DIGITAL IMAGE PROCESSING AND ENHANCEMENT OF GRAVITY DATA AS AN AID TO THE DEFINITION OF THE STRUCTURAL FRAMEWORK OF THE NORTH TUCANO-JATOBÁ BASINS, NORTHEASTERN BRAZIL

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KEY-WORDS: Digital image processing, gravity data, North Tucano-Jatobá Basins.

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ABSTRACT

Digitally processed and enhanced gravity data in raster format were used to improve the definition of the main structural features in the northern part of the Recôncavo-Tucano-Jatobá Rift. Image processing techniques included: (a) conversion of Bouguer and residual-Bouguer gridded data into contrast-enhanced gray-level images; (b) generation of enhanced hybrid pseudo-color composites; and (c) generation of a gravity digital elevation model in perspective views. The integrated analysis of this dataset permitted the recognition of subtle trends and intensity-related spatial variations in gravity data, tentatively related to the following tectonic units of the RTJ Rift: ramp platforms, structural lows and highs, along-length horsts, grabens, faulted borders and extensional faults.

RESUMO

Técnicas de processamento digital de imagens foram aplicadas a dados gravimétricos visando melhorar definição das principais feições estruturais na porção norte do *Rift* Recôncavo-Tucano-Jatobá. Os processamentos utilizados incluíram: (a) conversão de dados Bouguer e residual-Bouguer, no formato de *grids*, em imagens realçadas; (b) geração de composições falsa cor híbridas e (c) geração de modelos de elevação digital com visão em perspectiva. A análise integrada desse conjunto de dados permitiu reconhecer feições lineares e sutis variações espaciais nos dados gravimétricos, as quais foram associadas a unidades tectônicas no contexto do *rift*, tais como: plataformas em rampa, baixos e altos estruturais, horsts, grabens e falhas de borda.

INTRODUCTION

A geometrical and kinematic model was conceived by Magnavita (1992) for the evolution of the Recôncavo-Tucano-Jatobá Rift, aiming to account for its structural features and to explain satisfactorily its tectonic complexity. The general framework was based mostly on contoured gravity maps. However, gravity data are un evenly distributed throughout the rift,

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with a much higher concentration of stations in its southern part. Interpretation is thus more reliable in south, with inference increasing northward. Furthermore, contour maps are two-dimensional level slices with fixed but arbitrary intervals. They do not express all the intensity-related and spatial attributes of the raw data and degrade subtle features that may be otherwise discernible (Drury & Walker, 1987).

The use of geophysical data in raster format has several advantages compared to the discrete fixed arbitrary intervals of the contour maps and permits the maximum benefit to be obtained from the data. Besides allowing the use of digital enhancement techniques, images show the data in a continuous range of values, more suitable for visual interpretation. When viewing a color image, the interpreter easily identifies color zones which may be assigned to different magnitudes of the measured geophysical parameter . Thus, the objective of this paper is to apply digital processing techniques to gravity data acquired in the northern portion of the RTJ Rift, in order to obtain new structural and tectonic information.

REGIONAL GEOLOGY AND STRUCTURE OF THE STUDY AREA

The study area covers approximately 18,000 km^2, bounded by latitudes 8°30' and 10°30'S and longitudes 37°45' and 39°15'W in Bahia and Pernambuco states (Fig. 1), northeastern Brazil,.

The Recôncavo, Tucano and Játobá basins constitute an intra-continental rift formed during the early stages of the South Atlantic opening in Early Cretaceous times and filled with non-marine sediments (Milani & Davison, 1988; Santos et al., 1990). The outline of the main outcrops of sedimentary sequences in the study area is shown in Figure 2. Continental Silurian/Devonian sedimentary rocks, constituted mainly by sandstones, siltstones, shales and conglomerates, occur at the northeastern border of the rift. Upper Jurassic to Lower Cretaceous pre-rift sediments occur on both margins of the rift and comprise continental red bed sequences made up mainly by sandstones, siltstones, shales and conglomerates. Rifting started in Valanginian times, associated with extensional fault systems. Sedimentary sequences of this phase are represented by lacustrine and deltaic shales and sandstones, as well as by fluvial sandstones associated with the end of rifting. These sequences are covered unconformably by post-rift Aptian fluvial and alluvial conglomerates and sandstones, as well as by restricted lacustrine shales and limestones. Quaternary alluvial deposits occur mainly along the valley of the São Francisco River.

Figure 1 - Location of the study area.

The RTJ Rift comprises a series of asymmetric half grabens, separated by basement highs and oblique transfer faults, with each half-graben having its own structural and stratigraphic charac-

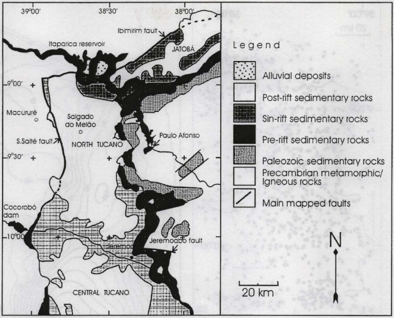

Figure 2 - Generalized geological map of the study area (modified from MME/DNPM, 1981; and Magnavita, 1992).

teristics (Magnavita, 1992). The NW-SE-trending Vaza-Barris Arch splits the Tucano Basin into Central and North Tucano Sub-basins. The Central Tucano Sub-basin presents an antithetic set of NE-SW extensional faults, and a general dip to SE. The North Tucano Sub-basin, which has as its western limit the São Saité Fault, shows inverse polarity in the regional subsidence as the half-graben dips to W. The Jatobá Basin marks an inflection in the direction of rift opening. This basin is elongated E-W and dips to the north toward the Ibimirim Fault.

DATA PROCESSING AND ENHANCEMENT

Gravity data were acquired by Petrobrás (1985a) in a number of gravity stations (Fig. 3a). These data were Bouguer-reduced and gridded in a cell size of 500 x 500 meters. Figure 3b shows a contour map of the Bouguer reduced data. A second grid was also generated by applying a first vertical derivative filter to the Bouguer data (Petrobrás, 1985b). While Bouguer processing shows data in a continuous range, the first vertical derivative is very useful to enhance linear features associated with fault systems.

Table 1 shows types, formats, capture procedures, and attributes of the geocoded digital dataset used in this work. All the products in grid or raster format, as well as the geological map of the area presented in Figure 2 (which was manually digitized), were inserted in an Image Processing/Geographical Information System developed by INPE (SITIM/SGI). The geocoded dataset permitted drawing spatial comparisons

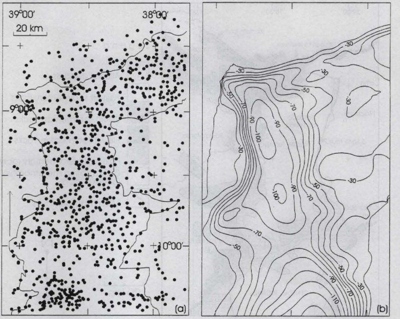

Figure 3 - Gravity stations in the study area (modified from Magnavita, 1992) (a), and contour map (in mGal) of the Bouguer reduced data (b).

Table 1 - Types, Formats, Data Capture, and Attributes of the Geocoded Digital Dataset

Data	Format	Data Capture	Attributes
Bouguer image	Raster	Bouguer grids	Gravity information
Residual-Bouguer image	Raster	Bouguer grids	Gravity information
Hybrid Bouguer image	Raster	Digital processing	Gravity information
Bouguer elevation model	Grid/Raster	3-D model generation	Gravity information
Geologic map	Polygonal	Digitazed map	Lithology; Structure

of the multisource information and to draw the interpreted features directly on the screen.

Digital processing applied to gravity data started with the conversion of the available grids into raster format. Data were scaled to 256 gray levels to match the number of output levels of the TV monitor. Four types of image data were generated representing Bouguer (Fig. 4a), residual-Bouguer (Fig. 4b), pseudo-color composites (Fig. 4c), and 3-D elevation models (Fig. 4d).

Pseudo-color composites were obtained by applying a color transform to the Bouguer image. This procedure yielded three different lookup tables (LUT) that gave red, green and blue renditions, as follows: the green LUT enhanced the mid range of the image, while setting to zero and to 255 the low and the high ranges, respectively; the blue LUT produced the reverse of the green one; the red LUT set to zero the

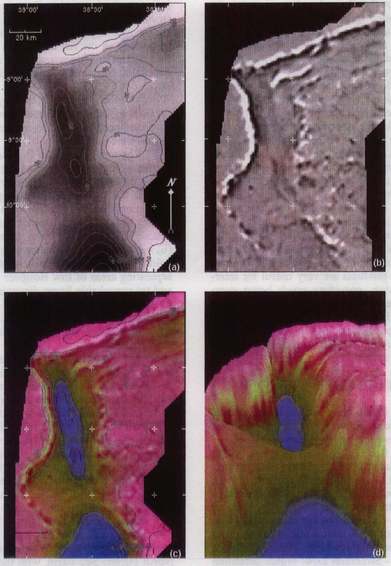

Figure 4 - Gravity data from the study area: Bouguer image (a); residual-Bouguer image (b); hybrid color composite (c); and a 3-D view from south to north, enhancing the "relief" of gravity data (d).

low and mid ranges and enhanced the high range. The combination of these three contrast stretched bands produced an artificially colored version of the Bouguer gray-level image. Different combinations of all images produced were analyzed. The best result was obtained by combining residual-Bouguer, Bouguer, and the blue band of the pseudo-color as red, green and blue, respectively (Fig. 4c). This enhanced hybrid color composite proved to be very helpful for structural interpretation, because human vision is able to distinguish hundreds of thousands of colors in a color-composed image, in contrast with only a few gray levels of a black-and-white image.

Different perspective views of the study area were obtained by merging the Bouguer image with the hybrid color composite. As they faithfully reproduce the "morphological" features of the data, these products are very useful for interpretation, providing much better comprehension. Figure 4d is a perspective view from south to north, with a vertical exaggeration of 300 times, enhancing the "relief" of the gravity data in the study area.

RESULTS AND DISCUSSIONS

Over the past years, several structural features have been identified as constituting the framework of the RTJ Rift (Milani & Davison, 1988; Magnavita, 1992; Yamakawa et al., 1994). According to Magnavita (1992), the building-block units in the study area are as follows:

- Faulted Border: characterized by a major fault with a heave of the order of several kilometers;

- Structural Low: highly subsiding area acting as a depocenter during the whole history of the rift;

- Ramp Platform: tectonically stable region, which may constitute a ramp in the upthrown block of two interfering faults;

- Accommodation structure: may be recognized as either Transfer Zones (truncating all other structures within the rift and responsible for the inversion of polarity in the rift tilting), or Along-Length Horsts (basement highs roughly parallel to the general half-graben infrastructure);

- Graben: unit bounded by faults on its long sides, which may preserve a complete section of a determined geological time interval.

The analysis of the Bouguer data shown in Figure 4 permitted the recognition of the following distinctive features in the study area: (a) strong negative anomalies associated with depocenter areas, which appear in blue shades in the hybrid color composite; (b) high Bouguer anomalies in greenish colors associated with structural highs separating areas of low Bouguer values; and (c) remarkable linear discontinuities in the residual-Bouguer image developed throughout the study area, which sometimes define the limits of the sedimentary basins.

The main low Bouguer anomaly occurs in the southern part of the area, in the Central Tucano Sub-basin, constituting the Cícero Dantas Low (Figs. 4 and 5). According to Milani & Davison (1988), this -130 mGal anomaly suggests a pile of more than 10,000 meters of sedimentary rocks in this region.

The Cicero Dantas Low is limited to the north by a zone of high Bouguer values, associated with the Vaza-Barris Arch, which splits the Tucano Basin into South Tucano and North Tucano Sub-basins. This structural feature causes an inversion in rift polarity in the North Tucano Sub-basin, with the depocenter moving westward. Two areas of low Bouguer anomalies of -100 mGal have been identified in this sub-basin, which were named the Salgado do Me-

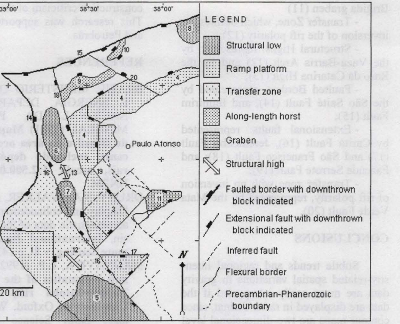

Figure 5 - Structural framework of the North Tucano-Jatobá basins based on the interpretation of gravity data. See text for explanation of numbered features.

lão Low and the Raso da Catarina Low. These two depocenters are separated by a high Bouguer area, which we propose in this paper to be named the Raso da Catarina High.

A moderately low Bouguer anomaly of -50 mGal occurs in the northeastern part of the area (Jatobá Basin). Positive features in the residual-Bouguer image of this area (Fig. 4b) are associated with structural horsts along the main axis of the basin.

Remarkable features depicted by residual-Bouguer data are linear discontinuities associated with fault systems. The Ibimirim Fault limits the Jatobá Basin to the north, and the São Saité Fault limits the North Tucano Sub-basin to the west. As a southeastward extension of the São Saité Fault, the Caritá Fault defines the eastern border of the Cícero Dantas Low, and the western limits of the Salgado do Melão and Raso da Catarina lows, thus delimiting the change in polarity of the rift. The São Francisco extensional fault limits the North Tucano and Jatobá Basins. The São Francisco and Mata Verde Faults truncate the western and eastern limits of the Icó Horst, in the Jatobá Basin.

The map of the main interpreted structural features in the study area is shown in Figure 5, which includes:

- Ramp Platforms: four ramp platforms were identified in the study area (1 to 4);
- Structural Lows: represented by the Cícero Dantas Low (5), Salgado do Melão Low (6), Raso da Catarina Low (7), and Ibimirim Low (8);
- Along-Length Horsts: represented by the Icó Horst (9) and Northern Icó Horst (10);
- Graben: represented by the Santa

Brígida graben (11)

- Transfer Zone, which defines the inversion of the rift polarity (12);

- Structural Highs: represented by the Vaza-Barris Arch (12) and by the Raso da Catarina High (13);

- Faulted Borders, represented by the São Saité Fault (14), and Ibimirim Fault (15);

- Extensional faults: represented by Caritá Fault (16), Jeremoabo Fault (17) and São Francisco Fault (18); and Fazenda Serrote Fault (19);

- Transfer zone with no inversion of rift polarity, represented by the Mata Verde Fault (20),

CONCLUSIONS

Subtle trends and regional intensity-related spatial variations in gravity data are more easily interpreted if the data are displayed in raster format, since contour maps are two-dimensional level slices with fixed arbitrary intervals, which do not express faithfully the spatial attributes of the data. Besides allowing the use of digital enhancement techniques, image data show a continuous range of values, becoming more suitable for visual interpretation. The use of such a procedure for enhancing gravity data proved to be very useful in regional structural mapping of sedimentary basins and surrounding basement. The integrated analysis of the dataset permitted the recognition of subtle trends and intensity-related spatial variations in gravity data, tentatively related to the following tectonic units of the RTJ Rift: ramp platforms, structural lows and highs, along-length horsts, grabens, faulted borders and extensional faults.

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