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Palynofacies analysis of the late Holocene San Nicolás terrace of the Cauca paleolake and paleohydrology of northern South America

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ABSTRACT

The detailed palynofacies analysis of the late Holocene laminated succession of the San Nicolás terrace in the middle Cauca Valley, northern Colombia, is interpreted as the product of sedimentation in a lacustrine to fluvial dominated setting. Radiocarbon analyses reveal that the succession was deposited between ~3500 and a few hundreds of years with sedimentary rates in excess of ~600 cm/ka. The milimetric laminae and the high frequency fluctuations in the content of the palynodebris of terrestrial origin, i.e., the high altered ligno-cellulosic debris/amorphous organic matter ratio, together with diatoms typical of fluvial conditions, such as *Aulacoseira granulata* do suggest an intermittent and continuous hydrological and biological connectivity with the Cauca River, akin to a varzea lacustrine environment. Drier to wetter conditions appear to occur, moving upward in the succession. This might reflect regional precipitation conditions all along the Cauca Valley and the southern migration of the intertropical convergence zone.

1. Introduction

Climate dynamics in the northern Andes is modulated by global impact mechanisms, i.e., the latitudinal displacement of the intertropical convergence zone (ITCZ; Fig. 1), the El Niño–Southern Oscillation (ENSO) phenomenon, the westerly low atmospheric Chocó jet, the easterly San Andrés jet, and the North Atlantic Oscillation (NAO; e.g., Poveda et al., 2006). Even though this unique location has provided a wealth of Holocene paleoclimate information, e.g., at the Cariaco Basin (Venezuela; e.g. Haug et al., 2001) and the Pallcacocha Lake (Ecuador; Rodbell et al., 1999; Moy et al., 2002), still more data from high resolution continental records are needed if we want to capture the whole range of climate variability at a regional scale.

Along the middle Cauca Valley in northern Colombia (Fig. 1) three late Holocene terraces, Obregón, San Nicolás, and Olaya, were previously identified and radiocarbon dated at 3100, 1500 and 800 yr BP, respectively, and interpreted as being formed by the episodic damming of the Cauca River (Page and Mattsson, 1981). A laminated silt and mud sedimentary succession was reported for the San Nicolás terrace (Page and Mattsson, 1981), which was purported to be a potential high resolution recorder of paleoclimate for the late Holocene (e.g., Ruiz et al., 2005). This paper moves a step forward by presenting a paleoenvironmental and paleoclimatological reconstruction of the San Nicolás sedimentary succession at La Caimana Creek (Fig. 1), based on its organic matter content.

We hypothesize that these laminated silt and mud sedimentary facies were deposited during lotic and lentic hydrological phases, respectively, thus reflecting climate dynamics between periods of drought and precipitation. This climate dynamics should be reflected in the composition of organic matter (OM). Furthermore, we will demonstrate that the San Nicolas succession was deposited at an unprecedented sedimentary rate and that it resulted from the dynamics of its connection with the Cauca River, i.e., its sedimentary and organic matter composition can be explained by the "flood pulse concept" (e.g., Amoros and Bornette, 2002).

1.1. Climatology and hydrology of the Cauca River system

The Cauca River, located between the Western and Central Cordilleras of Colombia, runs along 1183 km and drains into the Magdalena River, which ultimately ends in the Caribbean Sea. The Cauca River discharges 2,373 $m^3.s^{-1}$ and yields 49.1 $Mtn.a^{-1}$ of sediments in suspension, collected from a 59,615 km^2 basin (Restrepo et al., 2005). Sediment yield is modulated by the bimodal, seasonal pattern of precipitation, which varies between 2100 and <1500 $mm.a.^{-1}$ (Restrepo et al., 2005). This pattern is altered during the warm phase of the ENSO phenomenon, i.e., when the Chocó jet weakens there is a

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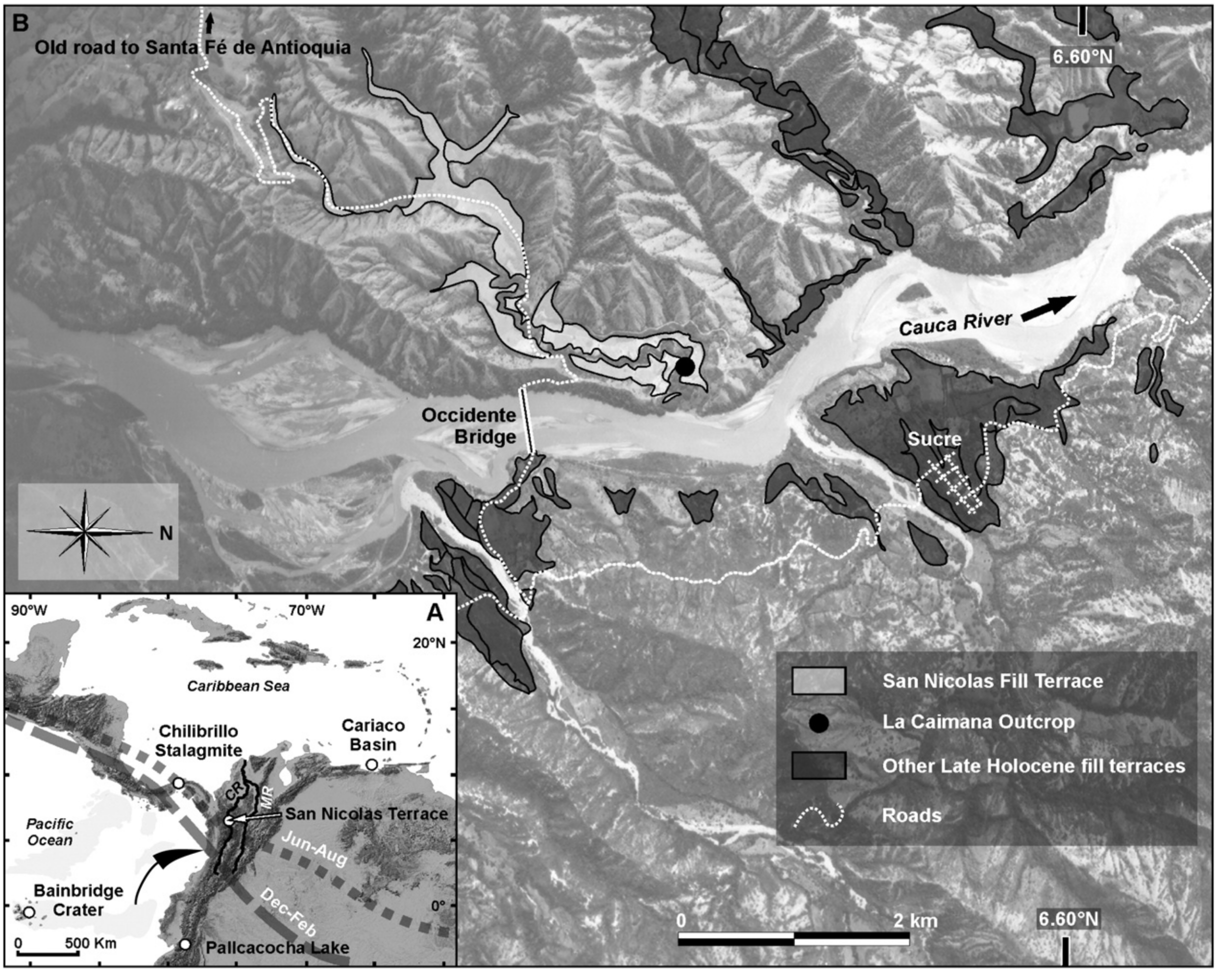

Fig. 1. La Caimana outcrop in the San Nicolás terrace. Note other late Holocene terraces. Inset: Regional map showing other high resolution sites and the mean position of the intertropical convergence zone (ITCZ) for Jun–Aug and Dec–Feb. Note the path of the Chocó jet (black arrow). CR = Cauca River. MR = Magdalena River.

reduction in precipitation and in the mean water discharge (e.g., Poveda and Jaramillo, 2000; Restrepo et al., 2005; Poveda et al., 2006; Fig. 1).

The Chocó jet results from the Coriolis deflection of the easterly winds once they cross the equator in the eastern Pacific Ocean. Then, the Chocó jet enters the continent at 5ºN to deliver most of its moisture along the western flank of the Western Cordillera. There, the Mistrató Pass allows a fraction of the Chocó jet to continue its path into the Cauca Valley and beyond (Poveda and Mesa, 2000). Because of the reduced moisture, there is a local "island effect" in the inter-Andean valleys (Lopez and Howell, 1967; Mesa et al., 1997) and in particular in the Santa Fé – Sopetrán Basin.

The Santa Fé–Sopetrán Basin is located along the Cauca–Romeral System Fault that runs all along western South America from Guayaquil (Ecuador) to the lower Magdalena Valley of Colombia. In the northern Cauca Valley the Cauca–Romeral System Fault is inverse, sinestral, and braided. This suggests that the Santa Fé–Sopetrán depression is a pull-apart basin partly filled with late Holocene fluvio-lacustrine sediments (Suter and Martínez, 2009: Suter et al., in preparation).

1.2. Methods

The sedimentary succession of the San Nicolás terrace was studied along La Caimana Creek (Fig. 1). Sampling retrieval of the full section was done by means of the box sampling method (Mangili et al. 2005). Samples were then transported and stored at the Department of Geology, Universidad EAFIT, at 4 °C. At the lab, 15 g of sample were collected every 8 cm, from < 0.6 cm laminae, for a total of 194 samples. A 10 g bulk sediment sample was processed for palynology and 5 g for diatom analyses. Palynological samples were processed using standard procedures, which included hydrochloric (HCl) and hydrofluoric (HF) acids to remove carbonates and silica, respectively (Faegri and Iversen, 1989). Flotation of organic matter was done with $ZnCl_2$ (D ~2.2 g/ml). Pollen and charcoal concentrations were estimated adding tablets of the exotic spore *Lycopodium* to each sample (Finsinger and Tinner, 2005; Stockmarr, 1971).

Three categories of OM were used in this study: (1) palynomorphs, (2) ligno-cellulosic debris or phytoclasts (Lc D), which can be preserved as translucid (Tr.), altered (Alt), or gelified (G), and (3) amorphous particles, which can be amorphous organic matter (AOM) or gelified, i.e., G-AOM (e.g., Batten, 1996; Carvalho et al., 2006; Mendonça Filho et al., 2002; Tyson, 1995). Approximately 500 particles of OM were counted per sample following standard procedures (e.g., Tyson, 1993, 1995), whereas 200 particles including charcoal and *Lycopodium* were counted to obtain the concentration of the former. Only particles that appeared black, completely opaque and angular under the light microscope were counted as charcoal (cf. Clark, 1988). A qualitative assessment of diatom content was obtained by mounting a solution of 0.3 to 0.4 g of sediment in 40 ml of distilled water on slides glued with Zrax (R.I. 1.7+).

The chronology of the San Nicolás succession is based on 11 radiocarbon (*accelerator mass spectrometry*, AMS^{14}C) analyses on bulk sediments. Samples were retrieved from the outcrop by means of *Shelby* cores in order to minimize sample contamination. Analyses were done at the University of Tokyo. Radiocarbon ages were transformed to calibrated years, applying a 500 years reservoir

Table 1
Radiocarbon analyses of bulk sediment samples from La Caimana Creek, Cauca paleolake.

Sample	cm	Lab Code	^{14}C yr BP	cal yr BP (−2 sigma)
LC-12	1384	MTC-13130	4000 ± 50	4467 ± 121
LC-11	1000	MTC-13129	2695 ± 195	2807 ± 462
LC-10	815	MTC-13128	1945 ± 130	1863 ± 297
LC-09	684	MTC-13127	2985 ± 45	3165 ± 107
LC-08	571	MTC-12702	2395 ± 50	2441 ± 103
LC-07	459	MTC-12701	3765 ± 50	4136 ± 159
LC-06	443	MTC-13126	2435 ± 35	2451 ± 98
LC-05	338.5	MTC-12700	2970 ± 135	3128 ± 287
LC-04	245	MTC-12248	2965 ± 50	3121 ± 147
LC-03	140	MTC-12247	5705 ± 110	6516 ± 220
LC-01	25	MTC-12246	5235 ± 50	6018 ± 106

University of Tokyo (Japan). Calibrated C-14 ages with CALIB 5.0.1. Reservoir correction, 500 (± 100) yr.

correction, by means of the CALIB^{14}C software, version 5.0.2 (Stuiver et al., 2005). Therefore, in the present paper all ages indicated refer to calibrated years before present (cal yr BP).

2. Results

2.1. Chronology and stratigraphic succession at La Caimana Creek

The radiocarbon ages obtained for the sedimentary succession of the San Nicolas terrace can be grouped in two sample families: "young" and "old" (Table 1, Fig. 2). We adopted the "young" age model by considering the "old" ages as the product of reworking of OM. Two reasons support our selection: (1) a high percentage of altered phytoclasts are dominant in the "old" samples and (2) reworked samples probably came from the underlying Obregón terrace.

Even though there is no chronologic control for the lowermost 2 m and the uppermost 7.5 m, due to the absence of enough OM for radiocarbon analysis, linear extrapolations are made, thus suggesting that the top of the sedimentary succession is hundreds of years old. Therefore, the succession varies in age between ~3500 and ~1000 cal yr BP (Fig. 2) and the mean sedimentation rate exceeds ~600 cm/ka. This is consistent with other age models for the San Nicolas terrace located elsewhere in the Santa Fe–Sopetran basin.

The sedimentary succession lies unconformably on a debris flow capped by a paleosoil (Mejía, 1983). It is 15.5 m thick and is composed of laminated dark gray (organic rich) mud, and light yellowish and orange silts and fine-grained sands (Fig. 2). The stratigraphic succession begins with a 245 cm interval composed of yellowish and orange laminated mud. Dicotyledon imprints occur 5 cm above, whereas charcoal laminae occur at 4 and 13 cm above the paleosoil, respectively. The overlying interval (245 to 477 cm) is composed of yellowish to dark gray and orange laminated mud. Here, the occurrence of gypsum crystals in the orange mud, as well as the presence of syneresis cracks, and scour and drape structures are conspicuous. The third interval (477 to 669 cm) is composed of yellowish to orange laminated clays and silts; whereas at 630 cm there is a conspicuous ~20 cm thick, volcanic ash layer. Similarly, the presence of vertical burrows, soft sediment deformation structures, and cross lamination is conspicuous. The fourth interval (669 to 1069 cm) is characterized by laminated yellowish clay to dark gray mud. The latter is inter-bedded with gypsum-bearing orange laminae. Toward the top of the interval, horizontal burrows, scour and drape structures, and a mottled brown to dark gray bed with soft sediment deformation structures occur. The fifth interval (1069–1509 cm) is composed, at the base, of laminated creamy yellow mud and silt. In the middle upper part of the interval, yellowish fine-grained sands become common. They are characterized by their erosive bases, cross lamination, and mottling (plant bioturbation?). The succession ends

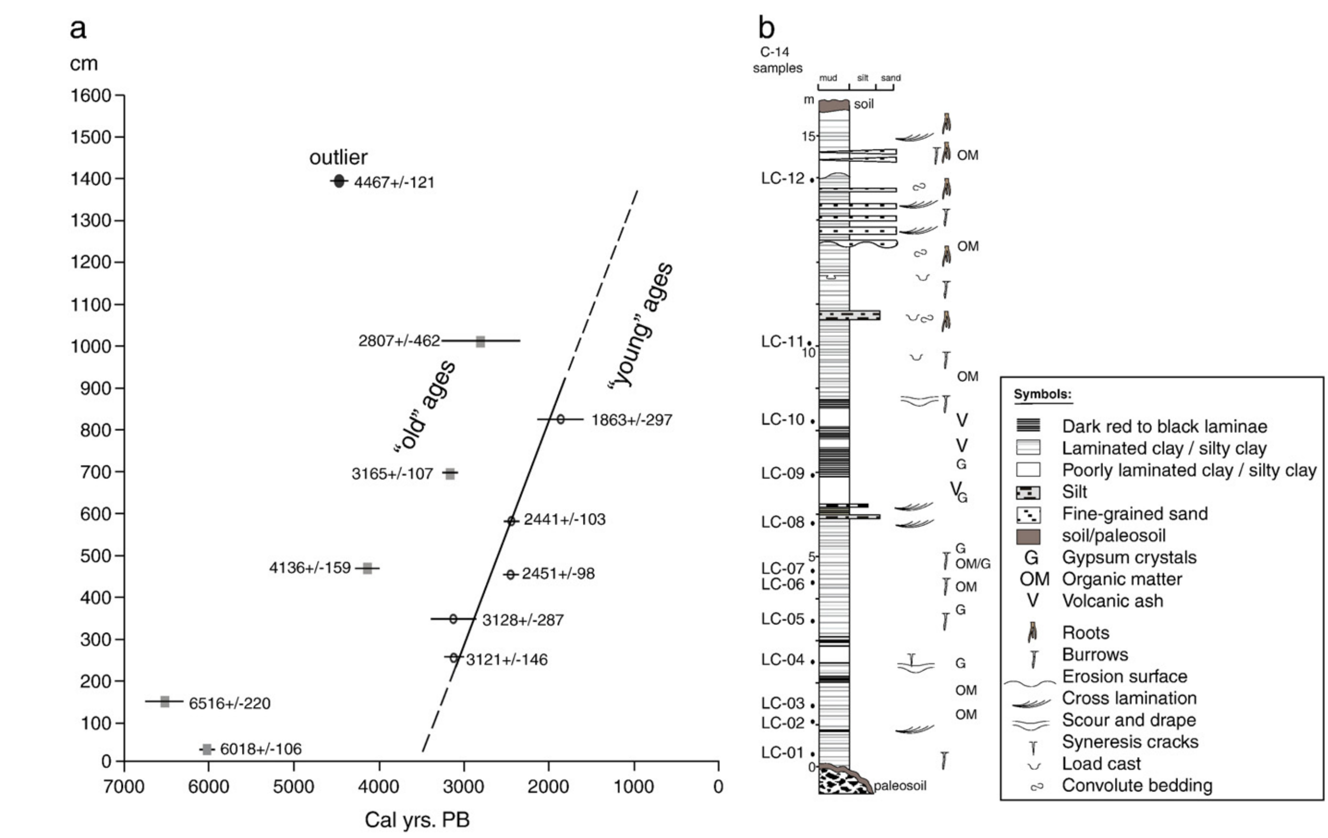

Fig. 2. Stratigraphic column and age model for the sedimentary succession of the San Nicolás terrace at La Caimana Creek based on AMS^{14}C calibrated dates (cal yr BP). Error bars as in Table 1. Note the two group of ages, i.e., "young" (circles) and "old" (squares). The dotted line indicates the linear extrapolation towards the base and the top of the succession.

in the sixth interval (1509–1550 cm), which is characterized by a set of clay and fine-grained sands, macrophyte remains, and mottling (plant bioturbation?).

2.2. Palynofacies, OM zonation and diatoms

From the CONISS analysis (Grimm, 1987) of the OM content, six biostratigraphic zones were recognized, namely, A6-1 to A6-6 (Fig. 3). This zonation is analogous to the physical stratigraphic intervals defined in Section 2.1. The average OM content for each zone is presented below as percentages of each organic constituent, together with the qualitative occurrence of diatom taxa (its quantitative study is under way, Vélez et al., in prep.). From base to top, beginning 5 cm above the paleosoil, biostratigraphic zones are characterized as follow:

Zone A6-1 (0–213 cm above base (ab); ~3500 to −3150 cal yr BP; Fig. 3). This zone is dominated by gelified (~20%), and translucent (~18%) phytoclasts, pollen (~18%), and pterydophyte spores (~16.6%). These compare with gelified AOM (~14%), and altered phytoclasts (~10%) which occur in moderate abundance, and with AOM (~4.4%), fungi spores (~1%), and polliades (~0.1%) whose presence is very low. Charcoal content displays strong oscillations around an average of 96471 particles/g (pt/g; Fig. 4). The presence of macrophytes in this zone is conspicuous. Diatoms include aerophil and epiphytic taxa such as *Orthoseira* spp., *Luticola mutica*, and *Cocconeis* spp., and planktonic shallow water taxa such as *Aulacoseira granulata*, and *Synedra ulna*.

Zone A6-2 (213–477 cmab; ~3150 to ~2730 cal yr BP; Fig. 3). This zone is characterized by an increase in the percentage of altered (~26.5%) and gelified (~23%) phytoclasts. Translucent phytoclasts decrease moderately, whereas pollen (~11,5%), pteridophyte (~9%) and gelified AOM (~9%) show a marked decrease in abundance. AOM shows a slight increase (~6%) and a peak (~25%) towards the top of the zone. Fungi spores (~0.6%) and poliades (~0.09%) show low values. Charcoal concentration dropped to ~73516 pt/g (Fig. 4), whereas diatoms include planktonic and planktonic littoral water forms such as *A. granulata*, *Cyclotella stelligera* and *S. ulna*.

Zone A6-3 (477–589 cmab; ~2730 to ~2550 cal yr BP; Fig. 3). This zone is defined by a conspicuous increase in the percentage of pollen (~20%), and pterydophytes (~14%), in tandem with the reduction of altered (~16.5%), translucent (~11,8%), and gelified (~19%) phytoclasts. The percentage of gelified AOM remains constant (~8.4%), whereas AOM increases to 8.5%. Polliades and fungi spores occur as traces, i.e., 0.3% and 1%, respectively. Charcoal concentration decreases

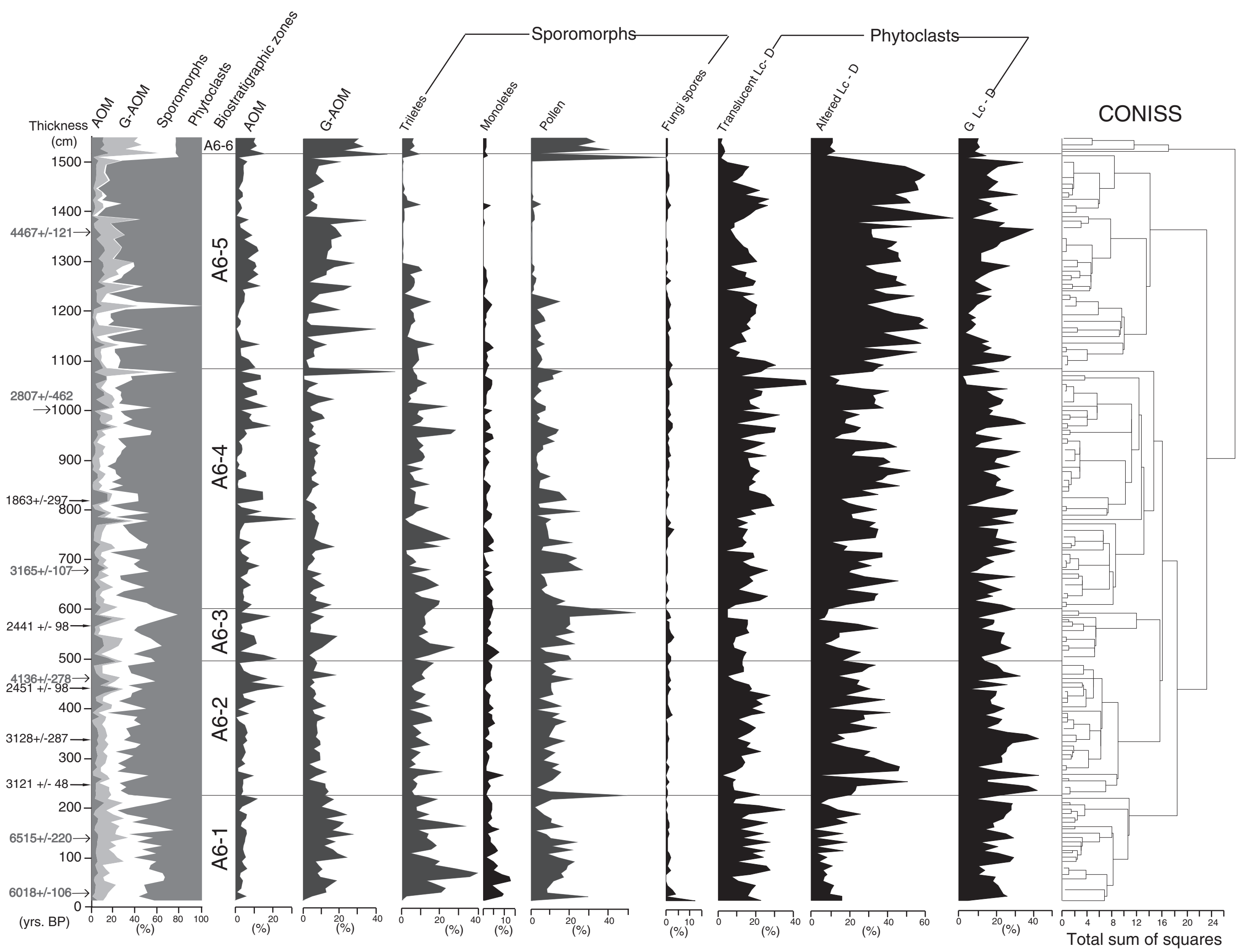

Fig. 3. Organic matter (OM) percentage abundance diagram for the stratigraphic succession of the San Nicolas terrace at La Caimana Creek. From left to right: Age in cal yr BP (broad arrows indicate ages attributed to reworking), thickness in cm, OM groups, biostratigraphic zones, percentage of OM, and CONISS diagram. AOM = amorphous organic matter, G = gelified, and Lc-D = ligno-cellulosic debris.

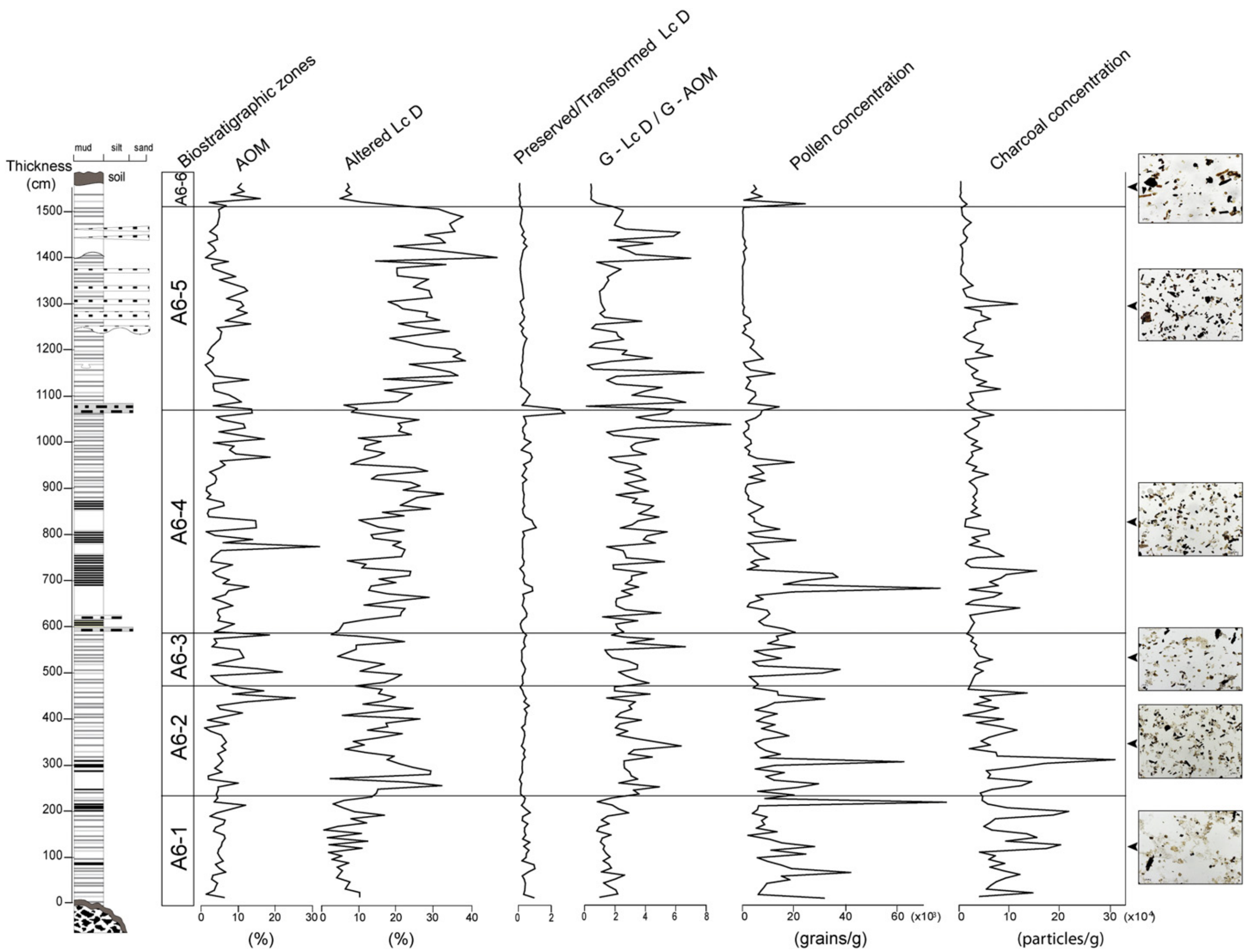

Fig. 4. Optical indices of organic matter (OM) of the San Nicolas stratigraphic succession at La Caimana Creek. From left to right: Stratigraphic column (symbols as in Fig. 2), biostratigraphic zones, and optical indices for palynological micrographs typical of each zone. AOM = amorphous organic matter, Lc D = ligno-cellulosic debris, and G = gelified.

to ~32118 pt/g (Fig. 4). The planktonic and epiphytic diatoms *A. granulata*, and *Planularia gibba* occur at the base of the zone, whereas *Nitzschia amphibia* dominates at the top.

Zone A6-4 (589–1.080 cm; ~2550 to ~2200? cal yr BP; Fig. 3). In this zone there is a conspicuous increase in translucent (~19%) and altered (~27.8%) phytoclasts. Pollen abundance decreases from base to top, whereas pteridophyte spores remain constant along the zone. AOM shows marked fluctuations in its percentage, varying between 0.76% and 32% with an average of ~6.5%, whereas gelified AOM decreases to ~7%. Poliades (~0.1%) and fungi spores (~0.7%) occur as traces. As in the underlying zones, charcoal (~44 445 pt/g) show marked oscillations, but a tendency to decrease upwards (Fig. 4). Shallow water diatom taxa such as *N. amphibia* and *A. granulata* occur.

Zone A6-5 (1.080–1.509 cmab; ~2200? to ~1100? cal yr BP; Fig. 3). This zone is defined by a conspicuous increase in the percentage of altered phytoclasts (~44.6%), and gelified AOM (~11%), in tandem with the decrease in translucent phytoclasts to ~15%. Pollen (~3.8%) and pterydophytes (~3.9%) decrease to values close to 0.3% towards the top of the zone. The AOM content decreases to ~5.3%, whereas polliades, and fungi spores are scarce, i.e., ~0.041% and ~0.6%, respectively. Charcoal content is of the order of ~23578 pt/g with a reduction in the middle of the zone (Fig. 4). Shallow water diatom taxa such as *N. amphibia*, *Diadesmis confervacea*, *S. ulna*, *Cocconeis placentula*, *P. gibba*, and *Amphora libyca* occur.

Zone A6-6 (1.509–1.550 cmab; ~1100? and ~1000? cal yr BP; Fig. 3). This zone is defined by a sharp decrease in the percentage of translucent (~2.5%), altered (10%), and gelified (~10.6%) phytoclasts. The percentage of pollen (~27%), gelified AOM (~31.7%), and AOM (~10%) conspicuously increase. Pteridophyte spores increase to ~6%, whereas polliades, and fungi spores occur as traces (~0.2%). Charcoal concentration is ~2545 pt/g (Fig. 4). No diatoms were recovered from this interval.

3. Palynofacies and depositional environments

From base to top in the succession, the OM composition of A6-1 zone (~3500 to −3.150 cal yr BP) corresponds to terrestrial material (e.g., Sebag et al., 2006a,b; Figs. 5 and 6). The low gelified phytoclast/AOM ratios, and the low percentage of altered phytoclasts (Fig. 4), suggest pedogenetic input or sub-aqueous degradation, and a reduced fluvial influence, respectively (Sebag et al., 2006b; Sifeddine et al., 1995, 1996). The presence of aerophilic and planktonic diatoms support this interpretation; whereas the high percentage of translucent phytoclasts, palynomorphs, and the presence of macrophytes could be related to autochthonous vegetation from proximal areas (e.g., Sebag et al., 2006b; Traverse, 2007).

This OM composition and the reduced AOM content suggest the early flooding of La Caimana site by the Cauca River. The low

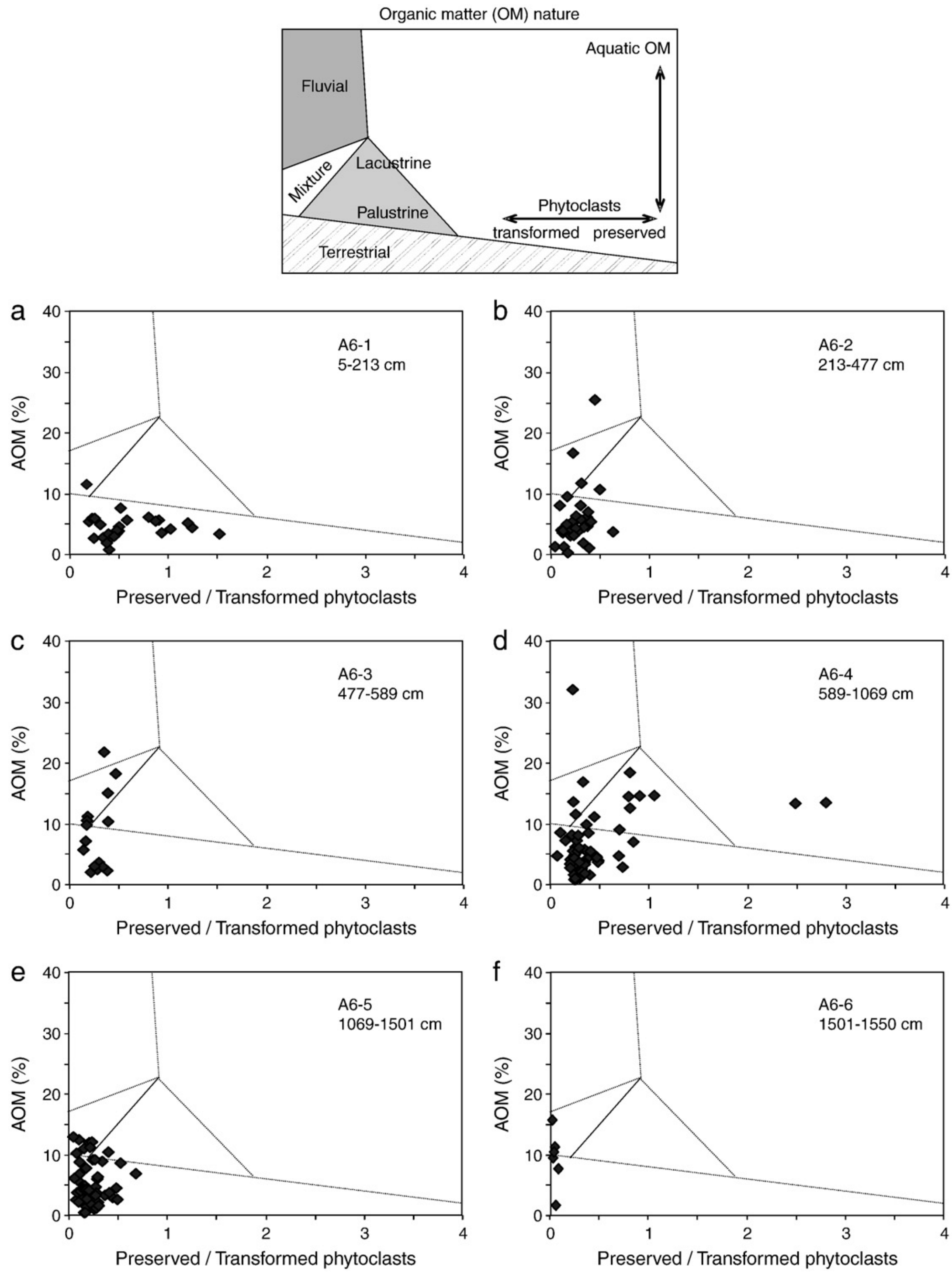

Fig. 5. Organic matter (OM) nature as defined by the relation between preserved/transformed phytoclasts and amorphous organic matter (AOM) for each biostratigraphic zone along the San Nicolas succession at La Caimana Creek (from Sebag et al., 2006a,b).

productivity could be due to either (1) a high content of dissolved organic carbon and/or (2) high suspended sediment yield, which would have reduced the availability of light and, with this, photosynthesis (cf. Karlsson et al., 2009; Wetzel, 2001).

The sharp increase in the percentage of altered phytoclasts at ~3150 cal yr BP (A6-2 zone, Figs. 5 and 6) marks the establishment of fluvio-lacustrine conditions. However, their high frequency fluctuations and the presence of millimetric laminae do support the interpretation of intermittent connections with the Cauca River. The presence of palynomorphs and the high gelified phytoclasts / gelified AOM ratio (Figs. 4 and 6) suggest diverse 'source' areas (Martín-Closas et al., 2005), whereas the occurrence of orange laminae and syneresis cracks, which occur together with gypsum phenocrystals, do suggest a negative precipitation–evaporation (P–E) balance (e.g., Tucker, 1982), at least for brief periods. Similarly, the high charcoal values would suggest an increase in regional fires. However, it is no possible to assess the degree of charcoal reworking, bearing in mind that there was an increase in fluvial discharge (cf. Jacob et al., 2004). The

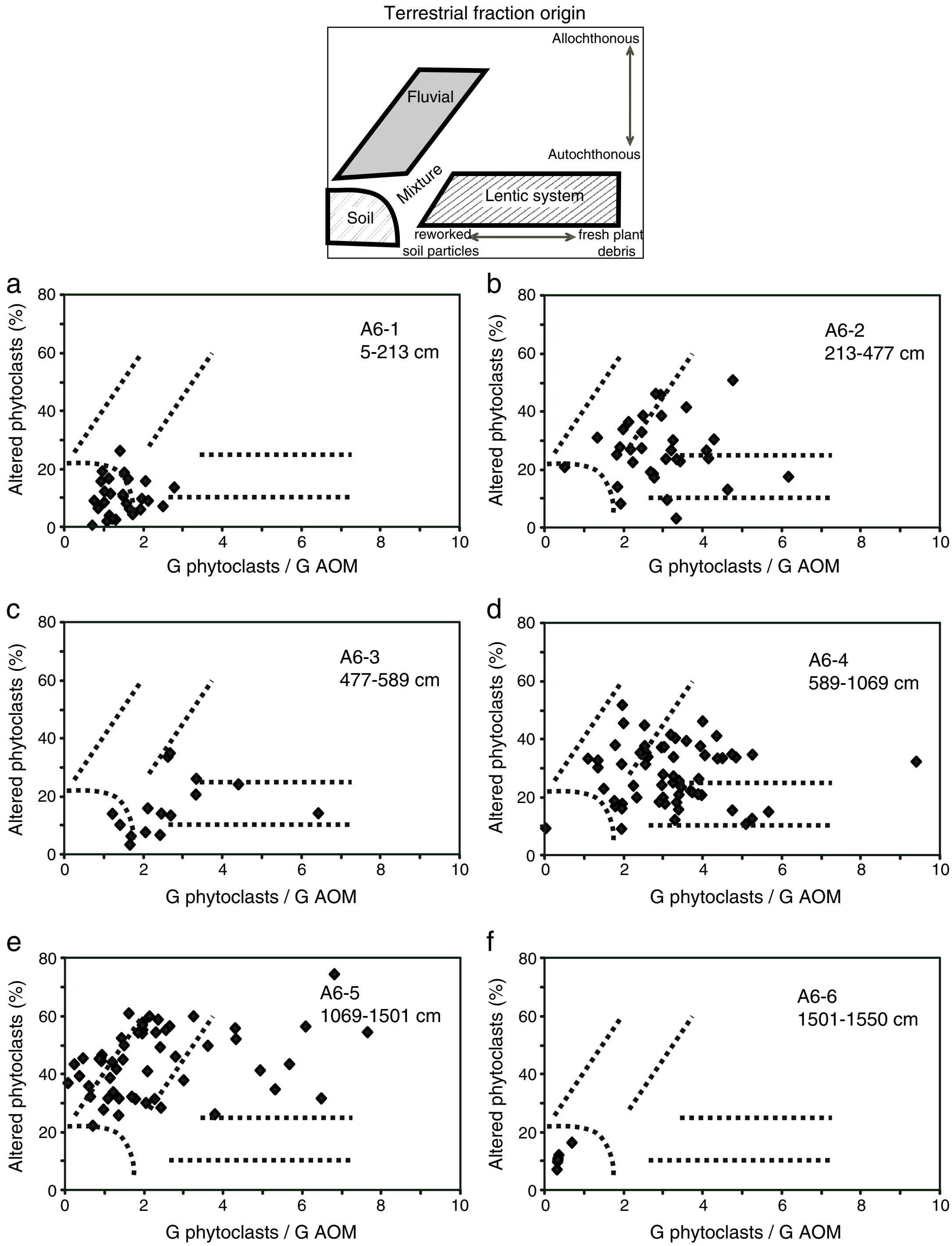

Fig. 6. Organic matter (OM) origin as defined by the relation between gelified phytoclasts/gelified AOM and the percentage of altered phytoclasts, for each biostratigraphic zone of the San Nicolás terrace at La Caimana Creek (from Sebag et al., 2006b). G = gelified. AOM = amorphous organic matter.

presence of diatoms such as *A. granulata*, and *C. stelligera* and *N. amphibia* suggest episodes of river flood and the establishment of lakes (Reid and Ogden, 2009), respectively.

By ~2730 cal yr BP, mixed OM, together with a sharp increase in AOM, and a decrease in transported OM (altered phytoclasts and charcoal; Fig. 4, A6-3 zone), suggest high frequency fluctuations in hydrological connectivity with the Cauca River. Similarly, diatoms such as *A. granulata* suggest the intermittent connection with the Cauca River, whereas *P. gibba*, *Fragilaria nanana*, *N. amphibia* and *Gomphonema gracile* testifies for the formation of a more permanent lentic body at La Caimana site (cf. Figs. 5 and 6).

Horizontal burrows (the *Mermia* ichnofacies), are more common than the vertical ones (the *Scoyenia* ichnofacies). The former are typical of the center of lakes, as compared to the latter which are typical of flood plains (cf. Buatois and Mangano, 2009). However, the occurrence of the *Scoyenia* ichnofacies, in the La Caimana site, could result from the response of the horizontal burrowing organisms to the very high sedimentation rate regime in order to keep close to the sediment–water interface. Therefore, a paleobathymetric reconstruction of the succession based on trace fossils deserves more study.

The sharp decrease in charcoal suggests either, a decrease in regional fires, or a reduced hydrological connection with the Cauca

River. Whatever the case, this pattern is analogous to the one reported for the Neotropics (e.g., Power et al., 2010).

By ~2550 cal yr BP there is a mixture of terrestrial and lacustrine OM, an increase in translucent phytoclasts, high frequency fluctuations in altered phytoclasts and AOM, a slight increase in the gelified/AOM ratio (Figs. 4–6, A6-4 zone), the occurrence of epiphytic diatoms such as *N. amphibia*, and the preservation of laminae and OM (dark gray mud), which once again, suggest the episodic hydrological connectivity with the Cauca River. The occurrence of gypsum crystals at discrete intervals, do suggest a negative P–E balance (e.g., Tucker. 1982). Fine-grained sands and yellow mud became common upward the sedimentary succession, thus suggesting an increasing fluvial influence. The decreasing trend in charcoal content, associated to the lacustrine phase, suggests regional fires and probably air transport.

By ~2200 cal yr BP the conspicuous increase in the percentage of altered phytoclasts and gelified AOM, at the expenses of a decrease in AOM, together with the increase in grain size to fine sand (base of A6-5 zone), confirm the terrestrial nature of the OM and suggest that fluvial conditions prevailed (cf. Figs. 5 and 6). This marked fluvial influence would be responsible of the dilution of sporomorphs and the infilling of La Caimana valley at a rate that might be well in excess of our estimate of ~600 cm/ka. The conspicuous increase in the gelified AOM suggests high degradation rates and aerobic diagenesis (Sebag et al., 2006b; Sifeddine et al., 1996). This, together with the diatom assemblage, suggests sub-aerial exposure. By this time, regional fires appear to be less frequent.

It is, however, after around 1100? cal yr BP that the increase in sporomorphs of Malvaceae herbs, OM of terrestrial origin, and the decrease in altered phytoclasts, together with paleosoils (oxisoils?), macrophytes, and sedimentary hiatuses suggest the final phase of sedimentary infilling of La Caimana Valley (cf. Figs. 5 and 6).

As evidenced by the dispersion of data in Figs. 5 and 6, all over the succession, the high frequency fluctuations in the palynodebris and diatom content do indicate that there was an intermittent hydrological and biological connection between the Cauca River and La Caimana Valley (lake). This episodic lacustrine sedimentation was not restricted to La Caimana region but occurred along other creeks in the Santa Fe–Sopetrana Basin. The narrowness, and rough relief, of the middle Cauca Valley, together with the braided pattern of the Cauca River prevented sedimentation to occur in oxbow lakes. This depositional system was first known as "the incomplete flood plain" in the Magdalena River in central Colombia (Tanner, 1974), and as varzea lakes in the Amazon (e.g., Baker, 1978; Putz, 1997). The hydrological and biological connection between rivers and their floodplains is known as the "flood pulse concept," a dynamical model proposed to explain water characteristics, organic matter composition, and diversity (e.g., Amoros and Bornette, 2002; Junk and Wantzen, 2004).

4. Paleoclimate implications and regional comparisons

As suggested above, fluctuations in the percentage of OM would reflect hydrological connectivity, which could be interpreted as resulting from precipitation pulses all along the Cauca Valley (Fig. 1). In this way, for example, high altered phytoclast contents when compared to low AOM contents (Fig. 4) would reflect the dilution of the latter by the input of terrestrial OM transported by the Cauca River (cf. Sebag et al., 2006a,b), and possibly a positive P–E balance. Our interpretation is supported by the occurrence of fluvial diatoms such as *Aulacoseira granulata* (e.g., Bormans and Webster, 1999; Reid and Ogden, 2009). Conversely, low altered phytoclast contents when compared to low AOM contents (Fig. 4) would suggest a negative P–E balance. This is supported by the occurrence of lacustrine diatoms such as *N. amphibia* (e.g., Moro and Fürstenberger, 1997), and dark gray, organic rich mud.

Over-imposed on the hydrological connectivity of the Cauca River, the sedimentary succession and the palynofacies pattern do reflect the sedimentary infilling of La Caimana valley, i.e., the decrease in the accommodation space (e.g., Emery and Myers, 1996). The reduced occurrence of AOM, pollen grains, and diatoms could reflect: (1) the very high sedimentation rates, which would have caused terrigenous dilution, and/or (2) a reduction in productivity resulting from the presence of dissolved organic carbon of humic (?) origin. In both cases, the amount of light in the epilimnium would be limited thus affecting productivity (e.g., Karlsson et al., 2009; Wetzel, 2001).

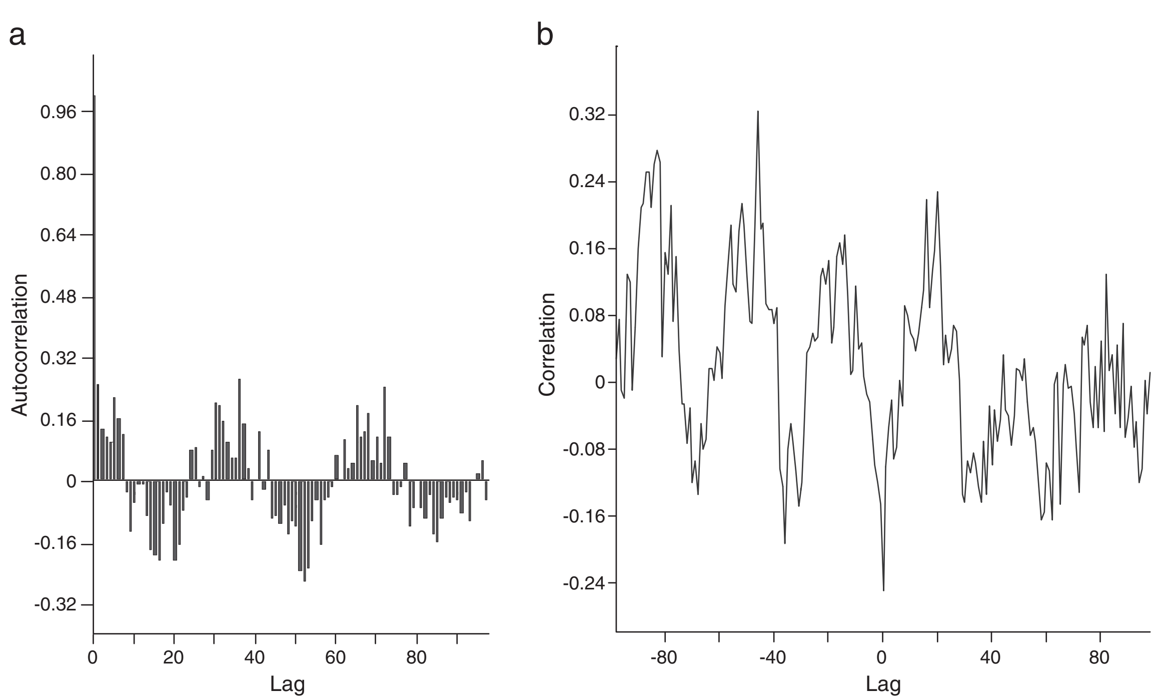

Fig. 7. Amorphous organic matter (AOM) periodicity and its correlation with the percentage of altered phytoclasts. (a) Autocorrelation of the percentage of AOM and (b) autocorrelation between AOM and altered phytoclasts.

The dominance of terrestrial OM transported from a distal source by the Cauca River, which would have been intermittently deposited in La Caimana valley, suggest a regional climate control. This regional signal is modulated by climate and fluvial system dynamics all over the Cauca River, which runs along 1183 km (Restrepo et al., 2005). Conversely, the autochthonous lacustrine OM would reflect local climate conditions.

The apparent cyclicity of the AOM and the autocorrelation between it with altered phytoclasts (Fig. 7) do indicate a recurrence of 150 cm, which suggest a periodicity of flooding in the order of hundreds of years, over-imposed on annual to decadal pulses. However, this estimate is based on our preliminary age model, built on linear interpolations, which is based on the assumption of continuous sedimentation at a constant rate (e.g., Enters et al., 2006). This might not be the case of La Caimana succession, particularly towards its top where stratigraphic discontinuities are common, bed thickness and grain size increases, and fluvial sedimentary facies are evident.

Previous attempts to reconstruct the dynamics of the ENSO phenomenon in fluvial successions from northern Colombia, include the palynological study of lacustrine deposits in the lower Magdalena Valley, i.e., where the Magdalena, Cauca and San Jorge rivers converge (Fig. 1; e.g., Plazas et al., 1988; Van der Hammen, 1984; Van de Hammen and Cleef, 1992). Peat records are interpreted as resulting from droughts during El Niño – like events. These events, apparently correlate with low lake levels in the northern Andes (Van der Hammen, 1984).

From the comparison between Alt Lc-D /AOM with the lower Madgalena valley peat records and the low lake levels of the northern Andes (Fig. 8) there appears some possible correspondence between a negative P–E balance in the San Nicolas succession and the peat frequency. This comparison is very tentative due to: (1) limitations in our age model and (2) the unpublished radiocarbon data from the lower Magdalena Valley. However, it is interesting to note that there are some similarities and that sedimentation rates in both, the middle Cauca, reported here, and the lower Magdalena (Van de Hammen and Cleef, 1992) valleys are analogous.

Even though the San Nicolas succession, at La Caimana Creek, possibly does not contain the whole record of the paleolake due to irregularities in the basement, it is of interest to note that the lowermost interval corresponds to a period of expansion of the dry forest and/or unstable conditions in southern Colombia (e.g., Marchant and Hooghiemstra, 2004; Veléz et al., 2005), and less frequent ENSO events in the Brainbridge Lake (Galapagos; Riedinger et al., 2002). This would mean that the beginning of lacustrine deposition is related to an increase in water discharge of the Cauca

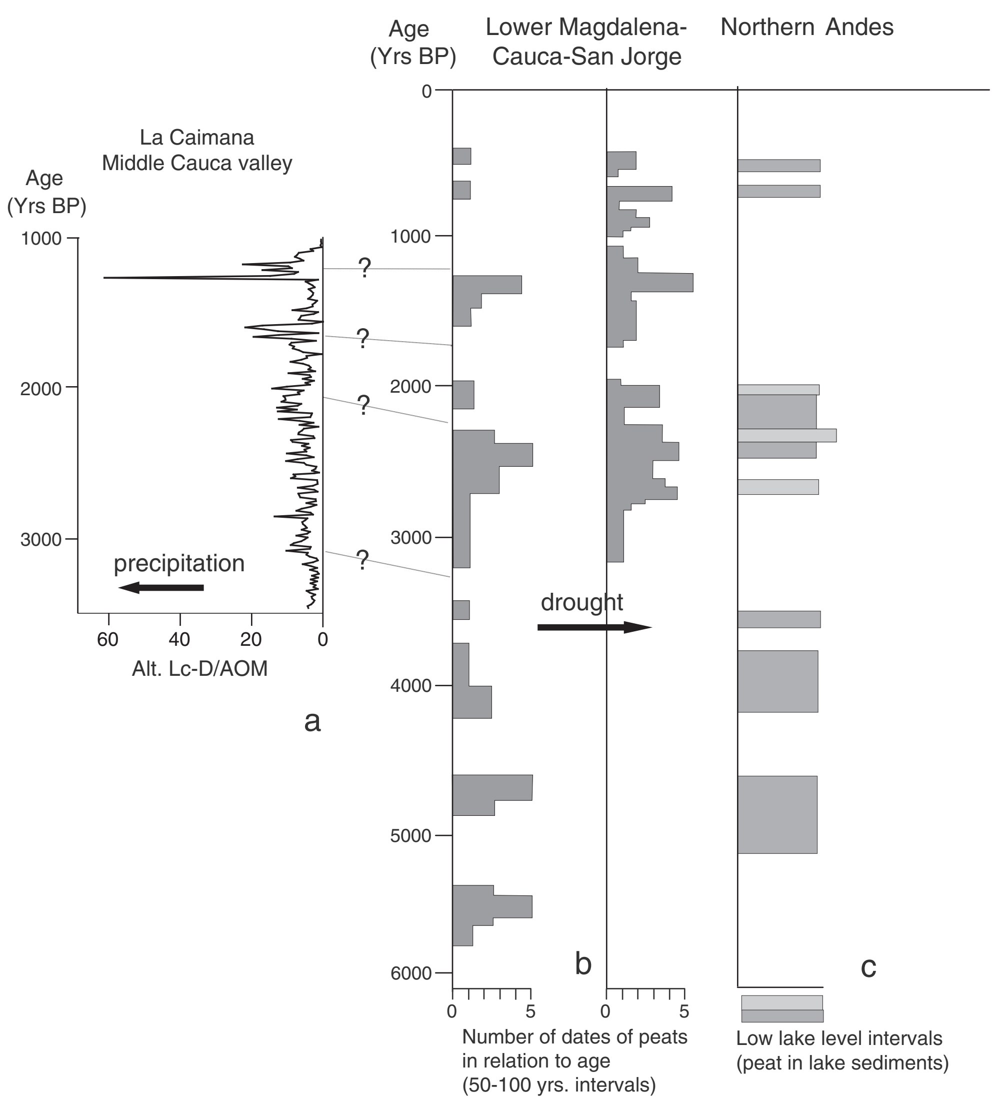

Fig. 8. Precipitation record (Alt Lc-D /AOM) of the San Nicolás terrace (a) compared to the drought record of the lower Magdalena and Cauca valleys (b), and low level lake intervals from the northern Andes (c) (from Van der Hammen, 1984, and Plazas et al., 1988). Note that differences among the Cauca and the other records could be due to age uncertainties.

River resulting from a regional and positive P–E balance. High charcoal values might be related to human intervention as has been reported up in the Cauca Valley and elsewhere in northern South America (e.g., Veléz et al., 2005) and regional turnover in the precipitation regime to wetter conditions (e.g., Marchant and Hooghiemstra, 2004). This possibly applies to the Cauca watershed but not to its middle and lower course which was possibly affected by the southern migration of the ITCZ and strong ENSO variability (e.g., Haug et al., 2001; Tedesco and Thunell, 2003).

5. Conclusions

The detailed palynofacies analysis of the San Nicolás terrace at La Caimana Creek reveals that:

1. The succession was deposited in a lacustrine to fluvial dominated setting between ~3500 and few hundreds of years with sedimentary rates in excess of ~600 cm/ka.
2. The milimetric laminae and the high frequency fluctuations in the content of palynodebris of terrestrial origin, i.e., the high altered lignocellulosic debris / amorphous organic matter ratio, together with diatoms indicative of fluvial conditions, such as *A. granulata* do suggest an intermittent, and continuous hydrological and biological connectivity with the Cauca River. This flooding behavior appears analogous to the varzea lake dynamics in the Amazon basin.
3. Drier to wetter conditions appear to occur moving upward in the succession. This might reflect regional precipitation conditions all along the Cauca Valley and the southern shifting in the mean position of the ITCZ.

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