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.

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.

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 unevenly distributed throughout the rift,
with a much higher concentration of
stations in its southern part. Interpreta-
tion is thus more reliable in south, with
inference increasing northward. Fur-
thermore, contour maps are two-dimen-
sional level slices with fixed but arbi-
trary intervals. They do not express all
the intensity-related and spatial attrib-
utes of the raw data and degrade subtle
features that may be otherwise discerni-
ble (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 per-
mits the maximum benefit to be ob-
tained from the data. Besides allowing
the use of digital enhancement tech-
niques, images show the data in a con-
tinuous range of values, more suitable
for visual interpretation. When viewing
a color image, the interpreter easily
identifies color zones which may be as-
signed 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 approxi-
mately 18,000 km², bounded by lati-
tudes 8°30' and 10°30'S and longitudes
37°45' and 39°15'W in Bahia and Per-
nambuco states (Fig. 1), northeastern
Brazil.

The Recôncavo, Tucano and Jâ-
tobá basins constitute an intra-conti-
ental rift formed during the early
stages of the South Atlantic opening in
Early Cretaceous times and filled with
non-marine sediments (Milani & Davi-
son, 1988; Santos et al., 1990). The
outline of the main outcrops of sedi-
mentary sequences in the study area is
shown in Figure 2. Continental Silu-
rian/Devonian sedimentary rocks, con-
stituted mainly by sandstones, silt-
stones, shales and conglomerates, occur
at the northeastern border of the rift.
Upper Jurassic to Lower Cretaceous
pre-rift sediments occur on both mar-
gins of the rift and comprise continental
red bed sequences made up mainly by
sandstones, siltstones, shales and con-
glomerates. Rifting started in Valan-
ginian times, associated with exten-
sional fault systems. Sedimentary se-
quences of this phase are represented by
lacustrine and deltaic shales and sand-
stones, 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.

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

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...
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 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

<table>
<thead>
<tr>
<th>Data</th>
<th>Format</th>
<th>Data Capture</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouguer image</td>
<td>Raster</td>
<td>Bouguer grids</td>
<td>Gravity information</td>
</tr>
<tr>
<td>Residual-Bouguer image</td>
<td>Raster</td>
<td>Bouguer grids</td>
<td>Gravity information</td>
</tr>
<tr>
<td>Hybrid Bouguer image</td>
<td>Raster</td>
<td>Digital processing</td>
<td>Gravity information</td>
</tr>
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<td>Bouguer elevation model</td>
<td>Grid/Raster</td>
<td>3-D model generation</td>
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<td>Geologic map</td>
<td>Polygonal</td>
<td>Digitized map</td>
<td>Lithology; Structure</td>
</tr>
</tbody>
</table>
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 Cicero 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-
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 Carita 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
Brigida 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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