The Pantanal Basin: Recent Tectonics, Relationships to the Transbrasiliano Lineament

PAULO CÉSAR SOARES[1]
MARIO LUÍS ASSINE[1]
LUCIANO RABELO[1]

[1]UFPR--Universidade Federal do Paraná
Departamento de Geologia Caixa Postal 19011
81531-990, Curitiba, Brazil
e-mail soares@setuva.geologia.ufpr.br

Resumo. Este trabalho trata o neotectonismo na Bacia do Pantanal e suas relações com a construção dos lobos aluvionares, usando ferramentas de sensoriamento remoto. No oeste brasileiro, movimentos tectônicos associados ao soerguimento andino e o lineamento Transbrasiliano intracontinental, controlam a deposição dos lobos aluvionares nesta bacia Cenozóica. Sendo uma das maiores bacias intracratônicas do mundo, com extensa deposição aluvial em clima semi-úmido.

Keywords: Remote Sensing, Quaternary Geology, Neotectonic

1 Introduction

The Pantanal Basin it is developed over the medium altitudes lands that run parallel and outside to the Andean foreland basins (figure 1). In this way from the geotectonics viewpoint it seams to be a Cenozoic sedimentary basin associated with the Andean forebulge as it was proposed first by Almeida (1945) and simulated in a mechanical model by Shiraraiwa (1994). In conjunction with the forebulge context there are a continent-wide structural zone that was called Transbrasiliano Lineament (TBL), firstly identified by Shobbenhouse et al. (1984). Both elements have special role in the present day development of the basin. It is a low lying region, around 150m above sea level, extending 200kmx300km, located at eastern margin of the middle to high Paraguay river basin; The Pantanal is well known by his spectacular fauna in the lacustrine and fluvial environments around the basin ranges and escarpment as result of regressive erosion of the recent uplifting shield and margin of Paraná Paleozoic basin form the relief with altitudes up to 600m. Both highlands and alluvial plains are being extensively occupied by extensive agriculture and cattle breeding. The basin has a pile up to 600m thick of Cenozoic sandy sediments. The study has used multi source data, although scarce, including topography, gravimetric, well log, Landsat (TM) images, geological, geomorphological field work; the data were processed in digital form, analyzed, interpreted and modeled in order to identify some characteristics of present day tectonics and sedimentation dynamics. The topography is well represented by a 2nd degree convex trend surface (Soares et al., 1996). The

FIG.1

field, wells and gravimetric data indicate a flexural and faulted geometry of basement. Field and Landsat analysis and interpretation brought the indications of neotectonics and dynamics of sedimentation. Neotectonic elements are interpreted from rectilinear trace of alluvial and pediment terrace boundaries and lineaments over the basin area. The main morphologic elements analyzed in processed images were small arcuated and sigmoidal linears defined by changes in reflectance, linear and areal combinations of this forms, and zones of different morphology or reflectance limited by lineaments, contour lines or transitions. Almost all the area of Pantanal basin is covered by the giant Taquari alluvial fan system, covering 32,000km^{2}, with a nearly circular to hexagonal form of 200 km diameter. The alluvial fan is being constructed at the front of the escarpment of São Jerônimo-São Lourenço, with his source are made by Paleozoic and Mesozoic sedimentary rocks. In the alluvial fan plain there are mapped several lobes of distributaries, each one constructed in different phases of Quaternary.

The Taquari Alluvial Fan (Soares et al. 1978) is the largest fan of the region, with a geometry nearly circular and 180 km of diameter. The fan is being constructed over the subsiding basin of similar size, the Pantanal Basin. Many questions arrive about the Taquari fan: their geometry, their large dimensions in absence of high topography, their very low gradient, their polilobate character, the thickness of sediment pile, the present day semi-humid climate, the sandy sedimentation, the distributary flooding dynamics, the large depositional and erosional forms and the recent tectonics. The work done was drove to give a least a preliminary answer the question about the tectonic relationship between morpho-structural and fan evolution.

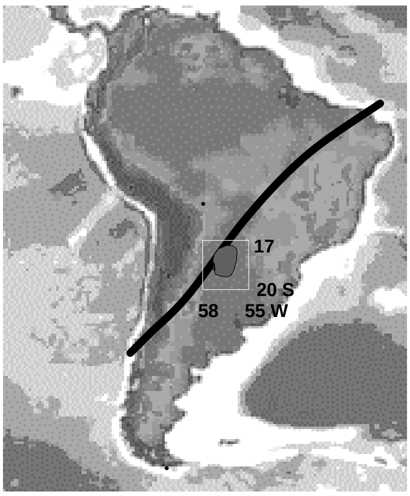

Figure 1 . Location of Pantanal Basin related to the main phisiografic features of South America. Thick line shows the position of Transbrasiliano Lineament (TBL). Thin line indicates the retroarc main overtrust zone.

The present day Taquari Novo lobe is made of a distributary drainage and many crevasse splays that are controlled by tectonic elements, specially the Transbrasiliano Lineament. At the external zone there are peripheral collecting drainage, with the main rivers meandering over alluvial plains, controlled by fracture zones, whose directions are NW, at northeast side and NE at the northwest side NNE, at the west side. The eastern range is a present fault line escarpment retracted about 4 km. Between this escarpment and the fan there are a fringe of small pediments, along the eastern fault escarpment. The relationships between recent tectonics and sedimentation are very important to understand the evolution of Pantanal basin. Structures coordinate lobes and their sediments, and besides rupture changes occur. Neotectonic element controls lobe development and represent potential sites for catastrophic change in water flow.

2 Data Collection and Processing

The main sources of data are Landsat MSS and TM images, for the complete cover of Taquari fan and its extensions to Chaco. Geological maps, specially stratigraphic and structural ones were analyzed in order to identify depositional and erosional patterns, possibly associated to the TBL. Geologic maps of Paraguay and north Argentina were investigated in order to follow the Transbrasiliano Lineament toward the Andean region. The scenes of 1973 and 1993, for the flooding and dry seasons were compared. The images either in copies, transparency and tape were supplied by INPE (Instituto de Pesquisas Espaciais, Brazil). The composition of a complete image of the Pantanal Basin was realized. Topographic maps used are from IBGE (Instituto Brasileiro de Geografia e Estatística). Geomorphological and geological maps are from Projeto Radam (MME, Brazil) as showed in figure 2. Gravimetric and earthquake data and were used from Geophysical Data Bank of USGS (USA), in order to relate morpho-structures to deep and recent movements.

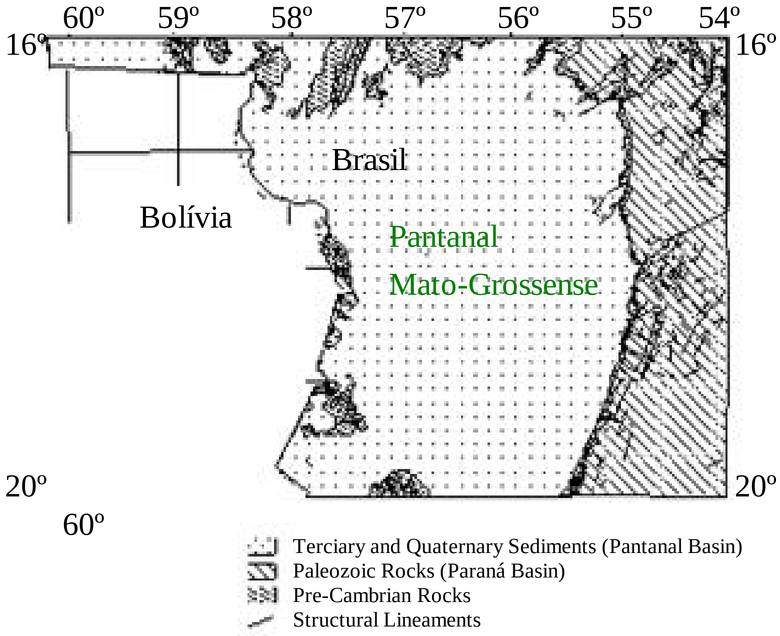

Figure 2. Simplified geologic map of Pantanal and Borders adapted from Radam (1982).

Fieldwork was developed only in the dry season, in order to know and describe characteristics of the morphological features, type of sediments and fracture data collecting. The work was realized in the eastern and southeastern margins. Altitude data from may sources were collected and processed composing a present day general topographic surface. Thickness data of deposits obtained from Petrobrás wells for petroleum exploration and from others companies for water exploitation were reprocessed, trying to access the basin geometry and structural framework.

3 Main Results

Basin Morphology

The analytical image (figure 3a) composed of geomorphic features were extracted from Landsat images of the dry season (October, 1993, fig. 4) and the drainage network (figure 3b) was taken from IBGE maps. The maps show the main geographic characteristics of the fan. Its plant geometry is grossly circular slightly elongate in the NNE-SSW direction.

FIG. 3
FIG. 4

At the eastern side there are the highlands, the escarpment and the pediplane; at the north and at the south sides the collecting drainage; at the west the front of present day distributaries.

The boundary of this province is marked by an abrupt escarpment, striking N20E, about 300m high, in the form of *cuesta* sculptured in Ordovician and Devonian sandstones. Local names include Serra de São Jerônimo-São Lourenço. A high density of drainage in the form of obsequent gullies erodes actively the fault line scarp.

At the foot of the escarpment, it is present a 4 to 15 km wide and 200 km long fringe of pre-recent pediments, seeming a pediplane. The unlevelling o pediments reach 50 m, from 210m at the foot of escarpment to 160m at the base of pediment, with a gradient of 3 to 5 m/km. In some places, the base of pediments is terraced with a straight front striking N20E, with 2 meters high then the alluvial fan upper plain. This boundary between terraced pediplane and alluvial fan plain is marked by badly defined wide channels called *corixos* (e.g. Corixo de Itiquira), were the stream may flow in either sense. Many gullies are eroding this pediplane, exposing them in the form of terraces, one to two meters above the local base level. Sandy conglomerate and coarse sands are the sediments as correlative deposit of the pediments. The pediplane west boundary is considered to be result of an active fault (N20E), and all the pediplane surface is result of erosional backward of escarpment fault.

The main morphostructural lineaments were draw in images and represented in the maps. The eastern escarpment is the most evident, but the NE fault line is about tem kilometers to west. The NW morphostructure is very clear over the northeast lobe of the alluvial fan, in the basin and follows the strong NW fracture zone in Coxin area, in Parana Basin.

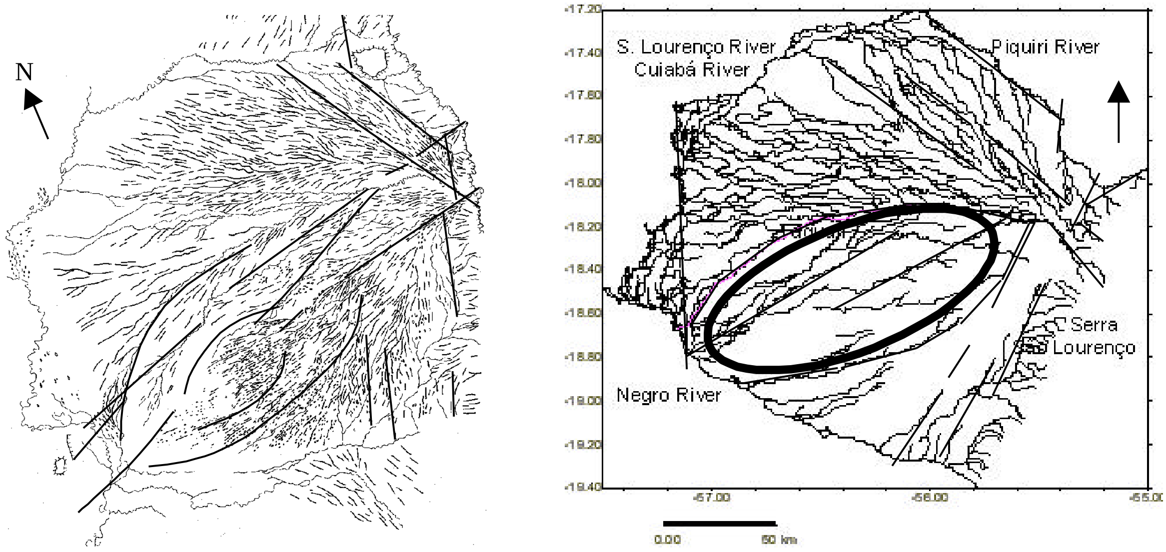

Figure 3. a - Analytical image composed of geomorphic features extracted from Landsat images of the dry season (October, 1993.)
B - Drainage network was taken from IBGE maps.

At the external zone the peripheral drainage is controlled by fracture zones, whose directions are NW; at northeast side, Piquiri River, and NE at the northwest side, Cuiabá river, NNE, at the west side, Paraguay river.

In the south zone of the alluvial fan there are a large elliptical NE oriented morphostructure bounded by Taquari Novo and Vazante rivers. At their axial zone strong lineaments of vazantes (tributary draining channels) are aligned at NE directions ant constitute the main manifestation of the TBL known more at northeast. Toward southwest. Toward northwest the lineament control segments of Paraguay river and aligned elevations in the Chaco plain.

In the west, the Paraguay River presents a large flooding plain that receives the water and the sediments of the distributary channels of the active lobe, composing a disorganized drainage.

The Taquari River running toward west is superimposed over the east dipping structure of Paraná Basin. It crosses the reverse side of the cuesta caving a wide canyon. At the beginning of the canyon, near Coxin city, the river is rectilinear and present high-energy flow grading to meandering channel in a narrow flooding plain, with marginal dikes. This plain about 1 km wide is 1 to 3 meters bellow the level of the alluvial fan and extends about 100 km down river, where it begins the construction of their present lobe, the Taquari Novo lobe.

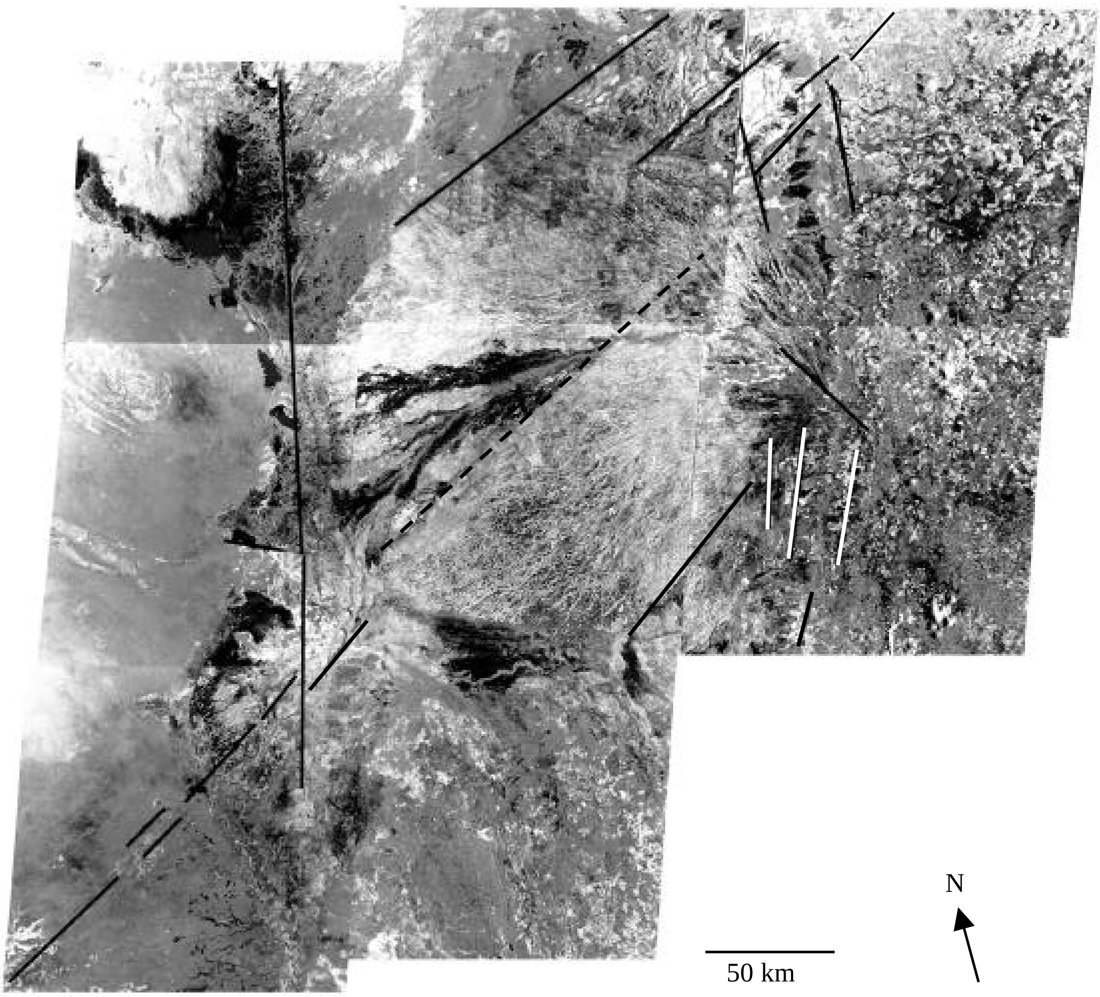

Figure 4. Image composed from Landsat (original R3B4G7) of the dry season (October, 1993) with main lineaments around the basin.

Structural Aspects

The recent structures associated with the Pantanal Basin was accessed by means of morphostructural analysis in images and drainage maps, field observations, contour of topographic data and structural contour of basement of Cenozoic sediments.

The morphostructural analysis reveals the following main elements:

- the strong structuration of the east escarpment, striking N20E (figure 3); FIG. 3
- the strong alignment of the base of pediments formed at the foot of the escarpment, and development of rectilinear disorganized drainage elements (Itquira River);
- Strong features alignment in image (figure 5) in the central part of the Basin, striking N45E; FIG. 5

•The strong elliptical morphostructural anomaly showed by the main channel of Taquari Novo lobe and Vazante river (figure 3). FIG. 3

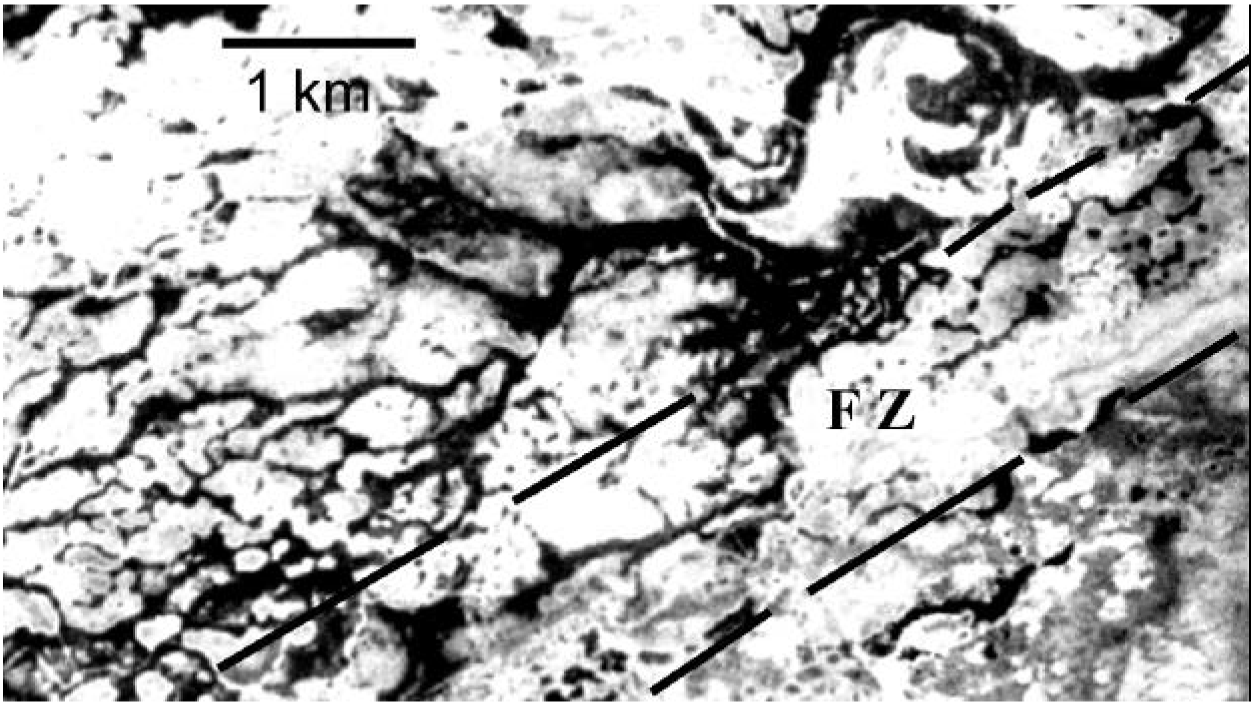

Figure 5. Geomorphic features represented by anomalous straight paleochannels, over the interpreted fault zone at 55° 15`W, 18° 40`S (Landsat TM R3B4G7 – stretching and edge contrast).

Field observations brought two main elements to the reasoning. The first is done by the flexure of relief shown by the remnants of Tertiary Planation surface; this is the top surface in the region and its remnants in the east highlands are dip slightly toward east, while the remnants at the west side of the escarpment are dipping toward west; this west dip indicates a flexure associated to fault movements with the down side at the west.

The second are the surprising feature, found in Morrinho Farm (coordinates 50,27^{o}W by 18,55^{o}S): the presence of an inselberg of Botucatu sandstone in the interior of the alluvial fan. An erosional pediment that ends in a sand sheet involves it. The difference in altitude from the terrace to the top of the hill is about 30m; the exposed rocks are silicified and strongly brecciated, homogeneous fine to medium sandstone. By the lithologic characteristics (selection, homogeneity, cross stratification, red color is attributed to Botucatu Formation. Many joints are vertical and oriented to N30W, with no cinematic indicators.

The contour of topographic data (figure 6) shows some irregularities not expected if depositional processes whole controlled the surface. The main anomaly shown by abrupt deflection in contour FIG. 6

indicates an fault with NE-SW direction and low side at NW. This match with the Morrinho inselberg and fault breccia and agrees with the direction of the fault line escarpment.

The contour of the basement using data of petroleum and water exploration wells is presented in figure 6. The scarcity of data and their inhomogeneous distribution in the area presents a major problem to access the basement geometry. The contour shows a axial zone at the west, with a N20E direction, that is the same of the eastern margin fault. A circular depocenter was draw in the mid fan area, with deepness down to 250m. Summing with the topography data it means a maximum thickness of sediments with about 400 m. The higher gradient and abrupt deflection of curves that usually reflect active fault are not easily visible. The traces obtained by morphostructural analysis of faults match with the depocenter and with deflection of curves.

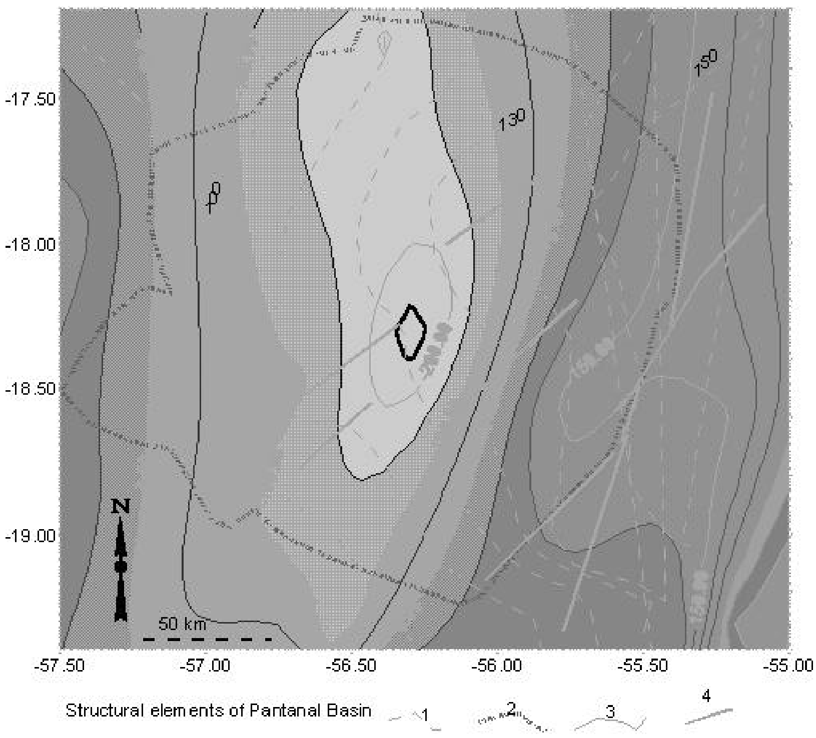

Figure 6. Contour of subsurface data of the basement in the interior of Pantanal Basin, in the area of the Taquari Alluvial Fan compared with the fan boundary and trace of faults obtained in morphostructural analysis. (Geographic coordinates, from Soares et al., 1996). 1- topographic contour;, 2- Taquari alluvial fan boundary; 3- structural contour; 4- morphostructural lineaments.

4 Discussions and Conclusions

The giant Taquari alluvial fan system cover almost all the area of Pantanal basin about 32,000km^{2,} with a nearly circular form of 180 km diameter. The unexpected good selection of sandy sediments of the fan may be explained by the recycling of Ordovician to cretaceous sandstones of Paraná basin. The extension of source area of the Taquari River is similar to the depositional area of the fan, and the volume of sediments with a maximum thickness of 300m is similar to the erosional volume from the Pliocene peldiplanation surface (600m) to the present day base level (250m).

The constructional dynamic of the alluvial fan plain is clearly made by successive lobes of distributaries, each one constructed in different phases of Quaternary. The presence of fossil distributary drainage in the upper plain of early lobes shows that the lobe was constructed by the forward advancement of the main river discharge zone, until the extension of the river generates a so low gradient, with insufficient energy to transport the sedimentary load. At this moment the load is left in the main and in the distributary channels creating barriers to the water flow. So the water does find another position with higher gradient and begins the construction of new lobe. Thus, the lobe abandonment are the result of abrupt change of position and not by drift. The recent Taquari Novo lobe is being constructed along the north side of Transbrasiliano Lineament. At the position that Taquari river main channel crosses the lineament zone, it begins distributary lobe construction. Upstream of the lineament of the river is meandering along his alluvial plain.

The present Taquari Novo lobe is being constructed by a distributary drainage and many crevasse splays that promote the dispersal of water and sediments from a main channel over a low flood plain, this changing pattern is over the lineament. It is a distant construction relatively to the fan head, with a consequent very low gradient for the river; this imposes a meandering regime for the upper course of Taquari Novo River in a narrow flood plain caved on early lobes upstream of the lineament. An increasing influx of sediments in lasts years, with a strong process of bedforms and bars construction and channel obstructions. It may be associated with the unlevelling of the recent base level relatively to the fan surface of about 3 meters and may signify a lowering of the profile in the erosional course of the river, upstream the fan area or a uplifting of fan surface at SE of Transbrasiliano Lineament.

The present fault line escarpment is retracted about 4 km and this regressive erosion is associated with the formation of a fringe of small pediments.

Over the highlands there are remnants of two paleosurfaces: Sul-Americana Planation surface in the Serra das Araras and Chapada dos Guimarães with altitude around 650m to 800m; high watershed pediplanation surface lying over São Jerônimo highlands, with altitudes around 500 to 600m (Soares et al., 1976). These areas of Paleozoic, Mesozoic rocks and Cenozoic unconsolidated sandy surficial formations are the main sources of sediments deposited in Pantanal, transported by rivers of the left margin of Paraguay River.

The structural result points to an NS elongated fracture associated basin. The shoulders in both east and western (Serra do Amolar) margin of the basin indicates that the basin was developed over a bulge as modeled by Shirawa (1994). In the eastern shoulder (Serra de São Jerônimo) the Ordovician Rio Ivai and later formations of Paraná Basin dips toward east; the Jurassic Botucatu sandstone, with an stratigraphic separation of about 500m over the Ordovician Rio Ivai outcrops about 20km east in the Serra das Araras at a altitude of 600m.

The presence of Botucatu inselberg inside the alluvial plain is an evidence of a subsiding block of about one thousand meters, before the erosive leveling in the highlands of Serra de São Jeronimo at the stratigraphic level of Paleozoic beds. This pediplanation surface was developed in Pliocene, after the South American Miocene planation that has remnants at Serra das Araras an Campo Grande (Soares et al. 1976). This reasoning conduce to the conclusion that the faulting generating Pantanal basin, putting Botucatu beds side by side with Rio Ivai beds and Precambrian basement, is of late Miocene age, at a time of high erosional relief buried by Pantanal sediments. This is in agreement with Shiraywa (op. cit) reasoning of a maximum forebulge uplift of Pantanal region at a time between 10 and 2.5 Ma based on Andean shortening.

East of Corumbá, the Paraguay river form a kink and recover it's flow to southwest over a plain constructed along the Transbrasiliano Lineament; the present day northeast channel has been drift from an early north-south paleochannel. The Transbrasiliano Lineament along about 50 km imposed the new direction. The Transbrasiliano Lineament lose it control over Paraguay river and impose an elevated morphological feature in Chaco region, well observed in the images (figure 4). These morphostructure control the north boundary of the Pilcomayo alluvial fan and is over a fault zone that controls the abrupt thickness change in Tertiary and Quaternary deposits of Chaco basin (Wiens, 1997). FIG. 4

The dynamics of Taquari Alluvial Fan is characterized successive lobe construction and abandonment, and not by continuous drifting of the constructional lobe. As the subsidence proceeds the sediments are being piled and the lobe grows forward by channel fill, flood silting and crevasse splay processes. The advance of the lobe causes a gradient reduction in the main channel behind the lobe and the construction of the meandering plain. The river looses energy and sediments. The water infiltrates in high rates, reducing the river section. These processes promote the stacking of sediments and both the main channel and the lobe become topographically higher than the neighborhood. The differential subsidence between both sides of Transbrasiliano Lineament makes space to receive the sediment, creating an unstable equilibrium to the dispersal of water and their sedimentary load.

The Pantanal basin has been developed after the South American planation and after the successive regional pediplane that are preserved over the Serra de São Jeronimo. This pediplanation surface was developed in Pliocene (Soares et al. 1996).

The structural result points to an elongated fracture associated basin. The shoulders in both east and western (Serra do Amolar) margin of the basin indicates that the basin was developed over a bulge as modeled by Shiraiwa (1994).

The reasoning presented conduce to the conclusion that the faulting generating Pantanal basin, putting Botucatu beds side by side with Rio Ivai beds and Precambrian basement, is of late Miocene age, at a time of high erosional relief buried by Pantanal sediments. This is in agreement with Shiraywa (op. cit.) reasoning of a maximum forebulge uplift of Pantanal region at a time between 10 and 2.5 Ma based on Andean shortening.

The result shows that at present time Transbrasiliano Lineament is influencing strongly the dynamics of erosion, sedimentation, fan lobe establishment and channel flow location in the Pantanal and Chaco basins. It works like a transcontinental lineament linked to the South America plate borders.

5 Acknowledgments

This research has been supported by PADCT funds (ct. 065.91.0303), project "Geological Evolution: processes and products..." , and by European Union funds, project "Geo-environmental Dynamics of Pantanal-Chaco: Multitemporal Study and Previsional Modelling"

Thanks to Prof. Alberto Pio Fiori, brazilian coordinator this project, for his contribution and discussions. Thanks to Juarez T. Ballão for his help on manipulating maps.

6 References

Almeida, F.F.M. *Geologia do Sudoeste Matogrossense*. Bol. Nº116; Div. Geol. Min. – DNPM. 118 p. Rio de Janeiro. 1945.

Shiraraiwa, S. - *Flexura da litosfera continental sob os Andes Centrais e a origem da Bacia do pantanal*. Tese de Doutoramento. Instituto Astronômico e Geofísico, USP. São Paulo Brasil. 1994.

Shobbenhouse, C. Campos, D. de A.; Derze, G.R. & Asmus, H.E. *Mapa Geológico do Brasil e da área adjacente incluindo depoósitos minerais*. DNPM. Brasília, Escala 1:2.500.000. 1984.

Soares, P.C.; Assine, M.L.; Rabelo, L., Ballão, J.T. *The Giant Taquari alluvial fan in Pantanal Basin, Central South America*. 30th Internatinal Geological Congress. Beijing, China. (Abstract e Pre-print). 1996.

Soares, P.C.; Gamma Jr., E.G.; Landim, P.M.B., Weyler, G.; Seignemartin, C.L. *Foto-interpretação Aplicada a Sedimentação Recente na Bacia do Pantanal*. I Simpósio Brasileiro de Sensoriamento Remoto. São José dos Campos, SP., 2:35-38. 1978.

Soares, P.C.; Assine, M.L. *The Giant Taquari Alluvial Fan in Pantanal Basin, Brazil*. Texto Inédito. 1997

Wiens, F. *Aspectos de la Sedimentación Cuaternaria de la cuenca del Chaco*. 2º Simposio Sobre Aguas Subterraneas y Perforacion de Pozos en el Paraguay. Assunción, Paraguay. 1995.