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GRANULOMETRIC ASPECTS AND SOURCE AREAS OF THE SEDIMENTS FROM THE CONFLUENCE OF TOCANTINS AND ITACAIÚNAS RIVERS: MARABÁ CITY, PA - BRAZIL

ASPECTOS GRANULOMÉTRICOS E ÁREAS FONTE DE SEDIMENTOS DA CONFLUÊNCIA DOS RIOS TOCANTINS E ITACAIÚNAS, CIDADE DE MARABÁ

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ABSTRACT - The Tocantins and Itacaiúnas Rivers, located in Marabá city, southeast of Pará State, represent the main rivers of the region and they are distinguished by the significant number of tributaries and sediment transport. The lack of sedimentological studies along the confluence of the Tocantins and Itacaiúnas Rivers encouraged this research, in order to provide considerations about the sediment transport and provenance through granulometric analysis and heavy mineral assemblages. The granulometric analysis was based on sediments collected along three profiles I-III, 20 samples total. The transverse profiles I and II, along the Tocantins river, measure approximately 1.290 to 1.821 km of extension, with a distance between points of 174 to 480 m, displayed particle size variation due to differences in transport energy. The longitudinal profile III, along the Itacaiúnas River, measures approximately 1.732 km, as a distance between points ranging from 100 to 536 m. In this profile there was little particle size variation, indicating high and homogenous flow energy. The identified heavy minerals were zircon, tourmaline, staurolite, rutile, sillimanite, and garnet, which demonstrate a diversity of shapes, roundness, colors, and textures, suggesting igneous, metamorphic and sedimentary sources. The ZTR index (zircon + tourmaline + rutile) indicate a high degree of mineralogical maturity for sediments from the Tocantins River and moderately in the Itacaiúnas River.
Keywords: Granulometric analysis; Heavy minerals; Tocantins River; Itacaiúnas River.

RESUMO – Os rios Tocantins e Itacaiúnas situados na cidade de Marabá, sudeste do estado do Pará, representam os principais rios da região e eles distinguem-se pelo número significativo de afluentes e transporte de sedimentos. A falta de estudos sedimentológico ao longo da confluência dos rios Itacaiúnas e Tocantins incentivou esta pesquisa, a fim de fornecer considerações sobre o e proveniência transporte de sedimentos através da análise granulométrica e assembleias de minerais pesados. A análise granulométrica baseou-se em sedimentos coletados ao longo de três perfis I a III, total de 20 amostras. Os perfis transversais I e II, ao longo do rio Tocantins, com cerca de 1.290 a 1.821 m de extensão, com uma distância entre pontos de 174 a 480 m, exibindo variação do tamanho das partículas devido às diferenças em energia de transporte. O perfil longitudinal III, ao longo do rio Itacaiúnas, que mede aproximadamente 1.732 m, como a distância entre os pontos que variam de 100 a 536 m. Neste perfil, houve pouca variação de tamanho de partícula, indicando a energia de fluxo elevado e homogênea. Os minerais pesados identificados foram zircão, turmalina, estaurolita, rutilo, sillimanita e granada, que demonstram uma diversidade de formas, arredondamento, cores e texturas, sugerindo fontes de rochas ígneas, metamórficas e sedimentares. O índice ZTR (zircão, turmalina + rutilo) indicam um alto grau de maturidade mineralógica dos sedimentos do rio Tocantins e moderadamente no rio Itacaiúnas.
Palavras-chave: Análise granulométrica; minerais pesado; Rio Tocantins; Rio Itacaiúnas.

INTRODUCTION

The confluence of the Tocantins and Itacaiúnas Rivers, near Marabá city, southeast of the Pará state, belongs to the Tocantins and Araguaia Hydrographic Basin (TAHB), with about 967,059 km2. This confluence is marked by the development of a longitudinal bar of a kilometric extension called Tucunaré bar. The fluvial system (Tocantins-Araguaia) stands out for representing the most extensive drainage area in Brazil and the second largest in area and flow (ANA, 2009).

Although it is an important fluvial system of the region, its fluvial dynamics are still little understood. Under those circumstances, sediment samples from the downstream and upstream of the Tucunaré bar and in the confluence of Tocantins and Itacaiúnas Rivers were collected to perform granulometric analysis and heavy mineral typology along three profiles, to address transport and deposition competence considerations as well as to suggest likely sources of sediments.

GEOLOGICAL CONTEXT

The study area is situated in the regional context that comprises geological terrains of different ages and geotectonic domains such as Amazonian Craton, Araguaia Belt, Parnaíba Basin and Marajó Basin (Figure 1).

Amazonian Craton

The Amazonian Cráton is placed in the South American Platform and it has distinguished amongst the geotectonic units of the Precambrian for its dimension (about 4.500.000 km²).

This craton is characterized as a continental lithospheric plate of Archean nucleus, surrounded for orogenic bands Paleo to Mesoproterozoic (Almeida et al., 1981; Brito Neves & Cordani, 1991; Schobbenhaus & Brito Neves, 2003).

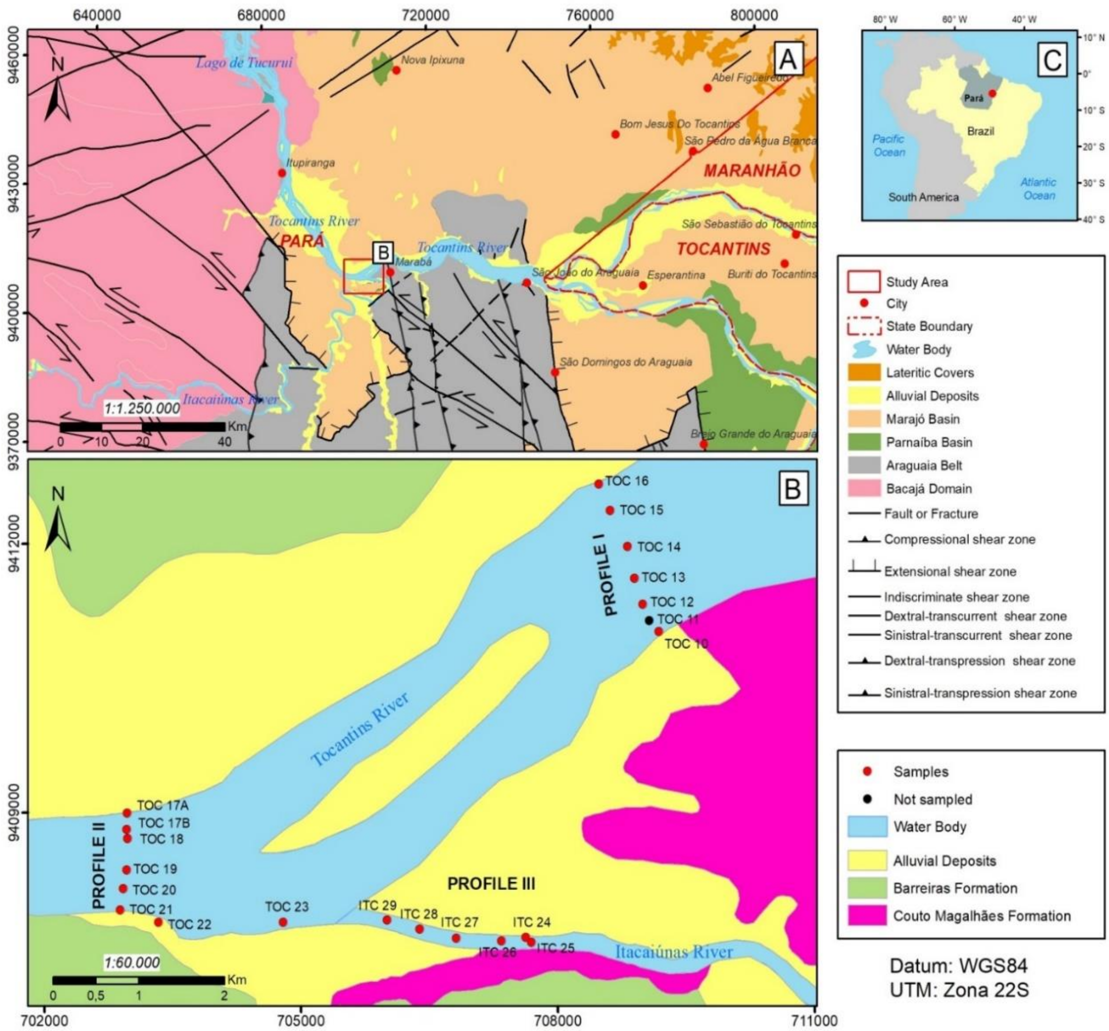

Figure 1 - Geological context and study area location. (A) Regional geological map, modified by Vasquez et al. (2008). B) The study area, located in Marabá city with the profiles and sediment sample points, modified by Silva (2012). (C) Map of Brazil indicating the area of study.

Amongst the provinces that are part of the Amazonian Craton, the Transamazonas occurs in the study area, represented for the Bacajá Domain (Tassinari & Macambira, 2004; Vasquez et al., 2008). This domain, located to the Southeast of the Amazonian Craton, represents the southern segment of the Maroni-Itacaiúnas Province, made up of granitoids, charnoquitic rocks, para- and orthoderived granulites, supracrustal and metavolcanic-sedimentary sequences (Santos, 2003; Vasquez et al., 2008; Macambira & Ricci, 2014).

Araguaia Belt

The Araguaia Belt is a geotectonic unit from the Neoproterozoic belonging to the Tocantins Province, characterized for a prolongated band N-S, from approximately 1.200 km and width of up to 100 km, this belt is located on the eastern edge of the Amazonian Craton, east-Southeast of Pará state and west of the Tocantins state (Almeida et al., 1981; Vasquez et al., 2008).

The Araguaia Belt is represented by metasedimentary rocks (metapelitic and metapsammitic), carbonatic (marbles and metalimestones), magmatic (metabasalt, metagabros, meta peridotites and granite bodies), volcano-sedimentary succession of basaltic spills and sills of diabase intercalated with siliciclastic deposits belonging to the Estrondo, Tocantins and Tucuruí groups (Abreu, 1978; Gorayeb, 1981; Vasquez et al., 2008)

In the study area, rocks from Tocantins group are represented for the formations: Pequizeiro, consisting of abundant, abundant quartz-chlorite schists, chlorite schists and bodies of metabasites; and Couto Magalhães, consisting of slates, pelitic phyllite, graphitic phyllites, meta-arkoses, metasiltstone, meta-mudstones, biotite-muscovite schist and quartzite lenses (Hasui et al., 1977; Abreu, 1978; Gorayeb, 1981; Almeida et al., 2001; Felipe, 2012).

Parnaíba Basin

The Parnaíba Basin is one Paleozoic sineclise, intracratonic of circular form that was originated on Proterozoic and Cambro-Ordovician rifts. Moreover, it has depocenter of up to 3.500 m thickness, represented for stratigraphic successions since the Paleozoic until the Mesozoic Era. This Basin is located in the northeast of Brazil, occupying an area of approximately 600,000 km^2 along the States of Maranhão, Piauí, Tocantins, Ceará, Bahia and Pará (Caputo, 1984; Cunha, 1986; Góes & Feijó 1994; Góes, 1995; Brito Neves, 1999; Milani & Zalán, 1999; Brito Neves, 2002; Bizzi et al., 2003; Almeida & Carneiro, 2004; Caputo et al., 2005; Vaz et al., 2007; CPRM, 2009, Parra, 2012; Klein et al., 2013). Surrounding the study area, occur the following formations: Poti, Pimenteiras (Canindé Group), Piauí, Pedra de Fogo, Sambaíba (Balsas Group), Mosquito, Sardinha, Bastos, Corda, Codó, and Itapecurú. Pimenteiras formation is composed of dark bioturbate shale, intercalated with siltstones, while Poti Formation consists of sandstone with sigmoidal cross-stratification, tabular, through cross-stratification, climbing ripple cross-lamination and parallel. In addition, conglomerates, siltstones, rhythms of fine sandstone/shale/shale and silex (Góes, 1995; Della Fávera et al., 2003; Pedreira da Silva et al., 2003; Parra, 2012). Piaui Formation is represented by thin, thick sandstones, clay, feldspathic, intercalated with red siltstone, clay and silex level at the top (Lima & Leite, 1978; Souza et al. 2010).

Pedra de Fogo Formation is composed of silex, oolitic limestone, pisolitics, and stromatolite interspersed with thin to medium yellowish sandstones, greyish shales, siltstones, anhydrites and dolomites (Fernandes & Borges, 1994; Góes & Feijó, 1994; Dino et al., 2002; Pedreira et al., 2003; Andrade, 2012; Medeiros, 2013). Motuca Formation is characterized by red and brown siltstone, fine and medium white sandstone, shale, anhydrite and rare limestone (Lima & Leite, 1978; Pedreira et al., 2003; Abrantes Junior 2013; Andrade et al, 2014). Sambaíba Formation is represented by fine to medium sandstones, sub-angular to sub-rounded, whitish pale cream, with tabular, through and scalloped cross-stratification (Lima & Leite, 1978; Caputo, 1984; Góes & Feijó, 1994; Dino et al., 2002; Vaz et al., 2007; Abrantes Junior, 2013). Mosquito and Sardinha Formations are represented by amygdaloidal basalts, possibly interspersed with red sandstones with silex lenses, (Góes & Feijó, 1994; Mocitaiba et al., 2017). Pastos Bons, Corda, and Itapecuru Formations are characterized by sandstones, thin to medium, with parallel, tabular, stratification, through and scalloped cross-stratification, greenish gray siltstones, shales, limestones and evaporites (Lima & Leite, 1978; Caputo, 1984, Anaisse Jr. et.al, 2001; Rossetti, 2001; Silva et al., 2003; Paz et al., 2005; Mocitaiba et al., 2017).

Marajó Basin

The Marajó Basin, located in Pará state, is formed by four Sub-basins: Mexiana, Limoerio, Cametá and Mocajuba, which is characterized by a system of extension faults NW-SE, NE-SW and EW to ENE-WSW from the opening of the Equatorial Atlantic Ocean in the Upper Cretaceous (Lima, 1987; Azevedo, 1991; Galvão, 1991; Villegas, 1994; Costa & Hasui, 1997; Góes & Rossetti, 2001; Costa et al., 1996; Schobbenhaus & Brito Neves, 2003; Silva et al., 2003; Soares Jr., 2007; Soares Jr, et al., 2008). In the study area, there are sedimentary deposits from the Mocajuba Sub-Basin, represented by the Ipixuna (Upper Cretaceous/Lower Tertiary), Barreiras (Miocene) and Post-Barreiras (Plio-Pleistocene) sediments) (Villegas, 1994; Santos Jr., 2002; Vasquez et al., 2008; Felipe, 2012; Souza & Santos Jr., 2012).

The Ipixuna Formation is characterized by thick /very coarse, grayish-whitish, quartz-feldspathic (kaolinized) sandstone (Santos Jr., 2002; 2006; Santos Jr. & Rossetti, 2003). The Barreiras formation is represented by quartz sandstones-feldspathic sediments with tabular cross-stratification, covered sporadically by clay films on the bottomsets, topsets and/or foresets, and laminated mudstone or massive, organized in cycles of normal gradating (Souza, 2012; Souza & Santos Jr.; 2012; Rodrigues, 2014). Post-Barreiras sediments consist of yellowish, sandy-clay, massive sediments (Souza & Santos Jr., 2010; Rossetti et al., 2013; Rodrigues, 2014).

MATERIALS AND METHODS

To perform this research, 20 sediment samples were collected along three profiles in the Tocantins and Itacaiúnas rivers, near Marabá-PA city: 6 samples in the Tocantins River (profile I - Tucunaré bar); 6 samples along the Itacaiúnas River (profile II) and 8 samples at the confluence of the Tocantins and Itacaiúnas rivers (profile III - downstream of the Tucunaré bar). These sediments were submitted to granulometric analysis and characterization of heavy mineral assemblages. Samples were collected with Van Veen Grab sampler. For granulometric analysis, samples were oven dried at 100°C (New Instruments NI 15 12). Then 100 g of sediment was separated by sieving using: 2.0; 1.0; 0.5; 0.125 and 0.0625 mm sieve intervals, coupled to a mechanical stirrer for 10 minutes. Each fraction obtained was weighed and used for granulometric frequency studies. These procedures were taken in the Ore Treatment Laboratory from the Faculty of Mining Engineering and Environment at UNIFESSPA.

The separation of heavy minerals was carried out by gravity through immersion of sediments in bromoform (2.89 g / cm 3). The heavy minerals in thin sections were mounted in Canada balsam. For the identification of minerals under the optical microscope (AxiosKop 40), the Atlas of Heavy Minerals was used, focusing on the diagnostic properties: shape, color, pleochroism, cleavage, inclusions, alteration, zoning, and others (Mange & Maurer, 1992). The grain counting was made through the line method (300 grains of transparent minerals, non-opaque and non-micaceous, per thin section) (Galehouse, 1971; Harwood, 1988).

Approximately 1950 grains of heavy minerals were counted, on the 0.125-0.063 mm fractions, from the twenty samples collected along the profiles I-III. The quantitative results obtained in the form of data, on the frequency number, are represented in percentage and normalized to 100%. To indicate the degree of compositional maturity the ZTR index of Hubert (1962) was used, the calculation was done by the sum of the percentages of single zircon, tourmaline, and rutile. These procedures had been carried out in the Petrography Laboratory, Faculty of Geology at UNIFESSPA.

The software used has been ArcGIS ® 10.6, Google Earth Pro 7.3, CorelDraw 2017 and Microsoft ® Excel for the production of maps, tables, and charts, which were made in the Geoprocessing Laboratory at UNIFESSPA.

DATA PRESENTATION

Granulometric analysis

The granulometric distribution analyses are in tables 1, 2, 3 and graphs of figures 2, 3 and 4.

Profile I, Tocantins River

The sediments along the profile I, Tocantins River, upstream of the Tucunaré bar, are represented by the samples: TOC-10, 11, 12, 13, 14, 15 and 16. The sediments granulometry ranges from very coarse sand to very fine sand and, subsequently, silty-clayey sediments (Table 1, Figure 2). The TOC 10 and 12 samples show the predominance of very coarse sand (35.2 - 47.3%), coarse sand (33.1 - 40.6%) and medium sand (12 - 30.7%). TOC 13, 14 and 15 are characterized by the diminishing fraction of coarse /very coarse sand (1.8% - 24.6%), and increasing of medium sand (43.8% - 59. 55%) and fine sand (1.2 - 35.1%). TOC 16 is characterized by an ample grain size distribution of sediments, with the predominance of very coarse sand (32.2%) and very fine sand (34.8%), with the occurrence of silty-clayey sediments (6.3%). TOC 11 is represented by flagstones of metamorphic rocks, phyllite.

Table 1 - Percentage distribution of the granulometric classes of the TOC 10, 12, 13, 14, 15 and 16 samples (Profile I).

	Sample					
Granulometric range	***TOC 10***	***TOC 12***	***TOC 13***	***TOC 14***	***TOC 15***	***TOC 16***
Very coarse sand	47,3	35,2	24,6	8,3	1,8	32,2
Coarse sand	40,6	33,1	25,3	31,0	8,2	5,3
Medium sand	12,0	30,7	43,8	59,5	54,5	2,3
Fine sand	0,1	1,0	6,3	1,2	35,1	19,1
Very fine sand	0,1	0,0	0,1	0,0	0,4	34,8
Silt and Clay	0,0	0,0	0,0	0,0	0,0	6,3

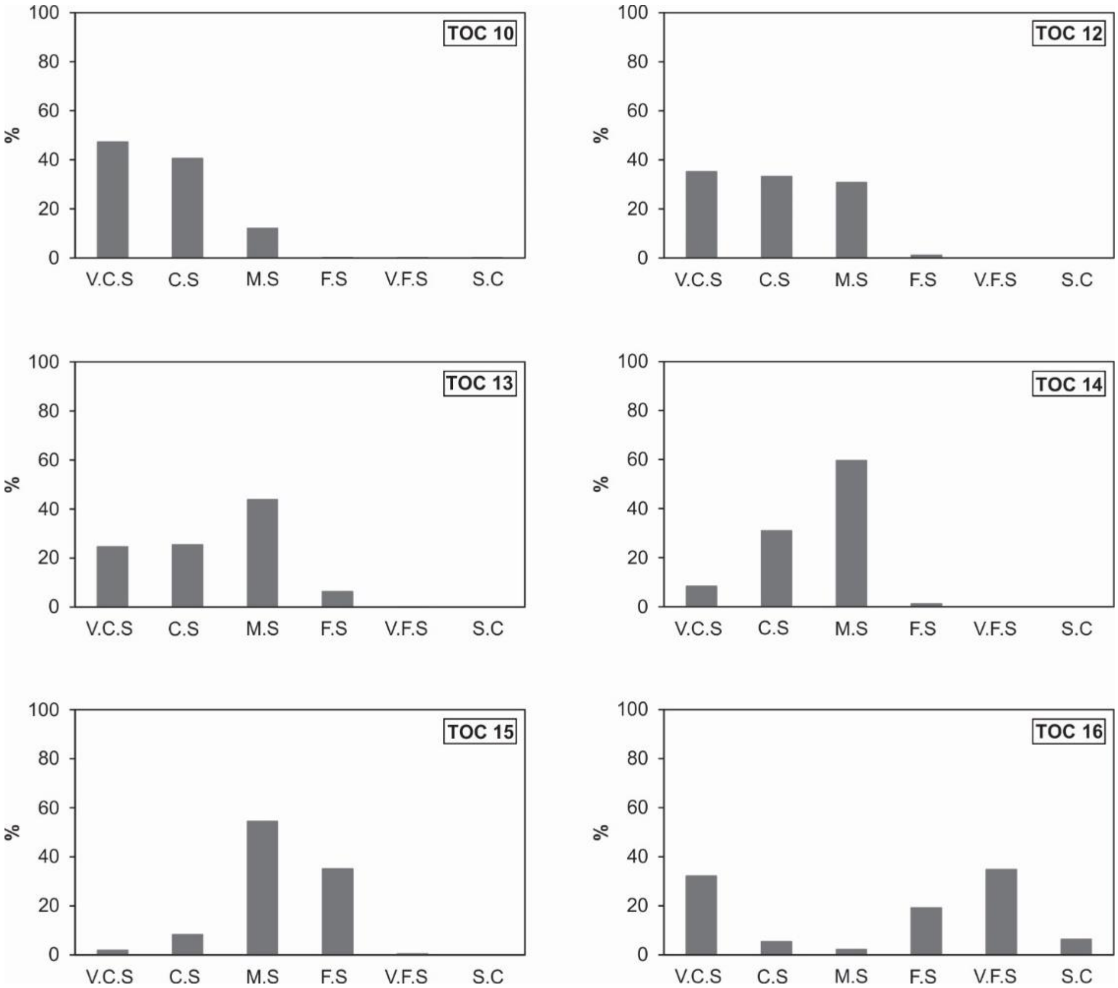

Figure 2 - Graphs showing the percentage distribution of the granulometric classes of the samples from the profile I, along the Tocantins River (upstream of the Tucunaré bar).V.C.S = Very Coarse Sand, C.S = Coarse Sand, M.S = Medium Sand, F.S = Fine Sand, V.F.S = Very Fine Sand, S.C = Silt and Clay.

Profile II, Tocantins River

The sediments from the samples TOC 17 A-B, 18, 19, 20, 21, 22, 23, profile II, Tocantins River, downstream of the Tucunaré bar, have granulometry ranging from very coarse sand to very fine sand, including silty-clayey sediments (Table 2; Figure 3). This profile is close to the confluence with the Itacaiúnas River.

The 17A sample presents a wide particle size variation since very coarse sand (23.3%) to very fine sand (30.9%). The sediments of the samples TOC 17 B, 18 and 19 have predominantly medium sand (45% to 75.9%), with contributions from very coarse sand (1.8-20.8%), coarse sand (18.6-32.3%) and fine sand (1.8-12.4%). The TOC 20 sample is marked by the predominance of very coarse sand (47.3%) and coarse sand (40.6%). The TOC 21 displays a higher percentage of fine sand from all samples collected (36.2%). The TOC 22 has a predominance of coarse sand fractions (37%) and medium sand (37.5%). The TOC 23 presents the greatest percentage value of very coarse sand from all the samples collected (94.3%).

Table 2 - Percentage distribution of the granulometric classes of the TOC 17 A, 17B, 18, 19, 20, 21, 22, 23 samples (Profile II).

	Sample							
Granulometric range	TOC 17A	TOC 17B	TOC 18	TOC 19	TOC 20	TOC 21	TOC 22	TOC 23
Very coarse sand	23,3	1,8	7,6	20,8	47,3	17,7	14,6	94,3
Coarse sand	14,2	18,6	23,8	32,3	40,6	8,8	37,0	2,3
Medium sand	9,6	75,9	54,5	45,0	12,0	23,0	37,5	2,5
Fine sand	7,1	2,9	12,4	1,8	0,1	36,2	9,1	0,8
Very fine sand	30,9	0,3	1,1	0,0	0,1	12,8	1,3	0,0
Silt and Clay	14,7	0,5	0,5	0,0	0,0	1,5	0,5	0,0

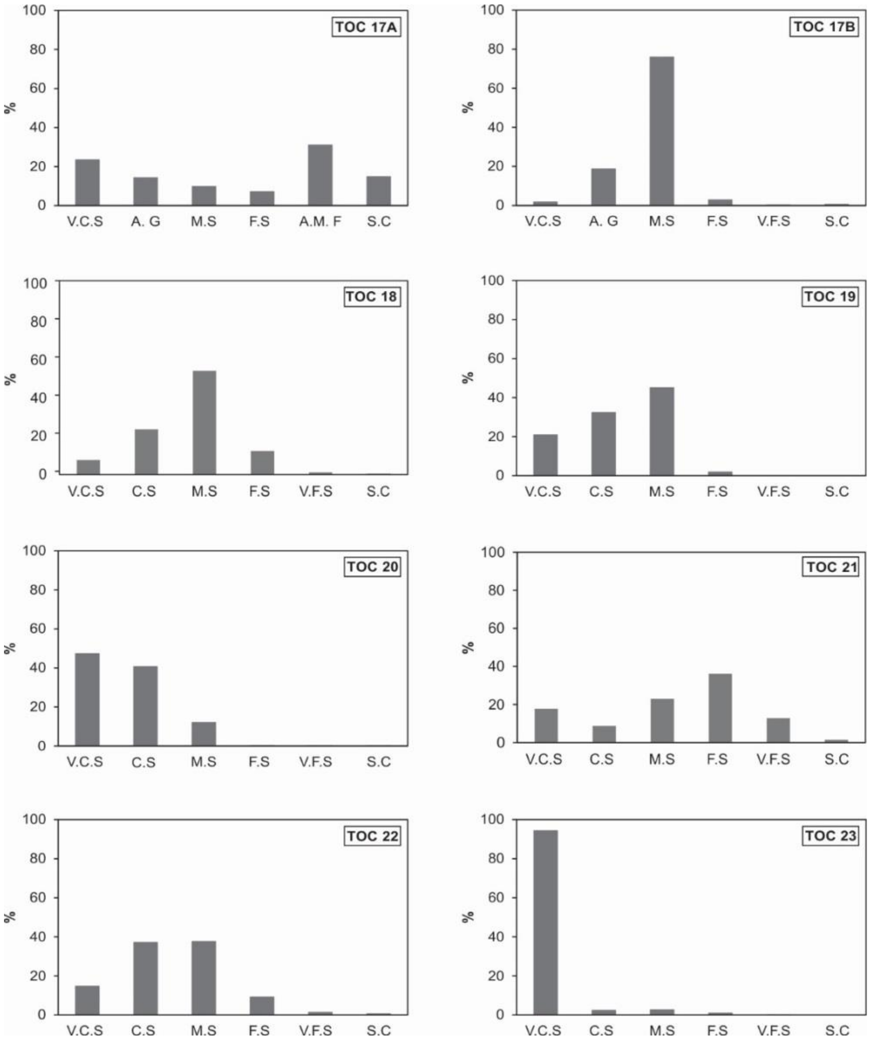

Figure 3 - Graphs showing the percentage distribution of the granulometric classes of the samples from the profile II, along the Tocantins River (upstream of the Tucunaré bar).

Profile III, Itacaiúnas River

The sediments from profile III, Itacaiúnas River, are represented by the TOC 24 to 29 samples, with granulometry varying from very coarse sand very fine sand and silty-clayey subordinately (Table 3; Figure 4). The ITC 24 sample is marked by very coarse sand (14.1%), coarse sand (25.4%) and fine sand (43.4%). The TOC 25, 26, 27, 28 and 29 samples display similar granulometry distribution, ranging in percentages: very coarse sand (14.4 - 75.2%), coarse sand (14.9 -38.1%) and medium sand (3.1 - 46.4%).

Heavy minerals & ztr index

The heavy minerals identified in three profiles are zircon, tourmaline, staurolite, rutile, kyanite, sillimanite, and garnet (Table 4; Figure 5).

The zircon grains have wide morphological diversity, lightly colored gray and brown, angular + sub-angular (An+Sub-an) and sub-rounded + rounded (Sub-ro + Ro) colorless, zoned, fractured and containing inclusions.

This mineral ranges in profiles: I (10.3 - 84.0%), II (2.6 - 57.0%) and III (5.6 - 61.8%). The profile I is An+Sub-an (7 - 20%) and Sub-ro + Ro (80-100%), with 33% and 67% anomaly

(TOC 12), respectively. In the profile II, two percentage groups represent the zircons: An+Sub-an (41 - 81% and 0 - 28%; TOC 17 A, B and 18) and Sub-ro + Ro (19 - 59% and 72 - 100%; TOC 19 to 23). The profile III is characterized by An + Sub-an (9 - 27%) and Sub-ro + Ro (35 - 91%) with 35% and 65% anomaly, respectively (ITC 26).

Table 3 - Percentage distribution of the granulometric classes of the TOC 24, 25, 26, 27, 28, 29 samples (Profile III).

	Sample					
Granulometric range	TOC 24	TOC 25	TOC 26	TOC 27	TOC 28	TOC 29
Very coarse sand	14,1	75,2	41,0	15,9	14,4	17,8
Coarse sand	25,4	14,9	38,1	37,4	33,7	33,9
Medium sand	7,2	3,1	17,4	45,8	46,4	42,7
Fine sand	43,4	2,2	2,8	1,0	2,7	4,0
Very fine sand	7,0	2,6	0,5	0,0	2,4	0,9
Silt and Clay	2,9	1,6	0,3	0,0	0,4	0,7

Table 4 - Percentage frequency (%) of the heavy minerals and ZTR index contained in the samples analyzed along the I, II and III profiles. Zir = Zircon; Tur = Tourmaline; Rut = Rutile; Sta = Staurolite; Kya = Kyanite; Sil = Sillimanite; Gar = Garnet; ZTR = Zircon + Tourmaline + Rutile.

	Sample	Zir	Tur	Rut	Est	Cia	Sil	Gra	TOTAL	ZTR
PROFILE I	TCO-10	63,3	29,7	3,0	3,3	0,0	0,0	0,0	100,0	96,0
	TCO-12	10,3	17,1	2,1	10,3	10,3	0,0	0,0	52,1	29,5
	TCO-13	78,3	14,3	2,7	3,7	0,0	0,0	0,0	100,0	95,3
	TCO-14	27,3	57,3	1,7	11,0	0,0	0,0	0,0	98,3	86,3
	TCO-15	84,0	10,0	1,7	1,7	0,0	0,0	0,0	98,3	95,7
	TCO-16	69,6	24,0	1,3	2,9	0,0	0,0	0,0	98,7	94,9
PROFILE II	TCO-17A	18,2	58,6	3,6	5,5	5,5	5,0	0,0	100,0	80,4
	TCO-17B	34,5	65,5	0,0	0,0	0,0	0,0	0,0	100,0	100,0
	TCO-18	57,0	20,8	2,9	6,7	3,5	4,0	5,0	100,0	80,7
	TCO-19	2,6	48,1	0,0	17,3	16,5	4,3	11,3	100,0	50,6
	TCO-20	40,9	51,0	1,7	2,3	1,0	0,0	4,0	100,9	93,6
	TCO-21	44,1	38,8	0,0	5,8	4,3	7,0	0,0	100,0	82,9
	TCO-22	39,1	51,3	0,6	1,6	7,4	0,0	0,0	100,0	91,0
	TCO-23	46,7	31,9	3,0	4,0	5,7	2,7	6,0	100,0	81,6
PROFILE III	ITC-24	47,4	22,4	2,0	13,6	8,9	5,0	1,2	100,6	71,8
	ITC-25	36,5	22,6	0,0	10,0	17,3	10,0	4,0	100,4	59,1
	ITC-26	23,6	47,3	0,0	11,7	12,4	2,8	3,0	100,8	70,9
	ITC-27	5,6	40,0	0,0	20,0	16,0	14,0	5,0	100,6	45,6
	ITC-28	27,3	35,5	0,0	4,5	22,7	5,0	5,0	100,0	62,8
	ITC-29	13,5	47,6	0,0	5,0	13,5	12,7	5,0	97,3	61,1

The tourmaline grains are characterized by yellowish, greenish and brownish colorations, with strong characteristic pleochroism, An + Sub-an, Sub-ro + Ro, and may contain cleavage, fractures and mineral inclusions. This mineral is present in all samples of the profiles: I (10.0 - 57.3%), II (20.8 - 65%) and III (22.4 - 66.8%). The tourmaline, profile I, is characterized by An + Sub-an (9 - 29%) and Sub-ro + Ro (71 - 91%) grains. The profile II (TOC 17 A to 19 and 23) and (TOC 20-22): Sub-ro + Ro (56 - 91% and 2 - 22%) and Sub-ro + Ro (9 - 44% and 78 - 98%), respectively. In the profile III (ITC 25 and 28) and (ITC 24, 26, 27 and 29): An + Sub-an (0 - 2% and 73 - 91%) and Sub-ro + Ro (98 - 100% and 9 - 27%), respectively.

The rutile grains are the reddish color, An + Sub-an, and Sub-ro + Ro and fractured. This mineral occurs in few amounts, varying of I (1.3 - 3.0%), II (0.6 - 3.6%) and III (0 - 2.0%). The profile I An + Sub-an (0 - 23%) and Sub-ro +Ro (77 -1 00%). The profile II (TOC 17 A, B and 19 to 23) and (TOC 18): An + Sub-an (0% and 71%) and Sub-ro + Ro (100% and 29%), respectively. The profile III occurs only in the sample ITC 24: An + Sub-an (33%) and Sub-ro + Ro (67%).

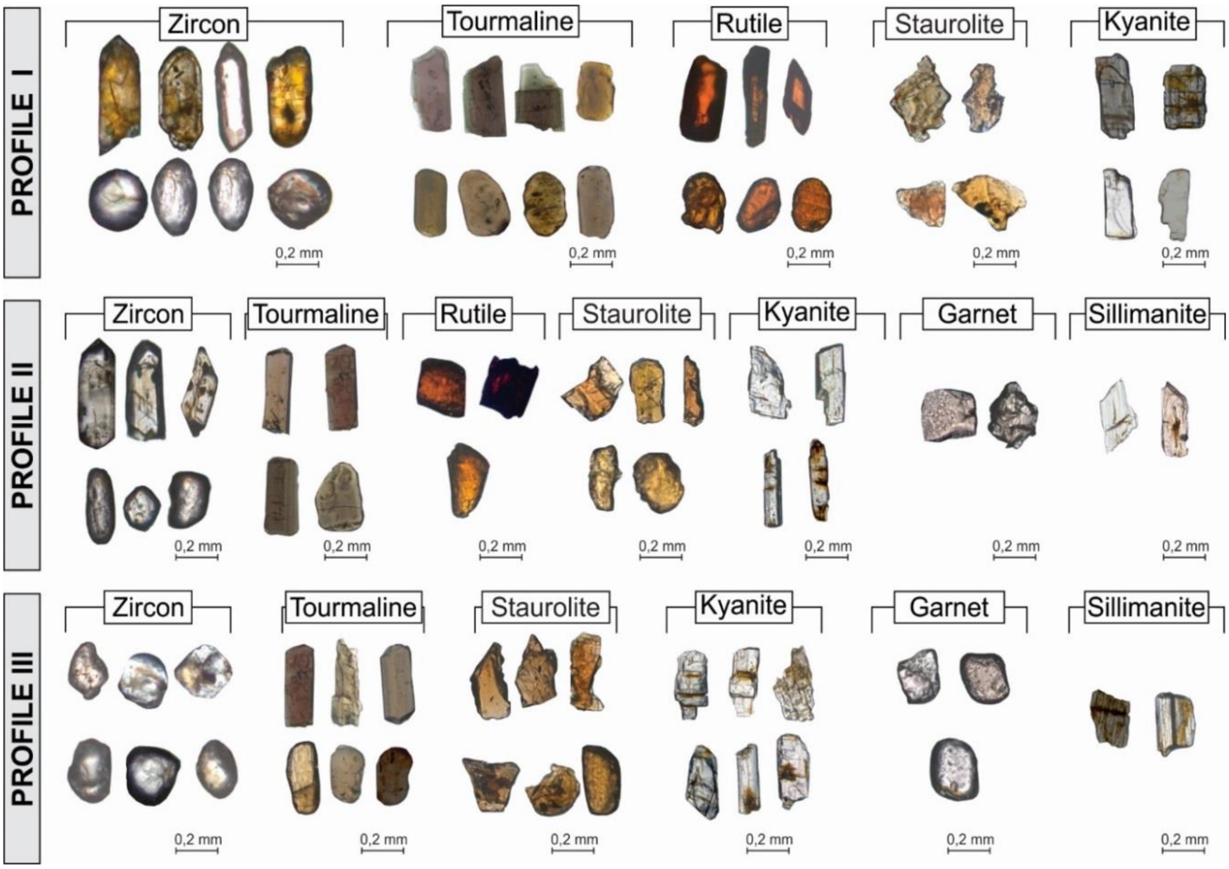

Figure 05 -Photomicrographs of heavy minerals representing the profiles I, II and III. The photomicrographs were obtained in 20x objective under natural light.

Staurolite grains are yellowish, An + Sub-an and Sub-ro + Ro, with "cockscomb" terminations. This mineral has a frequency of occurrence ranging from: I (1.7 - 11.0%), II (1.6 - 17.3%) and III (1.6 - 6.0%). Profile I (TOC 10 to 14, 16) and (TOC 15): An+Sub-an (0 - 33% and 60%); and Sub-ro + Ro (67 - 100% and 40%). Profile II (TOC 17 A, 18, 19) and (TOC 17 B, 20 to 23): An+Sub-an (71 - 100% and 0%) and Sub-ro + Ro (26 - 29% and 100%). In profile III (ITC 26, 27 and 29) e (ITC 24, 25 and 28): An + Sub-an (65 - 100% and 0 - 47%) and Sub-ro + Ro (0 - 35% and 53 - 100%), respectively.

The Kyanite minerals are colorless, have a prismatic tabular habit, An + Sub-an and Sub-ro + Ro, some are fractured. This mineral have frequency of I (0 - 10%), II (1.0 - 16.5%) and III (7.3 - 22.7%). In the profile I this mineral occurs only in TOC 12 and TOC 15, represented for An+Sub-an (13% and 67%) and Sub-ro + Ro (88% and 33%). Profile II (TOC 18, 19, 22) and (TOC 20, 21, 23): An+Sub-an (86 - 100% and 0 - 20%) and Sub-ro + Ro (0 - 100% and 80 - 100%). In profile III (ITC 24, 26, 27, 29) and (ITC 25 and 28): An + Sub-an (80 - 100% and 0 - 5%) and Sub-ro + Ro (0 - 20% and 95 - 100%), respectively.

The Sillimanite is presented with the predominance of tabular habit, An + Sub-an, and Sub-ro + Ro, colorless, high relief and high birefringence.

This mineral only occurs in the profiles II and III, with frequency varying from 2.7 to 7.0% (profile II) and 2.7 to 4.0% (profile III). In profile II it occurs only in samples (TOC 18 and 19) and (TOC 21 and 23): An+Sub-an (82 - 100% and 0 - 14%) and Sub-ro + Ro (0 - 18% and 86 - 100%). The profile III is characterized by An + Sub-an (70 - 100%) and Sub-ro + Ro (0 - 30%) with anomalies of 14% and 8 % (ITC 25), respectively.

The garnet grains are colorless and grayish, An + Sub-an and Sub-ro + Ro rough appearance and generally fractured. It occurs, also, only in profiles II (4.0 - 11.3%) and III (0.7 - 5.0%). In the profile II and III, when they occur, the garnet grains are essentially Sub-ro + Ro, occurring anomaly of An + Sub-an (64%) and Sub-ro + Ro (36%) in the ITC 27 sample.

The ZTR index throughout the studied profiles is characterized by I (86.3-96%), with an anomaly in TOC 12 (29.5%); II (80.4 - 100%), with variation in the TOC 19 sample (50.6%) and III (45.6 - 71.8%).

DISCUSSION

The granulometry data and heavy mineral assemblages from the sediments collected in the profiles I-III throughout the fluvial system Tocantins-Itacaiúnas had allowed evaluating transport dynamics and deposition aspects of the arenaceous sediments and its probable source areas. The sediment load is mainly represented by very coarse sand to medium sand and, subordinately, fine sand to silty-clayey.

In the profile I, upstream of the Tucunaré bar, the sediment-transport capacity is relatively low in the center of the canal of Tocantins River, increasing for its edges. The medium sand predominance in TOC 13 to 15 samples, in the center of the canal, grading for very coarse/coarse sand in TOC 10, 12 and TOC 16, in the edges of the canal, indicate that the development of arenaceous longitudinal bar in meandering fluvial systems, work as natural barriers, deviating the courses of the rivers (Christofoletti, 1981; Suguio & Bigarella, 1990; Morais et al., 2016; Bozi et. al., 2017). The sandy sediments accumulation can be attributed to variations in rainfall levels that affect transport competence (Christofoletti, 1981; Hooke, 1986; Santos et al., 1992; Luchiet al., 2010, Carvalho, 1994).

In addition, the anomalous Tocantins River width, up to 2.1000.17 m, at the confluence with the Itacaiúnas River, is an important factor to be considered. The TOC-16, on the right margin, upstream of the Tocantins River, presents bimodal granulometry, very coarse and very fine sand. The mixture of granulometric fractions can be attributed to the increase of water volume during flood periods of river systems that invade the floodplains (Christofoletti, 1981; Latrubesse et al., 2002).

In profile II, downstream of the Tucunaré bar, the TOC 20 sample has the largest percentage of very coarse and coarse sand. This demonstrate that the location of greater transport competence is close to the left margin, which is a common configuration in the curvatures of meandering river systems (Bayer, 2010; Christofoletti, 1974; Latrubesse et al., 2002; Morais et al., 2016). The samples TOC 17 B, 18 and 19, represented mainly by the medium sand fraction, which corroborate with the idea about a loss of transportation competence to the margins of the Tocantins River. The wide granulometric variation of TOC 17 A, 21 and 22, from very fine/fine sand and coarse/very coarse sand, shows a mixture of sedimentation processes between the floodplain and fluvial channel, comparatively similar to TOC 16 from the profile I. Moreover, the predominance of very coarse sand in TOC 23 represents the highest sediment transport competence of the Tocantins-Itacaiúnas Rivers confluence system.

In profile III, in the Itacaiúnas River, ITC 25 to 29, represented by very coarse sand to medium sand, constitute homogeneity of sediment transporting competency. This is probably due to the width of the Itacaiúnas River about 151.68 m, with shallow depths associated to natural rocky outcrops, found in the gutters of the river channel. The ITC 24 sample displays the same bimodal granulometric behavior of the samples TOC 16 and 17 A due to the variation of the transport energy in the floodplain.

Heavy minerals

The heavy mineral assemblages composed of zircon, tourmaline, rutile, staurolite, kyanite, sillimanite, and garnet, An + Sub-an (angular + sub-angular) and Sub-ro + Ro (Sub-rounded + rounded), occur along I-III profiles indicating igneous, metamorphic and sedimentary rock's source (Morton & Hurst, 1995).

The occurrence of An + Sub-an heavy minerals suggests the moderate and long distance transport of the sediments and/or the first sediment cycle, while Sub-ro + Ro grains may indicate distant sources. Zircon and tourmaline infer igneous and metamorphic sources, related to granites, pegmatites, schists, gneisses, and phyllites. Rutile grains indicate rock's sources as schists, gneisses, amphibolites and igneous rocks. Staurolite, kyanite, sillimanite, and garnet suggest metamorphic sources (Mange & Maurer, 1992; Nesse, 2004; Nascimento & Góes, 2007).

The high ZTR indexes in the profiles I and II indicate high mineralogical maturity, in association with the Sub-ro + Ro grains, indicate igneous and/or metamorphic rocks sources. Given that, these sources are probably from long distance that propitiated the reworking of these stable detrital heavy minerals: zircon, tourmaline, and rutile, eliminating unstable minerals, and/or may be related to sediments from others sedimentary basins near of the study area.

The Tocantins and Araguaia Rivers are river systems of kilometer extension, with the source in the Federal District and south of the Goiás state, respectively. Furthermore, these rivers drain across a broad substrate composed of igneous, sedimentary and metamorphic rocks, related to the Amazonian, São Luiz (Gurupi) and San Francisco Cratons, and also sedimentary basins from Amazonas, Parnaíba, Paraná, Paraná, Sanfranciscana and Parecis (ANA 2009).

The low ZTR index in TOC 12 is due to the percentage increase of metamorphic minerals such as staurolite and An + Sub-an kyanite, as a consequence of weathering/erosion of metamorphic rocks from the Couto Magalhães Formation by fluvial currents. In TOC 19 the ZTR anomaly may have been influenced by the addition of stable and moderately stable minerals of staurolite, kyanite, sillimanite, and garnet, probably related to the proximity of the Itacaiúnas River, which large amounts of sediments from metamorphic origin occur.

Moderates ZTR indices in the Itacaiúnas River, profile III, are resulting from proximal and distal heavy minerals sources. Probably sediments transported through long distances, containing essentially tourmaline and zircon and rutile were mixed with An + Sub-an kyanite and sillimanite from the erosion of metamorphic rocks from Couto Magalhães Formation, Araguaia Belt, and igneous rocks from the Amazonian Craton.

CONCLUSION

The granulometric characterization and heavy mineral assemblage analysis of the sediments from the Tocantins and Itacaiúnas Rivers, near Marabá city allowed concluding that:

Along the Tocantins River, the predominant granulometric classes are very coarse sand to very fine sand and silt-clay sediments, indicating a variation of transverse energy. The heavy mineral assemblage in this river consists of zircon, tourmaline, rutile, staurolite, being sillimanite and garnet restricted to the profile II. The diversity of shapes, roundness, colors, and textures of the heavy minerals suggest sources from igneous rocks of São Luiz and San Francisco Cratons, metamorphic rocks of Araguaia Belt and Sedimentary outcrop relate to Parnaíba Basin and Mocajuba Sub-Basin.

The sediments from Itacaiunas River is marked by the predominance of sediments with coarse to very coarse sand, indicating high energy of longitudinal flow.

The heavy mineral assemblage in this river consists of zircon, tourmaline, staurolite, sillimanite, and garnet. The heavy mineral occurrence angular/subangular indicates the proximity of source rock from igneous rocks and metamorphic rocks, probably from the Amazonian Craton and Araguaia Belt, respectively, and secondarily related to rocks of basins surrounding sediment known as the Parnaíba Basin and Mocajuba Sub-Basin, Marajó Basin.

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