QUATERNARY GEOLOGY OF THE CENTRAL AMAZONIAN LOWLAND AREA

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1 INTRODUCTION

Occurrence and distribution of plants and animals are explained in many parts of the world by climatological changes and by changing sea-levels during the Pleistocene. Large parts of the world's continental surface were reshaped during that time. Northern Eurasia and North America are characterized by landscapes resulting from glacial activity during the Pleistocene. Sediments along more than 10000 km of the world's coastal and island areas were deposited during the last sea-level rise. In North America and northern Europe, pollen analyses of peat bogs, lake sediments, together with ^{14}C-dating and radio isotope analyses contribute important information for understanding the geologial and climatological history of the Quaternary. Details of plant migrations are known and paleotemperature curves have been drawn. Considering the excellent knowledge of temperate Quaternary geology, surprisingly little is known about the tropical lowlands during this period of the earth's history. SERVANT *et al.* (1993) have given a summary of Quaternary studies in eastern equatorial Africa and of South America which shows that only four study areas are situated in Central Amazonian Lowlands.

The problem of the climatological history of Central Amazon basin is focused to the circumstances that some workers assume an arid to semiarid climate during the Pleistocene cold periods (e.g., DAMUTH & FAIRBRIDGE, 1970), while others do not find any proof of climatic changes (IRION, 1982). The main difficulty is that suitable deposits for studying Pleistocene history do not occur or are difficult to found in Central Amazon lowlands. This is in contrast to the well developed sediments found at higher latitudes, in particular glacial deposits, lake sediments, or organic deposits dating back to Pleistocene cold periods.

2 GEOLOGICAL FRAMEWORK

Northern South America is characterized by the contrast between the very old Precambrian shields south and north of the lower Amazon and the relatively newly formed Andean arc. The Andean arc is a high mountain range emerging through the collision of the Nazca and South American plates since the Miocene. Most of the western parts of the Amazon lowlands are covered by sediments eroded from the Andes. These sediments reach thicknesses of far more than 1000 meters. In the basin area between the Precambrian shields, sediments have accumulated since the Paleozoic. The surface of this area is formed by Cretaceous sediments, and outcrops of Paleozoic sediments occur only at the edges of the shield.

According to GRABERT (1983), the pre- and mid-Tertiary Amazon River was separated in two branches of which one entered the Pacific and the other the Atlantic. The formation of the modern Amazon drainage system is assumed to have taken place in the late Tertiary or early Pleistocene.

Erosion rates in the Andes are extremely high, reaching values of almost 1000 tons per square kilometer per year (NEDECO, 1973). Most of the material eroded from the eastern slope of the Andes is deposited in the sub-Andean sedimentary basin where it forms rapidly changing river systems (SALO *et al.*, 1986). Each year the Amazon and Madeira rivers carry 1.2 billion tons of river suspended material into the Atlantic ocean (MEADE *et al.*, 1985). The amount of sediments delivered to the lowlands may not have changed fundamentally since middle to late Quaternary, but the amount reaching the delta is controlled by sea-level changes and varies to some extent. DAMUTH & FLOOD (1984) estimated that about 700 kubic kilometers of sediments have been deposited in the Amazon deep-sea fan since the Miocene.

3 FLOODPLAIN-FORMATION IN THE WESTERN LOWLANDS DURING PLEISTOCENE HIGH SEA-LEVEL

To understand the Quaternary geology in the Amazon basin, the study of its morphology is one of the most important prerequisites. At Iquitos, 3600 km from the Atlantic Ocean, the level of the river is about 110 meters above recent mean sea-level, and at the confluence with the Rio Negro 1500 km from the sea, it is 23 meters (Fig. 1). Large parts of the upper and middle Amazon basin do not exceed elevations of more than 100 meters above recent mean sea-level. West of Santarém, which is 600 km from the Amazon River discharge into the Atlantic Ocean, the 100 meters contour line encloses an area of 1.3 million square kilometers with its largest proportion between 60° and 70° western longitude. This area could roughly be described as "Central Amazonian Lowland". In the lower Amazon the relief is higher, in some places reaching 300 meters elevation.
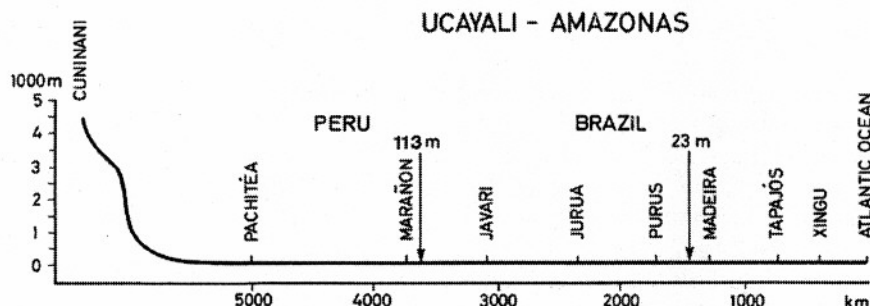

FIGURE 1 – Water-table of the Amazon river (from SOARES, 1959). From the low inclination of only 1-10 cm/km in the lower 3000 km results the subordination of the watertables in large areas of Central Amazonian Lowland from Quaternary sea-level stages.

Due to the extremely low elevation above MSL (Mean Sea-level) the water tables of Central Amazonian rivers, creeks and lakes are directly related to the sea-level. During high sea-levels, the ocean dammed up the waters, affecting the aquatic environment far away from the coast. Since the Pleistocene sea-level curve is only insufficiently known this effect is subjected to some uncertainity. KLAMMER (1971, 1984) described, from his own observation and from literature going back to KATZER (1903), river terraces from various areas within the lower Amazon region. The highest of these terraces reach an altitude of 80 m above recent MSL. Assuming that the terraces were of Pleistocene age, he correlated their altitude with sea-level height stages published from other areas. But according to recent knowledge of Quaternary sea-level curves at least the higher terraces should not have been formed as result of sea-level changes. From investigations done in south Brazilian coastal areas (SUGUIO et al., 1988) it may be assumed that the maxima of the sea-level reached at least 20-25 meters above MSL.

When sea-level reached a height of 25 meters above recent MSL in one of the earlier Pleistocene warm periods, the water table of the Amazon would have been affected at least up to 1500 km distance (by air) from the mouth. Large fresh water lakes may have formed, but after sufficient sediments were deposited new water ways developed with their characteristic ridges, swales, and levées as evidence of their presence (IRION et al., 1983). Due to great differences between the yearly high and low waters of the Amazon, which reach 10 to 15 meters in the middle Amazon area, the ridges and swales formed are very distinct. But the dense cover of forest makes it difficult to identify the Pleistocene systems of ridges and swales; only from radar maps showing the surfaces without vegetation cover the former floodplains are visible (Fig. 2). Analyses of radar maps for the upper Amazon show extensive areas where the Pleistocene floodplains occur (IRION, 1978). The floodplains are of different heights. We recovered sediment cores nearly 15 meters long from some selected floodplains (IRION, 1976a, 1976b, 1987). In the lower part, the mineral association in the unweathered sediments is the same as that of the modern river sediment load of the area, and hence it can be assumed that the sediment load during former Pleistocene warm periods was similar to the recent ones. In the uppermost decimeters of the sediment cores, the mineral associations change due to the intensive tropical weathering. In higher, and likely older floodplains, weathering reaches more advanced stages than in the youn-

ger floodplains which have formed during the last Pleistocene sea-level rise. The formation of these Pleistocene floodplains is not understood in detail and the extent of the floodplains is known only from the published radar maps. The geochemical and mineralogical studies are incomplete, particularly when comparing the extent of the floodplains with the areas studied. Nevertheless, it seems possible from our sedimentological and geochemical/mineralogical studies to establish the basic principles for the genesis of Pleistocene sedimentary deposition in the Amazonian Quaternary floodplains.

FIGURE 2 – Pleistocene Várzea – Lago Aiapuá on Rio Purus 80 km above its confluence with Rio Solimões. The "river-like" western part of Lago Aiapuá is the drowned valley of its affluent. North of this affluent the Pleistocene flood plain is best to be recognized. The ridges and swales are well developed. For scale: Lago Aiapuá has a N to S distance of 8 km.

4 QUATERNARY SEDIMENTATION AND EROSION OF THE AMAZON AND ITS TRIBUTARIES

During the maximum of the last Pleistocene cold period, sea-level dropped more than 100 meters below the recent mean sea-level. During that time there was a low erosional base level and the river beds of the Amazon and its tributaries were subjected to intensive erosion. The sediments of the Pleistocene river valleys may have been predominantly soft, and could be easily eroded away. The river beds in the lower Amazon valley near the mouth of the Amazon may have been cut down as far as 100 meters below its present levels. With increasing distance from the Amazon mouth the depth of the incision is assumed to decrease. In the lower parts of recent Rio Negro, the river bed which was eroded during the past and/or earlier Pleistocene

sea-level depression is preserved because of the low sediment transport in this river. Its depth may be taken as indication for the level of the nearby Amazon bed. In front of Manaus, the water depth of the Rio Negro is today close to 100 meters. If the water depth of Rio Negro did not exceed 50 meters, its water table may have been situated about 60 meters below the recent one. This is in contrast to our own investigations (MÜLLER et al., 1994) done by 3.5 KHz-profiling in the lower section of Central Amazonian tributaries. These investigations indicate a lowering of the mean Amazon level for only 20 to 30 m during the last glacial period. The differences between both values may result from the greater age of the Rio Negro bed which may still have the depth of an earlier glacial incision.

With increasing erosion of the deeper horizons, erosion in unweathered bedrocks and sediments must have taken place. This explains the

high amount of arkosic (feldspar rich) Amazonian sands encountered in sediment cores from the Amazon deep-sea fan (DAMUTH & FAIRBRIDGE, 1970). It does not indicate a dry climate in the drainage area of Amazon River, as supposed by some authors.

After 15000 B. P., when sea-level rose about two cm per year, the main stem of the Amazon valley was drowned because sedimentation rates in the river beds were not high enough to balance the rising water table. A large fresh water lake may have developed with a length of about 1500 km, extending from the mouth of the Amazon to 65° W, with a width not exceeding 100 km (IRION, 1976c). The maximum extent of the lake was reached when the rate of sea-level rise decreased around 6000 years B.P.

One indication for the supposed lake stage are the fine grained sediment deposits in the Amazon valley. Echo soundings show fine grained bottom sediments in the middle and upper Brazilian Amazon section (IRION, 1976a). They cannot have been deposited by the present river because its water velocity is too high for the deposition of fine grained material. Dredge samples from these river sections show a clay to silt composition which corresponds to the recent Amazon suspension load not only in grain size distribution but also in geochemistry and mineralogy. It seems reasonable to assume that these sediments have been deposited during the assumed lake stage.

During this time of the lake stage, the sediment delivery to the Atlantic Ocean decreased. In the sediment cores recovered from the Amazon deep-sea fan, DAMUTH & FAIRBRIDGE (1970) observed "an abrupt change to pelagic sediments at about 10000 to 11000 years B.P. in all 39 cores, demonstrating that with the beginning of the Holocene, large quantities of continental detritus no longer reached the continental rise and abyssal plains of the Guyana basin." This observation coincides with the existence of an Amazon lake which must have been an effective sediment trap.

As a result of the formation of the Amazon lake the lower reaches of lower and middle Amazon tributaries were drowned as the sea-level rose. There are many of these drowned river sections along the Amazon and its tributaries (SIOLI, 1957). Our 3.5 KHz in central Amazonian Ria lakes substantiated the presence of channels eroded during the low sea level stage of glacial maximum and their subsequent filling with sediments during the transgressional phase. The basis of erosion within these channels indicates, as already mentioned above, a lowering of

the mean Amazon level for about 20 - 30 m. Profiles also showed the existence of older erosional features; in some instances two additional horizons were recognized which are thought to represent land surfaces of older glacial periods.

In an earlier study we have taken sediment cores from lakes formed in drowned rivers (IRION, 1982, 1984a). The ^{14}C records show good agreement between sediment deposition and rising lake water-tables. It can be shown that the rising of the lake water-table is in accordance with the world-wide rising sea-level.

5 QUATERNARY TERRA-FIRME

By far the largest part of the five million square kilometers of Amazon lowlands has not been affected by the Pleistocene high inland water-tables. This area may be named the Quaternary Terra-firme.

In the lower Amazon, one of the most obvious features is the appearance of high plains at elevations of 100 to 300 meters above sea-level. SOMBROEK (1966) assumed that a clay which forms the uppermost horizons of these plains was deposited from a lake. This lake should have existed during the Calabrian at a sea-level height of 180 meters above recent mean sea-level. Based on the locus typicus of these clays, SOMBROEK (1966) named them Belterra clays. In the lower beds of the Belterra clays, a horizon of iron-oxide and hydroxide concretions often appear with thicknesses ranging from a few centimeters to decimeters.

JOURNAUX (1975), BROWN & AB'SABER (1979), and the authors of Volume 18 of Projeto RADAMBRASIL (1978) interpreted this horizon as a stone line, a feature which is believed to have its origin in areas of dry climate. The formation of a stone line is thought to take place in areas without or with very little vegetation. Strong winds promote blowing out of clay, silt and sand, whereas coarse-grained material remains in place and, therefore, accumulates on the surface. Under suitable conditions this process leads to the formation of a stone pavement. When this stone pavement later is covered by other material, it appears in a vertical profile (e.g., along a road cut) as a band which may be named a stone line. JOURNAUX (1975) attributes the stone line in the lower beds of the Belterra clays to a period of dry climate before the deposition of the clays. Like SOMBROEK (1966), JOURNAUX (1975) also places Belterra clays into the Calabrian. Hence, it follows that the stone lines should be older than 2 million years. BROWN & AB'SABER (1979) do not deal with the Belterra clays but

believe the stone line horizon to be of much later origin. They place its formation during the maximum of the Würmian glaciation, for which reason they postulate a dry climate throughout the Amazon lowlands.

Our mineralogical, geochemical, and sedimentological surveys, which were carried out along the cuts of Amazonian roads and in other areas with the help of small soundings, do not coincide with the stratigraphical interpretation of the genesis of the "stone line" and Belterra clay. On the contrary, it was shown (IRION, 1976b, 1984a, 1987) that Belterra clays, stone lines, and the horizon below – which is a first-stage weathered bedrock – belong to the same weathering unit. Their formation dates back into the Tertiary and is still continuing.

In our survey, we rarely reached the unweathered bedrock. In general, the studied sequences started in horizons where the structure of the bedrock was still preserved, but feldspars have disappeared totally and kaolinite has been formed. Above this zone, in a transition horizon of alternating stages of humidity and changing Eh-pH conditions, the formation of haematite rich pisoliths takes place through the dissolution of iron and precipitation of iron hydroxides. Here, very fine-grained kaolinites were also formed and the kaolinites of the lower horizon disappear. Simultaneously, the quartz content drops, generally to less than 20% and clay accumulates as residue, mainly due to dissolution of quartz. In a million years of weathering, the upper horizon may reach a thickness up to 10 meters or sometimes more. The kaolinites of the top layer are very resistant to further weathering.

The thickness of the uppermost clay horizon varies on the shields and on the Cretaceous sediments, and is greater than those on the Paleozoic sediments. Weathering of the shield and of the Cretaceous sediments results in the development of good vertical drainages, whereas the Paleozoic sediments, mainly consisting of slates of Devonian age, are badly drained, and therefore weathering is comparatively restricted. In the clays above the slates, geochemical and mineralogical features derived from their original composition are admixed. Considering this and the different thicknesses, it seems unlikely that the clays are lake sediments. If that was the case, the thickness and mineral admixture would not depend on bed rock prerequisites. Additionally, the Belterra clay does not show any sedimentological structures indicating that it was deposited in a lake, and its bimodal grain-size distribution with fractions finer than one micron and coarser than 63 microns, is very atypical for lake sediments.

From the difference between the quartz content in the bed rock and in the uppermost layers, it is possible, when assuming that the sequence is weathered in situ, to calculate a minimum age of the sediments. The calculated minimum age of 10 million years (IRION, 1984b) fits well with the hypothesis that the formation of the weathered units, the Quaternary terra-firme of eastern Amazonia, started in the Middle Tertiary or even earlier.

The hypotheses of in situ formation of the ochre colored clays from the bedrocks is supported by investigations of ORSTOM. CHAUVEL et al. (1987) and in more detail LUCAS (1989) came from their studies north of Manaus and in Rio Trompetas area to results which are in respect of the composition and formation very close to ours. Only as to the beginning of the in situ formation of the clays, they dated it at a 30 to 50 million years the minimum age, farther back than we did at 10 million years.

Due to a low sediment load of most rivers of the eastern lowlands, it can be assumed that surface erosion throughout the Quaternary was slow. For example Rio Uatumã, like many other rivers draining the Guyana shield and Cretaceous sedimentary deposits, does not carry more than three mg/l of suspended load. Together with the observations described above, it seems likely that in most surfaces of the shields and the Paleozoic and Cretaceous sedimentary deposits, deep weathered horizons have developed over millions of years, probably starting in mid Tertiary or earlier. Only in the southwestern lowlands, in the upper reaches of Rio Purus, Rio Juruá, and in the sub-Andean arc are the surfaces younger.

6 CONCLUSION

The Quaternary history of the Amazon lowlands is characterized by deposition of sediments of Andean provenance and by the influences of changing sea-levels. Most Andean sediments were deposited in the sub-Andean region, but on the average one billion tons per year may have reached the sea during Quaternary history. During periods of high sea-levels which dammed the Amazon drainage system, the deposition of sediments in the Amazon lowlands was favored. The high sea-level stages affected areas as far away as 3000 km upstream the Amazon river. Floodplains corresponding to the different Pleistocene sea-level heights were formed. During low sea-level, erosion in the drainage areas increased and the water levels of the central Amazon river systems were lowered.

Due to the dammings, valleys drowned and lakes formed in the lower reaches of rivers and creeks. These lakes remained in those valleys with rivers having a low sediment load. Results from the ^{14}C-dating of sediment cores recovered from these lakes correspond closely with the Holocene sea-level curve, after taking into account the inclination of the water table between the inland lakes and the sea.

Areas well above the present water tables were not reached by Pleistocene high water stages. These areas have been intensively weathered since the Tertiary, forming mighty lateritic weathering horizons. In their upper part, the laterites consist mainly of fine-grained kaolinite together with underlying horizons of pisoliths. The pisoliths are generaly in situ, and were formed simultaneously with the kaolinites during humid tropical climates.

The results of our studies do not show any climatic change or change in the vegetation cover in the Central Amazon lowlands during Pleistocene. But they reveal that during high sea-level extensive areas of the western Amazon lowlands were dominated by a fresh water aquatic system, and during low sea-level former existing floodplains were inactive and eroded near the main channels. During the latter periods the extent of water bodies may have decreased.

Sediment distribution, weathering horizons, and surface relief of the Central Amazon lowlands are best explained by relatively constant-humid tropical climate throughout the Quaternary.

7 ACKNOWLEDGMENT

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