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Structural Blocks as Flood Control in Brazilian Pantanal

Blocos Estruturais como Controle da Inundação no Pantanal Brasileiro

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Resumo

A formação e a evolução da bacia do Pantanal ainda não são bem conhecidas nem explicadas. Este estudo traz novas informações que mostram o controle estrutural sobre o meio físico do Pantanal, uma das mais importantes regiões do mundo devido à sua biodiversidade. Foram usados diferentes conjuntos de dados de sensoriamento remoto: o primeiro são os dados altimétricos SRTM corrigidos (Shuttle Radar Topographic Mission) e o segundo o mapa dos lineamentos principais do Pantanal, obtidos a partir de fotointerpretação de imagens de satélite. Ambos foram confrontados com os limites oficiais do Pantanal e outros dois limites definidos pela fitogeografia e imagens de sensoriamento remoto. É possível mostrar que há uma semelhança entre os limites internos do Pantanal e os linemaentos. As altitudes decrescem de N a S e de L a O, mas a análise mostra que a declividade não é homogênea, havendo alguns desníves no caminho. A diferença de altitude entre blocos adjacentes é de cerca de 3 a 4 metros. Além disso, as diferentes regiões apresentam diferentes altitudes e declividades médias, embora a declividade dentro de cada bloco seja homogênea. Considerando o Pantanal como uma bacia cenozóica ativa, este artigo propõe que a neotectônica controla esses blocos e assim a água flui na bacia, que por sua vez controla a fauna e flora da região.
Palavras-chave Sensoriamento Remoto; DEM; Tectônica; Sub-Regiões

Abstract

The Pantanal basin formation and evolution are not well known and explained. This work brings new information showing the structural control over the physical environment of the Pantanal, one of the most important regions all around the world due to its biodiversity. We used different data sets from remote sensing data, the first set is a corrected SRTM (shuttle radar topographic mission) altimetric data and the second is a map of the major lineaments of Pantanal extracted from photointerpretation of satellite images. Both sets were confronted with the official borderlines of Pantanal and to other two limits defined by phytogeography and remote sensing images. It is possible to show that there is a good match between the internal limits of Pantanal and the interpreted lineaments. The altitudes decrease from N to S and from E to W and the slope analysis shows that this declivity is not homogeneous on these directions. The height difference between adjacent blocks is about 3 or 4 meters. Moreover, different regions have different mean altitudes and slope, although the slope inside each block is homogeneous. Considering Pantanal as a Cenozoic active basin, this paper proposes that the neotectonic controls these blocks and so the water flow in the basin, which in turn controls the fauna and flora of the region.
Keywords Remote sensing; DEM; Tectonics; Sub-Regions

1 Introduction

The Pantanal is a tectonic basin is located in central-west Brasil in the Hydrographic Basin of Upper Paraguay (Assine & Soares, 2004) that contrasts to the surrounding highlands, supported by Paleozoic rocks of Paraná Sedimentary Basin or Precambrian rocks (Figure 01)

Riccomini & Assumpção (1999) have presented a compilation of important structural features on Brazilian Quaternary tectonics and described the presence of active faults in Pantanal basin. Soares *et al.* (1998) made a relationship between the tectonic recent moving in Pantanal and the deposition of the alluvial lobes that fill the basin nowadays. Rabelo and Soares (1999) have already described a probably active Holocene NE fault zone across the central Pantanal and have associated it with the reactivation of the TBL lineament, in the basement.

Assine & Soares (2004) explain that the "*active tectonics has been playing an important role in the development of the Pantanal landscape. Nowadays, the Paraguay River meanders in a large flood plain with extensive swamp surfaces, being structurally constrained by faults in the west border of the basin. Sedimentation within the Pantanal wetland is also affected by tectonic activity, especially along faults associated with the Transbrasiliano Lineament*".

The main lineaments present in Pantanal Basin have been described by Paranhos Filho *et al.* (2013) (Figure 08) and the NE structures have been associated to the Transbrazilian Lineament (TBL - Brasil, 1975). The same association was exposed by Hasui (1990), who affirmed the presence, in that region, of N45E lineament sets associated to TBL and also describing them as an example of neotectonic activities.

Another important reference about neotectonics is the earthquakes occurred in Pantanal, with an emphasis in the two biggest: 5.4 magnitude at Miranda, in 1964 and 4.8 at Coxim, in 2009 which have been associated to reverse faults (Facincani *et al.*, 2012; Assumpção & Suárez, 1988; Assumpção *et al.*, 2009).

Associated with this dynamic geological situation, Pantanal presents a not completely known and understood diversity of phytophysiognomies and habitats (Silva, 1995; Cunha & Junk, 1999; Silva *et al.*, 2000; Camargo & Fischer, 2005; Ab'Saber, 2006; Longo *et al.*, 2007), resulting in several different sub-regions.

The Pantanal is a human patrimony and one of the most important world's wetlands (Silva, 1995; Cunha & Junk, 1999; Silva *et al.*, 2000). The region is a continental humid depositional wetland characterized by annual flood regime (Prado *et al.*, 1994; Pinder & Rosso, 1998; Adámoli & Pott, 1999; Cunha & Junk, 1999; Zeilhofer & Schessl, 1999; Damasceno-Junior *et al.*, 2005).

Flooding on the Pantanal plain does not occur homogeneously because distinct sub-regions inside the basin are flooded in different periods. Besides, some regions are never under the water, even in the rainy season, and other areas are flooded only in some years or still every year. The diachronic flooding pattern is clearly recognized orbital data analysis, for example in the figures presented by Lemos *et al.* (2011) that used automatic unsupervised classification of satellite images from MODIS and WFI/CBERS sensors (Figure 2).

Pantanal total surface reaches over 140.000 km², but there is no agreement among the researchers about its borderlines, neither about its internal divisions. Indeed, Pantanal is a mosaic of quite different regions with local names (Table 1). The highlands around Pantanal are the source of the superficial water and sediments to the Pantanal Basin.

This paper aims to see if there is a structural control over the Pantanal different regions and if those regions have differences on their mean altitude and slope.

2 Material and Methods

Even with great similarities between themselves, three different internal limits have been analyzed: Adamoli (1982); Silva & Abdon (1998) both obtained from a mosaic built with different acquisition date and considering mainly the vegetal cover. And a newer one (Mioto *et al.*, 2012), obtained from two pairs of CBERS-2B-WFI and MODIS satellite images of the same date, and so not subjected to differences in

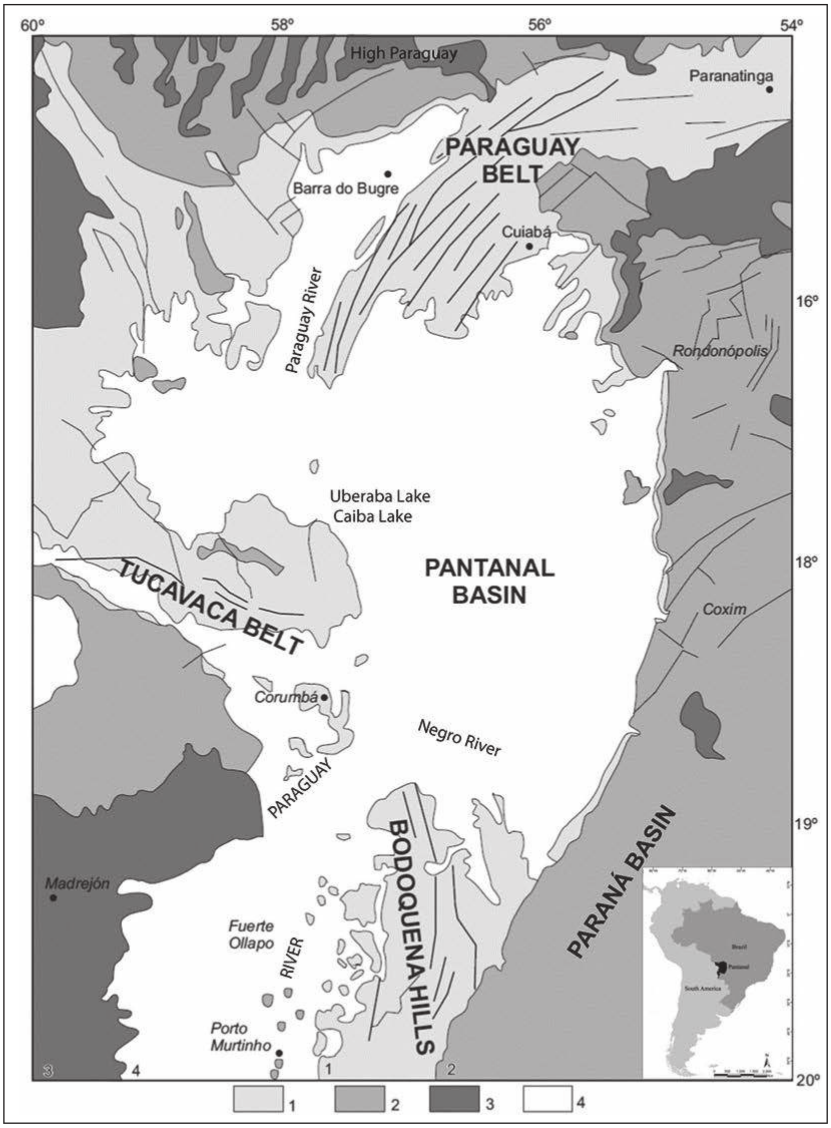


Figure 1 The geological context of Pantanal in relation to regional tectonic units (simplified from Paranhos Filho, 2017, and Schobbenhaus & Bellizzia, 2001) (1) Precambrian metamorphic rocks; (2) Gondwana sequence with Paleozoic sedimentary rocks; (3) Tertiary sedimentary rocks, and (4) Cenozoic sequences including Pantanal. It is important to observe the structural context with the metamorphic rocks of Paraguay Belt to the north; carbonates and other metamorphites of Bodoquena Hills to the south; the Paraná Basin to the east, and Precambrian rocks of the Tucavaca Belt and Bolivian Cenozoic sediments to the west.

phenology and humidity due to time variation, which occurs in the mosaics previously used in Pantanal sub-regions classifications. Comparing the NDVI of the different regions is possible to observe differences in chlorophyll and humidity among the regions (Mioto *et al.*, 2012). The same considerations about no phenology and humidity differences on the land cover have been used by Paranhos Filho *et al*. (2013) in the identification of Pantanal Basin main structures over CBERS-2B Satellite image, WFI sensor.

The SRTM data used on the slope study was corrected to remove sinks and peaks. Also, some of the sub-regions presented isolated hills, which could mask the statistics, so we had to remove them from the SRTM. To remove these hills, after their identification, an analysis was made of the histograms of each sub-region to determine a threshold value, so values higher than the threshold corresponded to the hills of each sub-region were transformed to No Data. There is also have been done a field control looking for ground control points over the different land covers and landscapes.

3 Results

The Figures 3 and 4 show that the sub-regions heights are different and that every single region took individually is flat, with very low slopes. Different flat regions with height differences should be another

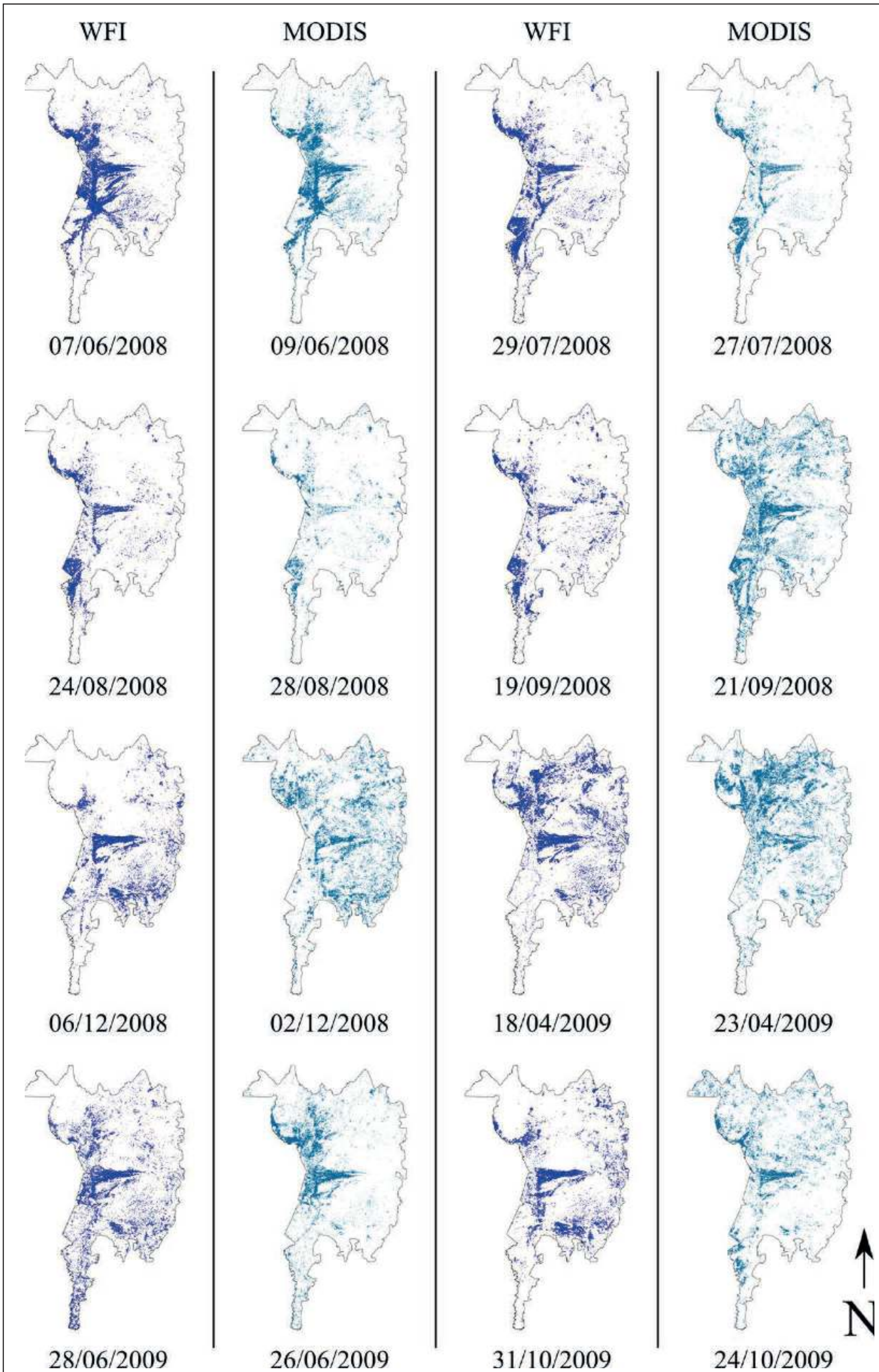


Figure 2 Pantanal flooded areas (dark blue). Lemos *et al*. (2011) made an unsupervised classification of the satellite images from TERRA/AQUA, sensor MODIS (NASA, 2008, 2009), between the years of 2008 and 2009 (monthly scenes) and identified how the floods on Pantanal occur. The results showed that the floods in this region have a cycle, although they occur in different moments on each sub-region. These floods follow two directions: NS and EW.

Author	Criteria adopted	Material used	Number of sub-regions	Area (km^2)
Stefan (1964)	Not specified	Not specified	Not analyzed	156,298
Brazil (1974)	Level curves (200 m) and geomorphological aspects	Topographic maps at 1:250.000 scale and aerial photographs	Not analyzed	168,000
Sanchez (1977)	Geomorphology, hydrology and fluvial morphology	Radar Images at 1:250.000 scale and topographic maps on 1:100.000 scale	17	Not quantified
Brazil (1979)	Geomorphology, hydrology and fluvial morphology	Radar Images at 1:250.000 scale and topographic maps on 1:100.000 scale	15	139,111
Franco & Pinheiro + Alvarenga et al. (1982)	Geomorphological and morphogenetic factors (relative altimetry, lithology and pedology).	Radar images at 1:250.000 scale	13	136,738
Adámoli (1982)	Phytogeography and hydrology	Previous studies EDIBAP (Brasil, 1979). LANDSAT-MSS Images on 1:250.000 and 1:1.000.000 scales.	10	139,111
Alvarenga et al. (1984)	Geomorphology and structural aspects, topography, hydrology, morphology, pedology and vegetation structure	Radar images on 1:250.000 scale. LANDSAT-MSS images on 1:500.000 and 1:1.000.000 scales.	12	133,465
Amaral Filho (1986)	Pedological and hydrological aspects	Previous studies (RADAMBRASIL) and 1:250.000 radar images.	6	153,000
Mato Grosso do Sul (1989)			14	
Silva (1998)	Physiological and morphological aspects and geopolitics	Previous studies, GPS and 1:250.000 Landsat TM.	11	138,183
Mioto et al. (2012)	Geomorphology/Physiography and hydrology	Field control, previous studies. MODIS and CBERS/WFI images.	18	140.640

Table 1 Studies related to the delimitation of the Pantanal.
Source: Silva (1995; 1998a, b), Mato Grosso do Sul (1989), Mioto *et al.* (2012).

evidence of structural control because there are plain regions that are higher than their plain neighbors.

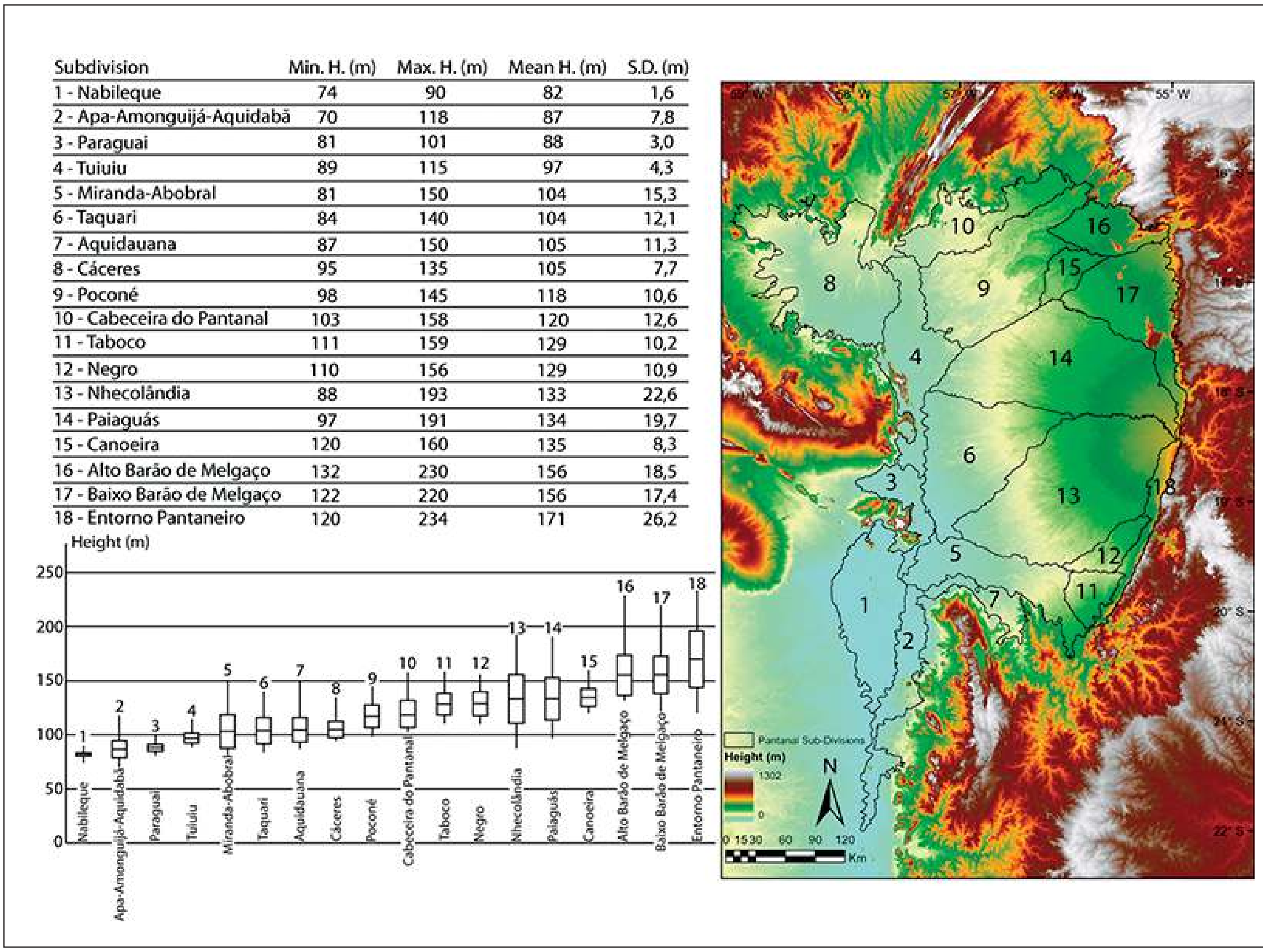
The floods are very important in the energy fluxes at the region and do not occur at the same time all over Pantanal, each sub-region may have its own regime. Another comparison is possible when the lineaments are overlaid on the sub-regions map. Most of the time the structures are coincident with the border lines of the different blocks identified on SRTM data (Figure 05).

This coincidence is also visible over MODIS images in Figures 06, 07 and 08, focused at Taquari Pantanal, Paiaguás, Nhecolândia and Poconé as examples and showing that these regions have different flood regime and that their borderlines are coincident to structural limits.

We can see in Figure 07 that Baixo Barão do Melgaço and Paiaguás are not flooded and the limit that separates the flooded areas are the lineaments, which are coincident with the sub-regions' limits.

4 Discussion

Pantanal is usually described as plain with a very low slope, with a few centimeters per kilometer (Girard *et al.*, 2003; Damasceno Júnior *et al.*, 2005). In regional scale this model fits the region, but locally, using SRTM data it is possible to observe a metric difference between the regions identified over satellite images. It is possible to observe the altimetric difference between the internal sub-divisions; also, it must be considered that they have a small amplitude and standard deviation, which means more homogeneous areas, making easier the characterization of the sub-



Subdivision	Min. H. (m)	Max. H. (m)	Mean H. (m)	S.D. (m)
1 - Nabileque	74	90	82	1,6
2 - Apa-Amonguijá-Aquidabã	70	118	87	7,8
3 - Paraguai	81	101	88	3,0
4 - Tuiuiu	89	115	97	4,3
5 - Miranda-Abobral	81	150	104	15,3
6 - Taquari	84	140	104	12,1
7 - Aquidauana	87	150	105	11,3
8 - Cáceres	95	135	105	7,7
9 - Poconé	98	145	118	10,6
10 - Cabeceira do Pantanal	103	158	120	12,6
11 - Taboco	111	159	129	10,2
12 - Negro	110	156	129	10,9
13 - Nhecolândia	88	193	133	22,6
14 - Paiaguás	97	191	134	19,7
15 - Canoeira	120	160	135	8,3
16 - Alto Barão de Melgaço	132	230	156	18,5
17 - Baixo Barão de Melgaço	122	220	156	17,4
18 - Entorno Pantaneiro	120	234	171	26,2

Figure 3 The table shows the mean altitude, standard deviation and range for each Pantanal internal division obtained in this study, showing that the sub-regions are different between themselves in this aspect (limits as proposed by Mioto et al. (2012). The geographical location refers to that of Figure 1 and Figure 5.

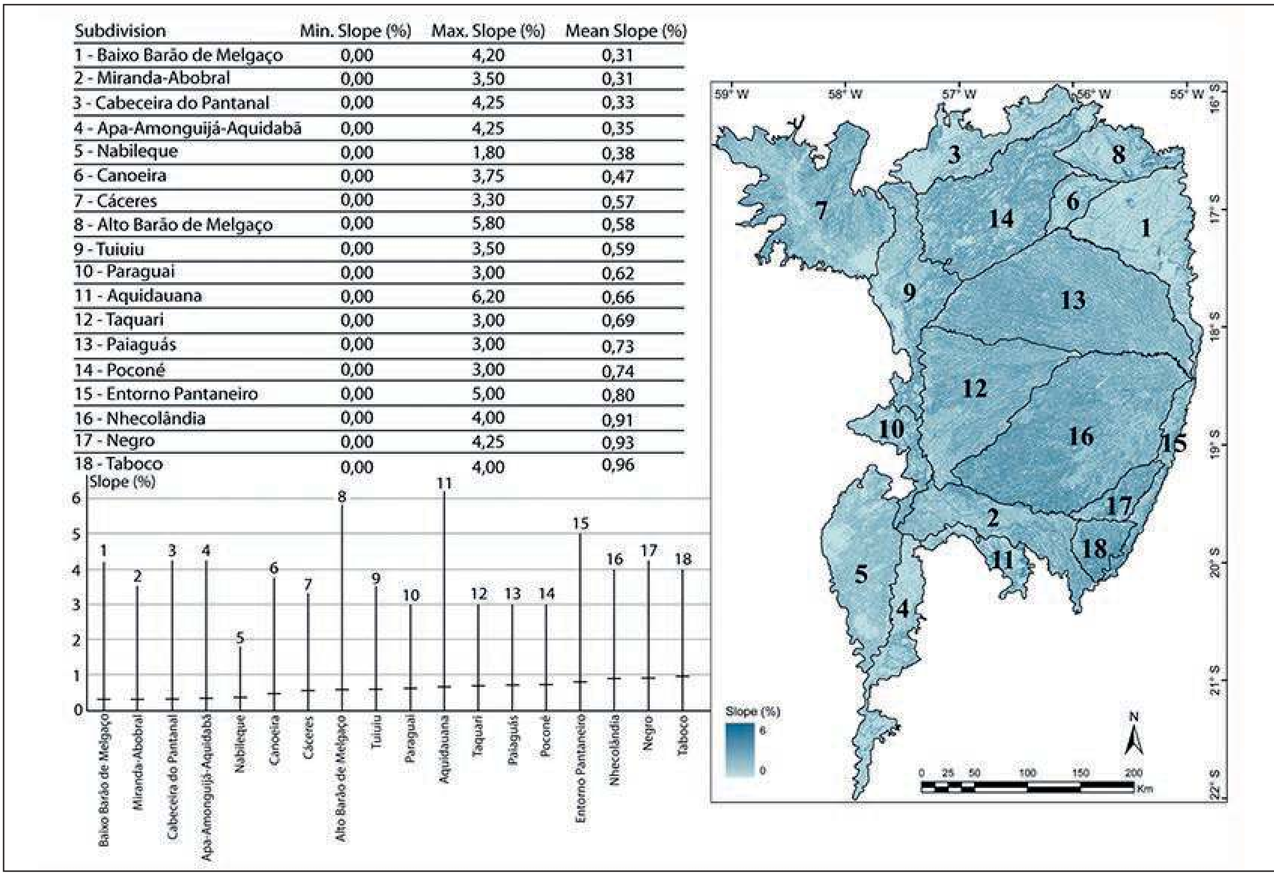
regions as different blocks. The results are compared and described as follow:

The higher parts are at the Pantanal of 'Barão de Melgaço', which has a hydrologic tributary regime, different from the distributary system that rules in Pantanal plain, mainly due to the low slope. The region of 'Entorno Pantaneiro', which means Pantanal surroundings (area 18 on Figure 3 and area 15 on Figure 4) is a landscape different from Pantanal sub-regions and maybe considered as no-Pantanal. The field control over this region has shown that the area is made up by gravity flow-dominated fans over a pre-Cambrian or Phanerozoic substrate.

All regions have flat areas (0% slope – Figure 4) and a very low and homogeneous declivity. We show in Figure 9, that there are differences between the height and declivity of each block by two longitudinal profiles crossing the subdivisions.

The Taquari Megafan has three different landscapes: The Taquari Pantanal corresponding to the current lobe, the lowest region among the three areas and under the water all over the year (Figure 6) with altitudes lower than Paiaguás (north) and Nhecolândia (south), which is unique due to its natural field of lakes, with more than 18.000 lakes with a great variation in pH and salinity. Paiaguás, on North of Taquari River, has no lakes.

The Pantanal of Paraguay is the lower main channel, which is structured and receives the flood water from the neighbor regions. At the extreme South part of Pantanal it is possible to observe that



Subdivision	Min. Slope (%)	Max. Slope (%)	Mean Slope (%)
1 - Baixo Barão de Melgaço	0,00	4,20	0,31
2 - Miranda-Abobral	0,00	3,50	0,31
3 - Cabeceira do Pantanal	0,00	4,25	0,33
4 - Apa-Amonguijá-Aquidabã	0,00	4,25	0,35
5 - Nabileque	0,00	1,80	0,38
6 - Canoeira	0,00	3,75	0,47
7 - Cáceres	0,00	3,30	0,57
8 - Alto Barão de Melgaço	0,00	5,80	0,58
9 - Tuiuiu	0,00	3,50	0,59
10 - Paraguai	0,00	3,00	0,62
11 - Aquidauana	0,00	6,20	0,66
12 - Taquari	0,00	3,00	0,69
13 - Paiaguás	0,00	3,00	0,73
14 - Poconé	0,00	3,00	0,74
15 - Entorno Pantaneiro	0,00	5,00	0,80
16 - Nhecolândia	0,00	4,00	0,91
17 - Negro	0,00	4,25	0,93
18 - Taboco	0,00	4,00	0,96

Figure 4 The table shows the range (Min. Slope, Max. Slope) and mean slope for each Pantanal internal division obtained in this study, showing that all regions have flat areas (0% slope) and a very low and homogenous declivity (limits by Mioto et al., 2012).

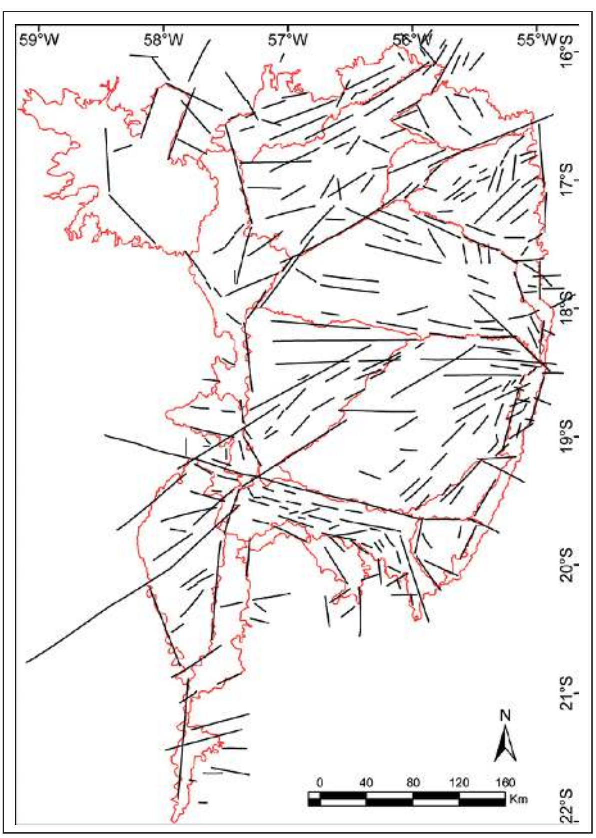


Figure 5 Pantanal internal limits are coincident, most of the time, with structural lineaments, what suggests a strong structural control over Pantanal sub-regions, the Cenozoic Age and the fact of being still active suggest that it is a neotectonic control (lineaments from Paranhos Filho *et al.*, 2013 and border lines from Mioto *et al*., 2012).

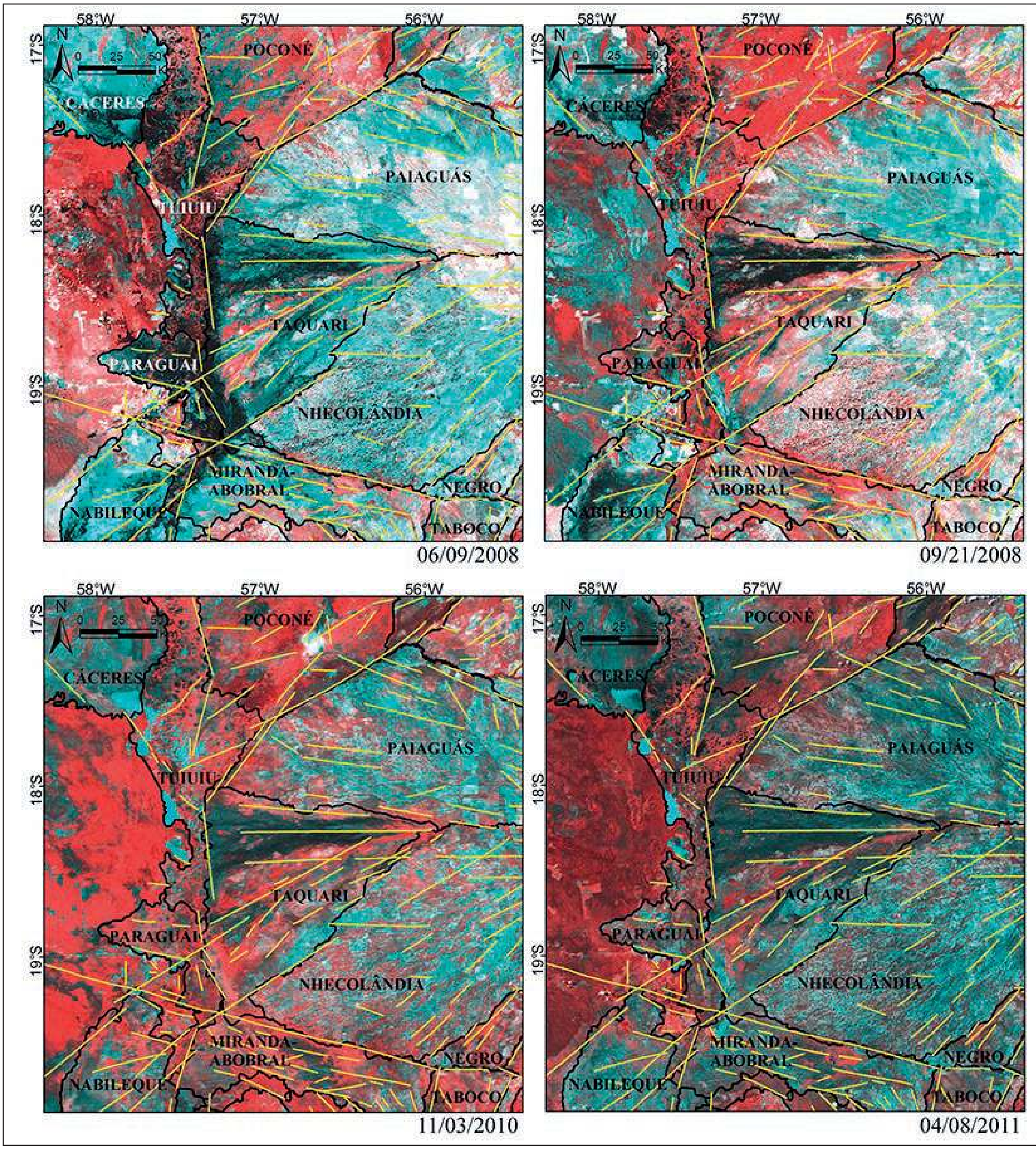


Figure 6 MODIS images (NASA, 2008 a, b, 2010, 2011) showing that in Taquari water runs throughout the whole year (see also figure 02). The dark colors are related to the presence of water. Whereas Taquari is flooded, Paiaguás to the north and Nhecolândia to the south have no running water. Observe that the limits of these regions coincide with lineaments (yellow lines).

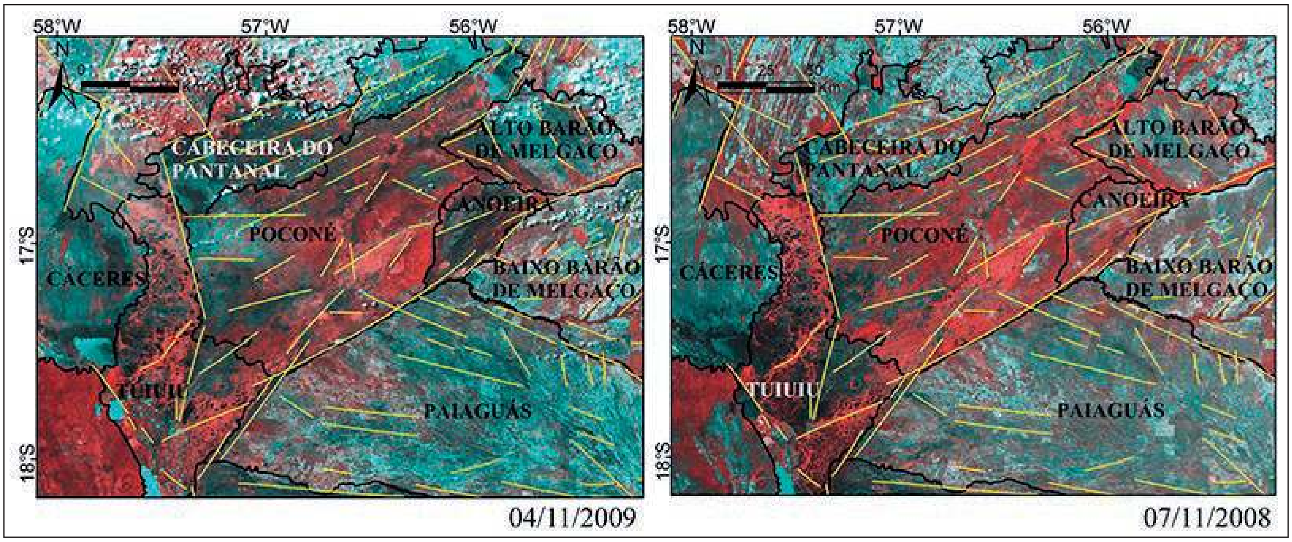


Figure 7 The Poconé Region is one of the first ones to be flooded. Observe that the flooding limits are coincident to the lineaments shown as yellow lines - MODIS images (NASA, 2008, 2009).

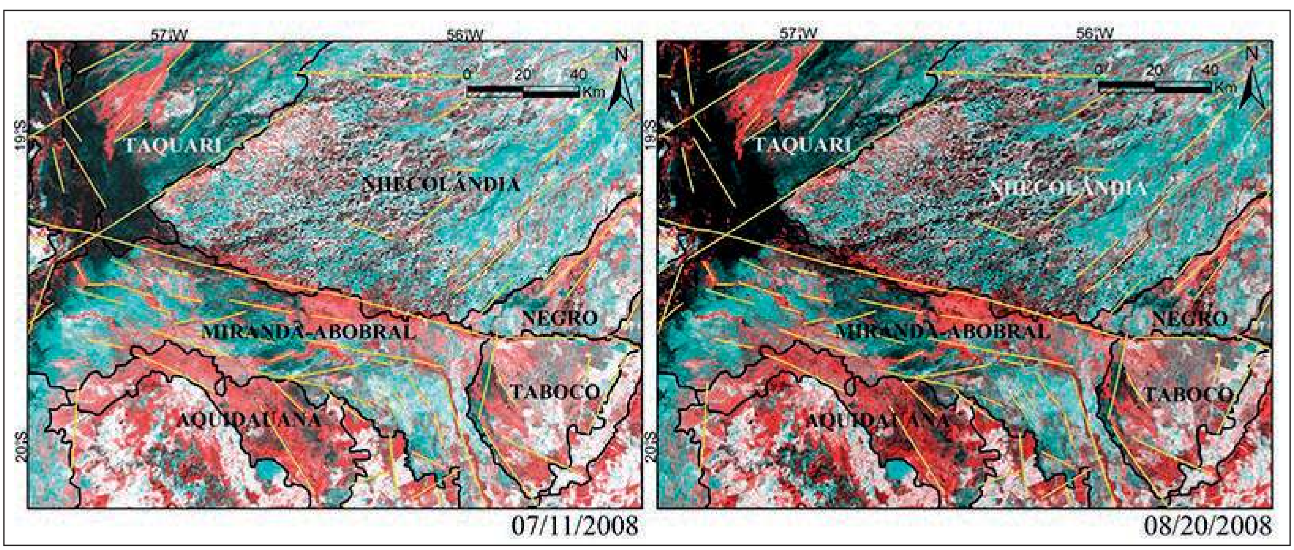


Figure 8 The limit between Miranda/Abobral and Nhecolândia is also controlled structurally (NASA, 2008, c, d). Toward to north, Nhecolândia is higher than Miranda/Abobral and comportsan 18.000 lakes field, while there are very few lakes toward to the South.

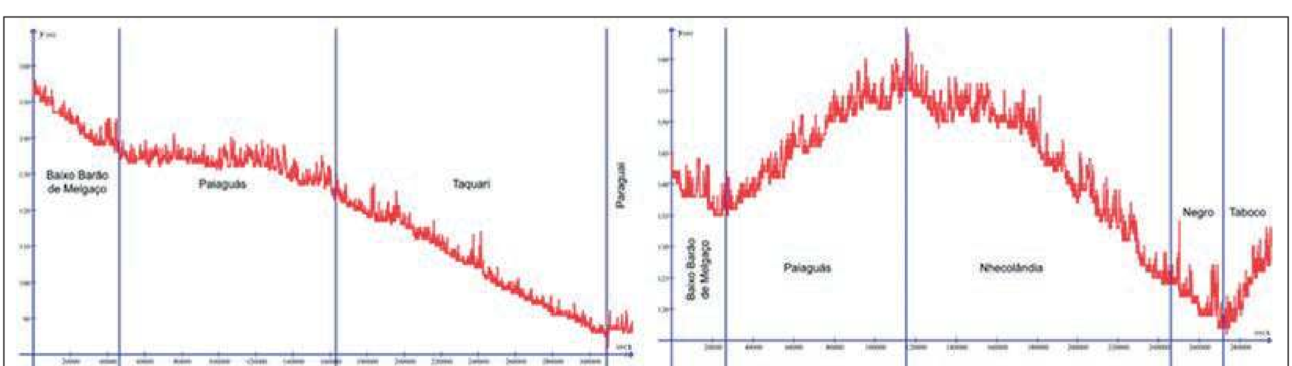


Figure 9 Longitudinal sections showing that heights (y) and declivities (x) are different, when comparing a domain with another. The left section trends NE to SW and the right section N to S.

the region southern of Nabileque - Apa-Amonguijá-Aquidabã/Porto Murtinho have a mean altitude higher than Nabileque's, what explains the remaining time of the flood at this region, since Paraguay River channel is the only way out to the floodwater. The low standard deviation of Nabileque's altitude and the small amplitude shows the uniformity of the plain at that region. The field control has shown that in vegetation terms it is more alike to Chaco than to Pantanal. The higher altitudes of its surroundings should be associated to its pre-Cambrian substrata.

5 Conclusion

The importance of this structural control over the physiography presented here confirms that there are important Cenozoic activities in the Pantanal basin contrasting to the alleged stability of the Brazilian platform (as discussed by Riccomini & Assumpção, 1999).

These structures control the high of the Pantanal internal blocks, what indeed rules the water distribution all over the region. By its time, the water controls the vegetation and so the fauna. This way, the neotectonic activities in Pantanal basin are one of the most important causes to its biodiversity.

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