

PALEOENVIRONMENTAL MODEL FOR THE LATE CENOZOIC OF SOUTHWESTERN AMAZONIA: PALEONTOLOGY AND GEOLOGY

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ABSTRACT — Our study provides paleontological and geological data substantiating a paleoenvironmental model for the upper Miocene-Pliocene of Southwestern Amazonia. The extensive Late Tertiary sediments of The Solimões Formation, outcropping in Southwestern Amazonia, were deposited by a complex megafan system, originating in the high Peruvian Andes. The megafan system was the sedimentological response to the Andean Quechua tectonic phase of Tertiary age, producing sediments that filled the foreland basin of Southwestern Amazonia. Occurrences of varied vertebrate fossil assemblages of the Huayquerian-Montehermosan Mammal age collected in these sediments support this interpretation. The fauna includes several genera and species of fishes, reptiles, birds, mammals and appears to be one that could have lived in or near a riverine habitat. In the Late Pliocene, the megafan system became inactive as a result of the influence of the Diaguíta Tectonical Phase.

Key-Words: Amazonia; Sedimentary model; Megafan; Vertebrate Paleontology; Mio-Pliocene.

Modelo Paleoambiental da Amazônia Sul-Occidental Durante o Cenozóico: Paleontologia e Geologia.

RESUMO — O presente trabalho refere-se à paleontologia e geologia como elementos de sustentação para um modelo paleoambiental da Amazônia Sul-Occidental durante o Mioceno Superior-Plioceno. Os sedimentos terciários (Formação Solimões) aflorantes nesta região foram depositados por um complexo sistema de megaleque originário dos Andes peruanos. Este sistema de megaleque representa uma resposta sedimentar à fase tectônica Quechua ocorrida nos Andes durante o Mioceno Medio/Superior. Os sedimentos foram acumulados na bacia sedimentar da Amazônia Sul-Occidental. A ocorrência de sítios com grandes quantidades de vertebrados fósseis de Idade-Mamífero Huayqueriense-Montehermosense (Mioceno Superior-Plioceno) nos sedimentos da Formação Solimões corrobora essa interpretação. A fauna consta de vários gêneros e espécies de peixes, répteis, aves, mamíferos. No Plioceno superior, o sistema de megaleque ficou inativo devido à influência da fase tectônica Diaguíta.

Palavras-Chave: Amazônia; Modelo Sedimentar; Megaleque; Paleontologia de Vertebrados; Mio-Plioceno.

INTRODUCTION

The objective of the present work is to propose a new model of paleoenvironmental conditions for the Late Miocene-Pliocene (Huayquerian-Montehermosan) of Southwestern Amazonia, on the basis of vertebrate paleontology and geology. The region considered includes part of western Brazil, Peru and Bolivian Amazonia (Fig. 1).

Field work was carried out in the

State of Acre, Brazil, at sections exposed along the Purus and Jurua river basins and roadside outcrops. The State of Acre belongs to the Southwestern region of Brazilian Amazonia and borders Peru and Bolivia.

The vegetation of this area is primarily tropical rainforest in which rainfall average 2000mm annually. Although moderately high, precipitation is seasonal. Due to poor accessibility of outcrops during the rainy season, field-

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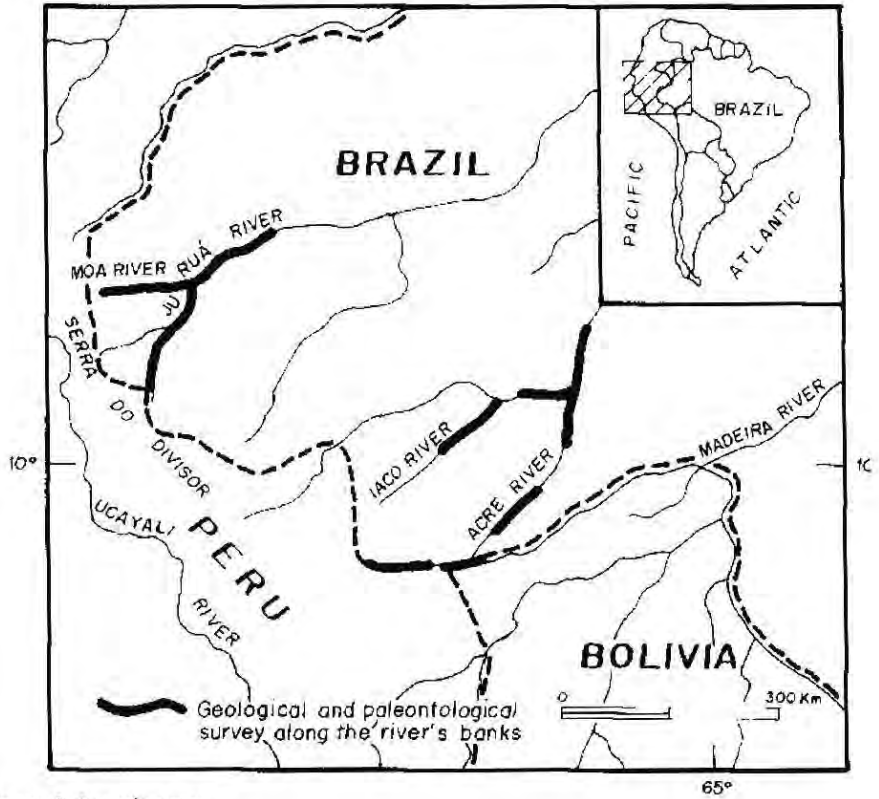


Figure 1. Location map.

work was carried out largely during the period from June to August.

The region under study is characterized by an undulating landscape (maximum elevation 250m above sea level) with occasional flat topped hills, which have a similar altitude. The maximum relative relief between the tops of hills and the water level of the rivers is about 70m.

In the Upper Tertiary, Southwestern Amazonia was an extensive aggradational plain. This plain was dissected between the Late Pliocene and the Last Glacial Maximum resulting in the present badland landscape of Southwestern Amazonia observed in radar images (TRICART 1985; RADAMBRASIL, 1976).

Geological Background

The Geology of Amazonia is dominated by four geotectonic elements: Guyana and Brazilian Shields, both composed of Precambrian and Paleozoic rocks; the Amazon intracratonic basin and the Andean Belt.

The sedimentary basin includes different sub-basins in western Amazon such as Marañón, Ucayali, Acre, Madre de Dios and upper Amazon. Toward the east, structural arches divide the Amazon basin in Middle and Lower Amazon.

Tertiary sediments cover almost the totality of western Amazonia, West of Manaus. These sediments are assigned

to the Solimões Formation. The eastern limit of the Tertiary basin fits approximately with the Purus structural arch. Other arches like Iquitos and Carauari were overlapped by the Tertiary sediments.

Clastic sediments formed principally by sandstones, siltstones and claystones of continental origin were assigned to the Tertiary and informally defined as lithostratigraphic units.

CAPUTO *et al.* (1971) combined the previously separately defined Puca (STEINMANN, 1929), Solimões (REGO, 1930) and Cruzeiro (OPPENHEIM, 1937) formations into a single formation, defined as the Solimões Formation.

The upper beds of the Solimões Formation have been correlated by FRAILEY *et al.* (1988) with the Iñapari Formation (CAMPBELL & FRAILEY, 1984), of Holocene age in Peru. KRONBERG *et al.* (1990; 1991) assigned a Late Pleistocene age for the Solimões Fm.

These reports increased the confusion that existed in the literature on the age of the Solimões Formation because previous reports from RADAMBRASIL (1975; 1976) assigned a Plio-Pleistocene age to the formation.

The maximum thickness of the outcrops is approximately 70m. Sediment cores taken by the Brazilian Oil Company Petrobras (RADAMBRASIL, 1975; 1976; 1977) revealed a maximum thickness of 1800m for the Solimões Formation.

The sedimentary sequence described above has been recognized by CAPUTO *et al.* (1971) to be Paleocene/Pleistocene in age. Analysing the same data, we suspect that the thickness of 1800m includes at least two

lithostratigraphic units, which could range from Paleocene /Oligocene to Mio-Pliocene in age.

The Quaternary sediments are of fluvial origin and are found in the alluvial belts of the Southwestern Amazon rivers. In these belts there are three terrace levels (LATRUBESSE & RAMONELL, 1991; 1992) (Fig. 2). The upper terrace (UT) reaches 34 to 38m, the intermediate terrace (IT) 15 to 20m and the lower (LT) 8 to 12m (relative to the lowest dry season water level). The more exposed unit in the banks is the lower terrace level (Purus, Acre, Iaco and Juruá rivers). In the Moa river, the terraces only attain heights of 20 to 25m, 9 to 12m and 2 to 4m, respectively.

The Solimões Formation

Based on new geological and paleontological data we consider the Solimões Fm. to be an Upper Tertiary unit in the uppermost levels. The Tertiary sediments exposed along the banks of the Acre, Iaco, Purus, Juruá and Moa rivers, and in outcrops along the roads of this region, are differentiated into two facies, a low energy and a high energy facies, within a fluvial-floodplain-lacustrine complex. The high energy facies (channel facies) is composed of sands, silty and clayey sands and some small gravels. This facies is red brown to brown, and shows cross-bedded stratification. The low energy facies is composed of green to gray-green clays and silty clays and belongs to floodplain-lacustrine-paludal environments. These sediments have planar lamination or massive structure. In the two facies,

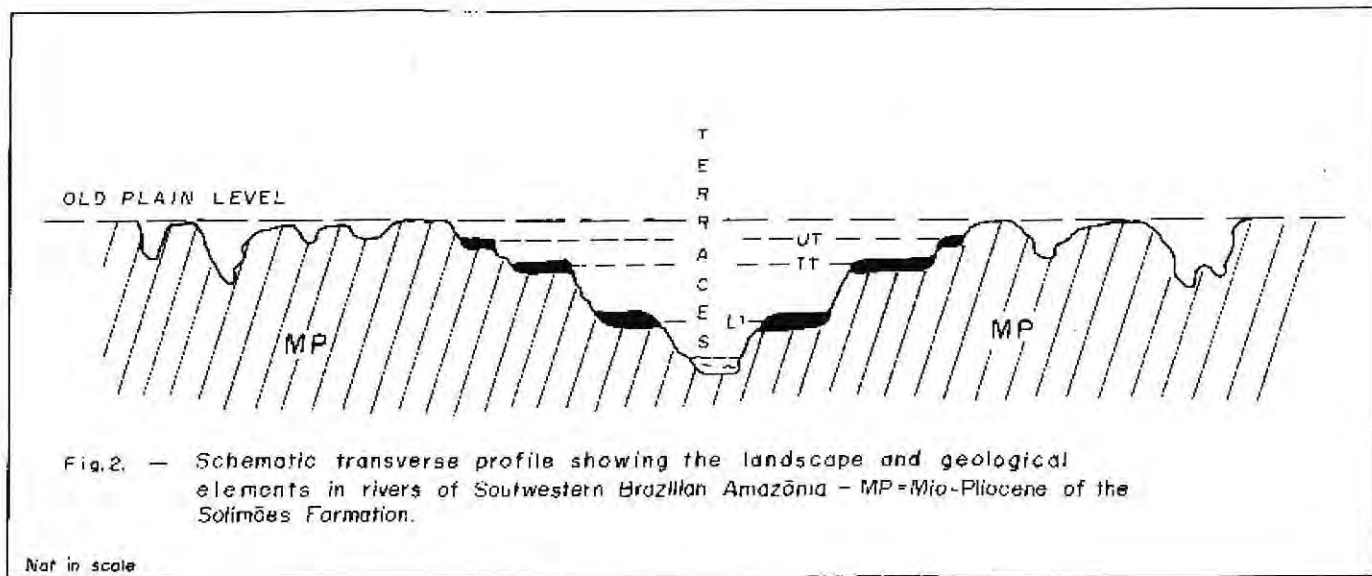


Figure 2. Schematic section showing the principal landscape elements of Southwestern Brazilian Amazonia.

fossil bones, gypsum veins and calcareous concretions are very common.

Comparatively, floodplain-lacustrine sediments are dominant and representative in the outcrops. These sediments occur as extensive horizontal beds with massive structure which occasionally shows laminar structure. Light variations in color ranging between green-grey green to light red can be attributed to differences in the depth of the level water and oxygenation. In some cases, the beds are wedged laterally in the form of large-scale pseudo-cross stratification. We interpreted this geometry of wedges of the beds in terms of paleochannel fill by clayey and silty sediments. The sediments are tapered in the direction of the paleochannel border by differential compaction.

The high energy facies is indicative of fluvial channels. These sequences are typically fining upward, with trough cross beds in the bottom generally cutting the lower energy facies sediments. The trough cross stratification becomes minor toward the top, changing to clayey and silty sediments.

These structures of cut and fill, and the typical channel sequence of fining upward sediments, are indicative of active and unstable channels. However, non-repetitive scroll structures were recognized. It can be inferred that avulsion have occurred.

Facies analysis of the Tertiary units of Southwestern Amazonian indicates that they were deposited as part of a megafan system with its headwater in the Peruvian Andes (IRIONDO, 1988; LATRUBESSE, 1992; LATRUBESSE & RAMONELL, 1992).

Megafans are typical widespread geomorphologic features of the Quaternary plains of South America (IRIONDO, 1992) and avulsion a characteristic mechanism in large Western Amazon rivers (DUMONT, 1994).

It has been proposed that a large megafan, together with smaller fans have created a very large aggradational plain in Southwestern Amazonia in the upper Tertiary (LATRUBESSE, 1992; LATRUBESSE & RAMONELL, 1992). At the time of the activities of this megafan system the tropical climate could only have been characterized by well delimited dry and wet seasons producing a strong seasonal contrast in sediment load and discharge. During the alluvial belts migration, new flooded areas were generated accompanied by the abandonment of the existing swamps and lakes. These abandoned swamps and lakes were probably maintained by local rains or could have dried out and been filled with clayey sediments gradually.

Our results show that this megafan system occupied the region south of the Solimões river and extended eastward at least to a longitude of 67° W (Fig. 3).

This megafan system was the sedimentary response to the Andean tectonic movements in the Amazon foreland basin. This tectonic phase was initiated in the Bolivian and Peruvian Andes approximately 10 ± 2 millions years ago (data review in JORDAN *et al.*, 1983).

The Diaguita Upper Pliocene tectonic phase of the Andes (DUMONT *et al.*, 1989; 1991; JORDAN *et al.*, 1983) created the present watershed of the Ucayali and fluvial basins of

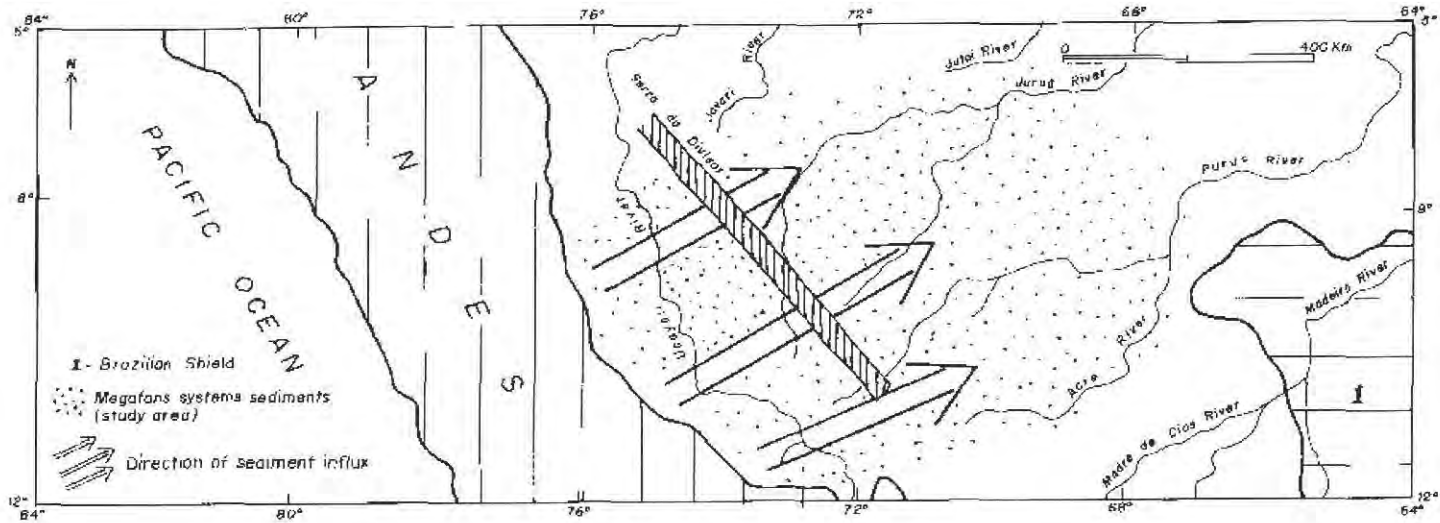


Figure 3. Megafans systems sediments of the Solimões Formation outcropping in Acre and principal direction of sediment influx.

Southwestern Amazonia. Thus, tectonic phase was responsible for the termination of the deposition of the Amazonia megafan system. Consequently Southwestern Brazilian Amazonia has become isolated from the Andean Range as a source of sediments since the Upper Pliocene. At this time, the present northward drainage pattern of the Ucayali river was established, beginning the development of the present Purus and Jurua fluvial belts and the drainage network of Brazilian Southwestern Amazonia. These fluvial belts have three Quaternary terrace levels.

Vertebrate Paleontology and Late Miocene-Pliocene environments

In 1866, Chandless published the first of many studies concerning fossil vertebrate faunas of the Western Amazon Region. RANCY (1985; 1991) provided historical reviews of previous research and emphasized the involvement of the Laboratory of Paleontology at the University Federal of Acre, in Brazil. The last decade has witnessed a marked increase in material collected and many of specimens reported in this paper were gathered by the local staff and colleagues in the State of Acre.

Material was recovered in the Tertiary sediments from the banks of the upper Purus river and tributaries (Talismã, Preventório, Niterói, Cavalcante and Patos sites; Fig. 4) and from the upper Jurua river (sites listed by PAULA COUTO, 1976). The fossiliferous beds along the upper Jurua and Purus sites are visible at low water (roughly June through October) in

isolated exposures. The fossiliferous outcrop called Lula is situated along both sides of a road embankment near the city of Sena Madureira. This fossiliferous locality is located at the top of one hill, and stratigraphically is situated in the topmost levels of the Solimões Formation.

Commonly the fossil bones are found in situ, and the bone beds are rich. Almost all of the bones and teeth collected, when found loose and out of the bonebed exposures, are broken, rolled and reworked. However, when recovered in situ, some specimens are very well preserved.

The majority of the specimens included in our revised list (Tab. 1) are deposited at the Laboratory of Paleontology of University Federal of Acre, in Rio Branco, Brazil.

Among the vertebrate fauna of Southwestern Amazonia, the fossil assemblages of the distinct localities show some differences. These differences are qualitative (occurrence or absence of determinate taxon) or quantitative (frequency of a determinate taxon) in accordance with the sedimentary variability.

The faunistic correlation was made with occurrences of various taxa previously described from the Huayquerian-Montehermosan mammalian strata (Late Miocene-Pliocene) of Argentina. These taxa are: the rodents *Potamarchus*, *Neoepiblema horridula*, *Phoberomys burmeisteri* and the toxodont *Trigodon*. The toxodont *Gyrinodon* found in the Urumaco Formation (Late Miocene-Pliocene) of Venezuela is present in the Solimões Formation as well.

In almost every paleontological

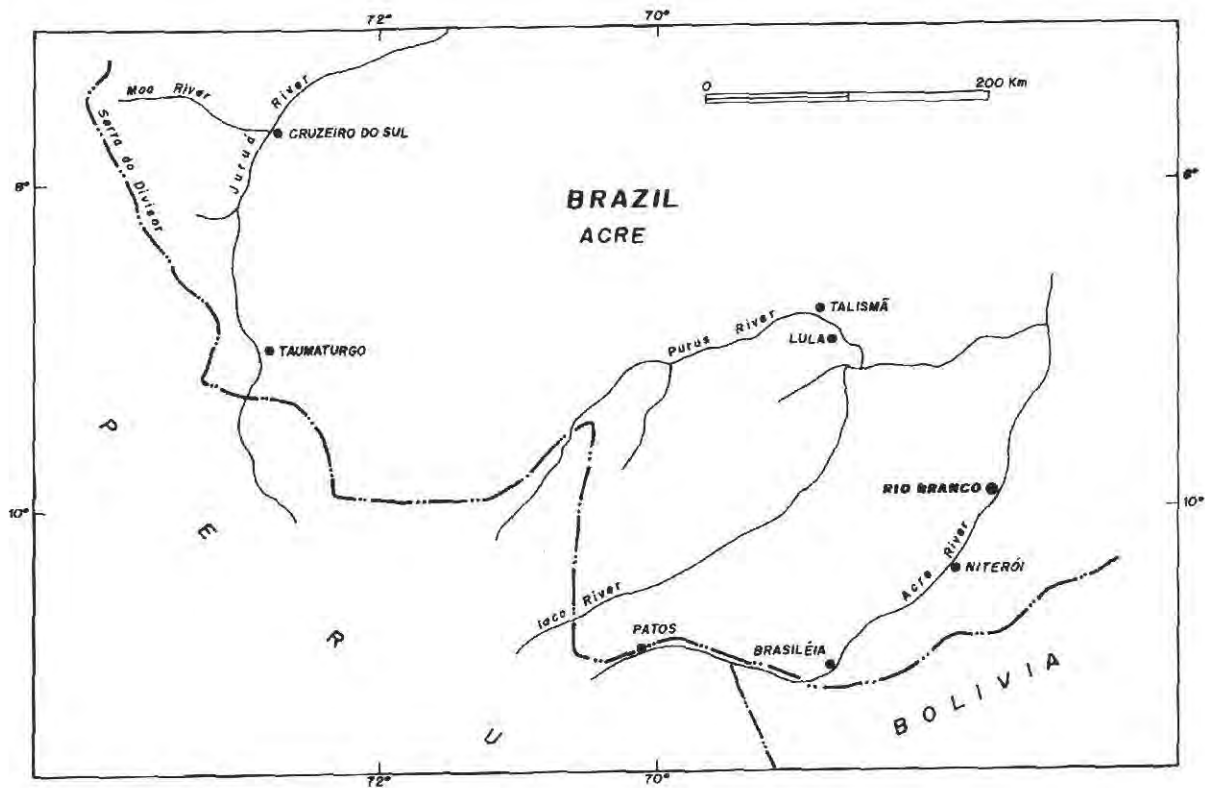


Figure 4. Principal paleontological localities in Southwestern Brazilian Amazonia (Talismã, Lula, Patos, Niterói, Thaumaturgo and Brasileia).

Table 1. Revised list of the Vertebrate Fauna referred to Late Miocene-Pliocene from Southwestern Amazonia. Taxa previously described from Huayquerian-Montehermosan of Argentina are labelled (*).

- CHONDRICHTHYES
 - SELACHII
 - Carcharhinus leucas* (Valenciennes, 1841)
 - BATOIDEA
 - PRISTIDAE
 - Pristis* sp.
 - POTAMOTRYGONIDAE
 - OSTEICHTHYES
 - LEPIDOSIRENIDAE
 - Lepidosiren megalos* Silva Santos, 1987
 - OSTEOGLOSSIDAE
 - DORADIDAE
 - PIMELODIDAE
 - Phractocephalus* sp.
 - CALLICHTHYIDAE
 - CHARACIDAE
 - Colossoma* sp.
 - ACREGOLIATHIDAE
 - Acregoliath rancii* Richter, 1989
 - REPTILIA
 - CROCODYLIA
 - ALLIGATORIDAE
 - Purussaurus brasiliensis* Barbosa Rodrigues, 1892
 - Caiman brevisrostris* Souza Filho, 1987
 - Caiman* nov. sp.
 - CROCODILIDAE
 - Charactosuchus fieldsi* Langston, 1965
 - Charactosuchus* nov. sp.
 - NETTOSUCHIDAE
 - Mourasuchus nativus* (Gasparini, 1985)
 - Mourasuchus amazonensis* Price, 1964
 - Mourasuchus* indet.
 - GAVIALIDAE
 - Gryposuchus jessei* Gürich, 1912
 - Hesperogavialis cruxenti* Bocquentin & Buffetaut, 1981
 - Hesperogavialis* sp.
 - Brasilosuchus mendesi* Souza Filho & Bocquentin, 1989
 - CHELONII
 - PLEURODIRA
 - CHELIDAE
 - Chelus colombiana* Wood, 1976
 - Chelus lewisi* Wood, 1976
 - PODOCNEMIDIDAE
 - Podocnemis bassleri* Williams, 1956
 - Stupendemys* sp.
 - CRYPTODIRA
 - TESTUDINIDAE
 - Chelonoidis* sp.
 - SERPENTES indet.
 - MAMMALIA
 - NOTOUNGULATA
 - TOXODONTIDAE
 - Abothrodon pricei* Paula Couto, 1944
 - Gyrinodon quassus* Hopwood, 1928
 - Gyrinodon* sp.
 - Trigodonops lopesi* (Roxo, 1921)
 - Toxodontherium listai* Ameghino, 1983
 - Trigodon* sp.
 - Plesiotoxodon amazonensis* Paula Couto, 1982
 - Neotrigodon utoquineae* Spillmann, 1949
 - Neotoxodon pascuali* Paula Couto, 1982

cont. Tabela 1.

- Mesenodon juruaensis* Paula Couto, 1982
- Mesotoxodon pricei* Paula Couto, 1982
- Minitoxodon acrensis* Paula Couto, 1982
- EDENTATA
 - TARDIGRADA
 - OROPHODONTIDAE
 - Octodontobradys puruensis* Santos et al., 1993
 - MEGALONYCHIDAE
 - Cf. *Pliomorphus*
 - MEGALONYCHIDAE
 - NOTHROTHERIINAE indet.
 - MYLODONTIDAE
 - Acremylodon campbelli* (Frailey, 1986)
 - Pseudoprepothierium* sp.
 - Cf. *Ranculus**
 - Urumacotherium* sp.
 - CINGULATA
 - GLYPTODONTIDAE
 - Cf. *Plohophorus*
 - Cf. *Paraglyptodon*
 - AMPATHERIIDAE
 - DASYPODIDAE
- RODENTIA
 - NEOEPIBLEMIDAE
 - Neoepiblema horridula** Ameghino, 1889
 - Neoepiblema acrensis* Bocquentin et al, 1989
 - Phoberomys burmeisteri** Ameghino, 1886
 - Phoberomys bordasi* Patterson, 1942
 - Neoepiblema* Cf. *N. ambrosetianus** Ameghino, 1889
 - HYDROCHOERIDAE
 - Kiyutherium orientalis** Francis & Mones, 1965
 - DINOMYIDAE
 - Potamarchus murinus** Burmeister, 1885
 - Telicomys** *amazonensis* Frailey, 1986
 - Tetrastylus** sp.
 - Cf. *Gyriabrus**
 - CAVIDAE
 - CARDIOMYINAE
 - ERETHIZONTIDAE
 - DASYPROCTIDAE
 - ECHIMYIDAE
 - HETEROPSOMYINAE
- ASTRAPOTHERIA
 - ? *Synastrapotherium*
- SIRENIA
 - TRICHECHIDAE
 - ? *Ribodon*
- CETACEA
 - INIIDAE
 - Plicodontinia mourai* Miranda Ribeiro, 1938
 - Cf. *Isquirohynchus**
- LITOPTERNA
 - MACRAUCHENIIDAE
 - Cf. *Cullinia*
 - PROTEROTHERIIDAE
- AVES
 - ANHINGIDAE, *Anhinga* sp.
 - PHORUSRHACIDAE, PHORUSRHACINAE indet.

locality of the region of Southwestern Amazonia, the majority of specimens collected, both in quantity and diversity, are crocodylians and aquatic turtles. According to GASPARINI (1981:195), the living crocodiles "...no son 'termómetros geológicos' pero pueden aportar interesantes datos al conocimiento paleoclimático y paleoambiental de una área y momento determinados. ...Con ciertas limitaciones se puede aplicar el actualismo a aquellas especies y aún géneros con representantes vivientes". The living small sized spectacled *Caiman crocodylus* of the Amazon are river bank or swamp dwellers. They are carnivorous, piscivorous and crustacean eaters (SIOLI, 1984). It is interesting to mention the occurrence at the fossiliferous Lula site of many fragments of crabs. The living black caimans (*Melanosuchus niger*) prefer large, quiet, deep river water and are stagnant pond dwellers. The large size of this species enables to eat a wide variety of animals (LANGSTON, 1965; SIOLI, 1984). Presumably, the most recognizable counterpart of *Melanosuchus niger* in the Southwestern Amazon fossil fauna is the big *Purussaurus brasiliensis*. It could be the largest terrestrial predator that ever lived, having become extinct during the Late Tertiary interchange of terrestrial fauna between the Americas (BOCQUENTIN VILLANUEVA, 1987). The river turtles of the family Pelomedusidae, a family endemic of South America, are presently widely distributed there. According to GASPARINI *et al.* (1986), the Pelomedusidae are good indicators of paleoenvironments:

"...indicam áreas bajas, inundables y cuerpos de agua estables, con abundante vegetación y un clima tropical a subtropical...". Cartilaginous and bony fishes, reptiles and river dolphins inhabited fluvial, lacustre and palustre environments. Like the living aquatic of Amazonia, the Late Miocene-Pliocene fauna was subjected to great fluctuations in water level due to a marked difference in precipitation during the rainy and dry seasons and high-lower flood. We believe that part of this fauna, isolated during the dry seasons in swamps and lakes, would have been able to circulate and mingle with river fauna, during rainy season as a result of changes in the water level. At the present time, many animals are able to avoid unfavorable conditions by horizontal migration. Many families of Amazonian fishes have air-breathing representatives. Many catfish have intestinal respiration. The swim-bladder of the pirarucu (*Arapaima gigas*) is modified to fulfill the function of a lung (SIOLI, 1984). There is no difficulty in comparing the huge *Lepidosiren megalos* from the Miocene and the living South American lungfish *Lepidosiren paradoxa*. The former is clearly related to the latter, differing principally in its great size (SANTOS, 1987). *L. paradoxa* inhabits stagnant ponds of the Amazonian region and is able to aestivate into a burrow during drier times.

Among the mammals, the rodents *Kiyutherium* (Cardiatheriinae) were probably herbivores like the present day capivara. The *Kiyutherium* inhabited areas near bodies of water just like the capivara (PASCUAL & BONDESIO, 1985). Some of the herbivorous Toxodontidae may have had partly amphibious behavior:

The protherothere (litopterns) are mammals of more terrestrial habits and have been reported only from the site Patos (Alto Acre River). These litopterns developed into horse-like types, and were probably browsing forms living along forest edges (ROMER, 1966; COLBERT, 1969). The giant *Synastrapotherium* was a big and heavy astrapothere, clearly adapted for pushing through the forests or wandering over the plains (COLBERT, 1969). Huge ground-sloths evolved during Miocene-Pliocene times, side by side with the Glyptodonts and giant pampatheres. The large-bodied mylodonts surely were not even semi-arboreal. They were, together with the Megatheriinae, essentially grazing forms. The small bodied nothrotheres and megalonychids were probably browsing forms that lived largely on leaves of trees and bushes (KRAGLIEVICH, 1931; SCILLATO YANE, 1977). Occurrences of primates may indicate gallery forest. The present day Platyrrhini rarely descend to the ground in their frequently flooded habitats and they evolved no specialized form of terrestrial locomotion (HERSHKOVITZ, 1977).

Therefore, the environmental necessities of the vertebrates that inhabited this region of Amazonia during the Huayquerian-Montehermosan mammals ages, were grasslands and gallery forests along with rivers, swamps and lakes that were subject to fluctuating seasons.

CONCLUSION

The Cenozoic sediments of the Solimões Formation, widely distributed through Southwestern

Amazonia, were deposited by a megafan complex system, whose headwater was situated in the high Peruvian Andes. Some occurrence of minor fans associated with the main system is probable. The megafan sediments were deposited in response to the Quechua Andean Tectonic phase (Fig. 3).

The paleovertebrate fauna recovered in sediments of the Solimões Formation, at the Purus and Jurua basins, are indicative of Huayquerian and Montehermosan Mammals ages. The faunal assemblage occurs throughout the sedimentary sequence exposed. According to these data, the Solimões Formation has Late Miocene-Pliocene Age in the uppermost levels.

The occurrence of medium and large vertebrates suggest floodplain and lacustrine-paludal environmental conditions associated with rivers, grasslands and gallery forests. These findings are in accordance with the sedimentary megafan model.

Fossil vertebrates are more abundant and diversified in the floodplain-lacustrine sediments, where the remains of bony and cartilaginous fishes, river dolphins, large crocodylians, turtles, rodents, toxodonts, ground-sloths, primates and birds were recovered. Taxonomical differences reported from distinct fossiliferous sites are related to different sub-environments in the main system (high and low energy sedimentary facies).

During the upper Pliocene, the megafan system was stopped by the effects of Andean tectonical movements (Diaguita phase) which generated the

formation of a watershed that separated the basin of Ucayali from the basins of southwestern Brazilian Amazonia rivers. The current fluvial system originated after the "Diaguita Tectonical Phase" during the Quaternary.

The Quaternary sediments are restricted to the fluvial belts of the present drainage systems, in the form of terrace levels.

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