LAGO AMAZONAS: FACT OR FANCY?

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SUMMARY

It has been suggested that a huge lake, Lago Amazonas, covered a large part of the Amazon basin until as recently as two thousand years ago. According to this hypothesis, the topmost sediments in western Amazonia are almost universally young deposits of lacustrine and deltaic origin. The hypothesis has gained some attention among biologists because of its implications for biological phenomena in Amazonia, especially biogeography and biodiversity. According to the available geological data, however, Amazonia is geologically far more complex than assumed by the lake hypothesis. In the following discussion we will point out the weaknesses of the Lago Amazonas hypothesis, and indicate alternative explanations of the surface geology that are based on tectonically controlled fluvial deposition.

INTRODUCTION

The Lago Amazonas hypothesis was preceded by, and partly based on, a hypothesis of catastrophic Holocene floods proposed by Campbell & Frailey (1984) and Campbell **et al.** (1985). These authors studied the topmost sediments along the rivers Acre and Beni in southwestern Amazonia, and found them to be stratigraphically similar to deposits reported earlier from other parts of western Amazonia. They dated four radiocarbon samples that all yielded less than 11 000 years, and concluded therefore that the sediments had been formed synchronously between 10 000 BP (years before present) and 2 000 BP, and should be referred to the same geological formation. Because of the apparently great geographical area of this formation Campbell & Frailey (1984) suggested that it had been deposited by massive floods that had periodically covered the whole of western Amazonia.

Frailey **et al.** (1988) and Campbell & Romero (1989) accepted the suggestions of both the equal age and the spatial correlation of the topmost sediments, but they interpreted the strata they studied between the rivers Acre and Purús as partly deltaic and partly lacustrine in origin. Therefore they discarded the flood hypotheses and proposed instead that Amazonia had been covered by a lake, Lago Amazonas. They postulated that the surface of the lake had reached the altitude of about 150 m, that its eastern edge had been either at the Iquitos Arch, the Purús Arch, or the Gurupá Horst (see Fig. 1), and that it had had an outlet along the present Río Orinoco. Campbell (1990) modified the lake hypothesis by proposing that the water had reached up to the elevation of 300 m, and that the outlets had been via the Parana and Orinoco rivers and possibly, through Guyana.

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On the basis of radiocarbon datings, Frailey **et al.** (1988) suggested that Lago Amazonas was formed about 40 000 BP. The collapse of the lake was referred to the date Campbell & Frailey (1984) had given for the youngest sediments, i.e. 2000 BP. Campbell & Romero (1989) suggested that the lake was drained already 12 500 years ago. Campbell (1990) referred to data on flow volumes in the Amazon river and proposed that drainage of the lake took place between 13 500 BP and 6 000 BP.

Correlation of Spatially Distant Formations

The Lago Amazonas hypothesis is based on the suggestion that the topmost sediments in all of western Amazonia can be correlated to the same depositional event. To confirm this it should be shown that the strata are stratigraphically uniform, spatially continuous, and that they were deposited synchronously.

Campbell & Frailey (1984), Campbell **et al.** (1985), Frailey **et al.** (1988), and Campbell & Romero (1989) argued that the topmost strata in the whole area where they had conducted field work can be correlated to the same formation. This conclusion was essentially based on the similar appearance of the deposits, as these included similar units of sand, silt and clay in the different sites. Some of the units were reported to be in the form of layers and others as lenses, some were thin and others massive, some were cross-bedded and others were not. It is obvious, therefore, that the formation was very heterogeneous within short distances both laterally and vertically.

The complexity of the stratigraphy led to rather loose criteria for the correlation between separate outcrops. Consequently, Campbell & Frailey (1984) and Frailey **et al.** (1988) found that the descriptions of several formations from other parts of Amazonia fitted these criteria. However, they did not visit any sites outside the Acre-Madre de Dios region to confirm the similarity of the stratigraphies.

According to RADAMBRASIL (1976), much of the surface sediments in western Amazonia can be referred to the Solimões Formation. Frailey **et al.** (1988) took this as evidence for the Lago Amazonas hypothesis, although the Solimões Formation itself is a heterogeneous complex of strata. It includes, apart from Pleistocene fluvial deposits (RADAMBRASIL, 1976), e.g. the Red Beds from the upper Tertiary (Singewald, 1928) and the Pebas Formation that was deposited in brackish conditions during the Miocene (Hoorn, 1988, 1990, in press). Obviously the application of a single name does not automatically mean that the deposits involved be similar in age or origin.

The extent and spatial continuity of the formations referred to by Campbell & Frailey (1984) and Frailey **et al.** (1988) remain speculative for the time being, because large areas of western Amazonia have been never geologically investigated.

Dating

Although it is vital to the Lago Amazonas hypothesis that the sediments ascribed to lacustrine deposition be even-aged, a total of only eleven radiocarbon datings has been produced to prove this. The four samples from Río Acre (Campbell & Frailey, 1984) yielded ages between ca. 5 600 and 11 000 years, while the seven from Río Madre de Dios (Campbell & Romero, 1989) yielded ages older than 35 000 years. All samples were taken from layers that were correlated and should therefore have been deposited synchronously if the lake hypothesis were correct.

Other datings from surface deposits in the Lago Amazonas area range even more widely in age. Simpson (1961) studied sediments along Río Juruá and concluded that most of them are geologically recent. Dumont (1989) reported radiocarbon dates of about 13 000 years along Río Ucayali. Räsänen **et al.** (1990) dated sediments from Madre de Dios and Loreto; their radiocarbon samples yielded ages between 7 500 years and infinite, while the thermoluminescence samples from different sites yielded between 23 000 and 180 000 years. Hoorn (1990, in press) dated palynologically sediments from the Pebas Formation to middle-late Miocene (more than 5 million BP).

Frailey **et al.** (1988) postulated that Lago Amazonas was drained 2 000 BP, because Campbell & Frailey (1984) had reported this to be the age of the youngest sediments along Río Acre. However, this date had not been obtained by direct measurement. It had been extrapolated, with the help of climatic theories, from radiocarbon dates obtained from lower

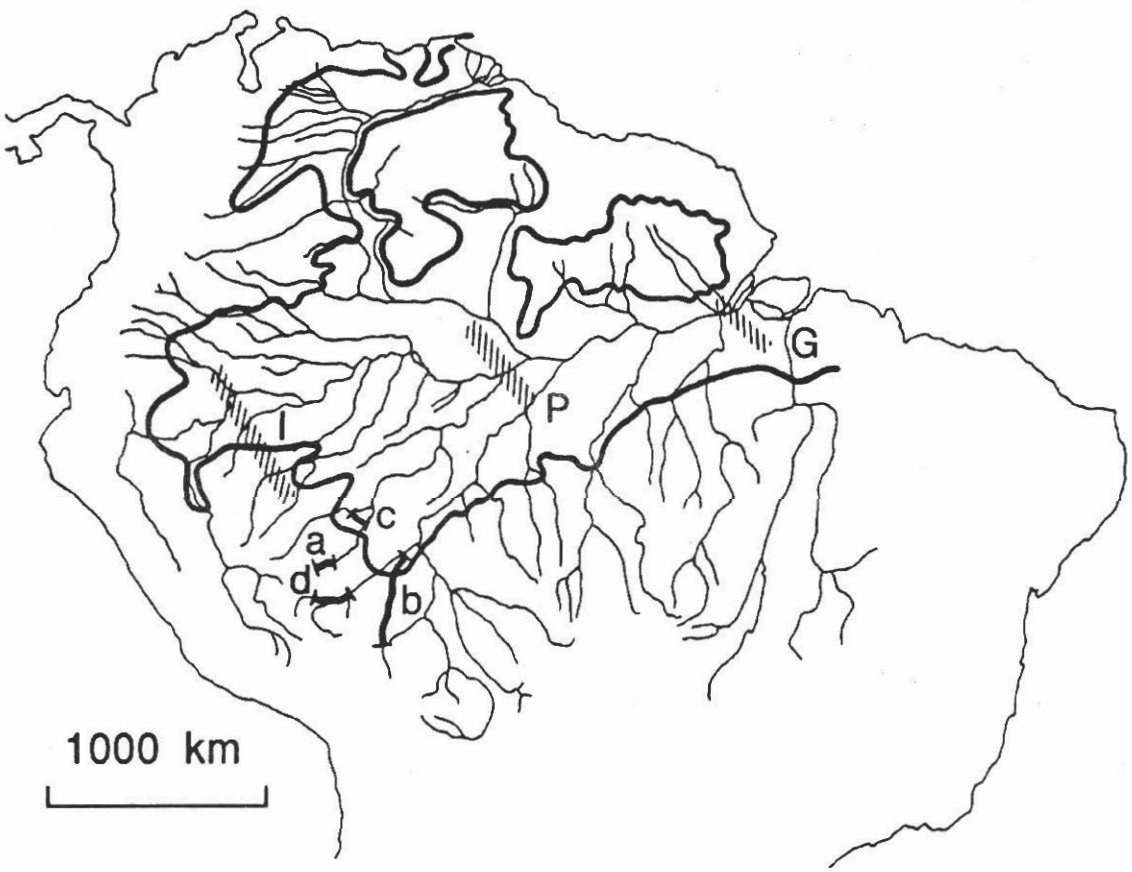

Fig. 1. A map of northern South America with the major river systems. The thick continuous line follows approximately the 200 m contour; the maximum water levels that have been suggested for Lago Amazonas are 150 m and 300 m. The bars indicate the areas where the proponents of the Lago Amazonas hypothesis collected their geological data: a = Campbell & Frailey (1984), b = Campbell **et al.** (1985), c = Frailey **et al.** (1988), and d = Campbell & Romero (1989). Shading indicates the alternative sites for the eastern margin of Lago Amazonas: I = Iquitos Arch, P = Purús Arch, and G = Gurupá Horst.

lying strata. Campbell & Romero (1989) suggested that Lago Amazonas was drained already 12 500 BP without citing any evidence in favor of this new date. Still another date was that of Campbell (1990), who proposed on the basis of outflow records of the Amazon River that Lago Amazonas dried between 13 500 and 6 000 BP.

The equal age of the different geological formations was assumed mainly on the basis of the similarities in either their sedimentary structures (Campbell & Frailey, 1984; Campbell **et al.**, 1985; Frailey **et al.**, 1988), or the branching patterns of rivers (Campbell, 1990). It should be realized, however, that these kinds of similarity only indicate that the environments in which the sedimentation took place were similar. The patterns of both fluvial and lacustrine sedimentation remain the same throughout geological time, and therefore without the support of independent dating methods there is no reason whatsoever to assume similarity of age for distant formations. In the case of fluvial deposits, age may vary considerably even within short distances.

Some technical aspects of the radiocarbon dating method are relevant to the Lago Amazonas hypothesis. In the predominantly fluvial environment of western Amazonia, material is constantly eroded from some places and redeposited elsewhere. Therefore the organic material that is dated may be older than the deposits themselves. The opposite is also possible, and too young dates can be produced e.g. by dating tree roots that have grown into old sediments. Young carbon may also seep through to the sediments and contaminate the samples if special care is not taken. This was shown by Räsänen **et al.** (in press), who subsequently argued that radiocarbon dates older than 30 000 years are so inaccurate that they should only be taken as an indication of the minimum age of the sample. As the seven radiocarbon samples of Campbell & Romero (1989) all yielded ages older than 30 000 years (five of them infinite) they lend no support for the postulated equal age of the sediments along Río Madre de Dios and Río Acre.

Tectonism and Geomorphology

Frailey **et al.** (1988) proposed that the formation of Lago Amazonas was caused by tectonical downwarping of western Amazonia, and that the present drainage system was formed after the lake collapsed when its western part uplifted above its eastern limit. Although Campbell (1990) did not find this tectonical model plausible, he postulated that practically all the rivers in the Beni area of Bolivia are presently flowing in their late Pleistocene channels, but exactly to the opposite direction. He did not explain how such a reversal could have happened in a network of rivers where all possible channel orientations are present.

Situated in the foreland area of the actively rising Andes, western Amazonia is indeed characterized by tectonical activity. However, the different parts of the foreland are experiencing different kinds of changes: there are several subsiding basins (Ucayali, Pastaza-Marañon, Madre de Díos-Beni, and Acre basins) that are separated from each other by uplifting arches (Fitzcarrald, Serra do Moa, Iquitos, Jutai and Purús Arches; see Ham & Herrera, 1963; RADAMBRASIL, 1976; Huerta, 1979; Cánepa & Laura, 1980; Räsänen **et al.**, 1987, 1990; Dumont **et al.**, 1988; Dumont & García, 1991). Therefore, western Amazonia is not a geologically uniform area at present, and it probably never was in the past either.

Sedimentation is most rapid in the subsiding basins, whereas the uplifting areas are not accumulating sediments but rather losing them by erosion. By changing the regional topography and the relative movements of land masses, tectonical activity causes migration of fluvial deposition centers. Räsänen **et al.** (in press b) explained with this process the

existence of fluvial deposits in e.g. those parts of Madre de Dios that at present are being eroded. The deposits in the Acre region could well have been formed in a similar way.

The topography of sedimentary environments is generally flat until accumulation of sediments ceases and denudation begins. Since the dissection becomes more pronounced with increasing age of the surface, the young deposits within the Lago Amazonas area should be clearly less incised than the more ancient formations outside. However, nothing resembling either a lake margin or a continuous less dissected area can be seen in the RADAMBRASIL (1976, 1977a, 1977b) material. Instead, the flat areas with Holocene sediments are restricted to the subsiding basins and immediate surroundings of rivers. These areas are separated from each other by older dissected terrain. For instance, between Río Acre and Río Purús, where Frailey **et al.** (1988) described recent ''deltaic'' sediments, the terrain is undulating and the local differences in altitude are about 30 m (RADAMBRASIL, 1976).

Frailey **et al.** (1988) speculated that if Lago Amazonas was not formed by a tectonic change in the west, it might have been formed by a blockage in the east. As possible sites of the eastern margin of the lake, they mentioned the Iquitos Arch, the Purús, and the Gurupá Horst (see Fig. 1). Under present topography, however, a blockage in the Iquitos Arch area would only result in the flooding of a part of northeastern Peru, and nothing would change in the Acre region. If the blockage had been at the Purús Arch or Gurupá Horst, massive earth movements must have taken place; the difference in altitude between these formations and the Acre region is between 100 m and 150 m. Although Campbell (1990) did accept a sediment dam as the cause for the formation of Lago Amazonas, there is neither evidence nor explanation for dam building and destruction of this magnitude within a time span of a few thousand years.

Reconstruction of the Sedimentological Environment

Sedimentation in the present-day Amazonia is predominantly fluvial, and especially along the largest white-water rivers sediment accumulation may be very rapid. Fluvial deposits are often cyclical with each cycle showing a sequence of upward fining grain sizes. The meandering or anastomosing river channels create typically cross-bedded sandy strata that have been widely reported in western Amazonia (Singewald, 1928; Chase, 1933; Oppenheim, 1937, 1946; Kummel, 1948; Simpson, 1961; RADAMBRASIL, 1976, 1977a, 1977b; Simpson & Paula Couto, 1981; Räsänen **et al.**, 1987, 1990, in press b, Dumont **et al.**, 1988). Although permanent lakes are rare, sedimentation of fine-grained particles takes regularly place in conditions that resemble lacustrine, e.g. during the annual floods in the floodplains, and in oxbow lakes. In a particular site sedimentation may also be repeatedly interrupted and resumed as the channel changes its course, giving rise to intermittent weathering surfaces. In short, very different kinds of deposits can be formed, and their spatial distribution is characteristically oatchy both laterally and horizontally.

In comparison with fluvial sediments, lacustrine ones are rather homogeneous. They include only the finer grain sizes, because the coarser material cannot be carried for long distances by the relatively stagnant water and is therefore deposited in the deltas. Sedimentation is continuous (although not necessarily constant) and no weathering surfaces are found within the sediments. The 350-m-deep core from Acre that was studied by Kronberg **et al.** (1989) showed a cyclical sedimentation pattern, and therefore supports a hypothesis based on fluvial rather than lacustrine sedimentation.

Frailey **et al.** (1988) and Campbell & Romero (1989) found mixtures of cross-bedded and aunstratified deposits along the rivers Acre and Beni, and interpreted them in terms of

lacustrine-deltaic sedimentation. Because of the speculated wide geographical extent of similar formations, Frailey **et al.** (1988) rejected the possibility of fluvial deposition. For the same reason, the delta was inferred to have been huge, and consequently also the lake was suggested to have been extensive. However, neither Frailey **et al.** (1988) nor Campbell & Romero (1989) referred to any area where true lacustrine sediments would be found, although a lake that covered most of Amazonia cannot have consisted of deltas only.

There is another hypothesis of a huge Amazonian lake, the ''Belterra lake'' of Sombroek (1966). This hypothesis was based on the presence in central Amazonia of fine clays, interpreted by Sombroek as lacustrine deposits. Irion (1984) has attacked this view; after an exhaustive study on the clay minerals of Amazonian soils, he concluded that they were weathering products formed **in situ** during millions of years, except in the Pleistocene alluvial plains. Although launched against the Belterra lake, these findings lend no support to the Lago Amazonas hypothesis either. In fact, they effectively falsify the proposition of Campbell (1990) that it was the sudden deposition of the Belterra clay that caused the formation of Lago Amazonas. In other respects the Belterra lake has little to do with Lago Amazonas: the former was proposed to have existed in the late Tertiary and the latter in the late Pleistocene and Holocene.

When Campbell & Frailey (1984) proposed their catastrophic flood hypothesis they suggested anastomosing rivers and extensive swamplands to have been the environment of deposition. They further proposed that all the deposition took place within a few thousand years; this view was also retained in the later lake hypothesis. However, most geological studies from western Amazonia agree that fluvial deposition has been an ongoing, regular process for millions of years, and that the rate of sediment accumulation varies remarkably from place to place (Guizado, 1975; Martínez, 1980; Räsänen **et al.**, 1987, 1990, in press b; Dumont **et al.**, 1988; Hoorn, 1988, 1990). Sediments essentially similar to the topmost ones are in subsiding basins found to great depths, even up to several kilometers (Sanz, 1974), which is in marked contrast to the shallowness of these sediments along emerging arches (RADAMBRASIL, 1977b; Räsänen **et al.**, in press b).

It is neither easy to explain how lacustrine sedimentation could lead to such differences, nor conceivable that the thickest sediments could have been deposited within 40 000 years (the maximum duration of Lago Amazonas). Therefore yet another mechanism would have to be evoked to explain the origin of the older strata. Unless convincing evidence is found for the contrary, the most parsimonious explanation remains that the older Amazonian sediments were formed by the same processes that are still operating on the recent ones.

Biogeography

Campbell & Frailey (1984), Campbell **et al.** (1985), Frailey **et al.** (1988) and Campbell (1990) claimed that in the light of their interpretations of Amazonian geology, the interpretations of Amazonian biogeography should be radically changed as well. However, their geological hypothesis are based on much speculation and little fact, and are not convincing enough to necessitate a reorientation along the lines they indicated.

Freiley **et al.** (1988) mentioned the distribution patterns of some groups, like ''small Amazonian fish'' and ''forest taxa'', as evidence for the Lago Amazonas hypothesis. These groups are rather vaguely defined, but even if they were not, it is easy enough to reach sweeping conclusions about Amazonian biogeography. The exact knowledge of the composition and distribution of the biota is so poor that with some good will the existing data can be fitted to very different geological scenarios.

We do not find it plausible that the whole of Amazonia would behave as if it were a single, homogeneous habitat, whether a lake or a forest or a fluvial basin. Rather, the complexity of the biota seems to conform to an idea of evolution in an environment that is heterogeneous both in space and time.

CONCLUSIONS

The hypothesis that Amazonia would in the recent past have been drowned in a huge lake does not get support from data available of Amazonian tectonism, geomorphology, stratigraphy and soils. Large areas in the Peruvian and Bolivian parts of the Amazon basin are at present characterized by fluvial deposition that is controlled by tectonical processes. These processes have been active for tens of millions of years, and account for the accumulation of the unconsolidated Quaternary sediments typical of western Amazonia. The topmost sediments vary widely both in composition and age due to the local influences of different factors. A hypothesis that the depositional environment has in the recent past been radically different from the present one would need for its acceptance more convincing evidence than the proponents of the Lago Amazonas hypothesis have presented.

Due to the instability and heterogeneity of the Amazonian environment it is necessary to be cautious when generalizing on the basis of observations from a restricted area. Different depositional systems can produce stratigraphically similar sediments independently of each other. Without good evidence of both continuity and simultaneous deposition, the correlation of formations from distant locations is very hazardous.

RESUMO

Foi proposta a idéia que uma parte importante da bacia do Amazonas foi coberta por um vasto lago, Lago Amazonas, até há época tão recente como dois mil anos atrás. Segundo esta hipótese os sedimentos de topo na região ocidental da Amazônia são quase universalmente depósitos recentes de origem lacustre e estuário. A hipótese tem chamado atenção dos biólogos pelas suas implicações com fenômenos biológicos na Amazônia, particularmente com a biogeografia e a biodiversidade.

A Amazônia, apresenta, contudo, uma unidade geologicamente muito mais complexa do que pressupõe esta hipótese de lago, hipótese que nem tem apoio dos dados disponíveis sobre o tectonismo, a geomorfologia, a estratigrafia e os solos. Vastas áreas nas regiões do Peru e da Bolivia da bacia do Amazonas se caracterizam atualmente pela deposição fluvial, dominada pelos processos tectônicais. São processos que foram ativos durante dezenas de milhões de anos explicando assim a acumulação dos sedimentos Quaternários não-consolidados, característicos da região ocidental da Amazônia. Há uma variação extensa dos sedimentos de topo tanto pela sua composição como pela sua idade devido às influências locais de fatores diferentes. A hipótese que pressupõe o ambiente de depósitos ter no recente passado diferido basicamente do ambiente atual, precisava, para ser aceita, provas mais convincentes do que foi presentado pelos proponentes da hipótese de Lago Amazonas.

Devido à instalidade e heterogeneidade do meio ambiente da Amazônia, é preciso prudência quando se generaliza baseando-se nas observações duma área limitada. Sistemas de depósitos

diferentes são capazes de produzir sedimentos estratigraficamente semelhantes, independentemente um do outro. Sem ter provas evidentes tanto da continuidade como da deposição simultânea, estabelecer uma correlação entre formações de locais remotos parece muito arriscado.

ACKNOWLEDGEMENTS

Our special thanks are due to Salomon Kroonenberg and Carina Hoorn for constructive criticism and fruitful discussions on the subject. We also thank Risto Kalliola, Ari Linna, Maarit Puhakka, Matti Räsänen, Wim Sombroek and Timo Vuorisalo for valuable comments. The study was financed by the Finnish International Development Agency (FINNIDA) and The Academy of Finland.

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(Aceito para publicação em 26.05.1992)