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Quaternary colluvial episodes (Upper Paraná River Hydrographic Basin, Brazil)

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ABSTRACT

Colluvial deposits occur extensively in the Upper Paraná River Hydrographic Basin (UPRHB) in Southeaster Southern, and Western central Brazil. These deposits were recognized as an allostratigraphic unit and related creeping during the Quaternary. Every studied colluvial profile is homogeneous, which indicates relatively long p riods of landscape stability that is sufficient for the development of a thick soil cover. The deposits were dated luminescence and indicate periods of more intense colluvial deposition between 6 and 220 ky B.P. These events corr spond approximately to the transitions between the oxygen isotope stages 2-3-4 and 5-6, suggesting that this aggradati was influenced by climatic changes. However, the most important alluviation episode was tentatively correlated wi the Middle to Upper Pleniglacial of the Wisconsin glaciation. The most intensive and frequent periods of precipitati that occurred during climate transitions are probably correlated with aggradation events. The regularity of the colluv deposits suggests continuous uplift accompanied by sediment deposition throughout the UPRHB due to neotector activity during the last million years.

Key words: colluviation, alluviation, Quaternary, luminescence dating, Brazil.

INTRODUCTION

Eustasy plays an important role in the stratigraphic organization of marine sedimentary environments, but in continental depositional environments, climate and/or tectonic controls predominate (Shanley and McCabe 1994). The erosional and depositional processes that prevail in the Upper Paraná River Hydrographic Basin (UPRHB) are not restricted to the present, but occurred during most of the Quaternary. These processes generated colluvial and alluvial deposits over the entire hydrographic basin currently represented by the Upper Paraná River Allogroup (Sallun et al. 2007b). Local studies of the colluvial deposits are relatively common, but regional

In the past, it was not possible to obtain a ages of colluvial deposits, due to the absence equate samples for radiocarbon dating, which i monly lacking in sediments that accumulated af sion. Luminescence has been used by several to date colluvial deposits (Lang 1994, Lang an scheidt 1999, Eriksson et al. 2000, Yanchou et al Lang 2003), with excellent results when the age compared with radiocarbon data (Clarke 1996, La Wagner 1996). These methods are becoming more important in the study of colluvial depos cause they are suitable in any situation when quart are available and, in contrast to techniques that e synchronicity between relief stability and soil d dating, the effects of insufficient exposure of the quartz grains to solar radiations can result in overestimated ages of colluvial deposits (Murray et al. 1995, Olley et al. 1998, Eriksson et al. 2000, Yanchou et al. 2002).

The first step for the regional analysis is to compile the chronological data on cumulative frequency curves, which provides a more complete picture than local analysis. However, the available data at the regional scale are restricted, and all events are not recorded in the colluvium. Moreover, the colluviation rate or quantity of sedimentation by time interval can hardly be estimated. Lang (2003) in southern Germany, and Hanson et al. (2004) in Wyoming (USA) were able to identify regional patterns in colluvial deposits from the distribution of luminescence dating data.

In addition, the colluvial deposits are geoarchives that might record information about climate (Leopold and Völkel 2007) because they are influenced by climatic processes. Solving these events and processes requires additional studies, but in together with field evidence and possible paleoclimate proxy records the colluvial deposits can provide data about the processes of erosion, transportation, and deposition during the time of its formation (partly controlled by paleoclimatic parameters) (Leopold and Völkel 2007).

The colluvial sediments were studied due to their short distance of transport, the easy identification of their source rock, and their application in the understanding of regional environmental changes. Nevertheless, dating of the colluvium generally results in only maximum ages of the material because of constant reworking over time.

PALEOCLIMATE *versus* COLLUVIATION

The paleoclimatic record includes cyclic and gradual changes with different intensities and frequencies through time, and it is controlled by astronomical, geophysical, and geological phenomena. These changes are not due to an unique cause but are, rather, multicausal, and they act at different temporal and spatial scales. According to Milankovitch's (1920) astronomical theory, the insulation or effective solar radiation incidence on the Earth's surface depends on the following planetary

Broecker (1965) recalculated and confirmed Milankovitch's (1920) curve, and it generally showed good correlations with other paleoclimatic factors. The astronomical theory offers a coherent explanation for the sequence of main paleoclimatic functions, including the Quaternary glaciations, but there is no doubt that other factors also influenced global changes of the climate in this period. $\delta^{18}O$ (‰) values of deep water submarine cores have allowed the recognition of cold and warm phases during the Quaternary (Emiliani 1955), as a consequence of global paleoclimatic changes represented by glacial (even numbers) and interglacial (odd numbers) stades extending to the Upper Pliocene (Shackleton and Opdyke 1976, Shackleton 1997). In the $\delta^{18}O$ (‰) curves, the glacial-interglacial transitions are sharper than the interglacial-glacial transitions because the glaciers expanded slowly but disappeared more rapidly. Broecker and Van Donk (1970) denoted the sudden glacial-interglacial change as "glacial termination", subdividing the curve into glacial-interglacial stades.

Ages obtained through luminescence dating have been used to date the aggradation pulses of colluvial and alluvial sedimentation and to establish their possible correlations with global climatic changes. At the beginning of the arid climate, which would have begun a glacial stade, the reduced vegetation cover would have exposed the soils and made them more vulnerable to erosion, which would cause rapid reworking of the sediments from slopes during the climatic transition (Wells et al. 1987, Bull 1991). Knox (1972) developed a model to explain the more frequent and intense pulses of sediments generated by slopes during the Holocene in Wisconsin (USA), where the precipitation increase caused a quick leveling of slope sediments, and the major vegetation density along stable slopes could have reduced the quantity of available sediments. The models suggested less accentuated erosion under stable climates and more abundant sedimentation during climatic transitions. Nevertheless, few studies have referred to colluvial sedimentation increases during climatic transitions through direct dating of the colluvial sediments. This study tentatively suggests a possible synchronicity be-

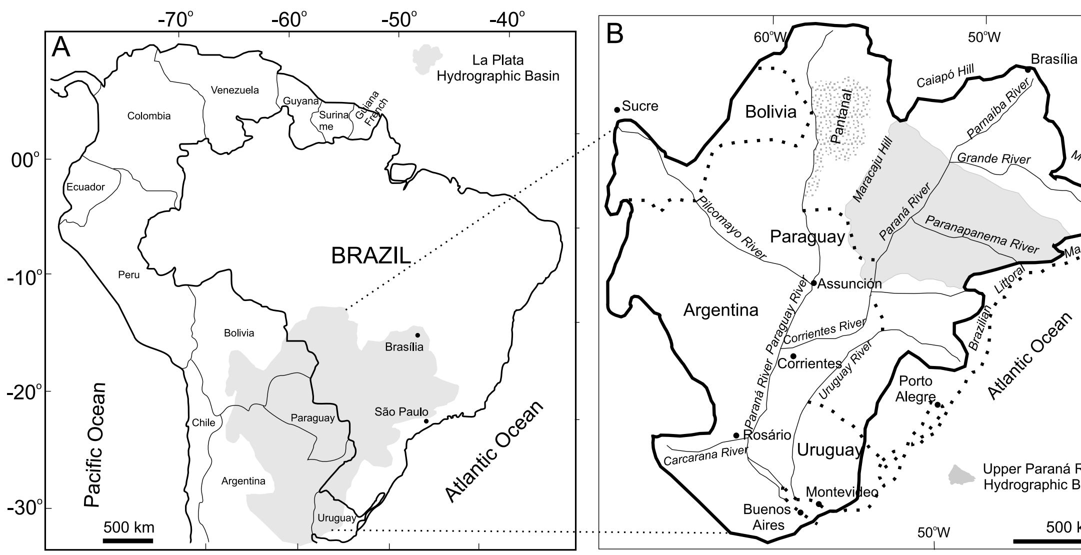


Fig. 1 – Geographic location map of the La Plata Hydrographic Basin in South America (A), emphasizing the UPRHE

Study Area

The Paraná, Paraguay, La Plata, Pilcomayo, and Uruguay Rivers, form the La Plata River Hydrographic Basin (Fig. 1). According to different characteristics, the Paraná River can be divided into five segments. This study was done in the sector called the "Upper Paraná River", which extends for about 619 km in the Southeastern, Southern, and Western-central regions of Brazil. The main geographic limits of the UPRHB are the Grande and Paranaíba Hydrographic Basins and Serra do Caiapó to the north, the Brazilian Littoral Massif (Serra do Mar) to the east, the Iguaçu River Hydrographic Basin to the south, and the Paraguay River Hydrographic Basin and Serra de Maracaju to the west. Due to differences in the uplift rates among the main rivers, tributaries in the eastern margin, whose headwaters are situated in the Littoral Massif crystalline rocks, are 400 to 600 km longer in comparison to the longest right margin tributaries. The latter with lengths less than 400 km, are situated in the Paraná Sedimentary Basin with their headwaters placed at Serra de Maracaju and Serra do Caiapó (Stevaux 2000).

As a consequence of the uplift of the Brazilian Littoral Massif, intense erosional processes were estab-

cles and the generation of flat surfaces, such as th
plains Pd_1, Pd_2, and Pd_3 (Bigarella and Andrade
and Pd_0 (O.J. Justus 1985, unpublished data) or
American Surface", the Velhas and Paraguaçu
(King 1956, 1967), or surfaces of "High Interf
"Middle Interfluves", and "Upper Terrace" (Soa
Landim 1976), and the "Guaíra Surface" (Bartl
1960).

GEOLOGICAL CONTEXT

In the study area, Quaternary deposits overlie Cret
sandstones (Bauru Supersequence) and basalts
wana III Supersequence), both belonging to the
Sedimentary Basin (Renne et al. 1992, Dias Brit
2001). Sallun et al. (2007b) formally proposed the
Paraná River Allogroup as Quaternary stratigraph
that occur overlying Cretaceous rocks of the Paran
in the UPRHB (Fig. 2). The Upper Paraná Ri
logroup is composed of colluvial (Paranavaí Allo
tion) and alluvial (Paraná Alloformation) deposi
Cretaceous sedimentary rocks are essentially sanc
therefore, the colluvial and alluvial Quaternary d
are also relatively homogeneous (grain-size distr
and mineralogical characteristics).

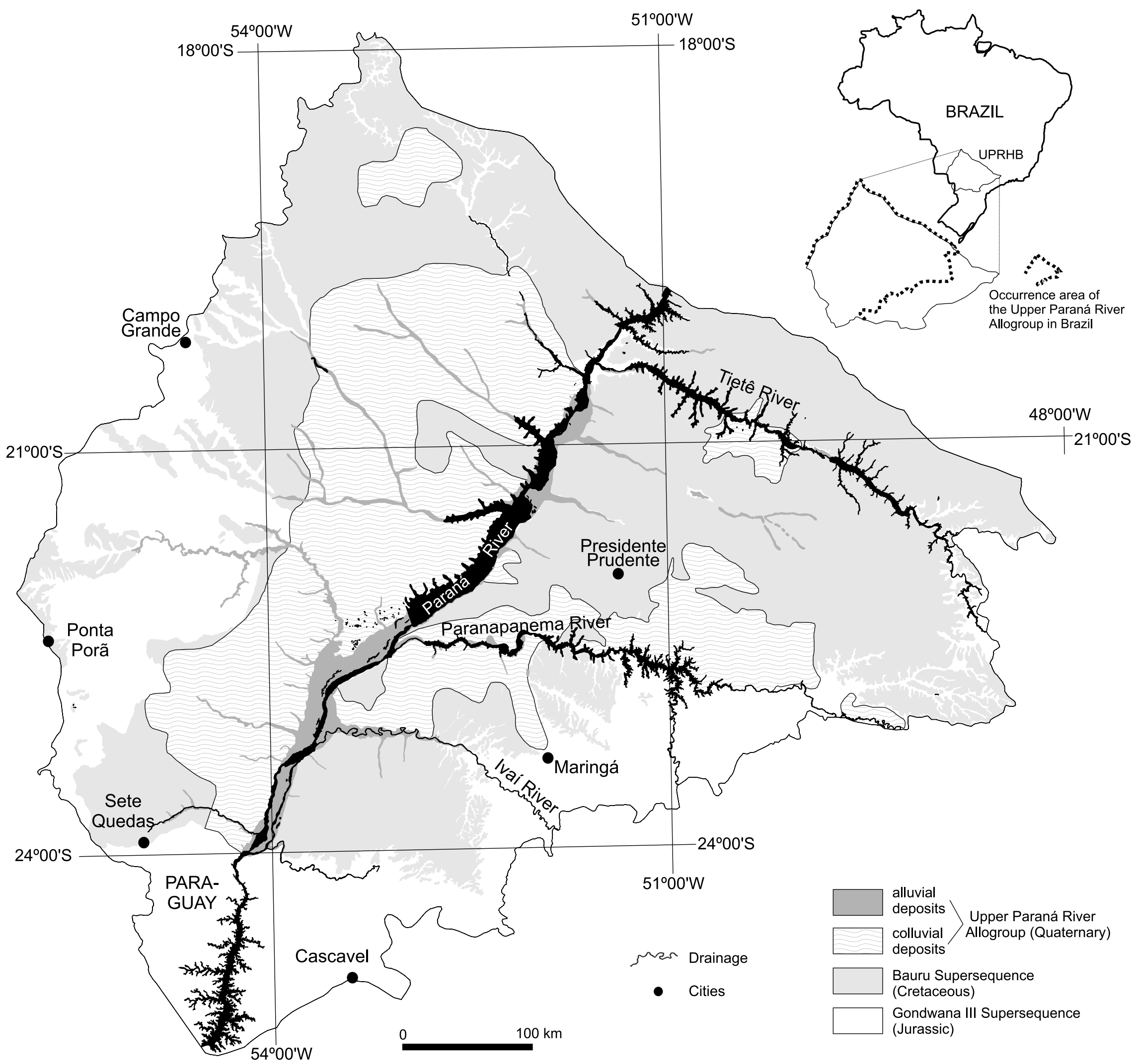


Fig. 2 – Geologic map of the occurrence of the Upper Paraná River Allogroup in the UPRHB according to Sallun et al. (2007a).

of unconsolidated, reddish-colored, very fine to coarse sands. The upper boundary corresponds to a horizon formed by present pedogenesis, and the lower boundary is represented by the contact with the Paraná Basin Cretaceous rocks of Bauru and Gondwana III Supersequences, which includes centimetric ferricrete nodules and stonelines.

The Paranavaí Alloformation colluvial deposits are mainly composed of sandy and clayey sandy. There are being probably formed in place or after transportation for a short distance by creeping. In general, they are oligomictic ortoconglomerates without internal arrangement that contain clasts from granules to subrounded to rounded boulders, properties that were probably inherited from the source rock (Sallun and Suguio 2008, Sallun et al. 2008). The fragments exhibit punctual and locally concave-convex contacts whose longest diameter can reach 1 cm. The pebbles are dominated by quartz

The Paraná Alloformation is composed of alluvial deposits associated with the Upper Paraná paleodrainage, besides the present course and tributaries, preserved as terraces or modern alluvial deposits of the Upper Paraná River tributaries within the Paranavaí Alloformation. The fluvial terraces are situated in several topographic levels (high, middle and low) along both margins of the Paraná River. The terraces are made up of sandy and pebbly deposits (sand with gravel and iron-hydroxide cemented conglomerates), massive, whitish-to dark grayish-colored facies, which are suggestive of channel, sandy sheet, floodplain, natural levee, crevasse splay, and point-bar deposits (Stevaux 2000). The lacustrine deposits formed on the Paranavaí Alloformation are also included in the Paraná Alloformation.

Geoprocessing techniques were used for mapping the distribution of Quaternary deposits of the Alto Rio Paraná Allogroup within the UPRHB (Sallun et al. 2007a). Through data crossing obtained by field surveys, remote sensing products and thematic maps using Geographic Information System (GIS), the morphostratigraphic characteristics of this allostratigraphic unit and their relationship with erosional surfaces were identified (Sallun et al. 2007a).

The occurrences of different lithoestratigraphic units in the Paraná Basin, as well as regional tectonic structures and differences in thicknesses of colluvial Paranavaí Alloformation and alluvial Paraná Alloformation, are responsible for the relief compartimentation. The surface is mainly composed of very flat hills conditioned by thicker Paranavaí Alloformation colluvial deposits, which gives rise to lower declivity and rugosity of extensive hillslopes (Sallun et al. 2007a).

MATERIALS AND METHODS

Due to the low diversity of Quaternary sedimentary deposits in the area, the colluvial deposits are the most important stratigraphic record. They are abundantly distributed throughout the study area. Moreover, they can be dated by luminescence methods back to about 1 My (Tatumi et al. 2006). All the luminescence dates obtained to date were gathered here to attempt a regional

to date the last exposure of the quartz grains in the
vium to sunlight. Before sampling, the outcrop s
were grazed for removal of more leached superfic
terials to avoid contamination by inclusion of r
grains with different ages. The samples were co
with opaque PVC tubes, which were introduced h
tally by percussion with a hammer.

The TL and OSL dating were carried out
Laboratory of Glasses and Dating of the Facul
Tecnologia de São Paulo, Brazil (FATEC-SP).
vent problems associated with the translocation
grains, quartz grains 88–180μm in diameter w
tained after chemical treatments with 20% HF
min, 20% HCl for 2 hours, and heavy liquid (SPT
ration. OSL measurements with infrared excitatio
performed on the samples in the absence of f
crystals. TL and OSL shine-down curves were o
with a Daybreak Nuclear and Medical Systems In
rated, Model 1100-Series Automated TL/OSL S
Quartz crystals were stimulated with green ligh
ted by a Xe-lamp and filtered with an optical fi
Hoya U-340 (290–370 nm) optical filter was u
detection of the OSL. All of the γ-irradiation w
formed with a ^{60}Co source, and, for bleaching
ments, the samples were submitted directly to s
for 16 hours. Natural radioactive isotope cont
the samples were determined with gamma spectr
using an Inspector Portable Spectroscopy Work
lead shield model 727, and a Canberra 802
detector.

Paleodose values were obtained using the t
generation method and multi-aliquot protocols (
1998). In this technique, one limitation is the frequ
currence of high levels of scatter with the growth
This occurs because of variations in the mass an
properties from aliquot to aliquot. Therefore, th
ural Normalization (NN) method was used in o
correct the OSL sensitivity variations of the gra
to avoid significant age underestimation (Stokes
In some samples, paleodose values were obtaine
the Single Aliquot Regeneration (SAR) method,
uses repeated measurements on a single sample (

TABLE I

Sample numbers, natural radioactivity, paleodoses (P), annual doses (AD), and ages by luminescence for samples from colluvial deposits. Green and blue stimulation were used for OSL measurements. (*OSL SAR).

Sample ID	Depth (m)	$^{235}U+^{238}U$ (ppm)	^{232}Th (ppm)	^{40}K (%)	AD (μGy/yr)	P-TL (Gy)	P-OSL (Gy)	TL Age (ky)	OSL Age (ky)
5	1.50	1.519 ± 0.038	2.20 ± 0.065	0.034 ± 0.003	943 ± 22	46.10	42.50	48.8 ± 6	45 ± 5.5
6	3.00	1.152 ± 0.029	0.309 ± 0.009	0 ± 0	593 ± 10	14.50	18.81	24.5 ± 2.8	31.7 ± 3.7
10	3.00	1.137 ± 0.028	2.063 ± 0.061	0.031 ± 0.003	755 ± 17	48.90	42.18	64.7 ± 7.9	55.8 ± 6.8
	8.00	1.218 ± 0.003	1.899 ± 0.056	0.036 ± 0.003	800 ± 19	104.00	97.9	130 ± 16	122 ± 15
13	4.00	1.013 ± 0.025	0.551 ± 0.016	0 ± 0	663 ± 12	64.70	62.0	97.5 ± 11.5	93.4 ± 11
14	1.00	0.739 ± 0.018	0.659 ± 0.019	0 ± 0	531 ± 9	16.20	18.13	30.5 ± 3.5	34 ± 4
	6.50	1.112 ± 0.028	0.710 ± 0.021	0.071 ± 0.007	785 ± 21	51.35	52.68	65.4 ± 8.3	67 ± 8.5
	16.50	0.675 ± 0.017	0.406 ± 0.012	0 ± 0	500 ± 9	79.40	82.39	158 ± 18.5	164 ± 19
16	2.00	0.598 ± 0.016	0.502 ± 0.015	0 ± 0	463 ± 8	13.25	15.49	28.6 ± 3.3	33.4 ± 3.9
18	3.00	1.124 ± 0.029	3.371 ± 0.087	0 ± 0	717 ± 14	32	69	44.6 ± 5.1	96.2 ± 11.1
19	5.00	0.582 ± 0.015	1.747 ± 0.045	0.022 ± 0.002	478 ± 14	55	33	115 ± 13.2	69 ± 7.9
20	9.00	0.691 ± 0.018	2.071 ± 0.053	0 ± 0	508 ± 9	140	343	275.6 ± 31.7	675.2 ± 77.7
21	1.00	1.703 ± 0.044	5.107 ± 0.133	0.014 ± 0.001	1010 ± 23	166	198	109.4 ± 12.6	130.4 ± 15
28	3.00	1.216 ± 0.032	3.648 ± 0.097	0 ± 0	761 ± 16	14	18	18.4 ± 2.1	23.7 ± 2.7
30	2.00	0.588 ± 0.016	1.763 ± 0.047	0 ± 0	458 ± 8	36	42	78.6 ± 9	91.7 ± 10.5
36	1.00	0.665 ± 0.016	1.995 ± 0.049	0 ± 0	495 ± 8	22	18	44.4 ± 5.1	36.4 ± 4.2
	6.50	0.557 ± 0.014	1.672 ± 0.042	0 ± 0	443 ± 7	149	192	336.3 ± 38.7	433.4 ± 49.8
40	1.00	1.158 ± 0.029	3.474 ± 0.024	0.0177 ± 0.0018	752 ± 11	8.20	6.9	10.9 ± 1.2	9 ± 1
	6.00	0.564 ± 0.014	1.692 ± 0.008	0.0526 ± 0.0054	501 ± 10	60.30	57.19	120 ± 14	114 ± 13.5
44	1.00	0.781 ± 0.021	2.343 ± 0.011	0 ± 0	551 ± 6	14.72	12.02	26.7 ± 2.9	21.8 ± 2.4
45	2.00	0.593 ± 0.015	1.779 ± 0.005	0 ± 0	461 ± 4	10.85	9.78	23.5 ± 2.5	21.2 ± 2.3
48	3.00	1.336 ± 0.033	4.008 ± 0.043	0.0424 ± 0.0043	863 ± 16	26.0	29.14	30 ± 3.5	33.7 ± 4
52	3.00	0.735 ± 0.018	2.205 ± 0.032	0 ± 0	529 ± 7	17.48	15.95	33 ± 3.7	37.7 ± 4.2
58	5.00	0.784 ± 0.020	2.352 ± 0.028	0.0439 ± 0.0045	598 ± 12	32.17	35.76	53.7 ± 6.4	59.8 ± 7
61	4.00	1.470 ± 0.037	4.41 ± 0.04	0 ± 0	884 ± 13	24.98	23.02	28.2 ± 3.2	26 ± 2.9
62	3.00	1.018 ± 0.026	3.054 ± 0.078	0 ± 0	666 ± 13	20.15	21.93	30.2 ± 3.6	33 ± 4
68	3.00	0.707 ± 0.018	2.121 ± 0.054	0 ± 0	516 ± 9	9.55	9.05	18.5 ± 2	17.5 ± 2
69	3.00	1.123 ± 0.027	3.370 ± 0.083	0 ± 0	717 ± 13	39.75	35.94	55.4 ± 6.5	50 ± 6
72	3.00	1.352 ± 0.034	4.055 ± 0.051	0 ± 0	827 ± 16	33	25	39.9 ± 4.6	30.2 ± 3.5
74	3.00	1.391 ± 0.037	4.172 ± 0.054	0 ± 0	674 ± 12	117	169	173.6 ± 20	250.7 ± 28.8
76	2.00	0.941 ± 0.024	2.822 ± 0.012	0 ± 0	846 ± 18	59	106	69.7 ± 8	125.3 ± 14.4
80	3.50	0.571 ± 0.015	1.714 ± 0.021	0.096 ± 0.010	628 ± 12	25	26	39.6 ± 4.6	41.2 ± 4.7
85	3.00	0.424 ± 0.011	1.273 ± 0.003	0 ± 0	548 ± 18	62	60	113.1 ± 13	109.5 ± 12.6
89	2.00	0.616 ± 0.017	1.848 ± 0.012	0 ± 0	379 ± 5	21	11	55.4 ± 6.4	29 ± 3.3
91	4.00	0.502 ± 0.013	1.506 ± 0.02	0.023 ± 0.002	472 ± 8	82	186	173.7 ± 20	394.1 ± 45.3
95	3.50	0.577 ± 0.015	1.732 ± 0.054	0 ± 0	440 ± 9	25	43	56.8 ± 6.5	97.7 ± 11.2
98	3.50	0.82 ± 0.02	2.46 ± 0.05	0.059 ± 0.006	475 ± 9	11	10	23.2 ± 2.7	21.1 ± 2.4
100	2.00	0.60 ± 0.01	1.82 ± 0.04	0 ± 0	453 ± 7	29	24	64 ± 7.4	53 ± 6.1
104	6.00	0.68 ± 0.01	2.06 ± 0.05	0.009 ± 0.0009	467 ± 7	12.74	13.76	27 ± 3	29 ± 3.5
105	2.00	2.17 ± 0.05	6.53 ± 0.17	0.013 ± 0.0013	517 ± 10	101.4	105	196 ± 22	203 ± 24
111	1.50	1.35 ± 0.03	4.07 ± 0.09	0.004 ± 0.004	1.420 ± 29	95.37	91.4	76.8 ± 9.5	73.6 ± 9
112	7.00	0.98 ± 0.02	2.94 ± 0.07	0.010 ± 0.001	591 ± 11	13.2	21.8	22.3 ± 2.5	36.3 ± 4.3
114	3.50	0.75 ± 0.01	2.27 ± 0.05	0 ± 0	660 ± 13	31.0	41.0	46.9 ± 5.6	46.9 ± 5.6
115	4.00	0.59 ± 0.01	1.77 ± 0.04	0.032 ± 0.003	716 ± 13	28.20	39	39.2 ± 4.5	54.2 ± 6.4
118	4.00	0.89 ± 0.02	2.68 ± 0.06	0.014 ± 0.001	541 ± 9	13.36	13.71	24.7 ± 2.8	25 ± 3
120	3.50	1.15 ± 0.02	3.46 ± 0.008	0 ± 0	622 ± 12	10.16	12.37	16.3 ± 2	19.5 ± 2.3
121	1.00	3.2851 ± 0.0857	1.0950 ± 0.0286	0 ± 0	630 ± 13	24.64	21.74	39 ± 4.5	50 ± 6
125	4.00	2.3492 ± 0.0631	0.7831 ± 0.0210	0.0096 ± 0.0010	885 ± 17	58	247	136.7 ± 15.7	279.1 ± 32.1
127	5.00	1.1289 ± 0.0269	0.3763 ± 0.0089	0.0043 ± 0.0005	638 ± 11	14	14	21.9 ± 2.5	21.9 ± 2.5
128	3.50	2.9031 ± 0.0766	0.9677 ± 0.0255	0 ± 0	812 ± 15	103	251	126.9 ± 14.6	309.1 ± 35.6
S01	2.00	1.06 ± 0.10	3.89 ± 0.39	0.0015 ± 0.002	760 ± 60	87.4	94.83	115 ± 14	124 ± 15*

TABLE II
Sample numbers, natural radioactivity, paleodoses (P), annual doses (AD), and ages by TL and OSL for samples from alluvial deposits.

Sample ID	Depth (m)	$^{235}U+^{238}U$ (ppm)	^{232}Th (ppm)	^{40}K (%)	AD (μGy/yr)	P-TL (Gy)	P-OSL (Gy)	TL Age (ky)	OSL Age (ky)
9	1.70	0.565 ± 0.013	0.455 ± 0.013	0 ± 0	446 ± 7	16.2	14.5	36 ± 4.1	32 ± 3.7
15	1.00	1.571 ± 0.041	2.469 ± 0.073	0 ± 0	933 ± 20	18.6	24.00	20 ± 2.4	25 ± 3
24	1.00	0.796 ± 0.019	2.386 ± 0.057	0 ± 0	558 ± 9	46	49	82.4 ± 9.5	87.8 ± 10.1
	9.00	0.462 ± 0.001	0.252 ± 0.007	0 ± 0	397 ± 6	15.3	13.5	38.5 ± 4.4	34 ± 3.9
96	9.00	1.41 ± 0.36	4.25 ± 0.11	0 ± 0	859 ± 18	88.64	88.43	103 ± 12.5	102 ± 12.5
99	6.00	0.47 ± 0.01	1.41 ± 0.03	0.221 ± 0.002	424 ± 8	49.65	71.40	155 ± 18	168 ± 20
103	1.50	0.79 ± 0.02	2.37 ± 0.06	0 ± 0	556 ± 10	48.50	50.40	87 ± 10	90.5 ± 10
108	1.00	0.35 ± 0.008	1.05 ± 0.026	0.007 ± 0.0008	352 ± 5	9.59	9.11	27.2 ± 3.1	25.8 ± 3
117	4.00	0.43 ± 0.01	1.31 ± 0.03	0 ± 0	386 ± 5	18.78	19.34	48.5 ± 5	50 ± 5.7

The cosmic ray contribution was virtually calculated for the study area (Engenheiro Sérgio Motta Dam at Porto Primavera), and a value of 174.22 μGy/yr was found (Sallun et al. 2007c) using the Prescott and Stephan (1982) protocol.

The regional analysis of the chronological data was done by graphical methods. For this, the ages obtained by luminescence of the colluvial sediments were considered according to the age distribution frequencies in the Gaussian curve. The occurrence probabilities were calculated for every 5,000 year interval, and Gaussian curves were generated, in addition to the age curves representative of the maximum and minimum ages obtained by luminescence. The curves were equally spaced at 50,000 year intervals, and the standard deviation for each curve was adjusted at 10%.

RESULTS

In this study, Quaternary ages were obtained for the colluvial and alluvial deposits (Tables I and II), as in Tatumi et al. (2006). The natural radioactive content of the colluvium and alluvium samples are shown in Tables I and II. The data indicate that ^{40}K contents were almost zero. We also did not observe the presence of feldspar crystals, which may explain the very low concentration of ^{40}K in the samples.

The comparison of ages obtained by luminescence (with the respective errors) in the colluvial deposits and the $\delta^{18}O$ (‰) global change curve of sunlight intensi-

concentration of ages occurs between 6,000 to 2 years B.P., which includes the period from the Il Glaciation, passing through the Sangamon Inter until the end of the Wisconsin Glaciation. There i in the record between 675,000 and 850,000 yea The ages of the colluvial deposits were also co with the $\delta^{13}C$ (‰) data obtained from speleothem Botuverá Cave in southern Brazil, which were stu Cruz Jr. et al. (2005). The record did not allow a relation with the $\delta^{13}C$ (‰) changes that are indica paleotemperature oscillations measured by those (Fig. 3).

The comparison between the ages obtained minescence, with the respective errors, of the Alloformation alluvial deposits and the global c of oxygen isotope ratios $\delta^{18}O$ (‰), insolation, sion, obliquity, eccentricity, and geomagnetic p are shown in Figure 4. The greater concentration is between 15,000 to 50,000 years B.P., which sponds to the middle to upper Pleniglacial of the W sinian glaciation, that is, the last North-American tion. The same ages of the Paraná Alloformatio 120,000 years B.P., were also compared with th (‰) obtained data from the Botuverá cave (Cru al. 2005), but they did not correlate them with th (‰) changes that are indicative of paleotemperat cillations (Fig. 4).

DISCUSSION

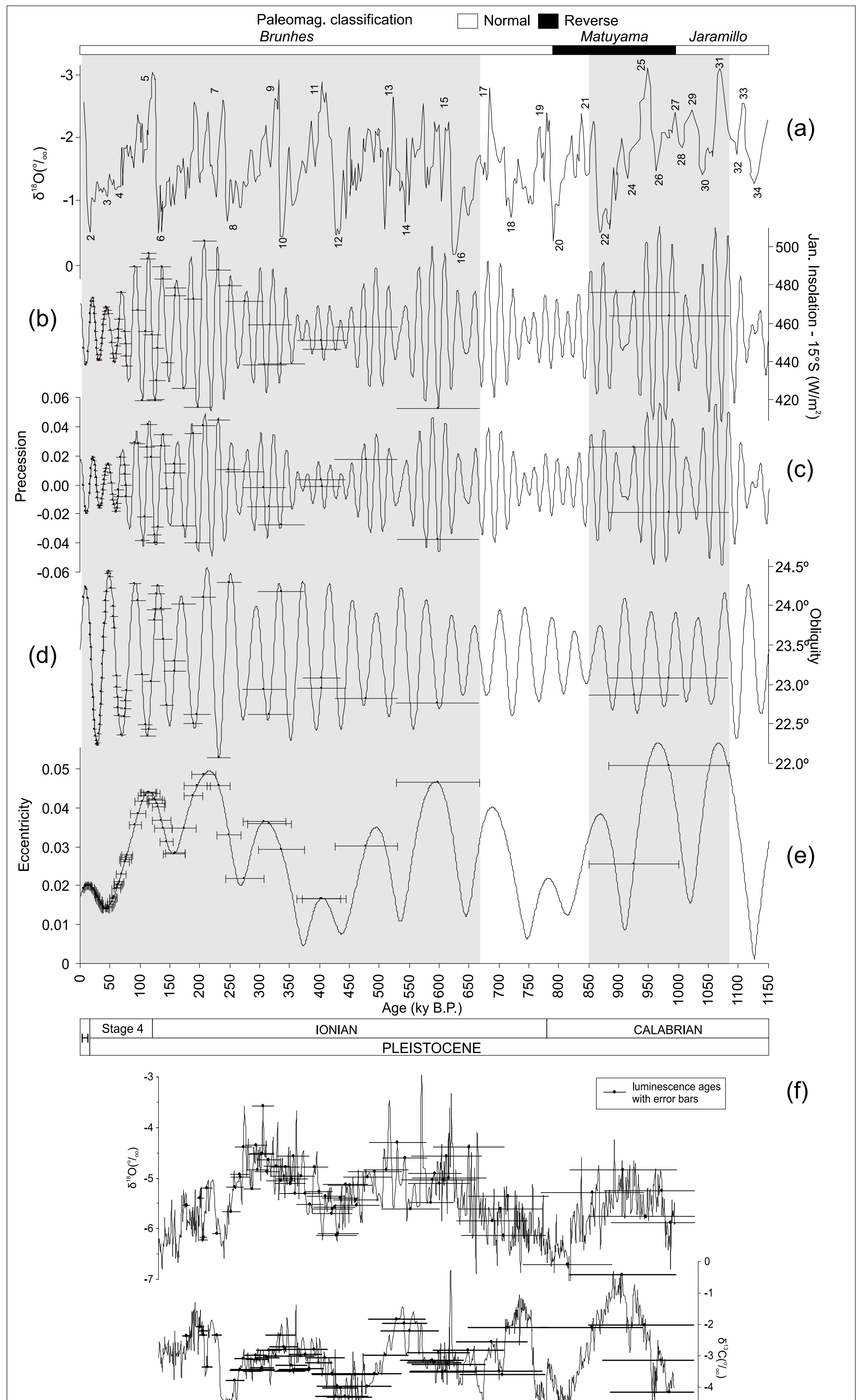

Paleomag. classification
Normal
Reverse
Brunhes
Matuyama
Jaramillo
(a)
(b)
(c)
(d)
(e)
(f)
Jan. Insolation - 15°S (W/m²)
Precession
Obliquity
Eccentricity
Age (ky B.P.)
H
Stage 4
IONIAN
CALABRIAN
PLEISTOCENE
luminescence ages with error bars

Fig. 3 – Comparison between the ages obtained by TL-OSL methods (in x10^3 years B.P.) and the respective analytical errors in the F
Alloformation colluvial deposits (circles with error bars) plotted with the same ages of several paleoclimatic proxy records: (a) δ^{18}O %
curves obtained from the compositional data of deepsea cores of the Pacific Ocean (Petit et al. 1999) – cores V19-30 (3S/83W – Sh
and Pisias 1985), ODP-677 (1°12′N/83°44′W – Shackleton et al. 1990) and ODP-846 (3°05′42″S/ 90°49′06″W – Shackleton et al. 19
indicators in numbers of glacial (below) and interglacial (above) stades based on Bassinot et al. (1994); (b) January insolation at 15
W/m^2 (Berger and Loutre 1991); (c) Equinoxial precession during the perihelium, when the Earth is nearest the Sun (Berger 1992); (d) E
obliquity (Berger 1992); (e) Terrestrial orbit eccentricity (Berger 1992); (f) isotopic curves (δ^{13}C and δ^{18}O) obtained from the Botuv
(Cruz Jr. et al. 2005) in the Southern Brazil (27°13′24″S/ 49°09′20″W). Quaternary geologic time scale is in accordance with Ogg an
(2008) (H: Holocene), and the geomagnetic polarity calibration time scale was taken from oceanographic data by S.J. Crowhurst (Delph
2002 – http://www.esc.cam.ac.uk/delphi/) and modified from Funnel (1996). Ages in x10^3 B.P., with origin 0 in year 1950 A.C.

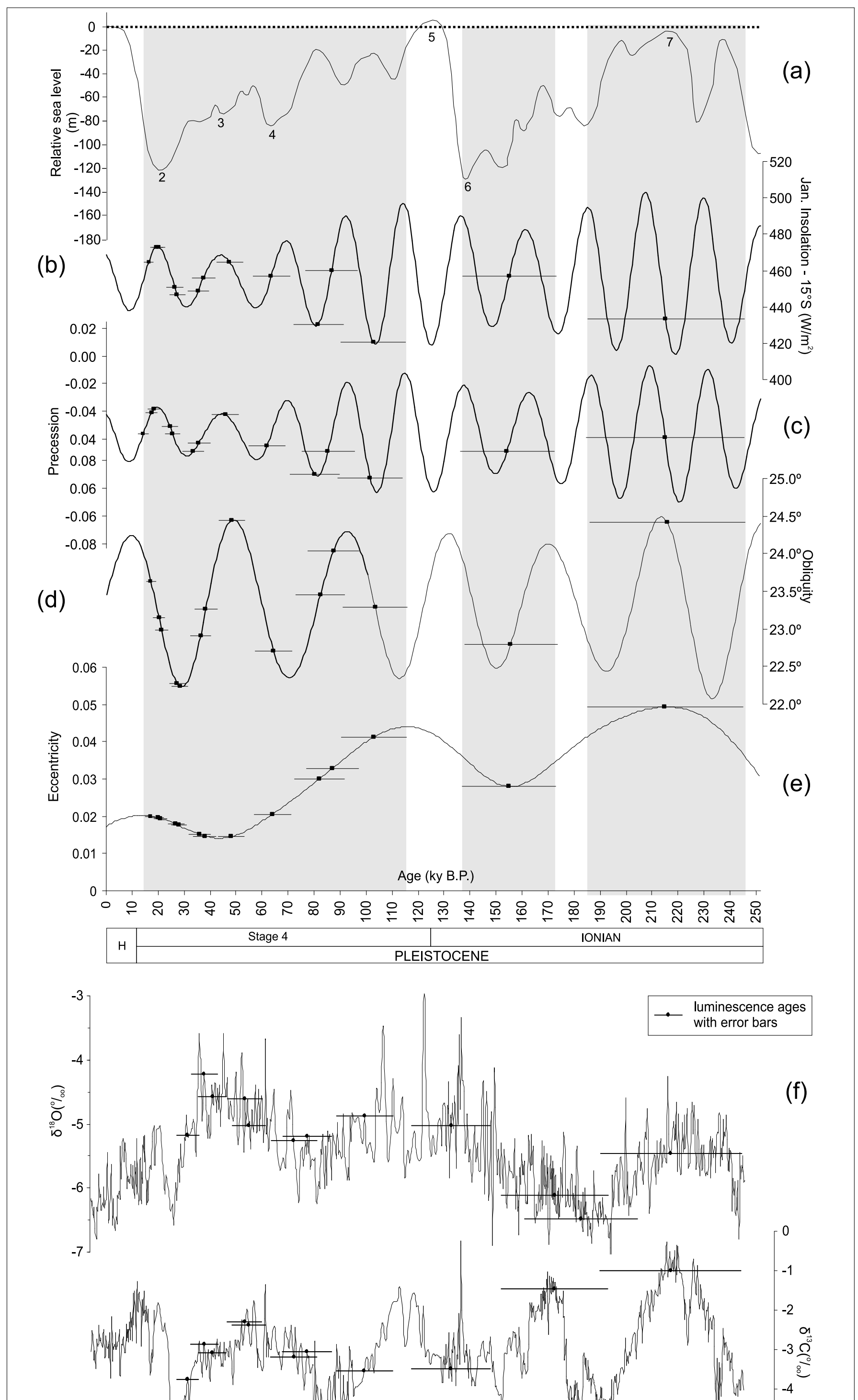
sidered by neglecting the deposited volumes. Therefore, the ages can represent the main or secondary colluviation episodes, but they do not distinguish them.

The obtained ages are shown in cumulative probability curves, wich are represented by Gaussian distributions generated from the ages and analytical errors of the colluvial deposits. The ages clearly indicate more intensive colluviation phases, and the better preservation of deposits for the last 135 ky record, probably associated with paleoclimatic fluctuations that occurred among the oxygen isotope curve shown in Figure 5A. The δ^{18}O (‰) isotope stage curves show correlations among inferred events of colluvial aggradation represented by the ages of the probability peaks. The diagram shows aggradational events, with most of luminescence ages situated on two probability peaks, between about 13,000 to 64,000 years and 125,000 to 135,000 years B.P. It is remarkable that the age records from 1,100,000 to 135,000 years are rare, erroneously suggesting that a lower frequency of colluvial processes has occurred. The considerable thicknesses of older deposits suggest that a reworking of the older colluvial deposits, aggradation and degradation events, toward younger cycles, probably occurred at ages less than 135,000 years B.P. There is a dominance of colluvial deposits with ages between 13,000 to 64,000 years B.P., possibly because the "zeroing" during the subsequent period was insufficient. The absence of deposits with ages between 675,000 and 850,000 years B.P. could indicate a period of paleoclimatic and paleotectonic quietness or a subsequent strong

The luminescence ages of the Paranavaí A
mation deposits suggest multiple episodes of ag
tion during glacial-interglacial transitions. It co
occur as an unique pulse sediment arrival in t
cial-interglacial transition, but as a series of aggr
events at the millennial scale, represented by seve
posits approximately correlatable with the identifie
gen isotope stages. We recognized at least two m
portant colluvial aggradation episodes, approxima
the transitions between isotope stages 2-3-4 and

The colluvial aggradation episodes could ha
curred during rapid climatic changes, detache
colder and drier stades, but the colluviation episod
probably more likely related to glacial-interglaci
sitions. A possible cause for accelerated slope
during periods of paleoclimatic change could be
to a reduction in the vegetal cover due to a rapid
ing, as in the models suggested by Wells et al.
and Bull (1991) that are better applied at millenn
glacial-interglacial time scales.

Neoctonic activity was recognized in the Up
Paraná River right margin by Fortes et al. (2005),
geomorphological evidence suggesting that the U
is controlled by tectonics that originated higher
terraces along the left margin than in the right
(Suguio et al. 1984, Fúlfaro and Perinotto 1994,
mini 1997, Sallun et al. 2007a). These paleoclima
neotectonic (uplift and/or subsidence) activities
have caused changes in baselevel, with consequ
shaping of the relief.



(a)
Relative sea level (m)
(b)
Jan. Insolation - 15°S (W/m²)
(c)
Precession
(d)
Obliquity
(e)
Eccentricity
Age (ky B.P.)
H
Stage 4
IONIAN
PLEISTOCENE
luminescence ages with error bars
(f)
δ¹⁸O(‰)
δ¹³C(‰)

←

Fig. 4 – Comparison between the ages obtained by TL-OSL methods (in x10^3 years B.P.) and the respective analytical errors in th
Alloformation alluvial deposits (circles with error bars) plotted with the same ages of several paleoclimatic proxy records: (a) sealeve
curve with indicators in numbers of glacial (below) and interglacial (above) stades, based on Bassinot et al. (1994); (b) January inso
15°00′S in W/m^2 (Berger and Loutre 1991); (c) Equinoxial precession during the perihelium, when the Earth is nearest the Sun (Berger 1
Ecliptical obliquity (Berger 1992); (e) Terrestrial orbit eccentricity (Berger 1992); (f) isotopic curves (δ^{13}C and δ^{18}O) obtained from the
Cave (Cruz Jr. et al. 2005) in the Southern Brazil (27°13′24″S/ 49°09′20″W). Quaternary geologic time scale is in accordance with
Pillans (2008) (H: Holocene), and the geomagnetic polarity calibration in time scale was taken from oceanographic data by S.J. Crowhurs
Project 2002 – http://www.esc.cam.ac.uk/delphi/) and modified from Funnel (1996). Ages in x10^3 B.P. with the 0 origin in year 1950 A

distribution of the Paranavaí Alloformation colluvial deposits suggests that these sediments were deposited on peneplain surfaces re-shaped during the Pleistocene, which were previously recognized by Bigarella and Andrade (1965) and O.J. Justus (1985, unpublished data). The South-American Surface (King 1956, 1967), developed at the Late Cretaceous-Paleogene transition (Riccomini et al. 2004), were correctable with Pd_3 pediplain (Bigarella and Andrade 1965).

After the identification of the antiquity relationships between the geomorphological surfaces (Sallun et al. 2007a), and absolute dating of the sedimentary deposits, the relative ages of these surfaces were immediately established. Geomorphological and sedimentological analyses of the Alto Rio Paraná Allogroup, in addition to their age distributions, allowed the recognition of a probable sequence of degradational and aggradational surfaces in the following order: Pd_3 pediplain in the Late Cretaceous-Paleogene, Pd_2 pediplain between 1,000,000 and 120,000 years, Pd_1 pediplain between 120,000 and 10,000 years, and Pd_0 pediplain between 10,000 years and today (Fig. 5B).

CONCLUSIONS

Previous studies have suggested that paleoclimatic changes could represent an important factor for the extensive and intensive colluviation that occurred within the UPRHB because geochronological data were completely absent. The Paranavaí Alloformation colluvial deposits were here interpreted as recording colluviation episodes whose ages were measured by luminescence

between isotope stages 2-3-4 and 5-6. Though te
ture and vegetal cover reductions can be used
tify the occurrence of several colluviation even
probable that brief periods of heavier precipitati
occurred during paleoclimatic transitions, which
explain the extensively occurrence of UPRHB c
deposits. Moreover, the intermittent colluviation
across the entire hydrographic basin suggests a c
arrival of sediments during the Quaternary, in add
a probable neotectonic activity.

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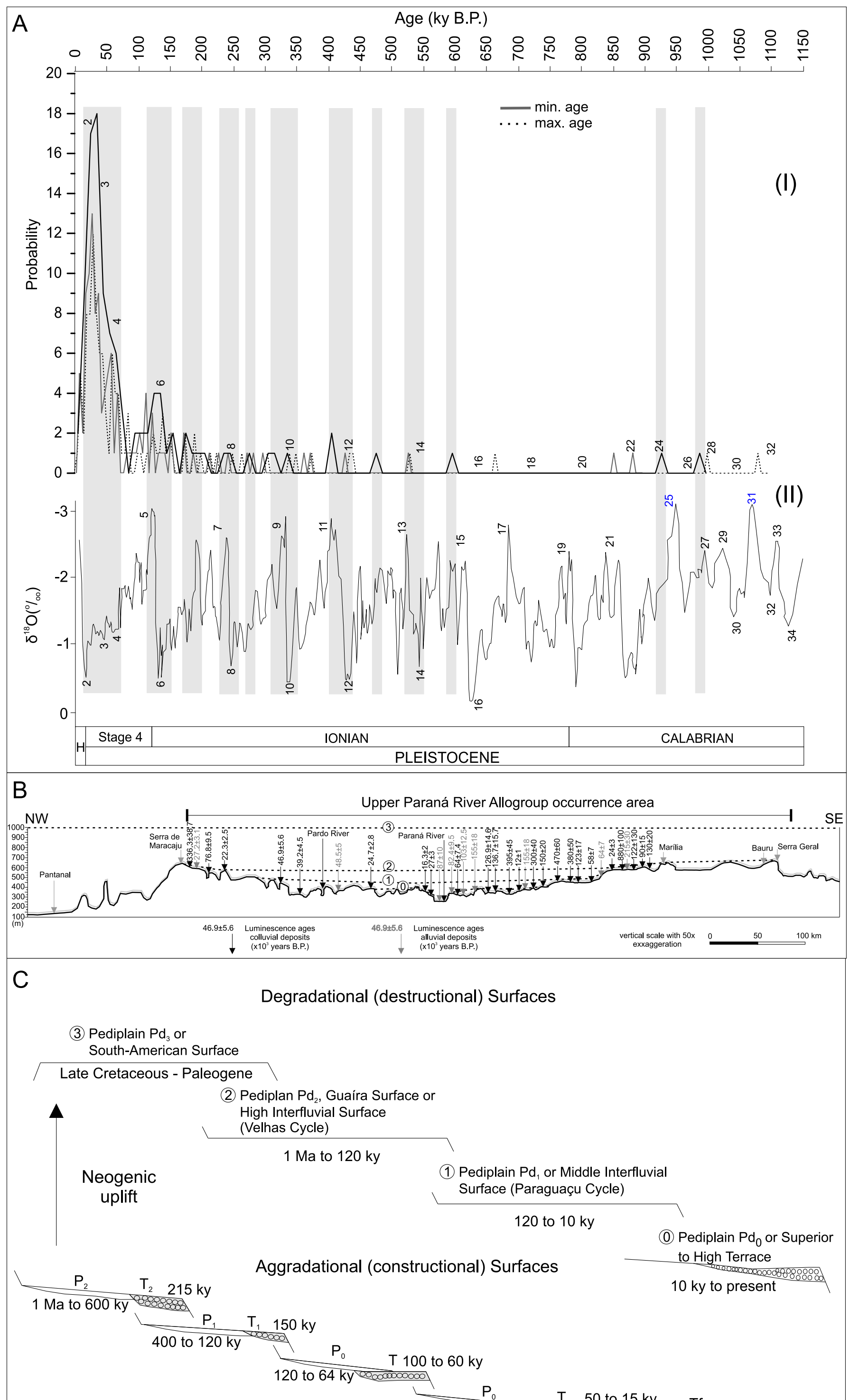
RESUMO

Depósitos coluviais ocorrem extensivamente na Bacia
gráfica do Alto Rio Paraná, no sudeste, sul e centro-
Brasil. Esses depósitos foram reconhecidos como u
dade aloestratigráfica, e são interpretados como depós
mados por processos de rastejo durante o Quaternári
perfil coluvial estudado é muito homogêneo, e indica
mente períodos longos de estabilidade da paisagem, s
para desenvolvimento de espessa cobertura. Estes d
foram datados por luminescência para estabelecer cr
camente períodos de deposição coluvial mais intensa


A
Age (ky B.P.)
Probability
min. age
max. age
(I)
(II)
δ18O(‰)
Stage 4
IONIAN
CALABRIAN
H
PLEISTOCENE
B
Upper Paraná River Allogroup occurrence area
NW
SE
Pantanal
Serra de Maracaju
Pardo River
Paraná River
Marília
Bauru
Serra Geral
Luminescence ages colluvial deposits (x10³ years B.P.)
Luminescence ages alluvial deposits (x10³ years B.P.)
vertical scale with 50x exxaggeration
100 km
C
Degradational (destructional) Surfaces
③ Pediplain Pd3 or South-American Surface
Late Cretaceous - Paleogene
② Pediplan Pd2, Guaíra Surface or High Interfluvial Surface (Velhas Cycle)
1 Ma to 120 ky
① Pediplain Pd1 or Middle Interfluvial Surface (Paraguaçu Cycle)
120 to 10 ky
⓪ Pediplain Pd0 or Superior to High Terrace
10 ky to present
Neogenic uplift
Aggradational (constructional) Surfaces
P2
T2
215 ky
1 Ma to 600 ky
P1
T1
150 ky
400 to 120 ky
P0
T 100 to 60 ky
120 to 64 ky
P0
50 to 15 ky

mudanças climáticas. Desenvolvimento aluvionar foi correlacionado ao Periglacial médio a superior da Glaciação Wisconsiana. Os períodos de intensidade ou frequência maior de precipitação que ocorre durante as transições climáticas estão provavelmente correlacionados com os eventos de agradação. A regularidade do registro coluvionar sugere constante soerguimento acompanhado de deposição sedimentar por toda UPRHB devido à atividade neotectônica durante o último milhão de anos.

Palavras-chave: coluviação, aluviação, Quaternário, datação luminescente, Brasil.

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