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Human occupation in South America by 20,000 BC: the Toca da Tira Peia site, Piauí, Brazil

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A R T I C L E I N F O

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1. Introduction

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ABSTRACT

When and how did the first human beings settle in the American continent? Numerous data, from archaeological researches as well as from palaeogenetics, anthropological and environmental studies, have led to partially contradictory interpretations in recent years, often because of the lack of a reliable chronological framework. The present study contributes to the establishment of such a framework using luminescence techniques to date a Brazilian archaeological site, the Toca da Tira Peia. It constitutes an exemplary case study: all our observations and measurements tend to prove the good integrity of the site and the anthropological nature of the artifacts and we are confident in the accuracy of the luminescence dating results. All these points underline the importance of the Toca da Tira Peia. The results bring new pieces of evidence of a human presence in the north-east of Brazil as early as 20,000 BC. The Toca da Tira Peia thus contributes to the rewriting of the history of the peopling of the American continent.

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Understanding the dynamics, knowing the age and the way the first peopling of America took place is, more than ever, a challenge for research, and is closely linked with societal issues. Different theories have been in contradiction for a long time, and the paradigm of a post-11,500 years BP occupation has remained predominant for a long time. Nevertheless numerous new pieces of data question the initial acceptance of a theory of a migration from Siberia to Beringia, and then from the north to the south of the American continent. Maybe, most of all, these new data question the values of the terminus post-quem imposed by a chronological limit fixed to the Last Glacial Maximum (LGM). As far as the southern part of the continent is concerned, until recently it was admitted that it had been quickly colonized after the diffusion of the Clovis culture in the north.

* Corresponding author. Tel.: +33 666862744. *E-mail address:* christelle.lahaye@u-bordeaux3.fr (C. Lahaye). As already stated there is a lot of data available. However, some are contradictory and what is needed is reliable chronological framework. So we propose to bring new chronological data to the issue by using luminescence dating in the study of a South American archaeological site, the Toca da Tira Peia site, the integrity of which is not under question. The site is located in Brazil, close to the Serra da Capivara National Park and its controversial Boqueirão da Pedra Furada archaeological site. It will contribute to the establishment of a chronological reference framework, that will allow us to reconsider the "Clovis first" paradigm and, potentially, to contribute to the rewriting of the history of the peopling of the South American continent.

2. State of the art: first peopling in South America

The oldest traces of human activity in the extreme south of the continent have been studied and the corpus concerning Patagonia is particularly well documented. The *Clovis-first* model predicts the arrival of the Pleistocene hunter—gatherers around 10,000 years BP (around 9500 years BC) in the southern part of the continent. It

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must be pointed out that, throughout this paper, we prefer to reason in terms of calendar ages, that is to say for radiocarbon ages with calibrated ages (by the INTCAL09 curve, Reimer et al., 2009), in order to be able to compare numerical values that are comparable. In fact the apparent radiocarbon ages (or conventional radiocarbon ages) are not directly comparable one with another because of the past variations in the C14 production in the high atmosphere. Dickinson (2011) reports for example that an interval of 250 years. between 12,600 and 12,350 years C14 BP, corresponds to 700 calendar years after calibration, while the same interval, between 10,950 and 10,700 years C14 BP, corresponds to an interval of only 100 calendar years after calibration. In order to avoid any confusion, the different ages cited in the rest of the text will always refer to calendar years. Moreover, we have chosen for this study to use the Gregorian calendar to express the calendar ages. In fact it appeared to us to be useless to complicate the chronological situation by referring to radiocarbon ages as "before 1950", or those obtained by luminescence dating methods as "Before 2000" or "B2k" (Duller, 2011) since, in both cases, it is only a shift with respect to the year 1 (1950 and 2000 being in fact dates that refer to the Gregorian calendar). For more clarity and simplicity we have thus chosen to express all the chronological data as dates AD or BC.

Within the last ten years in particular, new discoveries made in Patagonia and in the rest of South America have constituted anomalies with respect to the model. Sites like Monte Verde (Dillehay, 1989), Tres Arroyos (Steele and Politis, 2009), Cueva Lago Sofia I, Cerro Tres Tetas Cueva I and Piedra Museo question the model (Miotti, 2003) since they differ significantly from the North American Clovis sites by their function, but also by the faunistic species associated with them, the differences in the availability of raw material and of course by the taphonomic history of each site, in addition to the fact that they have radiocarbon ages which are contemporary, and sometimes older. The location of the sites is presented on the map in Fig. 1.

One of the elements that led to break the consensus around the Clovis-first paradigm is the discovery and the dating of the Monte Verde site, south of Chile. In fact the Monte Verde I site is largely accepted as being a proof of pre-Clovis occupation, dated to 12,400 years BC. The Monte Verde II, being 20,000 years older, remains the subject of controversy (see Dillehay, 1989 for the results, and Fiedel, 1999 for the questioning of the results). Some other sites have been the subject of controversy, which is more or less justified, and

1. Taima-Taima 2. El Abra Rockshelter 3. Guitarrero Cave 4. Pikimachay-Flea Cave 5. Quebrada Jaguay 6. Santa Elina 7. Boqueirão da Pedra Furada 8. Toca da Tira Peia 9. Toca da Pena 10. Baxão da Esperança 11. Sítio do Meio 12. Pedra Pintada 13. Lapa do Boquete 14. Santana do Riacho 15. Alice Boër 16. Quebrada Santa Julia 17. Monte Verde 18. Casa del Minero 19. Los Toldos Cueva 3 20. Cerro Tres Tetas 21. Piedra Museo 22. Fell's Cave 23. Cueva Lago Sofia 24. Tres Arroyos

Fig. 1. Map of South America, showing the main archaeological sites cited in the present paper. Most of them have been studied and dated, and question the Clovis first model.

which finally throws the same veil of suspicion over any discovery older than the LGM. The Boqueirão da Pedra Furada, Piauí state, Brazil, has shown a sequence of meters of thickness (Guidon, 1989) and dates, thanks to radiocarbon on charcoal (Guidon and Delibrias, 1986) and thermoluminescence on heated pebbles (Valladas et al., 2003) from 15,000 to 100,000 years BC. These results have been criticized because of the proximity between the archaeological site and the rock, constituted at its upper part by a sedimentary rock that presents big pebbles similar to the ones found in the archaeological levels. The opponents to the possibility of an old human occupation in the southern part of the continent argued that the lithic assemblage is constituted by geofacts made by the pebbles falling on one another, and they refuse any anthropic characteristic to the lithic artefacts found on the site. The Taima-Taima site in Venezuela, dated as 16,000-15,000 BC (Bryan, 1973) is also contested but for stratigraphical reasons (Miotti, 2003). Other sites spread all over the sub-continent, the occupation of which could be very old, have been excavated and soon after were criticized, for example El Abra Rockshelter in Colombia, dated around 12,860-12,190 years BC (Bryan, 1973), Cerro Tres Tetas Cueva in Argentina (Paunero, 1993-94, 1996) dated around 10,970-10,870 BC and 11,150–10,960 BC (Steele and Politis, 2009), and finally the Casa del Minero, Fell's Cave, Quebrada Jaguay, Quebrada Santa Julia, Pedra Pintada, Piedra Museo, Guitarrero Cave, Los Toldos Cueva 3, Pikimachay-Flea Cave, Santa Elina, Lapa do Boquete sites... The chronology of these sites, even if sometimes questioned by some authors, is presented in Fig. 2. It clearly appears that a great number of evidences are in contradiction with an acceptation without conditions of the Clovis-first model.

3. The Toca da Tira Peia rockshelter

3.1. Presentation

The Toca da Tira Peia site is located in Coronel Jose Dias, in the state of Piauí (north east of Brazil), next to the "Serra da Capivara National Park". It is situated in the calcareous massif of Antero. The site was named in 2008 after the small snake discovered in the morning lying in the first excavation hole. The site was excavated in 2008 and immediately became the object of great interest. Three archaeological test pits were excavated, over a 20 m wide zone



Fig. 2. Chronology of the cited dated archaeological sites from South America. PF stands for Pedra Furada phases. The "ice free corridor open" period is indicated, on the lower part of the graph. Note that the time axis has been interrupted, the oldest dates reported in PF I being much older than all the other (>70 kyears BC).

immediately below the calcareous rockshelter (Fig. 3). About twenty lithic artifacts were first identified and studied, including flakes and denticulate pebble-tools. A second phase of work, of extensive archaeological diggings and OSL sampling, was carried out in 2009. Two other archaeological campaigns were carried out in 2010 and 2011. Dozens of lithic artifacts were unearthed. We consider that the anthropic origin of the artifacts is indisputable. Moreover, the lithic industry is considered to be in its original position, since the surface condition is fresh and some refittings exist between the artifacts.

From a stratigraphic point of view, the filling is essentially constituted of 2.50 m clayey-sandy deposits (at the present state of digging). These deposits arise mainly by soil erosion of karstic clays which developed during more humid periods and to which have been added sands arising from the erosion of nearby sandstones massifs. These deposits are attached to the calcareous slope of the Antero massif. Eight levels were distinguished, based on colorimetric arguments, on the fraction of quartz micro-granules, on the variations of the percentage of aeolian sands and on variations in sediment plasticity. C1 is the superficial deposit, linked to the working of quarry and C2 corresponds to the humic layer of recent soil, from before the extraction of lime from the guarry. The C3 and C4 layers, respectively 30 and 50 cm thick, are clayey-sandy. The C5 and C6, around 20 cm thick, differ from the upper layers in color, which is more brownish, therefore suggesting the possibility of an eluviation print for C5 at the expense of C6.

The C7 and C8 layers, more than 1.50 m thick, have the same texture as the previous ones. The C8, which is more clayey, has a more plastic texture and a darker color. The base of this layer has not yet been reached.

Throughout the sequence some calcareous blocks which have come from the rock wall can be observed, varying widely in size. Some quartz pebbles are present, of which a great number are burnt, depending on the layer. Neither the sedimentary composition nor the deposit mode can explain the presence of such pebbles.

From an archaeological point of view (Fig. 4), at least five archaeological ensembles have been individuated (at the actual point of the digging operations). Three of them can clearly be recognized stratigraphically (C4a in the west zone, C6a and C8b in the east zone) and can be identified culturally. C4a is in the upper part of C4 layer. One sample has been taken for OSL dating in the C4 layer, but cannot be directly connected with C4a assemblage because it has been taken from the east part of the site. The artifacts vertical distribution is low, and in any case is less than 10 cm. The refittings of several horizontal artifacts confirm this observation. The lithic material of the second archaeological ensemble, C6a (Fig. 5), is located in the upper part of C6. Three refittings show a perfect horizontality. An OSL tube has been sampled in the archaeological layer. The third ensemble, C7a (Fig. 3), is lying under C6a by a few centimeters. It contains some artifacts and homogenous quartz pebble, some of them presenting traces of bipolar impacts, and some others being burnt. An OSL sample has been taken directly in the archaeological layer. The fourth ensemble, C8a, is in the upper part of C8 and contains less than a dozen of artifacts. It is completely horizontal, as confirmed by a refitting. No sediment has been sampled in the layer for the moment, because at the time of OSL sampling this layer had not been reached. Finally the fifth archaeological ensemble, C8b, is situated about 20 cm under the previous one. Few artifacts have been unearthed, but those that have present the same horizontality. It should be noted that both these archaeological ensembles are located at the north-west limit of the digging area.

Numerically, we must specify the quantities of artifacts found at each level. 113 knapped artifacts have been identified, found in concentrations (very localized spots): 14 artifacts were unearthed



Fig. 3. The Toca da Tira Peia Rockshelter during the 2008 excavations. The calcareous rockshelter has approximately an east-west orientation.



Fig. 4. Projection of the artifacts and pebbles of the Tira Peia of the east zone. The C4a ensemble is not represented because it is situated in the west part of the site.



Fig. 5. Lithic artifacts from Toca da Tira Peia. a) Artifacts on quartzite pebbles from level C4. b) Up: layer C6a convergent retouched edges tool on quartzite pebble. Down: layer C6a denticulate tool on siliceous limestone flake (retouched on lower face). c) Artifacts on quartzite pebble from the C7a layer. Up: Bifacially shaped tool.

in C4, 57 in C6, 6 pieces in C7, 13 in C8 and 2 in C9. 35 of them were interpreted as tools, 12 are cores and 67 are flakes. The other artifacts (small pieces) cannot be localized precisely because they were found in the sieve.

3.2. Why did we choose to study the Toca da Tira Peia archaeological site?

The reasons why we chose to study the Toca da Tira Peia are clear. Seeing that the scientific community has rejected some site for varying reasons we decided to select the sites for study very rigorously in order to bring new chronological data to the argument. Besides the imperative quality and reliability of the dating, conditions that can be satisfied by optically stimulated luminescence (OSL) dating techniques (Aitken, 1998; Wintle, 2008), it also appeared to be very important to study archaeological sites where the human occupation is not in doubt. It is also necessary to ensure the reliability of the data that can be deduced, particularly by verifying the absence of strong taphonomic problems and verifying that no mixing between the levels can be suspected. The Toca da Tira Peia archaeological site fits these requirements. First of all it is a very interesting site from an archaeological point of view. Dozens of artifacts were unearthed on this site, which doesn't run the risk of facing the same criticism as that addressed to the Boqueirão da Pedra Furada site, since there are no pebbles in the summit of the cliff, and very few other pebbles in the sediment, so we deduced that the pebbles were brought and knapped by human beings. Moreover from geologic and geomorphologic studies, the deposit modes of the sediments seem to be suitable for OSL dating. Finally the artifacts are in their original position; they had not been subject to movements since their burial. Dating the sediments by OSL techniques allows the dating of the deposit of the artifacts.

4. Sampling strategy and preparation

Four levels were sampled during the 2009 excavations. PVC tubes were sunk in the exposed stratigraphic profiles; their dimensions were 3 cm in diameter and 12 cm in depth. Their location can be seen in Fig. 6. Sample BR 15 corresponds to the layer C7, BR16 to C6, BR17 to C5 and finally BR18 to C4.

Back at Bordeaux University, laser grain sizes were analyzed in order to determine the granulometric profile of each sediment sample. Sieving under a water flow allowed us to select the 20– 41 μ m fraction, which was the dominant fraction in each case. The selected grain fraction was then submitted to the usual chemical treatments: HCl to remove carbonates, H₂O₂ to remove organic elements, 1 week in H₂SiF₆ to remove eventual feldspars, HCl again to remove fluorine that had possibly formed (from H₂SiF₆ and carbonates) and finally H₂O rinsing and a last sieving. The quartz fraction thus obtained was mounted on stainless steel discs (9.8 mm in diameter) covered with a thin film of silicon oil.

In a first series of measurements we chose to use "large aliquots", each quartz grain deposit being 6 mm in diameter and containing thousands of grains. A second batch of discs was made for BR 16 and BR 17 samples, a 1 mm mask being used when spreading the oil: this second batch of discs constituted a "small aliquots" group for each sample.

In each case the first measurements that were performed consisted in IRSL measurements to check the absence of feldspars (Duller, 2003). Equivalent doses were obtained thanks to OSL single aliquot measurements. It was performed with a Daybreak 2200 OSL reader (Bortolot, 2000), equipped with a calibrated ⁹⁰Sr/⁹⁰Y beta source delivering, at the time of measurements, 7.1 Gy/min to quartz. Green LEDs (Nichia NSPG310) emitting at 515 nm and providing a maximum power of 30 mW/cm² onto the measured disc were used for stimulation of the quartz grains. An Electron



Fig. 5. (continued).

Tubes 9235 photomultiplier tube measured the signal, after selection with a set of optical filters (7.5 mm of U-340).

5. Measurements

The basics and principles of luminescence dating in general and OSL dating in particular have been widely developed elsewhere (Aitken, 1985, 1998; Wintle, 2008). We will just recall that OSL dating requires the determination of two data: the equivalent dose and the annual dose. The measurements were performed in the IRAMAT-CRP2A laboratory, where researches on luminescence dating have been conducted for more than 40 years. Sample preparation and measurements were conducted by C. Lahaye and M. Hernandez.

5.1. Luminescence

In order to adopt the best experimental conditions for each sample, we first applied recovery tests to bleached aliquots, using a SAR protocol. The aliquots were first bleached in a solar simulator for a couple of hours, and then a beta dose (chosen to be of the order of magnitude of the ED value, approximately measured with three aliquots for each sample, that is to say 30 Gy for BR18, 50 Gy for BR17, 60 Gy for BR16 and 70 Gy for BR15) was given to each aliquot to simulate natural irradiation. The conditions (temperature and duration of the pre-heat for natural dose and regenerated dose on one hand, temperature and duration of the pre-heat administrated to the test dose on the other hand) were accepted as being good measurement conditions when the three analyzed discs

showed a recovery ratio between 0.95 and 1.05; that is to say when all the three tested discs gave a ratio of calculated dose to given dose equal to unity to within about 5%. The results of the tests are shown in Table S1. The chosen conditions, leading to good recovery ratios, are also given in Table S2.

The protocol mainly adopted for multi-grain single-aliquot regenerative doses (SAR) measurements was chosen (Murray and Wintle, 2000, 2003; Wintle and Murray, 2006). Linearly-modulated OSL signals showed that for all the samples, the signal was dominated by the fast component (Bailey et al., 1997; Jain et al., 2003). The SAR protocol was applied with the conditions determined as mentioned above. It led to recycling ratios close to unity and a recuperation signal ratio of less than 0.5%. Fig. 7 shows the radial plots obtained for the ED values for the four samples BR15. BR16, BR17 and BR18, for the first batch of discs, that is to say "large aliquots" of 6 mm in diameter. This kind of graphical representation, inherited from fission track analysis, is now largely used in luminescence dating. It allows us to simultaneously show three important data: the equivalent dose for each disc, the associated relative uncertainty, and the degree of concordance between ages of differing precision. The four radial plots show the same tendency for the four levels of sediments. In fact we can see in each case that the points are centered at a medium dose: only one population appears in all four cases, we cannot assume any mixing of different populations with different bleaching level (Galbraith et al., 1999). Moreover, we can observe that the results have a good degree of precision: in fact the huge majority of the points are on the right side of the radial plot, showing relative errors of <5%. But the radial plots of the log palaeodose estimates indicate they are not



Fig. 6. Sampling strategy: location of the OSL samples and in-situ gamma spectrometry measurements.

consistent with a common value (that is to say they are not all in the central band of ± 2 units on the *y*-axis, centered at the mean measured dose). These considerations thus allowed us to choose the Central Age Model as being the best adapted model for our four

samples (Galbraith et al., 1999): in fact this model takes into account an adjunct variation of the values around the true value. This variation can also be measured and is called "over-dispersion". This value (OD) expresses the dispersion between the values of ED that cannot be explained by the statistical variability. The higher the OD, the more important the processes that have to be taken into account (mixing of grains from different levels, bad bleaching or heterogeneity of the bleaching between the grains...). For all the samples the over-dispersion (OD) values are very small (Table 1) ranging between 4.7% and 6.4%.

In order to ensure that this low dispersion was not due to the averaging effect of the several grains measured per aliquot, we undertook measurements of small aliquots to ensure the absence of badly bleached grains. To perform this test we prepared and measured small aliquots of two of the four samples (BR 16 and BR 17). The results are presented in Inline Supplementary Fig. S1. It clearly shows that there is only one component in the signal. It confirms that all the measured grains were well bleached in the past, and confirms that we can use the Central Age Model (CAM) (Galbraith et al., 1999) to determine ED values (Table 1).

Inline Supplementary Fig. S1 can be found online at http://dx. doi.org/10.1016/j.jas.2013.02.019.

5.2. Dosimetry

The annual dose rate has been measured by a combination of measurements in situ and in the laboratory. The in situ measurements were performed with a NaI:Tl $2' \times 2'$ gamma-spectrometer (Canberra Nal Inspector). The external dose rate (sum of gamma and cosmic contributions) are reported in Table S1. The outer parts of the collected tubes, whose grains were exposed to sunlight during sampling operations, were used for laboratory radioelement contents measurements. These outer parts of each sample were first extracted from the tubes using a saw. The humidity at sampling time was measured and it reached values of between 3 and 8%. The



Fig. 7. Radial plots of the four samples, measured as "large aliquots" (A: BR18, B:BR17, C: BR16 and D: BR15).

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Radiometric data and OSL ages of the sediment samples from the Toca da Tira Peia s	ite.

Sample (layer)	External dose rate (mGy/a)	K% (HPGe)	U ppm (HPGe)	Th ppm (HPGe)	Total annual dose rate (mGy/a)	ED (Gy)	O.D. (%)	Age (years before 2011)	Date (years BC)
BR18 (C4)	1.34 ± 0.03	1.44 ± 0.02	6.50 ± 0.06	12.34 ± 0.13	3.65 ± 0.08	14.7 ± 0.1	2.5 ± 0.1	4000 ± 300	2000 ± 300
BR17 (C5)	1.60 ± 0.03	1.73 ± 0.02	$\textbf{7.49} \pm \textbf{0.06}$	14.38 ± 0.12	4.33 ± 0.09	55.8 ± 0.6	$\textbf{4.6} \pm \textbf{1.1}$	$12{,}900\pm900$	$10{,}900\pm900$
BR16 (C6)	1.62 ± 0.03	1.52 ± 0.02	$\textbf{6.14} \pm \textbf{0.05}$	13.09 ± 0.11	3.94 ± 0.08	$\textbf{67.3} \pm \textbf{0.5}$	1.8 ± 1.6	$17,\!100\pm1200$	$15{,}100\pm1200$
BR15 (C7)	1.59 ± 0.03	1.35 ± 0.02	$\textbf{4.56} \pm \textbf{0.04}$	12.42 ± 0.12	$\textbf{3.54} \pm \textbf{0.07}$	$\textbf{77.7} \pm \textbf{0.8}$	1.0 ± 5.0	$\textbf{22,000} \pm \textbf{1500}$	$\textbf{20,000} \pm \textbf{1500}$

dried sediment was then encapsulated in 12 cc plastic boxes and the radioelements contents were measured with a High Purity Gamma spectrometer (Guibert and Schvoerer, 1991) (Broad Energy Germanium Canberra). The measurements were always conducted after at least 3 weeks, and the plastic boxes were sealed with paraffin wax, to ensure that the equilibrium was reached between pre- and post-radon elements. The results are reported in Table S1. Our team is used to detecting and taking into account any notable disequilibrium in the uranium series (Guibert et al., 2009; Lahaye et al., 2012); in this case the values of $U(^{238}U)$ and $U(^{226}Ra)$ were determined, thanks to the contents of the elements of respectively the beginning of the ²³⁸U and ²³⁵U series and the post-²³⁰Th radioelements contents. The values are reported in Table S3. A small discrepancy between the U(²³⁸U) and U(²²⁶Ra) values can be observed; in any case this value of U(²³⁸U) never differs from the U(²²⁶Ra) value of more than 18% of the latest. Since 97% of the U gamma annual dose is due to U(²²⁶Ra) radioelements, the small observed disequilibrium will only influence the value of the annual dose very slowly. It can thus be ignored. We therefore consider the U(²²⁶Ra) as being the true U content. Generally speaking, we can observe that the contents of K and Th are quite similar from one sample to another, K varying between ~1.4 and ~1.7%, and Th varying between ~ 12.3 and ~ 14.4 ppm. U is more changing,



Fig. 8. The Toca da Tira Peia archaeological sequence and the OSL dating results. The arrows indicate the refittings.

varying between \sim 4.5 and \sim 7.5 ppm. In all four cases the radioelements contents are quite high.

6. OSL ages and discussion

The four OSL samples have been dated. The OSL ages (Fig. 8) are given in Table 1. Unsurprisingly, they follow the stratigraphic order. This confirms all our previous observations that led us to consider that there had not been notable post-depositional events. The OSL ages obtained refer to the last exposure of the quartz grains of the sediments to the light, that is to say the deposit of the layers. The obtained ages range from 20,000 \pm 1500 years BC for the C7 level, to 2000 \pm 300 years BC for the C4 level. The lithic artifacts were found to be numerous in the C6 and C7 layers, that is to say, in layers both attributed to the Pleistocene (20,000 \pm 1500 years BC and 15,100 \pm 1200 years BC). The C5 level is also dated to $10,900 \pm 900$ years BC. These results are much older than predicted by the Clovis-first theory. Moreover, the oldest age, obtained for the deposit of the sediment of C7 layer, gives a terminus post-quem for the artifacts unearthed in the C8 layer, during the 2011 excavations (that is to say after the OSL sampling had been done): it means that this level is older than 20,000 years BC, that is to say men lived and used quartz and quartzite knapping in this part of the world at least 10,000 years before predicted.

These results have to be compared with other archaeological layers dated in several South American sites (Fig. 2): the C7a layer from Toca da Tira Peia appears to be contemporaneous with some radiocarbon dates obtained in Pikimachay – Flea Cave 4 and with the older dates of the Pedra Furada III phase.

These results, composed of reliable and precise luminescence ages, obtained on sediments containing man-made lithic assemblages, reinforce the recent results obtained both in South and North America (Waters et al., 2011), showing that the first settlements of the continent may be older than predicted.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2013.02.019.

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