A PROPOSED PLEISTOCENE/HOLOCENE LAKE IN THE AMAZON BASIN AND ITS SIGNIFICANCE TO AMAZONIAN GEOLOGY AND BIOGEOGRAPHY.

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SUMMARY

Recent studies have described widespread stratigraphic units of Late Pleistocene and Holocene age in the western part of the Amazon Basin. The recognition of deltaic sedimentation in the uppermost of these units near Rio Branco, Brazil, at a modern elevation of approximately 500 feet, leads to the conclusion that this area was situated on the edge of a large Amazonian lake that existed in the recent past when Andean tectonism caused active downwarping of the western edge of the Amazon Basin. The ramifications of this "Lago Amazonas" hypothesis extend into every area of modern Amazonian geology and biology.

INTRODUCTION

The strata that are exposed in the western Amazon Basin have posed a considerable problem for geologists who have attempted to determine their temporal and geographic extent. The uniformity of sediments and the virtual absence of fossils that can be related to particular strata has led to age assigments of Amazonian strata that necessarily reflect exasperation and generalization. Because so little has been written of the geology of this area, any published geological observation on the strata or fossils has pivotal significance on further geological interpretation. As of the present, no fewer than seventeen formational names could be applied to strata in the vicinity of Rio Branco with age assigments ranging from Cretaceous to Holocene.

If these names apply to discrete stratigraphic units, one would have to say that the depositional history of western Amazonia is indeed complex. It is our opinion that

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there is substancial duplication in the formational names that have been applied to western Amazonia and that the age range suggested by these formations is extreme and likely incorrect. Following a number of recent papers on the geology of this area, we suggest that there are only two formations that are exposed over much of the upper Amazon Basin. However, rather than merely simplifying the previous interpretations of depositional history, our studies redirected our thinking toward the implications of thick, extensive, and apparently very young strata. If, as we suggest, these sediments accumulated in a huge lake, then not only is the Late Pleistocene and Holocene geologic history of the upper Amazon much different than what is now accepted, but the distribution of modern plants and animals, and perhaps humans, reflects the presence of this recent topographic feature.

Discussion of Previous Geological Work

The strata that are exposed in the vicinity of Rio Branco and along the Rio Acre in Brazil are referred to as the Solimões Formation in the most recent and extensive reference to the geology of this area (RADAMBRASIL, 1976). The Solimões has been described as being composed of clay, silt and fine sand. The clay units are massive to thin, with calcitic and gypsiferous concretions and veins, and large-scale cross stratification or simply variegated with fine laminations. The sands are fine to coarse, massive, frequently interfinger with silt or clay, poorly to well compacted, have calcareous cement, and may contain thin, organic-rich lenses. Cross-bedding can be of small or large amplitude. Also described for this formation are limonitic lenses and well-rounded conglomerates. This description accurately portrays the surface geology near Rio Branco. From personal observations of the authors, it also describes the surface geology in southeastern Peru, northern Bolivia, and as far north as the Rio Juruá. It undoubtedly is an adequate description of exposed strata as far north as the type section of the Solimões Formation on the Rio Solimões (central tributary of the Rio Amazon; Rego, 1930) and probably north of this river as well. This description therefore depicts the surface geology of the major portion of the western Amazon Basin despite the plethora of names assigned in the geological literature.

Attempts at correlation have been bedeviled by the nature of Amazonian geology. Small, usually unfossiliferous exposures that are nearly uniform in lithology and which may be separated by hundreds of miles have been described independently over the last century. No one researcher has seen the exposures throughout the Amazon Basin and the geological literature illustrates the limits of individual perspectives in so vast an enterprise. With the advent of large scale programs such as RADAMBRASIL, the problems have been brought into sharper focus although the definitive synthesis of Amazonian geology is yet in the future. Geological exploration in the western part of the Amazon Basin has provided several named formations whose relationships to each other are still in doubt (RADAMBRASIL, 1977). The most frequently encountered names are the supposedly temporally equivalent Red Beds of Singewald (1927); the "Puca Formation" of Steinman (1929; Branisa 1968, replaced the name Puca with Pilcomayo and considered this as a stratigraphic group although "Puca" or "Puca-type" continues to be used for Andean red beds and their supposed Amazonian equivalents, e.g., Simpson & Paula Couto, 1981); and the Cruzeiro Formation of Oppenheim (1937). These are generally thought to be Cretaceous or Early Tertiary. Younger beds have been given a variety of names such as Brown Beds (Singewald, 1928), Contamana Group (Kummel, 1948), and Corrientes Formation (Parra, 1974). An extreme position yet one that demonstrates the problems of Tertiary Amazonian geology was that proposed by Caputo, Rodrigues and Vasconcelos (1971). They proposed that all Tertiary formations were in fact only one formation and that one should be called the Solimões. In 1984, Campbell & Frailey identified two formations in the vicinity of Iñapari, Peru, and restricted the Iñapari Formation of ONERN (1977) to the uppermost stratum (Fig. 1). That formational name has now been suppressed in favor of the Madre de Dios Formation (Oppenheim, 1946; Campbell & Romero Pitmann, in manuscript). On the basis of radiocarbon dates, the Madre de Dios Formation (or Iñapari Formation, as restricted) was thought to be Holocene in age. Subsequent dates from wood samples taken from the lower units of this formation indicate that deposition of Member A of the Madre de Dios Formations (=Iñapari Formation) began approximately 35,000 years ago (modified to 36,500 years B.P. in Campbell & Romero Pittman, in manuscript). In Campbell & Frailey (1984) and elsewhere (Campbell **et al.**, 1985; Frailey, 1986), the underlying stratum was not referred to a named formation and identified only as the "Tertiary red beds". Vertebrate fossils found in the Tertiary red beds date this formation to the Huayquerian (Late Miocene) South American Land Mammal Age (Frailey, 1986). Clearly, two formations are exposed along the rivers of the upper Amazon Basin, but reference to previously named formations is not easy. In this context, the Solimões Formation in the vicinity of the Rio Acre is either the same as the Madre de Dios Formation (Iñapari Formation, as restricted), the same as the "Tertiary red beds", or equivalent to both In our understanding of RADAMBRASIL (1976), and in view of the initial difficulty in separating these two units along the Rio Acre (a difficulty that was only clearly surmounted when mammalian fossils of very different ages were found in the units), we suspect that the Solimões Formation as now defined in the State of Acre encompasses both units along the Alto Rio Acre.

The Madre de Dios Formations (= Iñapari Formation) is divisible into four members (Campbell & Frailey, 1984). The lowest member is a narrow, dark, often indurated, clay-pebble conglomerate that was designated the Acre Conglomerate Member (Campbell **et al.**, 1985). The upper three members are primarity thick units (5-20 m) of variegated clay or sandy clay and occasional paleochannels. Only the lowest of these three (Member A of Campbell & Frailey, 1984) displays great variation in sediment type and is apparently a complex series of channel deposits with cross-bedded sandstones and lenses of mature sands, variegated clay, and lignitic clay. This complex lensing sequence occasionally is replaced laterally by a variegated, blocky clay like that seen in the upper two units. The enviroments of deposition for the three upper units appear to be floodplain for the most part with perhaps deltaic deposition for part of Member A.

Published information about the Rio Juruá (Paula Couto, 1978; Simpson and Paula

Couto, 1981) and field inspection by one us (AR) indicates that the Acre Conglomerate Member of the Madre de Dios Formation (= Iñapari Formation) is present along the Rio Juruá as well. A recent publication identified the three clay members of the Madre de Dios Formations (= Iñapari Formation) along the Rio Beni (Campbell, Frailey & Arellano, 1985). Subsequent fieldwork in 1985 and 1986 located all the members of the Madre de Dios Formation (= Iñapari Formation) and the "Tertiary red beds" along the Rio Madre de Dios from Riberalta, Bolivia, to the border of Peru (C.D.F., A.R., and described in Campbell & Romero Pittmann, in manuscript). Older publications have described conglomeratic lenses overlain by horizontal clay units throughout the upper Amazon (Brown, 1879a; 1879b; Kummel, 1948; Rüegg & Rosenzwelg, 1949; Mousinho de Meis, 1971). In one publication (Denevan, 1980), a photograph taken in 1910 shows what appears to be the contact between Members B and C of the Madre de Dios (= Iñapari Formation) along the Rio Heath. These publications indicate that the stratigraphy of the Rio Acre as described by Campbell & Frailey (1984) extends throughout the region.

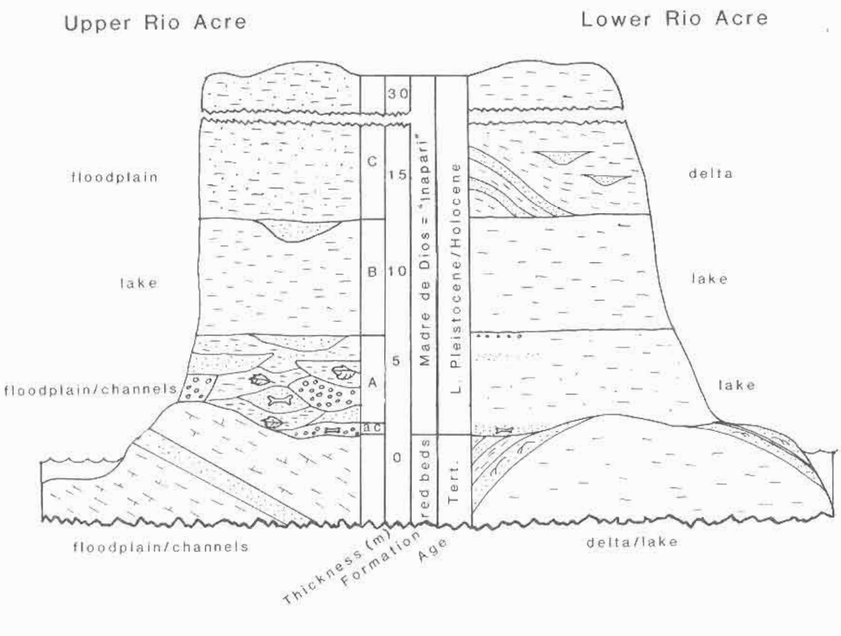


Fig. 1. A comparison between generalized geologic sections in the State of Acre, Brazil. Interpretations of the depositional environments for each unit are indicated. A. Along the Rio Acre, west of Assis Brasil (redrawn from Campbell and Frailey, 1984). B. Near the city of Rio Branco. Lithologic descriptions of the units are provided in the text. In Figure A, the lowest member of the Iñapari/Solimões Formation is the Acre Conglomerate.

Geology of the Rio Branco Area

Along the Rio Acre at Rio Branco, approximately 160 miles from the section described by Campbell & Frailey (1984), the horizontal "Tertiary red beds" and the four members of the Madre de Dios Formation (= Iñapari Formation) can be seen along the Rio Acre in sediments that are referred to as the Solimões Formation in current geologic literature (RADAMBRASIL, 1976; Fig. 1). The question then becomes: Which of the two names is correct? The question is more difficult than simple geographic extension of one of these formations in that yet another name that has been applied to some part of this unit may be the proper reference. Until someone can visit all the applicable type sections, determine the extent of the formations, and unravel the plethora of formational names, the matter is not likely to be resolved. For the moment, the question is necessarily left open. In this paper, the formation is identified as a combination of the two names, the Madre de Dios/Solimões Formation. One of these is probably the correct name for the sediments in the vicinity of Rio Branco. If these two formational names prove to refer to a continuous stratum, then the name "Solimões" (Rego, 1930) would take precedence. If it can be determined that the Solimões Formation does not extend to the Rio Acre, then the sediments are referable to the Madre de Dios Formation.

The upper part of the Madre de Dios/Solimões sequence, Members A, B, and C, are visible in roadcuts and along small streams south of Rio Branco and north to the Rio Puru's (Figs. 1-4). Members A and B are variegated clays throughout the area. Member A is light grey to green in color with nodular iron concretions and calcareous stringers. Member B is a red and green silty clay. On an exposed surface, both members weather into a blocky texture that is light red in color.

Member C is the uppermost stratum of the Madre de Dios/Solimões Formation and can be seen only on the crests of the low hills near Rio Branco. Member C is a complex stratum in which the lithology changes almost with each hilltop (Fig. 3, with our interpretations of depositional environment). In places, this unit is composed of fine sand and silt that is over lain by a thin clay unit with burrows or mud cracks in it that is in turn overlain by a thick, variegated clay. Elsewhere, Member C consists of cross-bedded, fine, brown sand with ripple marks that is overlain by variegated red/green clay. Member C also has thinnly laminations of clay and sand overlain by nodular clay conglomerate that is in turn covered by brown, fine-grained sand capped with a clay unit. Rapid lateral lithologic changes of this type are characteristic of deltaic sedimentation and indicates the many subenvironments found in a delta. Occasionally, one can see an obvious deltaic sequence such as that at km 15 (Figs. 3, 4). This clear example of progradation strongly supports the interpretation of other sediments as having resulted from the shifting of various localized deltaic subenvironments. At km 15, the finely laminated clay is overlain by silt that is in turn overlain by trough cross-bedded fine sand that is topped by a thin clay unit. At km 45, the cross-bedded clay and sand overlain by uniform clay indicates repeated (probably seasonal) changes of sediment as would result from a delta front that was superceded by quiet-water deposition. A crevasse-splay is indicated at km 143 by thick, cross-bedded sand and clay units. The divergent dips of these units would be due to the fan-shape of the splay. Sand lenses in thick clay units (km 85, km 144) could be interpreted as evidence for fluvial deposition were there not compelling evidence for deltaic deposition in the near vicinity. As such, and in view of the number and range of sizes that can be seen at one exposure, these sand units are interpreted as having been part of the delta plain or, as at km 144, part of the series of distributary channels.

At km 43, the sequence indicates a prograding deltaic environment that was advancing to the nothwest (approximately 315 degress, Fig. 2, 3). To the south of the Rio Acre, another prograding sequence is present but the direction of deposition is to the southeast (between 100 and 160 degress, Fig. 2, see arrows). If the directions of these prograding deltas are even approximately accurate, then one of two explanations is possible. Either two drainage systems were involved and the deltas bear no relation to each other, or they are part of one very large delta in which the sediments were fanning-out over a large depositional basin. It has been suggested that rivers in the Upper Amazon occupy the drainage channels of earlier, larger rivers (Almeida, 1975, in RADAMBRASIL, 1977). If the present-day Rio Acre follows the course of an earlier Rio Acre, then it also lies between the directional change of deltaic sediments as would have the ancient river. Because of this and the widespread uniformity and therefore probable lacustrine origin of Members A and B, we have built our model on the interpretation of a single, large delta. We propose that the uppermost sediments of the western part of the Amazon Basin are due to lacustrine deposition. Furthermore, this depositional environment included all or a major portion of the Amazon Basin. This enormous lake, here designated Lago Amazonas, is considered to have been a significant factor in the geomorphological and biological development of the Amazon Basin during the Late Pleistocene and Holocene. The termination of the older river would have been at Rio Branco during the time of deposition of Member C.

Member C has neither absolute nor relative age dates associated with it beyond the fact that it is younger than Members A and B. Wood samples taken from Member A along the Rio Madre de Dios near Candelaria, Bolivia, and on the Rio Acre near Belgica, Peru, and near Rio Branco, Brazil, have yielded dates between 10,000 and 36,500 years (Campbell & Frailey, 1984; Campbell & Romero Pitmann, in manuscript). The proposed cycles of deposition and erosion that created members of the Iñapari Formation in the Alto Acre (Campbell & Frailey, 1984) are reflected in sediment changes that mark the contacts between the units near Rio Branco. No channels were seen in these lower units at Rio Branco. They were presumably not exposed to extensive erosion this far into the basin.

Following the hypothesis of Kutzbach (1981), Campbell & Frailey (1984) proposed that the upper three members of the Madre de Dios (= Iñapari) Formation are correlative to world climatic conditions during the Late Pleistocene and Holocene. If this is true, than the deposition of Member C may have begun as recently as 2800 years ago. The current tipographic expression of this region, and by extension nearly all of the upper Amazon, may therefore be very young. The ramifications of this temporal re-ordering are staggering and extend into every field of Amazonian science. However, while certain views must either be modified or abandoned, other questions that have persistently evaded explanation now have a theoretical answer.

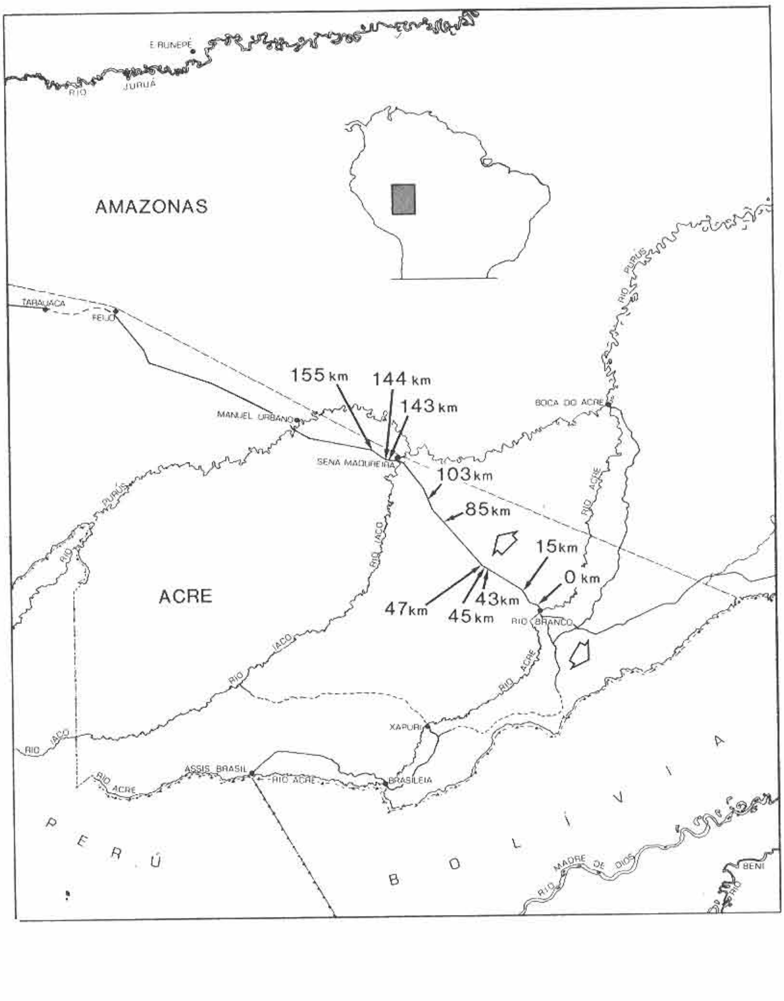


Fig. 2. The rivers and principle cities of the eastern half of the State of Acre. The TransAmazon Highway between Rio Branco and Sena Madureira (BR-364) is marked. Numbers indicate Kilometers north of the bridge at Igarape São Francisco at the northern edge of Rio Branco and correspond to sections illustrated in Figures 3 and 4.
Kilometer 155 is the Fazenda Lula Locality. The two hollow arrows near Rio Branco indicate the general direction of progradation in deltaic sediments of Member C, Iñapari/Solimões Formation.

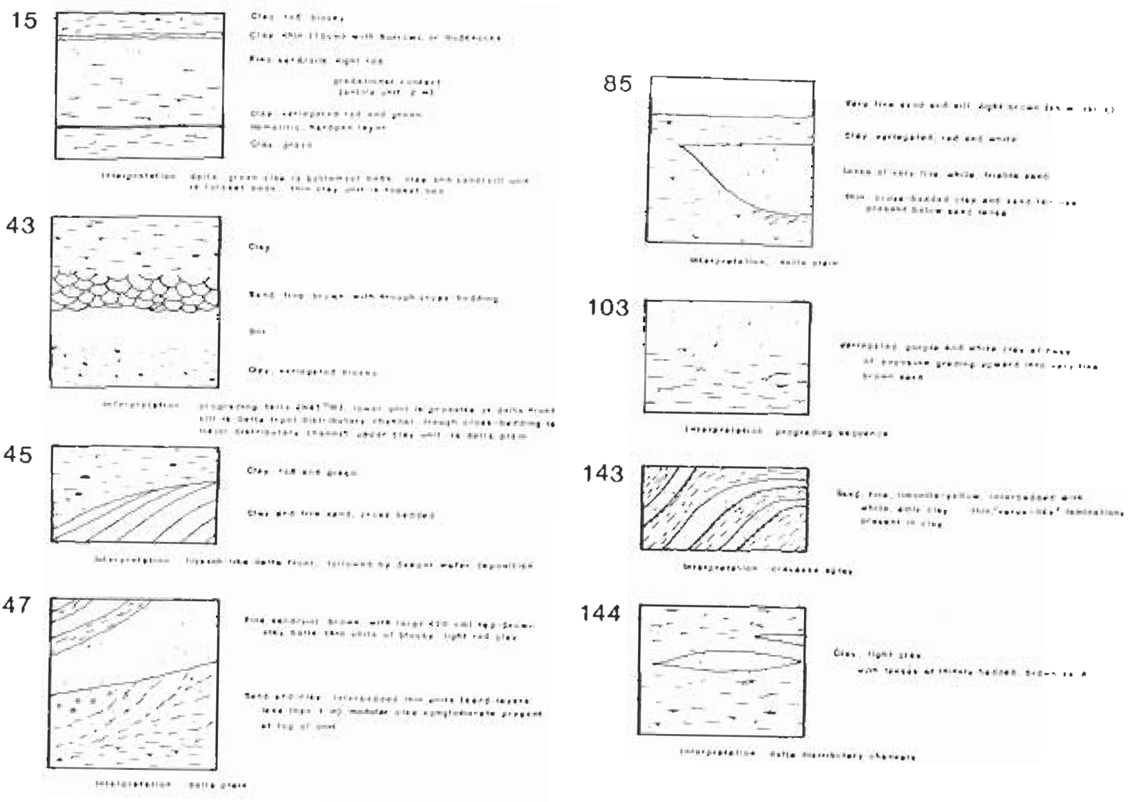
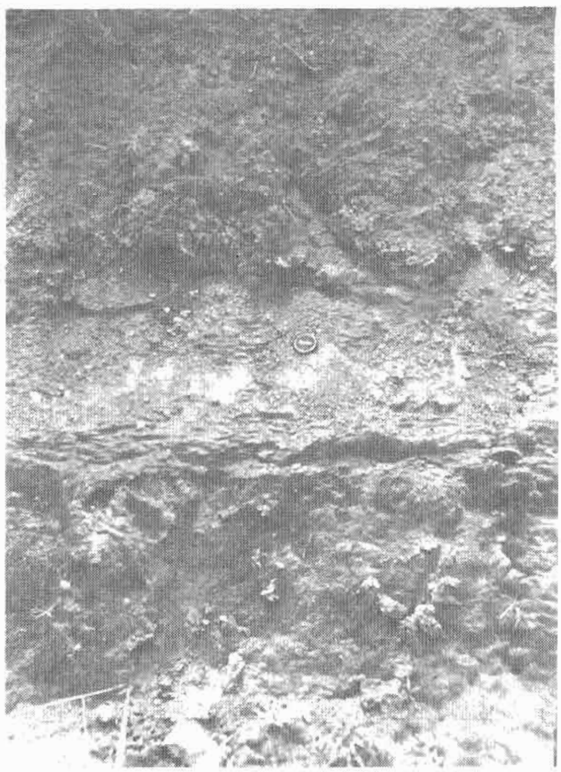


Fig. 3. Comparative lithologies and interpretations of depositional environments found in Member C of the Iñapari/Solimões Formation in the vicinity of Rio Branco and Sena Madureira. Kilometer designations refer to distances north of Igarapé São Francisco (Fig. 2) on the TransAmazon Highway. Vertical scale of the drawings is variable and given in parentheses after each Kilometer designation. A. Near Bujari, Km 15 (4 m); B. km 43 (2 m); C. Km 45 (1.5 m); D. Km 47 (2 m); E. Km 85 (10 m); F. Km 103 (10 m); G. Km 143 (4 m); H. Km 144 (4 m), approximately 1 km southeast of the Rio Caeté.

15 km



43 km

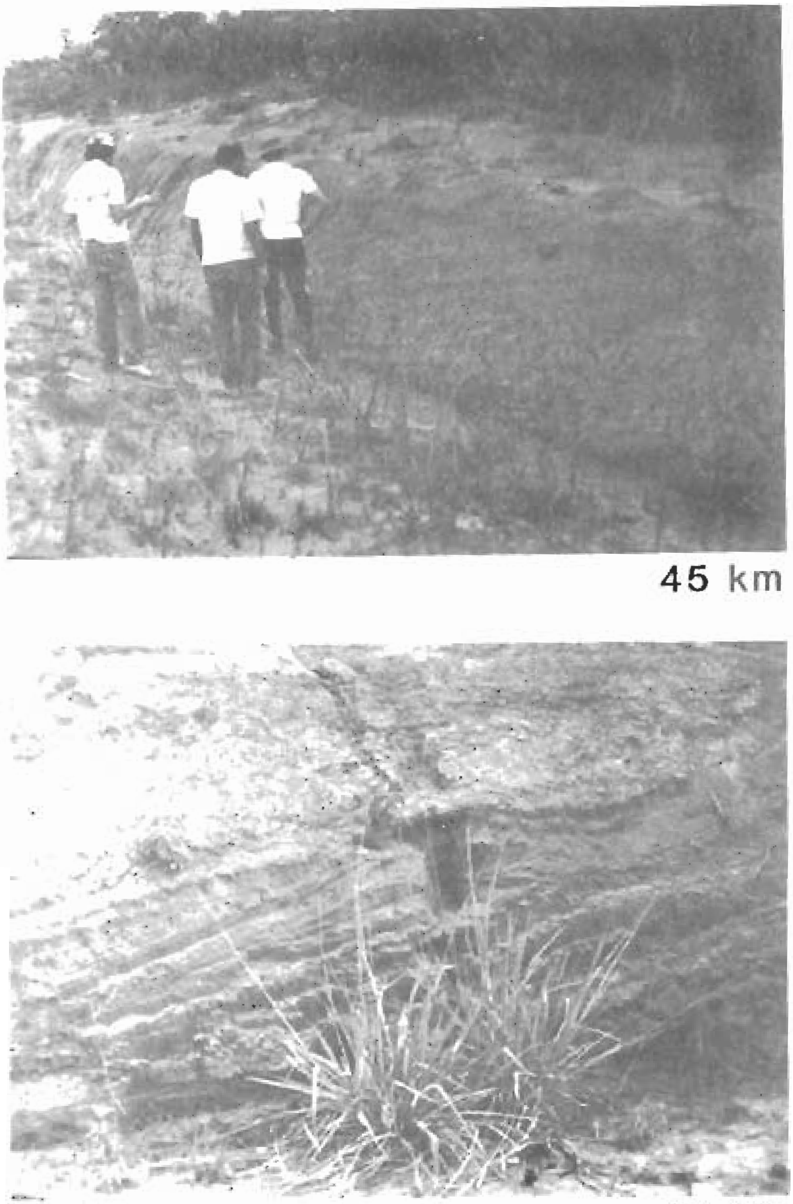


Fig. 4. Photographs of Member C, Iñapari/Solimões Formation. A. Near Bujari, Km 15. B. Km 43. C. Km 45. D. Km 47. The stratigraphy of these outcrops is described in Figure 3.

Implications of Lago Amazonas: Geology

The presence of a large Tertiary lake or lakes, an estuary, or even a marine embayment in the western part of the Amazon Basin is not an unusual concept and has been frequently mentioned in the scientific literature (Rüegg & Rosenzweig, 1949; Oliveira, 1956; Paula Couto, 1956; Sombroek, 1966; Sioli, 1968). This is, in fact, the usual explanation for the exposed, horizontal clay units although apparently based on older, highly speculative work. Our observations over the upper Amazon Basin from the Rio Beni, Bolivia, to the Rio Purus, Brasil, have convinced us that correlation of clearly defined, lithologically uniform strata is possible over considerable distances. That would be expected as a result of large-scale lacustrine deposition and not from a series of cut-off meanders. Furthermore, this lacustrine deposition if of Late Pleistocene/Holocene age. Irion (1976, 1984) suggests a depositional pattern for the lower Amazon of relatively large, temporary lakes during the Pleistocene and Holocene due to changing sea level. We are basically in agreement with his evidence yet suggest a much larger body of water and, at least in the upper Amazon, tectonic control of the depositional basin. Other evidence for late Holocene flooding, and perhaps a continuous lake, cames from a series of lakes in the upper Amazon basin of Ecuador at elevations between 300-700m (Colinvaux, **et al.**, 1985). Certainly, radically different environments of deposition are indicated for a great portion of the Amazon Basin in the recent past.

According to current thinking, the rising Andes blocked the drainage stsyems that extended westward from the Guiana and Brazilian highlands (Beurlen, 1970; Putzer, 1984, and others). During the Miocene and Pliocene, sediments from these systems and from the Andes accumalated in the region of the Upper Amazon. At some time, an outlet to the sea formed in the present location of the lower Amazon River. With downcutting through the exposed Precambrian rocks, the lakes of the upper Amazon were emptied and the present-day Amazon drainage was formed. It is our feeling that the structural framework behind the deposition of the late Pleistocene and Holocene sediments of the Madre de Dios/Solimões Formation is similar to that proposed for the same strata when it was thought they were Late Tertiary in age. The strata simply are much younger and therefore the tectonic events are more recent.

Interior basin formation as an extension of tectonism caused by converging plates has been suggested for Late Cretaceous and Cenozoic basins of western North America (Scholz **et al.**, 1971; Dickinson, 1976; Cross & Pilger Jr., 1978). Subsidence and sediment accumulation during the Cretaceous, for example, occurred in stages and exceed the response predicted from sediment loading alone (Cross & Pilger Jr., 1978). Cross & Pilger suggest that shallow plate subduction (Fig. 5A) rather than sediment loading was the cause of subsidence in the interior of North America during the Cretaceous. Furthermore, they suggest that the upper Amazon Basin is a modern analogue of shallow plate subduction. The recent identification of volcanic lakes in the Amazon Basin of Ecuador (Colinvaux **et al.**, 1985), is an argument for this hypothesis. Another possible tectonic mechanism is isostatic adjustment to the additional load of telescoped thrust sheets in an "Andean-type" converging boundary (Fig. 5B; Price, 1973; Dickinson, 1976). This mechanism is in accord with basin location, wedge-shape of the sediments, and intermittent depositional activity in the Niobrara Sea and the Amazon Basin. However, although this mechanism is postulated for depression in the upper Amazon Basin, the extent of basin depression is not thought to have produced an inland seaway equivalent to the Niobrara Sea. For concordance with the hypothesis of Lago Amazonas, the only needed modification is an increased rate of depression that at times exceeded sedimentation. The result would be a freshwater body of water that occupied the central Andean foreland basin at various times during the Late Cenozoic. Either hypothesis, shallow plate subduction or thrust sheet downwarping, is acceptable from our viewpoint. The critical factor is a reasonable tectonic mechanism that could have created a down-warped basin in an area that was an extremely low gradient and receives large volumes of precipitation and run-off.

Applying the concept of a foreland basin, deposition in the Amazon Basin is linked to the uplift of the Andes. The process of mountain-building in the Andes has not proceeded steadily but rather occurred in stages with long periods of quiesence between periods of active tectonism (Noble et al., 1974). The last of these postulated episodes of tectonism occurred from the Middle Miocene through the Pliocene. It is this episode that we correlate with the deposition of the Tertiary red beds. The lack of a complete temporal sequence is therefore a result of non-deposition during a time of relative quiescence (as for example, the absence of strata between the Late Miocene "red beds" and the Late Pleistocene Madre de Dios/Solimões Formation). The overlying Madre de Dios/Solimões Formation would represent a later period of activity (Late Pleistocene and Holocene). During this last period of uplift, we propose that sediments filled the foreland basin of the upper Amazon from large rivers that lay in the upper valleys of the present-day Amazon tributaries. The current period of relative quiescence and erosion rather than deposition in the Amazon Basin, may not be the advent of a post-tectonic phase, but may instead mark a quiet interlude in a larger episode.

Sediments also entered the basin from the Brazilian highlands to the east. At Esperanza Falls, approximately 30 km below Riberalta, Bolivia, the Rio Beni passes through a series of falls created by exposed Precambrian rocks of the Brazilian Shield. Here too, and extending westward toward Riberalta, is a thick conglomerate at the base of the Madre de Dios/Solimões Formation. By its stratigraphic position, this conglomerate would seem to be the same as the Acre Conglomerate Member, but that is not so. Unlike the Acre Conglomerate, this conglomerate comsists of fragments of the shield. Clast size reaches 30 cm at Esperanza Falls and diminishes to the east. Approximately 15 km east of the falls, the conglomerate is no longer separable from finer sediments of the Madre de Dios/Solimões Formation. Apparently, during the Late Pleistocene, the foreland basin of the upper Amazon was significantly downwarped and sediments entered both from the east and the west.

There presumably was an eastern margin to this great inland lake although we have seen no direct evidence other than the conglomerate that originated near Esperanza Falls. The elevation of the eastern margin of the upper Amazon basin may not have been higher than it is today, but need only have been higher than the downwarped upper Amazon. The eastern margin may have been located at the Iquitos Arch, the Purus Arch, or the Gurupá Horst. In that same order, the depositional basin during the Late Cenozoic could have included only the Acre Subbasin, the Acre Subbasin and the Upper Amazon Subbasin, or these two and the Middle Amazon Subbasin (Fig. 6, names of structural arches and subbasins follows Biggarella, 1973). Based on the thick wedge of sediments proposed by Biggarella (1973) and the relatively thin and horizontal upper strata in the middle and lower Amazonian subbasins, we suggest that Lago Amazonas existed primarily in the upper two subbasins. The apparent continuity of Cenozoic strata throughout these three subbasins (Fig. 7) suggests that at times the eastern margin of the Amazonian foreland may have extended much farther east and perhaps as far as the Gurupá Horst. If this is true, then all of the present-day Amazon Basin was a single depositional environment (lacustrine) and the Madre de Dios/Solimões Formation may extend from the base of the Andes to the mouth of the Amazon (Fig. 8). The correlation of oscillatory floodplains in the lower basin with glacial-eustatic floodplains found on passive coasts in other continents (Klammer, 1984), indicates that the lower basin was responding to worldwide sea-level changes. Although the level of hypothesized Lago Amazonas would have fluctuated with changes in world glaciation, it cannot be clearly shown whether trrracing in the lower basin is responding to oscillating sea-level (ultimate base level) or oscillating lake level (temporary base level). In our model, we propose a large, continuous depositional basin from the base of the Andes to the Gurupá Horst. Accordingly, much of this area (but not necessarily all, or all at one time) was covered by a vast lake with large oscillations in lake level indicated by the different lithologies of Members A, B, and C in the Madre de Dios/Solimões Formation (recent observations by Profª Rosalie Benchimol of the Universidade Federal do Amazonas indicate that these members, and therefore the lake oscillations that we suggest caused them, did not extend far into the upper Amazon Basin, personal communication, 11.29.87). The major downwarping occurred at the base of the Andes. Here, too, occurred the greatest accumulation of sediments and perhaps the most stable lake conditions. Eastern basinal deposition is likely to have been more influenced by sediments that originated from the exposed shield than by events along the western coast of South America. Therefore, sediment type as well as thickness of the units can be expected to change as the strata are traced eastward across the Amazonian subbasins.

Under the Lago Amazonas model, the end of the most recent phase of active tectonism brought an end to downwarping. Sediments ceased to pour into the foreland basin of the Upper Amazon, and isostatic adjustment lifted the basinal sediments to their current elevations (between 220 and 260 m). The newly developed drainage systems carved the undulating topography that is seen over the upper Amazon Basin.

One further, and considerable, difference between the proposed Amazon Basin of the recent past and that of today, is the location of the basin's outlet to the sea. The extraordinary size of the lower Amazon River and the great valley this river has seemingly carved through the shield rocks cause one to think that the present location of the lower Amazon River is as ancient as the river itself. However, several other factors, both geomorphic and biologic, indicate a northern outlet through the Orinoco Valley that has only recently ceased to be the primary outlet. Indeed, this connection in not yet fully severed. The Orinoco and the Rio Negro are connected throughout the year across the Casiquiare Canal. During each year, seasonal differences in rainfall causes water flow from the Orinoco to the Rio Negro or just the reverse (Lowe-McConnel, 1975, p. 73). This unusual, if not unique, connection between two major water systems may have formed by the normal process of headward erosion in both the Orinoco and Rio Negro. However, it seems unlikely that such a connection would long remain as a geomorphic feature even considering the tremendous rainfall this area receives. The Casiquiare Canal, in the context of a downwarping western edge of the Amazon Basin, may be seen as a lingering connection between a northern outlet that has ceased to be the primary outlet as it too adjusts to isostatic uplift (a hypothesis further supported by biogeography). However, the presence of a large deep-sea fan off the mouth of the Amazon River, the Amazon Cone, indicates that an Orinoco outlet was not the only drainage outlet during the Late Cenozoic (Damuth & Kumar, 1975; Kronberg **et al.**, 1986). We suggest that the drainage outlet oscillated between the Orinoco and lower Amazon valleys in correspondence with active downwarping of the upper Amazon Basin. During phases of active tectonism in the central Andes, the foreland basin of the upper Amazon would have been formed and Lago Amazonas would have drained through a likewise lowered Orinoco valley. During phases of relative tectonic quiescence, as at present, isostacy may have tilted the bowl of the Amazon Basin to the east until the eastern outlet was breeched and Lago Amazonas collapsed.

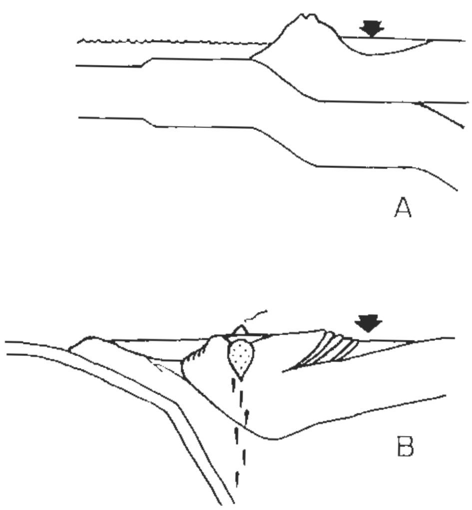


Fig. 5. Contrasting theories on the formation of a foreland basin. A. Foreland basin caused by a shallowly subducted plate (redrawn from Cross and Pilger, 1982). B. Foreland basin caused by isostatic adjustment to a backarc fold-thrust belt (redrawn from Dickinson, 1976). Arrows indicate subsidence in the foreland basin.

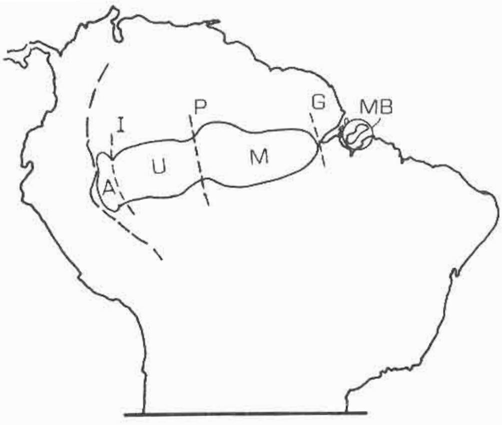


Fig. 6. The locations of significant arches and sub-basins in the Amazon Basin (modified from Bigarella, 1973). Sub-basins (from west to east): A, Acre; U, Upper, M, Middle; MB, Marajó. Structural arches (from west to east): I, Iquitos, P, Purus; G, Gurupá.

Implications of Lago Amazonas: Biogeography

Certain biogeographic aspects of the Orinoco and Amazon basins also support a previous connection between these two valleys. For example, the oeteoglossid fish appear unable to extend their ranges upriver beyond rapids (Goulding, 1980.). Yet the osteoglossids occur in both the tributaries of the Amazon (below the rapids) and in the Orinoco River (above the rapids). In the framework of a northward drainage of the Amazon Basin, this would not violate Goulding's hypothetical barrier to osteoglossid range extension. Those osteoglossids above the rapids of the Orinoco may be part of a once continuous range that extended northward from the Amazon Basin.

More direct evidence comes from a recently completed study of the fossil mollusks of the Amazon Basin (Nuttal, personal communication). The fossil mollusks of the Amazon are apparently more closely related to those of the Caribbean than to those the Pacific Ocean. This too indicates an extensive former connection between the Amazon and Orinoco drainage systems and a Caribbean drainage outlet.

Other zoogeographic aspects of Amazonian fish relate to the hypothesis of Lago Amazonas. Several species of small Amazonian fish are confined to the upper extents of tributary streams on the periphery of the basin and are not found in the Amazon River itself (Géry, 1964, 1984). Under the existing river pattern, the existence of the same species in small rivers on opposite sides of the main channel require either migration across the mouth of the Amazon River or channel-hopping (leaving no intervening populations) along the base of the Andes (Fig. 9A). Both routes are unlikely for small fish, as Géry, realized, but no alternative is possible if the modern drainage was established in the Early Cenozoic. A third possibility is that these populations represent a relictual distributions from recently widespread lake populations of these species (Fig. 9B).

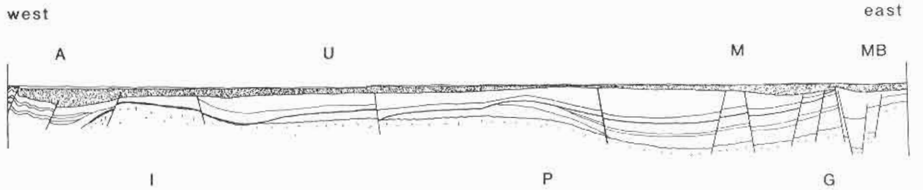


Fig. 7. Geological cross-section of the Amazon Basin (modified from Bigarella, 1973). Stippling indicates the youngest unit that is generally considered to be Tertiary. A thin veneer of horizontal, Quaternary sediments overlies these Tertiary sediments. Sub-basins (from west to east): A, Acre; U, Upper; M. Middle; MB, Marajó. Structural arches (from west to east): I, Iquitos; P, Purus G, Gurupá.

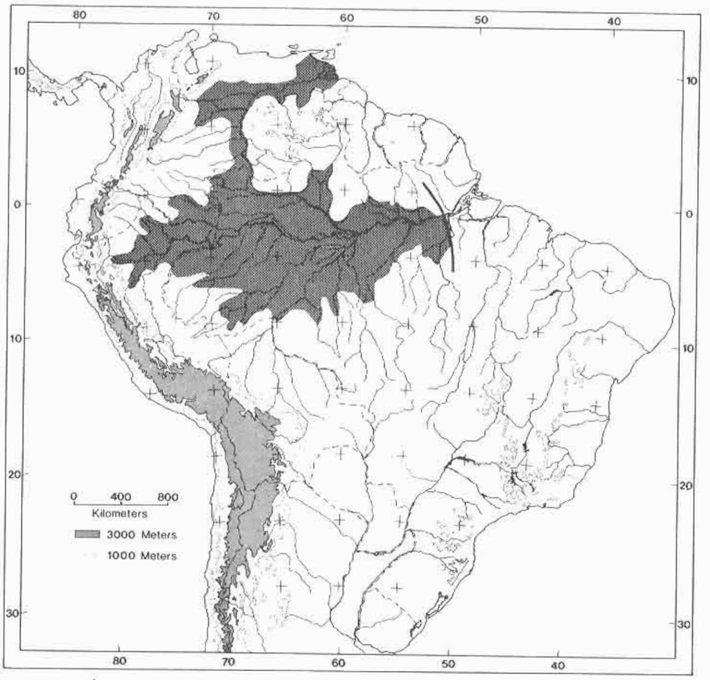


Fig. 8. A reconstruction of Lago Amazonas with a northern outlet through the Orinoco Valley. Lake margin is drawn on the 500 ft. (152.4 m) contour line.

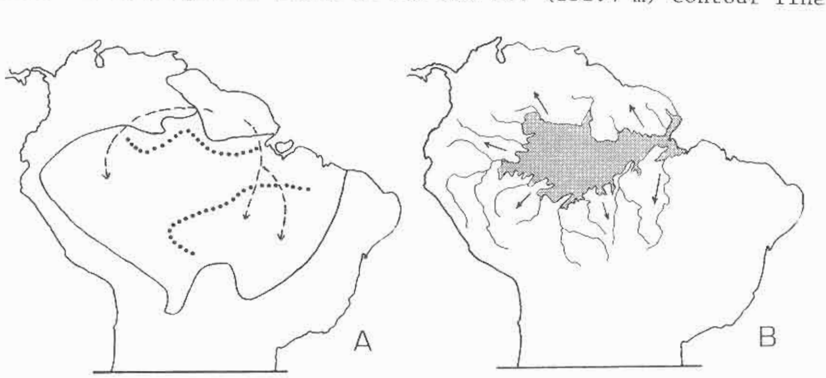


Fig. 9. A. Hypothesized paths of range extensions in some Amazonian fishes (from Géry, 1964). B. A reduced Lago Amazonas, drawn on the 100 m contour line, with hypothesized relictual distribution of lake fish in the newly formed river channels.

Normal vicariance biogeography can then be called upon to explain the disjunct distributions of small Amazonian fish.

The diversity of Amazonian fishes provides additional support for the former existence of a vast freshwater lake over the whole of the Amazon Basin. The great number of species (over 2400) is far greater than typical for a river system and invite comparison to the diversity of cichlid fishes in the great lakes of East Africa (Lowe-McConnell, 1975). The opportunity for resource partitioning in an enduring, stable environment such as a lake is a ready explanation for species diversity and has been documented in the fossil record (Smith, 1975). Also in Smith (1975), the return to river conditions was followed by a radical drop in species diversity. Species abundance among Amazonian fish may represent lacustrine resource partitioning that has not adjusted to riverine conditions due to the recency of this change. Perhaps this explanation has not been applied to the question of Amazonian diversity because of the extraordinary dimensions of the hypothetical lake. It seems as probable an explanation as those that propose speciation under current conditions of Amazonian drainage (Lowe-McConnell, 1975; Salo **et al.**,1986).

Species diversity of fishes in the Orinoco and Amazon basins contrasts sharply with diversity in the nearby Magdalena River of Colombia (Lundberg **et al.**, 1986). Although previous taxonomic similarity followed by extirpation in the Magdalena River may be a factor as Lundberg **et al.**, 1986, suggested, this lack of diversity may also be explained if the Magdalena River never developed diversity equal to that of the larger systems due to different geologic histories. This second explanation seems more in accord with the information presented by Weitzman & Fink (1985) on endemism of xenurobryconin fish in the Magdalena and Amazon basins.

The zoogeographic implications of a large lake in the Amazon Basin during the Late Pleistocene and much of the Holocene are of course profound. The seemingly disjunct ranges of the same or closely allied species that are difficult to explain due to present-day geomorphic features have been noted and commented upon by numerous researchers. For example, the centripetal migration of primates and flora from the peripheral highlands into the interior of the Amazon Basin (and the recency of that event) are discussed by Camp (1952) and Hershkovitz (1972). The extension of ranges and subsequent isolation due to the development of a large drainage system following the collapse of Lago Amazonas is a new interpretation for these observations.

In recent years, the Tropical Forest Refugia Model of Haffer (1969, 1974) and Vanzolini & Williams (1970) has been a model for biological studies in the Amazon (Duellman, 1979; and Prance, 1982). Until the discovery of the young age of the Amazonian sediments, it was the only comprehensive and plausible explanation for zoogeographic distributions. Under this model, as the forest retreated and fragmented before the expanding plains (presumably during the dry periods that corresponded to the glacial advances in the northern hemisphere), the forest taxa were isolated. The resultant allopatric speciation lingers as contiguous range boundaries among species of a now reunited forest.

The forest refugia model is elegant in its logic yet does leave some questions unanswered. For example, it seems most applicable to terrestrial animals and plants. Weitzman & Weitzman (1982) specifically addressed the question of the refugium model the Amazonian fish distribution. In what they stressed was an early study of this kind, they could find no clear relationship between hypothesized forest refugia and distributions of forest-restricted fish. Nor does the model allow for the likely occurrence of corridor forests along the margins of the presumed stable drainage pattern. In fact, although the hypothetical refugia are variously placed by different authors, the majority are situated in the upper reaches of the tributary streams at elevations between 500 and 1000 feet (Fig. 11). That is the the location and elevation of the hypothesized deltaic sediments of Zone C in the Madre de Dios/Solimões Formation as seen in the vicinity of Rio Branco. Using the lower figure (500 feet, approximately 150 m) to reconstruct the margins of a great lake, most of the proposed refugia can be accommodated along the lake border (Fig. 11).

The forest refugia model is further challenged in that palynological sampling of one presumed refugium in Ecuador gave evidence for a montane, Andean forest between 33,000-26,000 years b.p. (Kam-biu & Colinvaux, 1985). In this case, hypothesized lago Amazonas and altitudinal depression of the Andean flora, together, may have disrupted the rain forest in the western Amazon Basin.

Recent papers have suggested that habitat diversity and disturbance due to floodplain conditions provide a more parsimonious explanation of Amazonian diversity and distributions (Ra''sa''nen, Salo & Kalliola, 1987; Colinvaux, 1987). Although floodplain disturbance in a mature landscape cannot be denied under present conditions and is plausible for the recent past, these papers do not address the remarkable patterns of Amazonian distributions that provoked the formulation and ready acceptance of the refugium model.

The theories of forest refugia and Lago Amazonas are not incompatible. An integral part of the refugia model is the widespread presence of a plains biota in the Amazon Basin (and supported by palynological studies such as that of Absy & van der Hammen, 1976). Grasslands could have been present during lake level oscillations, or, if the collapse of Lago Amazonas was as rapid as suggested by the recent age of the sediments, normal ecological succession would have produced a vast grassland that then quickly succumbed to the climax forest.

An interesting addition to this discussion is that Amazonian linguistic homelands, like forest refugia, are placed on the periphery of the Amazon Basin and appear to support the refugium model (Meggars, 1979; Migliazza, 1982). Migration of language types (and people) into the interior of the Amazon is hypothesized to be very recent, between 2000 and 4500 years ago (Fig. 10). Furthermore, hypothesized paths of migration in the central basin after 2000 years ago more closely follows the main drainage of the Amazon River as would be expected if the drainage became established only after this time. The very young dates for the linguistic migrations correspond to hypothesized ages given to Zone C of the Madre de Dios/Solimões Formation (Campbell & Frailey, 1984). That date was created to conform with Holocene climatic events (described by Wendland & Bryson, 1974;

Fairbridge, 1976). The long absence of language in the central portion of the Amazon Basin is less easily explained by the refugia model than by our lake model. The suggested ages for the entrance of certain linguistic patterns into the Amazon Basin therefore serve as an independent test of proposed geological events in the Holocene and for the extremely young age of Zone C.

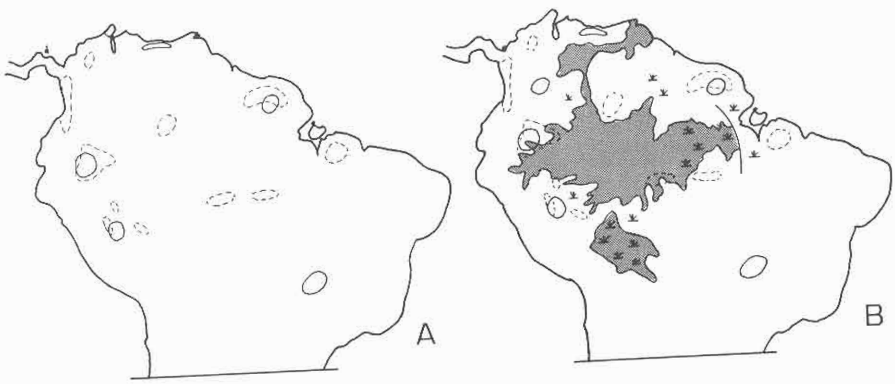


Fig. 10. A. Areas postulated by Vanzolini (solid black lines) and Haffer (dashed lines) as having been forest refuges during the Pleistocene (from Vuilleumier, 1971. B. Location of Lago Amazonas relative to the forest refuges. The hypothesized lake or marsh in southeastern Bolivia is drawn here following Wolff, **et al**. (in manuscript).

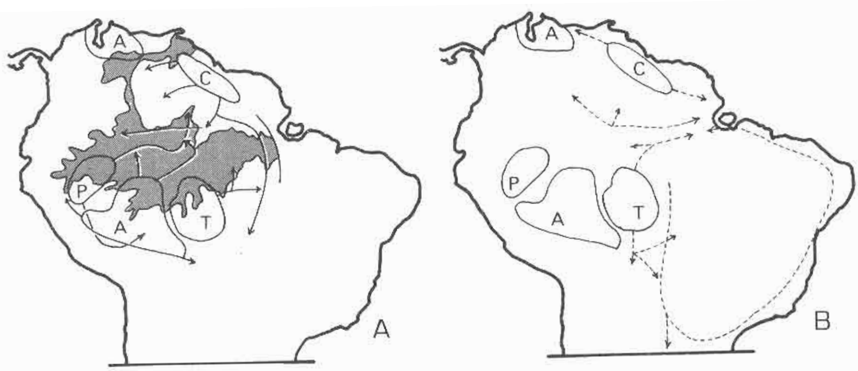


Fig. 11. Language centers and hypothetical dispersal routes of Amazonian languages (from Migliazza, 1982). A. Dispersal routes prior to 2000 years ago with Lago Amazonas present. B. Dispersal routes after 2000 years ago.

SYNTHESIS

The recent presence of a large freshwater lake in the Amazon Basin is supported by geologic and biogeographic data. In the vicinity of Rio Branco, Brazil, the current drainage systems are incised through the softer Late Pleistocene/Holocene sediments to the level of the Late Miocene clays. The formational names applied to exposed strata in western Amazonia are difficult to reconcile with our interpretation of the presence of two formations, the upper formation having at least four members. As the upper formation is the more fully exposed of the two, it surely has been the basis for formational descriptions in western Amazonia. The names Iñapari Formation (in Bolivia) and Solimões Formation (in Brazil) can be restricted to the upper stratum and, in so doing, most accurately retain the original designations. The lower stratum may be refferable to a previously named formation, but that cannot be determined until the type sections of those formations have been visited.

Deltaic sediments near the city of Rio Branco indicate that the modern course of the Rio Acre formed as a great inland lake diminished in size. The hypothetical lake is called Lago Amazonas in this paper. The channel system moved progressively into the basin perhaps as recently as 2500 years B.P. This is hypothesized as a model for all Amazonian drainage. An additional change of grand proportions is that the eastern outlet of the Amazon may be a recent development. An earlier nothern outlet through the Orinoco Valley, still partially open, may have been lost to stream capture as the drainage turned eastward. The opening of the present-day mouth of the Amazon River may have caused the Holocene collapse of Lago Amazonas. Then too, it may been only one more consequence of upward isostatic adjustment in the western part of the Amazon Basin as Andean tectonism and basin sedimentation subsided. If sedimentation in the Amazon Basin is linked to Andean tectonism as a foreland basin, Amazonian sediments that can be faunistically dated are another check of dates given for tectonic activity. As such, fossil vertebrates in Amazonian sediments indicate tectonic activity in the Late Miocene (Huayquerian) and Late Pleistocene and Holocene (35,000 to approximately 2500 years B.P.).

Finally, the geologic evidence offers an alternative to the Tropical Forest Refugia Model. Disjunct distributions of terrestrial species may have originated in pockets of tropical forest that were isolated along the margins of a great lake and not as remnants of forest amid plains. This model is additionally persuasive in that the diversity and zoogeography of Amazonian fishes, and not only the terrestrial biota, are readily explained. Under this model, the tremendous diversity reflects the species richness of a lacustrine environment that has not adjustated to riverine conditions. In this context, marginal basin fish populations can be viewed as relicts of once continuous populations rather than as miracles of migration.

The recent presence of a large lake in the Amazon Basin is conceivable from several lines of reasoning. Nonetheless, the enormity of this geologic feature requires for its acceptance a radical alteration of current thinking on both events and time. This paper cannot attempt to exhaust the ramifications of this hypothesis nor can we answer all contradictory evidence. However, widespread correlation of thick, very young sediments in the upper Amazon Basin grows ever more incontrovertible and must be incorporated into future studies of the geology, biology, and anthropology of the Amazon Basin.

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RESUMO

A grande distribuição geográfica das unidades estratigráficas do Pleistoceno superior e Holoceno na parte ocidental da Bacia Amazônica foi notada e descrita em vários estudos. O reconhecimento de sedimentação deltáica na parte superior destas unidades, nas proximidades de Rio Branco - Acre, Brasil, em altitude moderna de 160 metros, permite a conclusão de que esta área situou-se nas margens de um grande lago que deve ter existido no passado geológico recente, quando movimentos tectônicos na Cordilheira dos Andes causaram ativo rebaixamento da borda ocidental da Bacia Amazônica. As ramificações da hipótese deste "Lago Amazonas" tem prolongamentos nos estudos atuais da geologia e biologia da região Amazônica.

References

Absy, M. L. & Hammem, T. van der - 1976. Some palaeoecological data from Rondônia, southern part of the Amazon Basin. **Acta Amazonica**, (3):293-299.

Beurlen, K. - 1970. **Geologie von Brasilien**. Gebrüder Borntraeger, Berlin. 444 p.

Bigarella, J. J. - 1973. Geology of the Amazon and Parnaiba basins. **In**: Nairn, A.E.M. & Stehli, F. G. (eds.). **The Ocean Basins and Margins, volume I. The South Atlantic.** Plenum Press, New York. p. 26-86.

Branisa, L. - 1968. Hallazgo del amonite **Neolobites** en la Caliza Miraflores y de huellas de dinosaurios en la formación El Molino y su significado para la determinación de la edad del "Grupo Puca". **Instituto Boliviano del Petroleo, Boletim**, 8:16-29.

Brown, C. B. - 1879a. On the Tertiary deposits on the Solimoes and Javary rivers, in Brazil. **Quarterly Journal of the Geological Society of London**, 35:76-81, (with an appendix by R. Etheridge, p. 82-88, Plate VII).

---- 1879b. On the ancient river-deposit of the Amazon. **Quarterly Journal of the Geological Society of London**, 35:763-777. [Plate XXXVIII].

Camp, W. H. - 1952. Phytophyletic pattern on lands bordering the south Atlantic basin. **Bulletin of the American Museum of Natural History**, 99(3):205-212.

Campbell, K. E., Jr. & Frailey, C. D. - 1984. Holocene flooding and species diversity in southwestern Amazonia. **Quaternary Research**, 21:369-375.

Campbell, K. E., Jr., Frailey, C. D.; Arellano, J. L. - 1985. The geology of the Rio Beni: Further evidence for Holocene flooding in Amazonia. Contributions in Science. **Natural History Museum of Los Angeles County**, 364:1-18.

Campbell, K. E., Jr. & Romero, L. P. - (in manuscript). **The Quaternary Geology of Departamento de Madre de Dios**. Peru.

Caputo, M. V.; Rodrigues, R.; de Vasconcelos, D. N. N. - 1971. Litoestratigrafia da bacia do rio Amazonas. Belém, Petrobrás-renor. **Relatório Técnico Interno**:641-A.

Colinvaux, P. A.; Miller, M. C.; Kam-biu Liu; Steinitz-Kannan, M.; Frost, I. - 1985. Discovery of permanent Amazon lakes and hydraulic disturbance in the upper Amazon Basin. **Nature**, 313(5997):42-45.

Cross, T. A. & Pilger, R. H. Jr. - 1978. Tectonic controls of Late Cretaceous sedimentation, western interior, USA. **Nature**, 274:653-657.

---- - 1979. Origin of Basin-Range extension: Back-arc spreading controlled by North American plate motion. **Geological Society of America Abstracts with Programs**, 11:74.

---- - 1982. Controls of subduction geometry, location of magmatic arcs, and tectonic of arc and back-arc regions. **Geological Society of America, Bulletin**, 93:545-562, 9 figs., 1 table.

Damuth, J. E. & Kumar, N. - 1975. Amazon Cone: Morohology, sediments, age, and growth pattern. **Geological Society of America, Bulletin**, 86:863-878, 10 figs.

Davis, R. A. Jr. - 1983. **Depositional Systems, A Genetic Approach to Sedimentary geology**. Prentis-Hall, Inc., New Jersey. 669 p.

Denevan, W. M. - 1980. Field work as exploration: The Rio Heath savannas of southeastern Peru. **Geoscience and Man**, 21:157-163, 8 figs.

Dickinson, W. R. - 1976. Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America. **Canadian Journal of Earth Sciences**, 13:1268-1288.

Duellman, W. E. (ed.) - 1979. **The South American Herpetofauna: Its Origin, Evolution, and Dispersal**. Monograph of the Museum of Natural History, The University of Kansas, Lawrence, number 7: 485 p.

Fairbridge, R. W. - 1976. Shellfish-eating Preceramic Indians in coastal Brazil. **Science**, 191:353-359.

Frailey, C. D. - 1986. Late Miocene and Holocene mammals, exclusive of the Notoungulata, of the Rio Acre region, western Amazonia. Contributions in Science, **Natural History Museum of Los Angeles County**, 364:1-46.

Géry, J. - 1964. **Poissons characoides nouveaux ou non signalés de l'Ilha do Bananal**,

Brésil. Extrait du Volume Jubilaire dédié à Georges Petit, Supplément No. 17, "Vie et Milieu": 447-471.

---- - 1969. The fresh-water fishes of South America. Fittkau, E. J.; J. Illies; H. Klinge; G.H.. Schwabe: H. Sioli (eds.). **In: Biogeography and Ecology in South America**, 2:828-848. Dr. W. Junk N. V. Publishers, The Hague.

---- - 1984. The fishes of Amazonia. H. Sioli (ed.). **In: The Amazon, Limnology and Landscape ecology of a Mighty Tropical River and its Basin**. Dr. W. Junk Publishers, Dordrecht, Boston, Lancaster:353-370.

Goulding, M. - 1980. **The Fishes and the Forest, Explorations in Amazonian Natural History**. University of California Press, Berkeley. 280 p.

Haffer, J. - 1969. Speciation in Amazonian forest birds. **Science**, 165:131-137.

---- - 1974. Avian speciation in tropical South America. Publications of the Nuttal Ornithological Club, Cambridge, Number 14: 1-390.

---- - 1979. Quaternary biogeography of tropical lowland South America. Duellman, E. (ed.). **In: The South American Herpetofauna: Its Origin, Evolution, and Dispersal**. Monograph of the Museum of Natural History, the University of Kansas, 7:107-140.

Hershkovitz, P. - 1972. The recent mammals of the Neotropical region: A zoogeographic and ecological review. Keast, A.; Erk, F. C.; Glass, B. (eds.). **In: Evolution, Mammals, and Southern Continents**. State University of New York Press, Albany:311-431.

Irion, G. - 1976. Die Entwicklung des zentral - und oberamazonischen Tieflands im Spät -Pleistozän und im Holozän **Amazoniana**, 6(1):67-79.

---- - 1984. Sedimentation and sediments of Amazonian rivers and evolution of the Amazonian landscape since Pliocene times. Sioli, H. (ed.). **In: The Amazon, Limnology and landscape ecology of a mighty tropical river and its basin**. Dr. Junk,W., Publishers, Dordrecht, Boston, Lancaster:201-214.

James, D. E. - 1971. Plate-tectonic model for the evolution of the central Andes. **Geological Society of America, Bulletin**, 82:3325-3346.

*Jenks, W. F. - 1956. Peru. **In:** Handbook of South American Geology*, an Explanation of the Geologic Map of South America, Jenks, W. F. (ed.). **Geological Society of America**, Memoir, 65:215-248.

Kam-biu Liu & Colinvaux, P. A. - 1985. Forest changes in the Amazon Basin during the last glacial maximum. **Nature**, 318(6046):556-557.

Klammer, G. - 1984. The relief of the extra-Andean Amazon basin. Sioli, H. (ed.). **In: The Amazon. Limnology and Landscape ecology of a Mighty Tropical River and its Basin**. Dr. Junk, W. Publishers, Dordrecht, Boston, Lancaster:47-83.

Kronberg, B. I.; Nesbitt, H. W.; Lam, W. W. - 1986. Upper Pleistocene Amazon deep-sea fan muds reflect intense chemical weathering of their mountainous source lands. **Chemical Geology**, 54:283-294.

Kummel, B. - 1948. Geological reconnaissance of the Contamana region, Peru. **Geological Society of America, Bulletin**, 59:1217-1266.

Kutzbach, J. E. - 1981. Monsoon climate of the early Holocene: Climate Experiment with the earth's orbital parameters for 9000 years ago. **Science**, 214:59-61.

Lundberg, J. G.; Machado-Allison, A.; Kay, R. F. - 1986. Miocene characid fishes from Colombia: Evolutionary stasis and extirpation. **Science**, 234:208-209.

Lowe-McConnel, R. H. - 1975. **Fish Communities in Tropical Freshwaters, their distribution, ecology and evolution.** Longman, London and New York. 337 p.

Meggers, B. J. - 1979. Climatic oscillation as a factor in the prehistory of Amazonia. **American Antiquity**, 44(2):252-266.

Migliazza, E. C. - 1982. Linguistic prehistory and the refuge model in Amazonia. Prance, G. T. (ed.). **In: Biological Diversification in the Tropics.** Columbia University Press:497-519.

Mousinho de Meis - 1971. Upper Quaternary process changes of the middle Amazon area. **Geological Society of America, Bulletin**, 82:1073-1078.

Noble, D. C.; Mckee, E. H.; Farrar, E.; Petersen, U. - 1974. Episodic Cenozoic Volcanism and tectonism in the Andes of Peru. **Earth and Planetary Science Letters**, 21;213-220.

Oliveira, A. I. de - 1956. Brazil. **In**: Handbook of South American Geology, an Explanation of the Geologic Map of South America, Jenkes W. F. (ed.). **Geological Society of America**, Memoir, 65:1-62.

ONERN (Oficina Nacional de Evaluación de Recursos Naturales) - 1977. **Inventario, evaluación e integración de los recursos naturales de la zona Iberia-Iñapari** Lima, Peru. 334 p.

Oppenheim, V. - 1937. Geological exploration between upper Juruá River, Brazil, and middle Ucayali River Peru **American Associatiou of Petroleum Geologists, Bulletiu** 21(1):97-110.

Parra, V. S. - 1974. Geología preliminar del area Tigre-Corrientes en el nor oriente peruano. **Boletín Sociedad Geológica del Perú**, 44:106-127.

Paula Couto, C. de - 1956. Mamíferos fósseis do Cenozóico da Amazônia. Instituto Brasileiro de Bibliografia e Documentação, Conselho Nacional de Pesquisas, Rio de Janeiro. **Boletim**, 3:1-121.

---- - 1978. Fossil mammals from the Cenozoic of Acre, Brazil. 2. Rodentia, Caviomorpha, Dinomyidae. **Iheringia, Ser. Geol.**, Porto Alegre, 5:3-17.

Prauce, G. T. (ed.). - **Biological Diversification in the Tropics.** Columbia University Press, New York. 714 p.

Price, R. A. - Large-scale gravitational flow of supracrustal rocks, southern Rocky Mountains. De Jong, K.A. & Scholten, R.(eds.). In: **Gravity and tectonics**, Wiley, 491-502.

Putzer, H. - 1984. The geological evolution of the Amazon basin and its mineral resources. Sioli, H. (ed.). **In: The Amazon. Limnology and Landscape Ecology of a Mighty Tropical River and its Basin.** Dr. Junk, W. N. V. Publisher, the Hague:15-46.

RADAMBRASIL - 1976. **Levantamento de recursos naturais (geologica, geomorfologia, pedologia, vegetação, uso potencial da terra).** Folha SC. 19 Rio Branco. Volume 12. Rio de Janeiro, Departamento Nacional de Produção Mineral.

---- - 1977. **Levantamento de recursos naturais (geologica, geomorfologica, pedologia, vegetação, uso poteucial da terra).** Folha SB/SC. 18, Javari/Contamana. Volume 13. Rio de Janeiro: Departamento Nacional da Produção Mineral.

Rego, L. F. de M. - 1930. **Notas sobre a geologia do Território do Acre e da bacia do Javary**, Manaus, Imp. C. Cavalcanti. 45 p.

Rüegg, W. & Rosenzweig, A. - 1949. Contribución a la geología de las formaciones modernas de Iquitos y de la Amazonia Superior. **Sociedad Geológica del Perú**, Volumen Ju bilar, XXV Aniversario, Parte II, Fasciculo 3:1-24.

Salo, J.; Kalliola, R.; Häkkinen, I.; Mäkinen, Y.; Niemela, P.; Puhakka, M.; Coley, P. D. - 1986. River dynamics and the diversity of Amazon lowland forest. **Nature**, 322: 254-258.

Scholz, C. H.; Barazangi, M.; Sbar, M. L. - 1971. Late Cenozoic evolution of the Great Basin, western United States, as an ensialic interarc basin. **Geological Society of America Bulletin**, 82:2979-2990.

Simpson, G. G. & de Paula Couto, C. - 1981. Fossil mammals from the Cenozoic of Acre, Brazil. III. Pleistocene Edentata Pilosa, Proboscidea, Sirenia, Perissodactyla and Artiodactyla. **Iheringia, Geological Series**, Porto Alegre, 6:11-73.

Singewald, J. T. Jr. - 1927. Pongo de Manseriche. **Geological Society of America, Bulletin**, 38:479-492.

---- - 1928. Geology of the Pichis and Pachitea rivers, Peru. **Geological Society of America, Bulletin**, 39:447-464.

Sioli, H. - 1968. Hydrochemistry and geology in the Brazilian Amazon region. **Amazoniana**, 1(3):267-277.

Smith, G. R. - 1975. **Fishes of the Pliocene Glenns Ferry Formation, southwest Idaho.** Claude W. Hibbard Memorial Volume 5, Papers on Paleontology No. 14, The Museum of Paleontology, University of Michigan, iii-iv. 68 p.

Sombroek, W. G. - 1966. **Amazon soils, a reconnaissance of the soils of the Brazilian Amazon region.** Centre for Agricultural Publications and Documentation, Wageningen (Netherlands). 292 p.

Steinmann, G. - 1929. **Geologie von Peru.** Heidelber, Carl Winters Universitätsbuchhandlung. 448 p.

Vanzolini, P. E. & Williams, E. E. - 1970. South American anoles: The geographic differentiation and evolution of the Anolis chrysolepis species group (Sauria: Iguanidae). **Arquivos de Zoologia**, 19:1-298.

Vuilleumier, B. S. - 1971. Pleistocene changes in the fauna and flora of South America. **Science**, 173:771-780.

Weitzman, S. H. & Weitzman, M. - 1982. Biogeography and evolutionary diversification in Neotropical freshwater fishes, with comments on the refuge theory. Prance, G. T. (ed.). **In: Biological Diversification in the Tropics.** Columbia University Press. p. 403-422.

Weitzman, S. H. & Fink, S. V. - 1985. Xenurobryconin phylogeny and putative pheromone pumps in glandulocaudine fishes (Teleostei: Characidae). Smithsonian Contributions of **Zoology**, 421:1-121.

Wendland, W. M. & Bryson, R. A. - 1974. Dating climatic episodes of the Holocene. **Quaternary Research**, 4:9-24.

Williams, M. D. - 1949. Depósitos Terciários Continentales del Valle del Alto Amazonas. **Sociedad Geológica del Perú**, Volumen Jubilar, XXV Aniversario, Parte II, Fasciculo, 5: 1-13.

Wolff, R. G.; Maples, W. R.; Mueller, P. A.; Frailey, C. D. - **Paleo-Indian skeletal remains from Ñuapua, southeastern Bolivia.** [in manuscript].

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