Chapter 2
Development of the Amazon Valley During the Middle to Late Quaternary: Sedimentological and Climatological Observations

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Abstract Pleistocene sea-level changes affected the Amazon River as far as 2,500 km inland. This results on one hand with the formation of large floodplains of the Amazon and the lower parts of its tributaries during sea-level heights and on the other hand with a deeply incised river system during low sea-level stages. This was most effective since Mid-Pleistocene when the changes of sea-level got stronger. This could be shown from the deeply incised valleys of Negro and Tapajós Rivers. During Last Glacial Maximum the slope of the Amazon below its junction with Tapajós River increased by the factor 10, resulting probably in a braided River. Paleofactors of sediment cores taken from Central Amazonia lakes and from Tapajós River give no hint for a significant change in climate.

2.1 Introduction

While, in general, the effects of Quaternary sea-level changes are restricted to coastal areas, in estuaries they may be observed as far as several hundred kilometers inland. In the case of the Amazon River, the impact of such inland changes extends over more than half of the continent, some 2,500 km upstream from the mouth of the Amazon. This results in far-reaching sedimentary changes, especially in the main valley of the Amazon River and in the lower sections of its tributaries. Accordingly, the sedimentological development of the Amazon valley has long been the focus of great interest. When were the deeply incised valleys of the Amazon lowlands formed? What residues, mainly of the Pleistocene warm periods, can be found? What significance and ecological impact do these relicts have on the present appearance of the river floodplains? These questions, together with the important role played by lake deposits as paleo-indicators in respect to in climate and ecology will be discussed in this chapter.

2.2 Formation of Ria Lakes

Ria lakes are relicts of former, deeply incised river systems (Gourou 1950) and are filled with (fresh) water. In the Amazon basin, thousands of such lakes occupy the lower sections of rivers and creeks. In the case of the Negro, Xingú, and Tapajós Rivers, Ria lakes achieve lengths of more than 100 km, although there are also thousands of lakes whose lengths barely exceed 1 km. Ria lakes only occur in the valleys of rivers with a low sediment load. Rivers with a high sediment load, such as the Madeira, Purús, and Juruá Rivers, do not show this phenomenon as the corresponding valleys became filled with river sediments long ago.

All Ria lakes show a high degree of padding. In many of these lakes, the bottom is exposed during low water levels and creeks may form for several months, acting as a local drainage system. It is assumed that an equilibrium develops between sedimentation and erosion during high- and low-water stages. As a result, water depth in Ria lakes scarcely exceed 5 m during average water stages. This was observed in

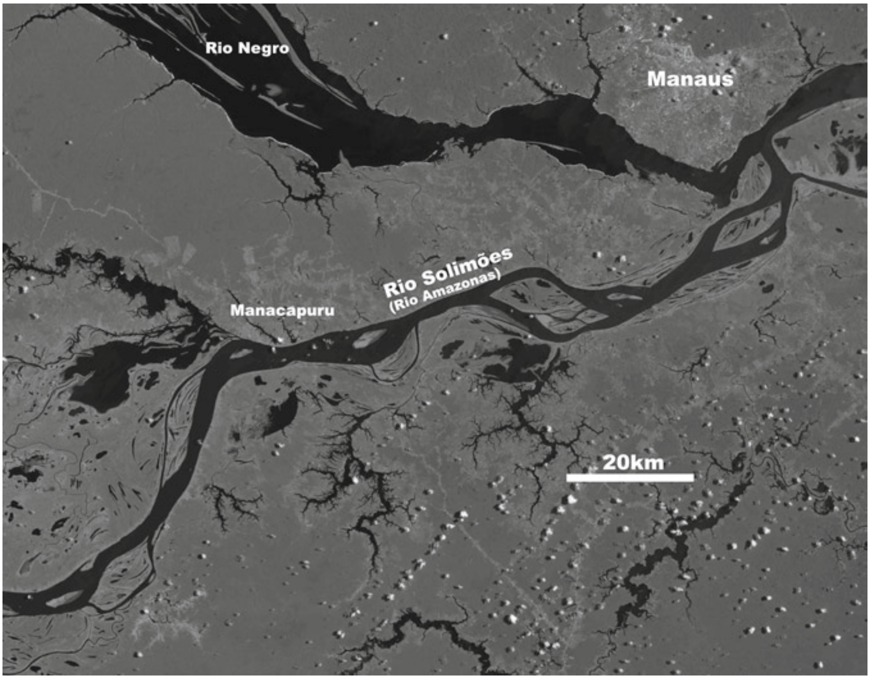

Fig. 2.1 Satellite image of the Solimões River and its surroundings, between Manacapuru and Manaus. Note the large numbers of smaller Ria lakes south of Rio Solimões. The lower section of the Negro River, as shown in the upper part of the figure, is itself a Ria lake

the intensively studied areas north and south of the Solimões River (Fig. 2.1), between Manacapuru and the Solimoes/Negro junction, and, e.g., for the Ria lakes of the Uatuma and Juruti Rivers (own field studies in 1992).

The large extension and comparatively low sediment load of the Negro and Tapajós Rivers results in higher water depths in the corresponding Ria lakes (respectively, 100 and 50 m), with one exception: the Trombetas River. The valley of this river is filled and a new riverbed has formed on top of the deposited lake sediments. However, in its tributaries, Ria lakes are still present.

It has been suggested that Ria lakes resulted from the filling of troughs that formed during low sea-level stages, when large parts of the Amazonian River system were deeply incised. While this explanation is generally accepted, the time component is still debated. It may be assumed that trough formation started with the initial lowering of the Pleistocene sea-level, or that it resulted, at least in part, from tectonic movements (Latrubesse and Franzinelli 2002), but unambiguous geological evidence is lacking. Many Ria lakes were formed during the Last Glacial Maximum (LGM), as is discussed later in this chapter. Other such lakes, mainly those surrounded by Tertiary geological formations, may be older. A closer study of the lower sections of the Negro and Tapajós Rivers, the largest Ria lakes of Amazonia, revealed important information regarding the evolution of the river valleys, which reaches back far beyond the LGM.

2.3 Mid to Late Quaternary Changes in the Lower Rio Negro Valley

Some 140 km downstream of the Negro and Branco River junction, the Negro River leaves an area of Devonian shale and enters one of Cretaceous sandstone, which is relatively vulnerable to erosion. Further downstream, there is a deeply incised riverbed that reaches a maximum depth of 100 m and is not completely filled with sediments (Fig. 2.2). Presumably, the valley was formed during the Pleistocene low-water stage, during which the low sea-level, 120–130 m below pMSL (present mean sea-level), was similar to that reached during the LGM. This resulted in a lowering of the water level of the Negro River by at least 40 m at its mouth (see below).

The results of 3.5-kHz profiling in the Negro River valley have shown that, in the Holocene, a 10-m-thick sediment layer was deposited in large parts of the valley during high sea-level stages (Irion et al. 1999). The volume of this Holocene deposit is estimated to be one third of the total sediment mass deposited during the existence of the deeply incised trough of the Negro River valley. Since similar processes occurred during each sea-level height of the Late Quaternary, the trough filling is comparatively young, i.e., not older than a few glacial cycles. This fits very well with

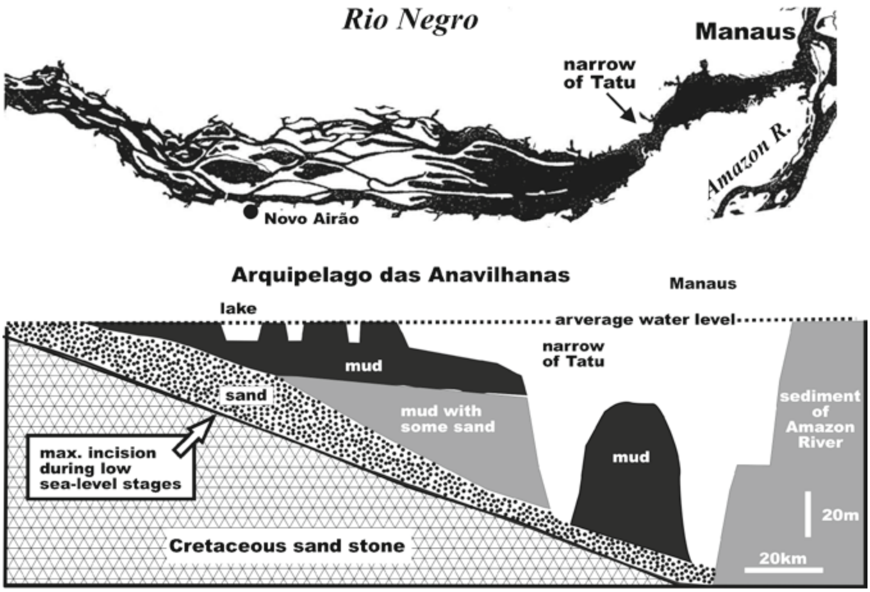

Fig. 2.2 Cross-section through the Ria lake of the Negro River. The archipelago of the Anavilhanas formed during various sea-level heights during the last about 800,000 years. The sediments are predominantly fine-grained and were deposited as a result of decreased flow in the upper 100 km of the river. At the narrow of Tatu, where the width of the river decreases to merely 1.6 km, the deposition of mud is interrupted, but it continues when the Ria lake expands again directly upstream of Manaus. Maximum incisions of the Negro River are reached during low stands of the sea-level

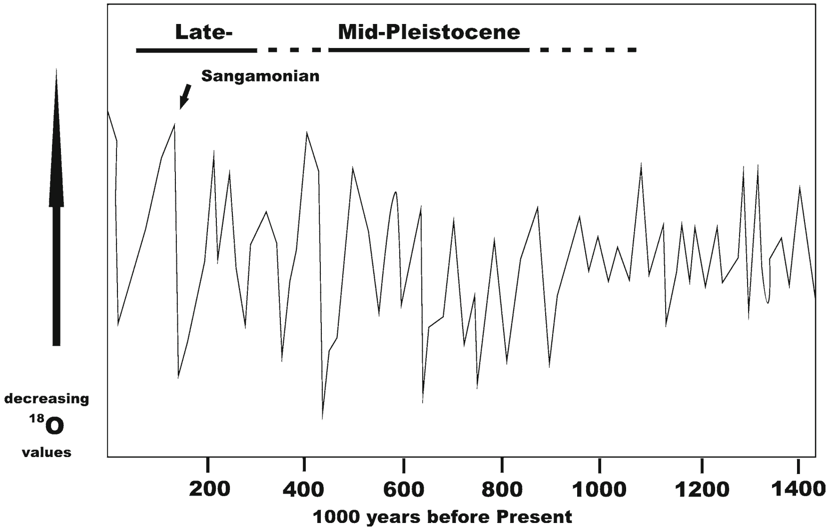

Fig. 2.3 Oxygen isotope curve of the foraminifer *G. sacculifer* as determined in a deep-sea core (ODP leg. 130 core 806 – redrawn from Berger and Wefer 1992). The difference in ^{18}O values is small but significant. Low ^{18}O values correspond to high sea-levels (recent time, Sangamonian, etc.) and high values to sea-level minima. Note the strong increase in the oscillation between high and low ^{18}O values at about 800,000 years BP. Deeply incised Ria valleys, such as those of the Negro and Tapajós Rivers, may have formed during these times as a result of fluctuating sea-levels

the general trend of sea-level fluctuations during the Quaternary, as determined from the $\delta^{18}O$ variations in deep-sea sediment cores. There is evidence that a change to more extended glaciations occurred approximately 600,000–900,000 years ago, the so-called Mid-Pleistocene revolution (Berger and Wefer 1992; Fig. 2.3).

It has been estimated that, during the Early Pleistocene, the drops in sea-level were significantly smaller than those that occurred during the LGM, i.e., in the range of 40 m. According to our analyses, performed on sediment cores recovered from Central Amazon lakes and from the Tapajós River (see below), a sea-level of 40 m below the pMSL would have lowered the mean river level at Manaus by a maximum of 13 m. This is only a few meters below the average yearly minimum level of the Amazon at this site. In contrast, during the LGM, the mean river level at Manaus was more than 40 m lower.

During the Mid-Pleistocene Revolution, the Negro River incised and formed its valley, destroying all relicts of a smaller pre-existing "Ria valley." The surrounding Cretaceous sandstone was easily eroded, weakened by weathering processes during the Tertiary. During the Mid-Pleistocene and Late Pleistocene, the high sea-level resulted in the deposition of fine-grained river sediments in the newly formed trough. Like those deposited during the Holocene, these sediments were soft and would have been immediately eroded by flowing water. However, during low sea-levels they were exposed to the atmosphere and consequently oxidized to a depth of several meters. All organic carbon was reduced, accompanied by the alteration and neo-formation of minerals, mainly lepidocrocite, Al-chlorite, anatas (TiO_2), and iron oxides (Keim et al. 1999). These processes led to extensive hardening of the sediment surfaces such that they became resistant to erosion. Similar hardened surfaces are found in many lakes below the Holocene mud, e.g., in those of the Negro and Tapajós Rivers and in smaller lakes in Central Amazonia (e.g., Lago Calado, Keim et al. 1999). Presently, the 140-km-long Ria lake of the Negro River valley is nearly completely filled with sediments between Airão and the narrow at Ilha Tatu. Additionally, sediments have been deposited in the enlargement north of Manaus.

2.4 Mid to Late Quaternary of the Lower Tapajós River Valley

The Ria of the Tapajós River is 150 km long and 20 km wide. During high-water stands, the backwater effect reaches as far as Itaituba, which lies about 225 km from the mouth of the Tapajós River. In contrast to the Negro River, there are no islands in the Tapajós River, but the upper half of the valley has filled to the extent that, during low-water periods, sediments covering an area of several hectares fall dry.

Since the high gas content of the sediment prevented 3.5-kHz profiling, the limits of the Holocene sediment masses were detected by about 50 profilings, reaching down to pre-Holocene sands or to the above-mentioned oxidized lake deposits. Figure 2.4 shows that the filling process is by no means complete. As a result, it seems that the original Tapajós valley did not form before the above-mentioned change in glaciation intensity.

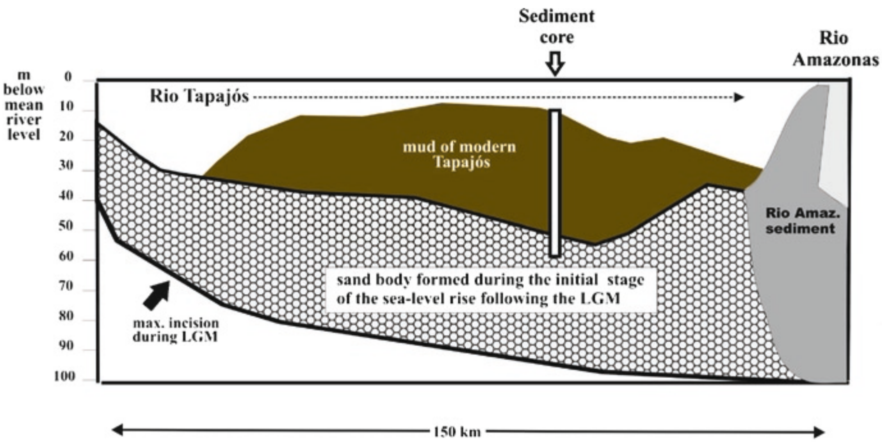

Fig. 2.4 Cross-section through the Ria lake of the Tapajós River as detected by profiling during field trips in 1999, 2002, and 2005. The profile follows the deepest incision of the Tapajós River bed, during the LGM; later, the river bed filled with fine-grained sediments. Older sediments extending on both sides of the deepest incision and reaching close to the surface – not shown in the graph – occupying more space than Holocene sediments

2.5 Formation and Distribution of the Palaeo-Várzea

Today's várzeas were formed during the Holocene, when large parts of the Amazon valley were submerged due to the backwater effect of the high sea-level. Consequently, in the Pleistocene, there must have been extended floodplains during each change in sea-level that was higher or similar to its precursors. The most extended várzea was formed during the last warm period, the Sangamonian. The extent of this palaeo-várzea can be estimated from radar maps of the Projeto Radam, published in 1970–1972. The total area remains difficult to estimate but must have been far greater than 50,000 km². The largest areas are located in the vicinity of Lago Amanã, some 70 km north of Tefé, between Lago Coari and the Purús River, south of the lower Rio Solimões, as well as at the rim of the várzea between Juruti, Óbidos, and Santarém. Palaeo-várzea can be recognized by the sequences of ridges and swales that resulted from rhythmic depositional processes occurring predominantly at the slip-off slope of the river course (Irion 1976a). The structure of the paleo-várzea is the same as the recent várzea, but its features have been significantly weakened. Additionally, in many areas of the paleo-várzea, Ria lakes are present. Those várzeas most probably have formed earlier than the LGM, during a sea-level higher than the present one.

Sediment cores taken from the paleo-várzea show significant alteration in mineral composition due to weathering processes at and near the surface; however, with increasing depth (several meters), the mineral composition is the same as that of nearby recent river deposits. The alterations consist of increased amounts of kaolinite, gibbsite, and iron oxides at and near the surfaces of the paleo-várzea (Irion 1984a), sometimes accompanied by a decrease in smectite. The well-preserved surfaces and the presence of only moderate alteration in the minerals of the surface sediments are in accordance with the Sangamonian age of the paleo-várzea. There are also relicts of older Pleistocene stages; these show a higher degree of alteration than those of the Sangamonian várzea (Irion 1984a).

Most of the smaller Ria lakes are situated in the várzeas that formed during the last sea-level high, the Sangamonian, and are approximately 110,000 years old (see below). The troughs of those lakes may have formed during the LGM but precursors of Mid-Pleistocene to Late Pleistocene age may have been present at the same place. For example, there are numerous smaller lakes in the paleo-várzea south of the Solimões River, between the city of Manacapuru and the Solimões/Negro junction; or in the triangle west of the lower Purus and Solimões Rivers. Here, two generations of paleo-várzeas may be clearly distinguished by their different altitudes, as shown by the georeferenced altitude program of NASA (Fig. 2.5). Sediments profiles taken from the paleo-várzea of the region surrounding Lago Aiapuá show, due to the well-preserved mineral association, that this várzea cannot be older than of Sangamonian age (Irion 1984a).

The NASA georeferenced altitude program shows that the paleo-várzeas are between 15 and 20 m higher than the recent várzea. The recent river level at Manaus is 20 m above pMSL and reaches 45 m above pMSL at Tefé. The surfaces of the paleo-várzeas rise from Manaus to Tefé, from 40 to 60 m above pMSL.

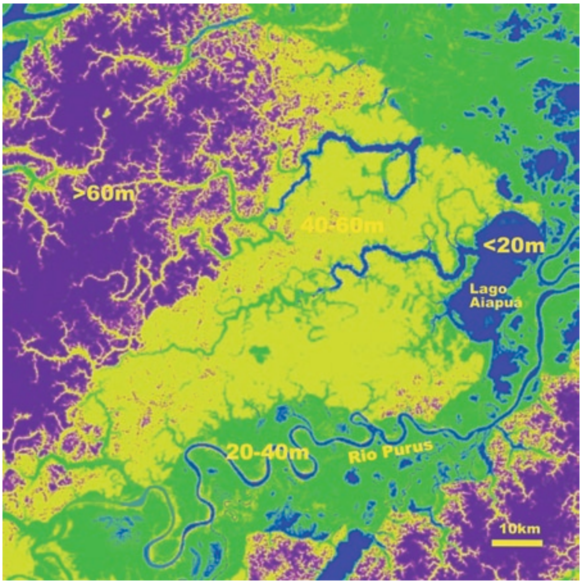

Fig. 2.5 Altitude map of the area west of the Purus River and showing Lago Aiapuá (NASA georeferenced map). Three different generations of várzea can be identified. In the south and west recent várzea 20–40 m above msl, lower paleo-várzea, most probably of Sangamonian age, 40–60 m above msl, and an older várzea >60 m above msl. The large relative differences in heights can be explained by slow, tectonically upward movement

These high positions of the paleo-várzeas can not only be explained by higher sea-levels in the Sangamonian and during older, warm Pleistocene periods; additionally, there should be a decreasing difference between recent várzea and paleo-várzea surfaces with increasing distance from the sea. Regarding paleo-várzea older than 110,000 years, slow tectonic upward movements at least partly explain this phenomenon. These results are in accordance with those of Dunne et al. (1998), who provided evidence for an upward tectonic movement in the western Amazon basin at Purus and Jutai Arch. An uplift in the eastern Amazon basin is less probable and explains why, in the region downwards of Óbidos, there is no significant height difference between recent and palaeo-várzeas.

Despite a serious lack of detailed studies of the paleo-várzea, we drew maps of their distribution using NASA radar maps and the results of the Projeto Radam. The three maps shown in Figs. 2.6–2.8 may be regarded as a preliminary approach to the distribution of the Amazonian paleo-várzeas.

As is the case for many other tropical lowland areas, the Amazon basin is characterized by extremely low fertility (Weischet 1977). However, in contrast to the large area of the Precambrian shields and the Cretaceous/Palaeozoic formation, the várzea is highly fertile (Sioli 1957). The Na, Ca, Mg, and K distributions in the fine fraction of the soils serve as representative benchmarks. Figure 2.9 shows the large differences between the old surfaces and the várzea, but there are also differences between Pleistocene and recent várzeas.

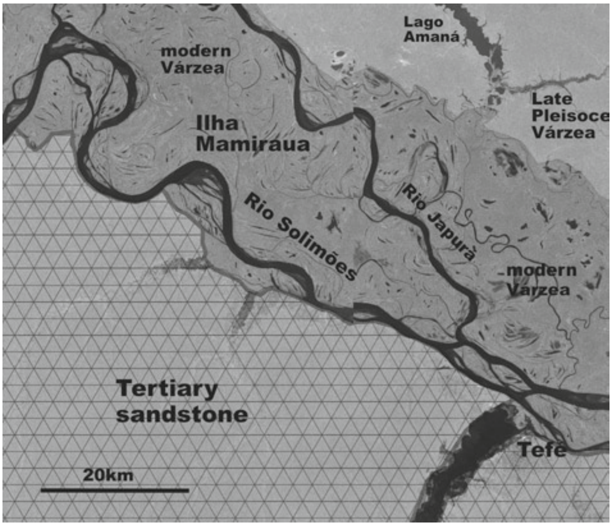

Fig 2.6 Radar map of the Lago Amanã area showing the palaeo-várzea and the recent várzea of Ilha Mamirauá, near Tefé. There are no detailed descriptions of the sediment profiles that would have allowed estimation of the age of the várzea; but from observations made during a field trip in 2002 (Inpa/MPI-Plön/Senckenberg-Inst.) it can be concluded that there are at least two generations of palaeo-várzea along the banks of Lago Amanã

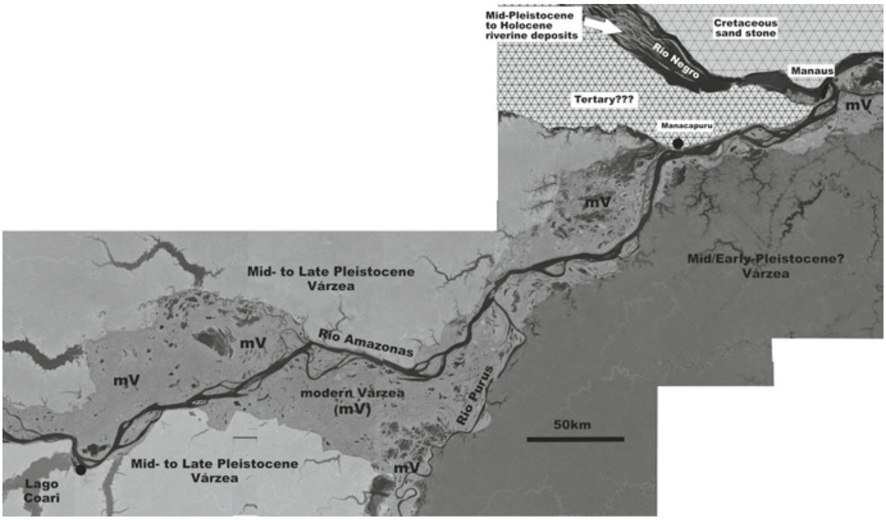

Fig. 2.7 The Amazon valley between Lago Coari and Manaus. Note the extremely large area occupied by Mid-Pleistocene and Late Pleistocene várzeas. Várzeas of three different ages are distinguished not only by differences in their heights but also by differences in the degree of alteration of their mineral compounds (Irion 1984a). The modern Amazon valley (50 km) is considerably wider between Coari and Manacapuru but subsequently narrows to less than 10 km

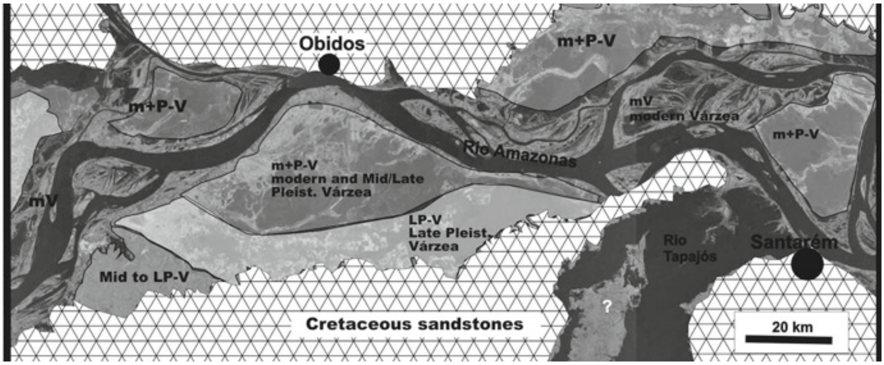

Fig. 2.8 The broad extent of the várzea of the Santarém/Óbidos area. Field studies done in 2005 (Irion unpublished) showed that modern várzea and Late Pleistocene várzea occur on similar levels. During flooding in June, July, and August, these areas are drowned. Sioli (1957) pointed out that this section of the Amazon River floodplain has not yet filled with sediments

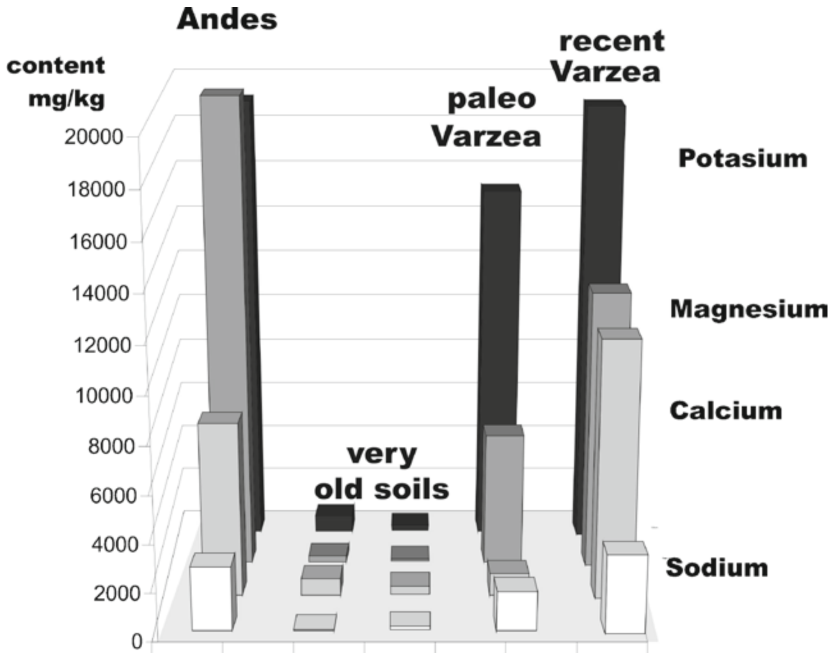

Fig. 2.9 Potassium, calcium, magnesium, and sodium in Amazonian soils in grain-size fraction <2 µm (After Irion 1976b). Note the large differences between the old surfaces and the várzeas and the Andes. The differences in the contents are between one and two orders of magnitude. The fertility of the somewhat richer soils of the Paleo-Várzea is higher, as shown, for example, by the higher density of rubber and paranut trees than of the Belterra clays (indicated as very old soils)

2.6 The Paleo-Climate During the Late Holocene: An Analysis of Palaeo-Proxies from a 50-m Core Recovered from the Sediments of Lago Tapajós

Climate development in the Amazonian lowland has been discussed vehemently over the last several decades (Haffer 1969; Prance 1982, Colinvaux et al. 2001), underlining the need for appropriate paleo-indicators. In this context, sediments and thus sediment cores of Ria lakes are an appropriate paleo-indicator. The following discussion is based on our studies of Ria lakes in central Amazonia (Keim et al. 1999; Behling et al. 2001) and in the Tapajós River (Irion et al. 2006). It focuses on the results obtained from a sediment core recovered from "Lake Tapajós" (Irion et al. 2006).

A 50-m sediment core (see Fig. 2.10 below) was removed from the Ria lake of the Tapajós River, at a location of about 2° 47′S and 55° 05.5′W′, 60 km south of the river mouth at Santarém (Irion et al. 2006). The initial expectation was to recover lake sediments deposited 14,000 years ago. However, this turned out to be

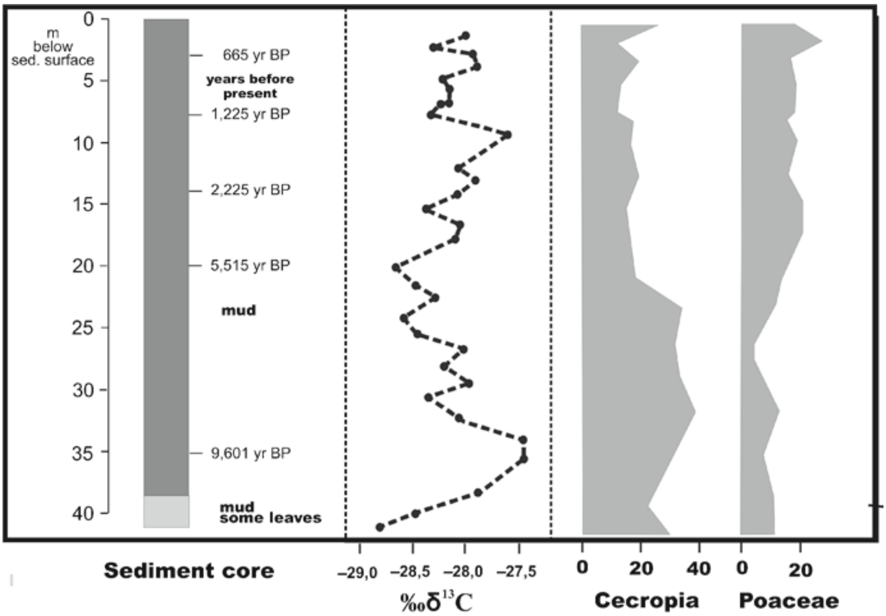

Fig. 2.10 δ^{13}C, and Cecropia and Poaceae pollen records in the long sediment core taken from the Tapajós Ria Lake, located at 02° 47'S/55° 05.5'W (Irion et al. 2006). δ^{13}C measurements showed that no or only small amounts of organic compounds are representative of C_4 plants, indicating that forest has always been the dominant vegetation in the drainage area of the Tapajós. The consistent vegetation cover is also evidenced by the mineralogy and the pollen distribution (see text)

impossible because a huge sand body had been pushed onto the older sediments during the Late Pleistocene rise of the lake level (caused by the rise in sea-level). This process may be compared with the “bulldozing effect” involving ocean shelf areas where, after the LGM, huge masses of sands were pushed landwards by the rising sea-level (Cowell et al. 1992). In the case of Tapajós River, sands has been pushed from Rio Amazon into the Tapajós valley. Consequently, the sands at the base of the Tapajós core may slightly predate the Holocene and can be associated with the rapid rise in sea-level. This hypothesis is consistent with the age of the oldest clay-rich sediments in this sequence, which date to the start of the Holocene (ca. 11,000 years BP).

The initial phase of lake formation, characterized by a transition from a relatively high-energy environment to one of slack water, is evident at a depth of 42 m. The fine-grained sediment found exclusively above 38 m is representative of still-water lakes and is perhaps unexpected in “Lago Tapajós,” where the average water discharge is 13,000 $m^3\ s^{-1}$. The fine grain size can be explained by the sufficiently large volume of the lake, in which sediments did not collect within a principal channel. Additionally, the tide of the Atlantic Ocean reaches “Lago Tapajós” and, during slack water, conditions favor the deposition of extremely fine-grained sediments. What is evident from these data is that a relatively large lake filled the “Lago Tapajós” basin in the Holocene.

The mineral content of the sediments comprising the <2 μm fraction reflects sediment derived from a typical tropical soil surface. In warm wet settings, where clays weather easily, kaolinite, together with some Al-chlorite and gibbsite, dominates. The kaolinite is b-axis-disordered, as is the case in most surface horizons of Amazonian lowland soils. Quartz and illite are relicts of the primary geological formations of the drainage area, but siderite is formed in the lake or in its sediments. As for variations in clay minerals, no changes were observed in the entire section of the lake analyzed (Irion et al. 2006). The formation of siderite and the presence of relatively high concentrations of Fe and Mn are consistent with redox values in the deeper part of the water column and in the lake sediments. As the lake stabilized and deepened, these values decreased to those measured in modern times (Irion et al. 2006).

The vegetation during the phase of lake formation was characteristic of closed-canopy lowland forest with an abundance of riparian forest (e.g., *Cecropia, Ficus, Mauritia, Serjania*), marshland (*Alternanthera, Borreria*, Cyperaceae, *Ludwigia, Utricularia*), and terra firme elements (*Alchornea, Brosimum*-type, *Pouteria, Sapium, Sebastiana, Socratea, Symmeria, Waltheria*). Poaceae pollen was present in all samples and originated from wetland grasses, bamboos, or disturbed landscapes. A normal abundance range for Poaceae in várzea systems is 5–10%; the values observed here were a little higher than would be expected from a record of pure closed forest. Overall, the pollen record is consistent with a closed canopy forest and predicts sediments with strongly negative $\delta^{13}C$ values, as we have found (Fig. 2.10). Taken together, the flora, $\delta^{13}C$ values, and geochemistry do not provide evidence of biome change throughout the core, i.e., during the Holocene.

A significant climatic drying either at the base of the core or in the mid-Holocene region would have contained signatures of savannah expansion. In a dry climate resulting in savannah expansion, the soft surface material of the lowland would have been incised. This gully formation would have resulted in the erosion of soil horizons several decimeters or meters deep, where the composition of the material is significantly different from that of the surface. Kaolinite would be well-ordered instead of b-axis disordered, Al-chlorite, restricted to the upper few decimeters, would have become scarce or completely absent, and gibbsite concentrations would have decreased significantly (Irion 1984a). However, no such changes were evident in the core, from which we inferred that aridity did not play a major role in shaping the vegetation in this watershed during the last 11,000 years.

The most notable shift in the pollen record of the entire core occurs within a region corresponding to about 6,000 years BP. At this time, the abundance of *Cecropia* pollen is halved and that of Poaceae pollen doubled. This was most likely caused by human manipulation of the landscape although it cannot be excluded that increased seasonality increased the probability of dry-season fires or even centennial-/millennial-scale drought, causing the expansion of grasslands. However, the Poaceae pollen signature remains elevated to the present, making it unlikely that this change was due either to a mid-Holocene climatic event caused by an insolation peak or to a major drought. Furthermore, the lack of a consistent and substantial change in charcoal abundance along with the lack of change in the forest pollen component argues against a broad change in vegetation type.

By contrast, a change in the intensity of land use by humans as early as ca. 5,500 calender year BP is not unlikely in this setting (Bush et al. 2000), since archaeological sites in central Amazonia document at least 11,000 years of human occupancy (Roosevelt et al. 1991). The first evidence of long-term settlement and the adoption of ceramics came from 7,000-year-old middens located close to the modern city of Santarém. These sites, lying at the confluence of the Tapajós and the main Amazon channel, are within a few days walk of the shoreline adjacent to our coring site. That human occupation may have been quite wide-spread along the major river systems was suggested and authenticated by evidence of intensive pre-Columbian land use in the adjacent drainage of the Xingu (Heckenberger et al. 2003).

2.7 The Slope of the Amazon River Since the LGM

The variation in slope of the Amazon River may be regarded as an outstanding phenomenon in Quaternary history, one that induced far-reaching changes in river-current velocity as well as in sedimentation processes in the main valley and the lower section of the river's tributaries. Detailed studies of Ria lakes in Central Amazonia (Keim et al. 1999; Irion et al. 1999) and the eastern Amazon River (Irion et al. 2006) have allowed estimation of the variance in slope over the last

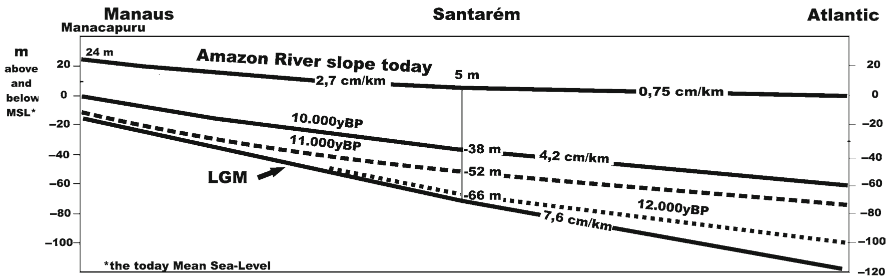

Fig. 2.11 Slope of the Amazon River since the Last Glacial Maximum (LGM), based on studies carried out in central Amazonia near Manaus and in the Tapajós River

20,000 years. In these studies, in which 3.5-kHz profiles of some of the smaller Ria lakes in Central Amazonia (Müller et al. 1995) and in the Negro River (Irion et al. 1999) along with profiles of the Tapajós River were obtained, the slope of the Amazon River during the LGM and at the start of the Holocene was measured. According to our results (Fig. 2.11), in the section between Manaus and Santarém the slope has decreased since the LGM from about 7.6 cm/km to about 2.7 cm/km, whereas between Santarém and the river mouth there has been a decrease from 7.6 to 0.75 cm/km.

Since high rainfall intensity is expected to have persisted during the entire Quaternary in most parts of the Amazon River watershed, the tenfold rise in slope must have dramatically affected the river floodplain system during the LGM. Kosuth et al. (2001) measured current velocity along the Amazon River and found maximum velocities of up to 3 m/s at Óbidos. This velocity is only reached by other large rivers during extreme floods. Most likely, the threefold to tenfold increase in slope during the LGM, assuming a similar water delivery, would have considerably increased the velocity of the water. However, much of the kinetic energy was probably absorbed by heavy erosion processes and sediment transport. In the pre-Andean zone, where there is high declivity, the tributaries of the upper Amazon displace their river beds with a velocity of up to 100 m/year (Salo et al. 1986). The middle and lower portions of the Amazon River have a rather stable river bed and floodplain. Most of the major hydromorphological structures have an age of several thousand years, as shown for the Marchantaria Island upstream of the confluence of Amazon and Negro Rivers (Irion and Junk 1989; Keim et al. 1999). We postulate that the Amazon River during the LGM was probably a braided river with a large very unstable floodplain. Thus, the turnover time of sediments deposited in the floodplain may have been reduced to centuries or even decades. Nonetheless, these time periods were sufficiently long to permit survival of the species-rich floodplain forest. Early successional stages, which developed over a few decades, may have prevailed but late successional stages, requiring several centuries, also occurred thereby maintaining the high species diversity that today characterizes Amazonian river-floodplain forests.

2.8 Discussion and Conclusions

From a geological point of view, there is no evidence for the occurrence of a significant dry climate period in central Amazonia during the last 10 million years (Irion 1978, 1984a, 1984b; Colinvaux et al. 2001). Based on analyses of the 42-m core from Rio Tapajós (Irion et al. 2006), we were unable to verify the occurrence of a dry period in the Amazonian lowland similar to the one that Absy et al. (1991) described for the Serra dos Carajás. Studies by Mayle et al. (2000) and Baker et al. (2001) also provided evidence of dry periods at the rim and outside the Amazonian lowland (Fig. 2.12). The paleoecological record from the core (Irion et al. 2006), representative of the last 11,000 years, indicates the continuous presence of a mesic forest landscape around "Lago Tapajós." On a landscape level, there were no substantial biome changes within the Holocene. While Holocene drying was strong enough to desiccate shallow lake systems, as documented in southeastern and southwestern Amazonia (Absy et al. 1991; Mayle et al. 2000), those records may have been more sensitive

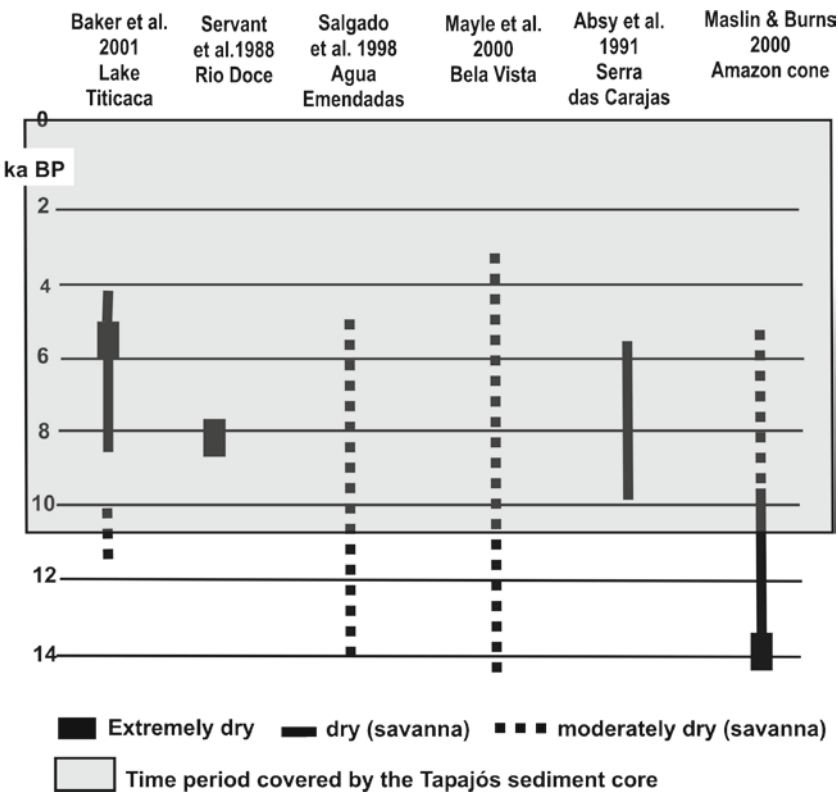

Fig. 2.12 The occurrence of dry periods during the Holocene, as suggested by various authors, is not supported by results obtained from the Tapajós sediment core

to local variations. The data of the sediment core obtained from the Tapajós River, by contrast, describe the largest part of the eastern Amazonian lowlands. The results are consistent with: (1) variations in the rise in sea-level as early as 11,000 BP, and (2) intensified human occupation of the lower Tapajós area from ca. 5,500 BP (Fig. 2.10).

It can be concluded that, at least in its largest parts during long periods of the Tertiary and throughout the Quaternary, the Amazon lowland was dominated by humid conditions. The waters of the Amazon River, which today course from the Andes to the Atlantic Ocean, formed during the Miocene, about 8 million years ago. Thereafter, the most characteristic event with respect to the aquatic system was the Mid-Pleistocene Revolution, when the huge ice shields of Laurentia (Canada) and Fennoscandia (Norway, Sweden, and Finland) penetrated many hundreds kilometers to the south and the sea-level dropped more than 100 m. At that time, the deeply incised Amazonian drainage system was created, giving rise to all the Ria lakes and the extremely large floodplain of the Amazon River.

The paleo-várzeas, first described by Irion 1976a, are still insufficiently analyzed. Physical data regarding their age are lacking, underlining the need for much more field and laboratory work.