Gravitational tectonics evidences at RGS (Brazil) Coastal Plain using Ground Penetrating Radar

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***Abstract*—This paper presents and discusses the gravitational tectonic influence on the geological evolution of the Coastal Plain of Rio Grande do Sul State (Brazil). The gravitational tectonic was identified from a series of normal faults recorded in GPR surveys, aerial photographs, high resolution imageries, and in re-interpreted geological sections based on drill-holes. The RGS Coastal Plain is the immersed part of the Pelotas Basin, which was developed from Barremian/Aptian on, after Gondwana rupture. The actual geomorphic and stratigraphic configuration of the RGS Coastal Plain is due to a deltaic alluvial plains and four lagoons/barrier systems developed as consequence of sea level changes from Middle Pleistocene to Holocene. Two long topographic scarps, arcuate in map view, coincide with normal faults identified in GPR surveys. GPR survey sections revealed that a holocenic peat layer equivalent radar-facie underwent normal fault displacement (synthetic and antithetic geometry) and arcuate close to faults (drag folds). The Lagoa do Peixe Fault is oriented N35E, while the Rio Grande Fault is regionally arcuate from N30E (southern segment) to N60E (northern segment). These both huge faults intercept each other in the Bujuru District area. Regionally, the peat layer radar-facie dips toward the continent. The peat layer dipping and fault geometry indicate gliding rotational process associated with faults. The fault gliding process developed associated depression (lagoons) and elevated fault block segment near the shoreline (structural barrier). The elevated bulkhead and structural barrier controlled the erosion and sedimentation in the area under influence of these gravitational structures, which corresponds to previously defined Lagoon-Barrier system IV (5.6 ka).**

Keywords*—*Gravitational tectonics, normal faulting, GPR survey, Southern Brazil coastal plain

I. INTRODUCTION

The Rio Grande do Sul (RGS) Coastal Plain is the immersed part of the Pelotas Basin, which was developed from Barremian/Aptian on, after Gondwana rupture. The RGS coastal plain is 20 to 80 km wide, and more than 600 km long. The actual geomorphic and stratigraphic configuration of the RGS Coastal Plain is due to a deltaic alluvial plains and four lagoons/barrier systems developed as consequence of sea level changes from Middle Pleistocene to Holocene [1,2]. The first lagoon/barrier system (I) was formed during 400 ka transgressive/regressive period, and the following ones were related to 325 ka (II), 121,5 ka (III), and 5,6 ka (IV) MIS, respectively (Fig. 1).

In the Bujuru District area (north of the São José do Norte city, RGS, Brazil), Holocene sands (3.5 ka), peat (1,4 ka) and heavy mineral rich sands (< 1.0 ka) crop out at beach and backshore face [3], and the peat layer demonstrated to be an excellent key radar-facie in order to follow stratigraphic units and structural features onshore.

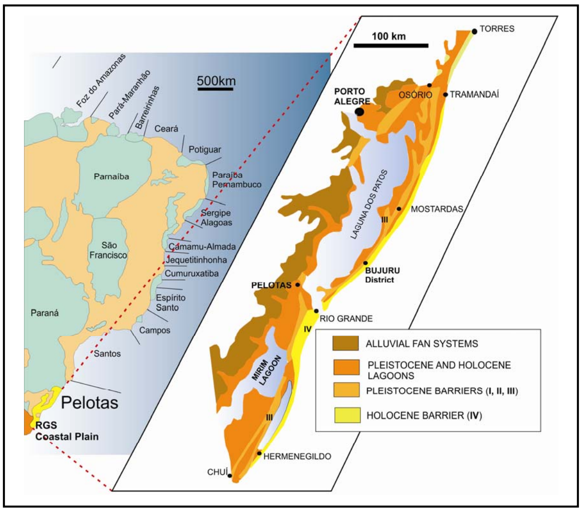

Fig. 1. Regional location and sketch geological map for Pelotas Basin and RGS Coastal Plain (Brazil).

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Aerial photographs, high-resolution images and drill-hole sections show evidences for significant normal fault displacement affecting Upper Pleistocene (III) and Holocene (IV) barriers, according these authors observations. Some neotectonic geomorphic features where previously reported in the northern segment of the RGS Coastal Plain [4]. However, no specific study or surveys were still carried out to determine the structural geometry and nature of Holocene faulting process.

This paper presents and discusses the results of geomorphic and GPR survey specially designed to evaluate structural features observed by these authors. In order to show such structural features, some long GPR surveys line were acquired perpendicular to shoreline and parallel to drill-hole sections.

II. Geomorphic Evidences for Large Faulting in the RGS Coastal Plain

Besides aerial photographs, high-resolution DEM images provides one of the best evidence for large faulting in the RGS Coastal Plain. Fig. 2 shows a SHUTTLE DEM image for the RGS Coastal Plain near the southern Atlantic Ocean.

The DEM image shows linear topographic scarps located in between Upper Pleistocene (III) and Holocene (IV) barriers. North of Bujuru District, the topographic scarp controls the western margin of the Lagoa do Peixe lagoon. To the south, two topographic scarps (Retiro-Estreito and Quinta) correspond to partially filled lagoons.

The topographic difference between each side of the scarps reaches more than 10 m, mainly in the Lagoa do Peixe lagoon, since this one is not highly filled by Holocene sediments.

The evidences for a fault scarp come from drill-holes sections. Previous models interpreted that Upper Pleistocene (III) Barrier controls the deposition of the Holocene sediments making part of the IV Lagoon-Barrier system [3]. The key sediments is made up by Holocene sands (3.5 ka), peat (1,4 ka) and heavy mineral rich sands (< 1.0 ka). However, drill-hole section correlations showed that peat and sands layers are present in both sides of the scarps. Additionally, peat layer, as a key stratigraphic unit, shows to be located at different elevations, which can be adequately explained by faults.

III. GPR Surveys

The GPR survey lines were acquired perpendicular to shoreline and parallel to drill-hole sections in the Bujuru District area (São José do Norte, RS, Brazil). This area was choose mainly because Retiro-Estreito and Lagoa do Peixe scarps intercept each other.

The GPR surveys were carried out in two 3-5 km long sections (Fig. 2), 50 (RTA) and 100 (shielded) MHz antennas. Pro-EX GPR System (MALA-RAMAC) performed survey lines acquisition, and Reflex-W was used for data processing. The GPR surveys were acquired in high lateral resolution (20 cm shot spacing) and were adjusted to investigate down to 20 and 10 m, respectively.

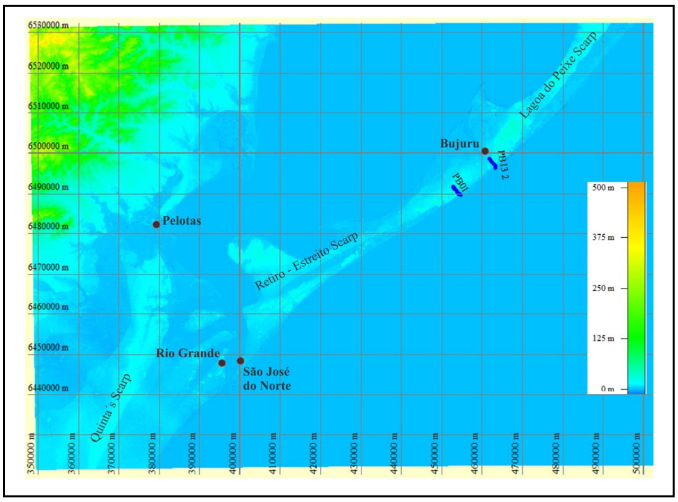

Fig. 2. Digital elevation model (SHUTTLE) for the central segment of the RGS Coastal Plain (Brazil). Note the elevation differences defining the scarps. (22J UTM coordinates, SIRGAS geodetic system).

Data processing include the following steps: i) moving start time; ii) dewow filter; iii) bandpass filter (trapezoidal or butterworth); iv) migration (v = 0,3 m/ns) for removing surface reflections in unshielded antenna; v) topographic correction; vi) 3D topographic migration (v = 0,09 m/ns, mean velocity according depth to peat layer top in drill-holes); vii) butterworth filtering.

IV. GPR Results: Faulting Deformation

Fig. 3 shows radargram segments for PB-013 and PB-01 GPR survey line.

These both radargrams show peat layer dipping toward the continent (Fig. 3a,c), and displaced by high angle normal faults. The movement in each fault block is also accommodated by drag folding on soft sedimentary layers.

It is noteworthy that high angle normal faults dip land and ocean ward, and sometimes are distinguished to give rise to horst and graben structures. The greatest normal displacement is seen on PB-013-001 survey section (Fig. 3b) an amount 6-7 m, in a normal fault dipping ocean ward.

It can also be notice that upper sedimentary layers are not displaced by normal faults. In fact, the stratigraphic reflectors for the upper sedimentary layers fill the fault depressions created by normal movements (local scale grabens, Fig. 3d). Fig. 3b also show that peat layer was eroded in the upper footwall fault block.

V. Discussion: Gravitational Tectonics

The geometry of the structures distinguished in the Bujuru District area (São José do Norte, Brazil) enables to consider some conditions for deformational process. First, the key stratigraphic layers dipping toward the continent and being displaced by high angle normal faults dipping toward the ocean indicate that gliding process took place during deformation.

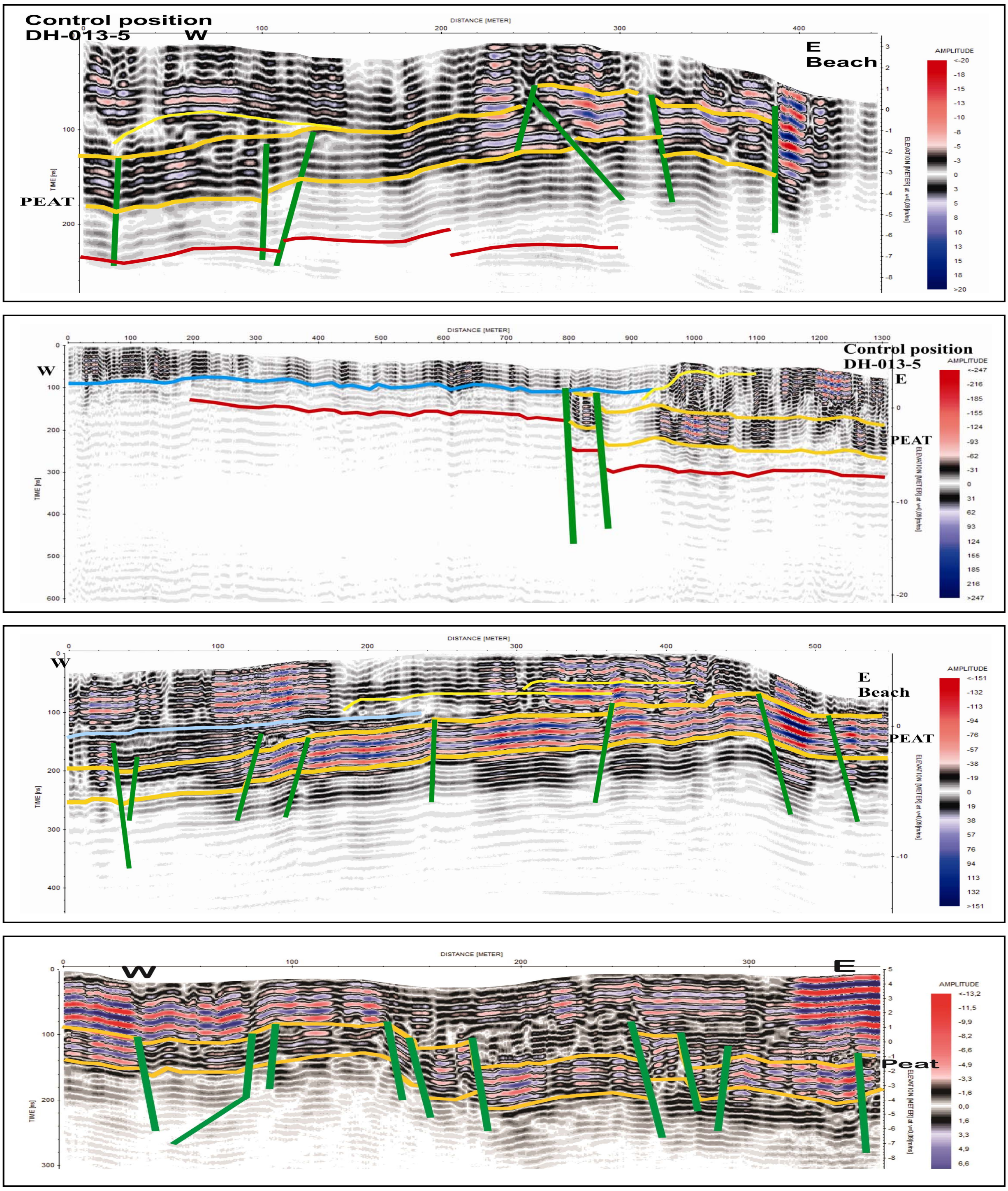

Fig. 3. Segments of radargram for 50 MHz GPR surveys in the Bujuru Disctrict area (RGS Coastal Plain, São José do Norte, Brazil). A) Eastern segment of the PB-013 drill-hole section (upper image). B) Westward continuation of the previous radargram segment (upper central image). C) Eastern segment of the PB-01 drill-hole section (lower central image). D) Westward segment of the PB-01drill-hole section (lower image).

Second, the different dipping directions for the high angle normal faults indicates that synthetic and antithetic were developed during deformation process. The synthetic ones show the greatest displacements and dip toward the ocean, while the antithetic ones show minor vertical displacement and dip toward the continent.

The high angle normal faults distinguished in the Bujuru District area enable to interpret the previously characterized topographic scarps as fault scarps. The Lagoa do Peixe topographic scarp follows and intercept the PB-013 GPR survey section exactly at position of the greatest vertical fault displacement in Fig. 3b. The Retiro-Estreito topographic scarp also intercept PB-01 GPR survey section at its most deformed interval.

The regional geomorphic characteristic of these fault scarps in the RGS Coastal Plain is also important. From fig. 2, it can be realized that Quintas (N30-35E) and Retiro-Estreito (N60E) fault scarps are the segments of the same fault, which arcs in the Rio Grande and São José do Norte area. This fault is named Rio Grande Fault. The Lagoa do Peixe fault scarp, on the other hand, do not show a well developed arcuate map view. The Bujuru District area is located at the tip zone of both intersecting faults. The Lagoa do Peixe Fault is oriented N35E, while Rio Grande Fault is oriented N60E in the Bujuru District area.

These local and regional structural features permit to interpret the deformational process as consequence of gravitational tectonics in the Pelotas Basin. It is interesting that such deformational process is Holocene, according geochronological data [3].

Fig. 4 shows a structural model, which encompasses the deformational structures distinguished and discussed in this paper. The rotational character of gravitational normal faults develops depressed and elevated fault block segments. These structural positions control the Holocene lagoon and barrier system. The elevated fault block segment is the main source for sediments filling the depressions (lagoons), and given rise to heavy mineral deposits in the Bujuru District area [6].

The Rio Grande master normal fault is the longest identified fault, and shows an arcuate map view. It is located in the continent and matches with Rio Grande cone of the Pelotas Basin. Recently, [5] distinguished clay diapirs and normal faults in upper Holocene units in seismic sections at the edge of the Pelotas Basin continental platform (Rio Grande cone area). These deformational structures are compatible with a gravitational tectonic process taking place in Holocene: i) the Rio Grande and Lagoa do Peixe normal faults are the upper, extensional segment of the gravitational structure, while ii) clay diapirs formed in the compressional tip of the structure, close to the continental slope.

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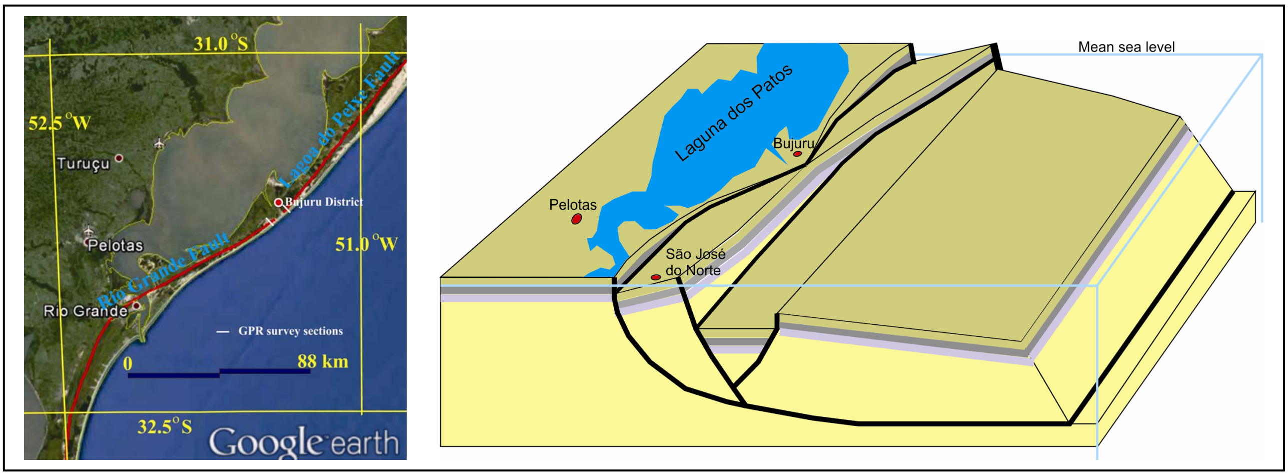

Fig. 4. Regional sketch for the Rio Grande and Lagoa do Peixe faults, RGS Coastal Plain (Brazil). A) Satellite Image and location of faults (left). B) 3D Structural model for normal faults and their control on Lagoon Barrier system IV.