ISOTOPE STUDIES OF FOSSIL SHELLS GIVE INSIGHT IN THE MIOCENE PALEOGEOGRAPHY OF WESTERN AMAZONIA

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INTRODUCTION

The Cenozoic landscapes of South America have been governed by the interaction of its large scale geological units. On the one hand these are the tectonically quiescent cratonic units of the Guyana and Brazilian Shields, that formed the core of the continent from the moment it separated from Africa in the Cretaceous. On the other hand, there is the Andean mountain chain that has been developing since that time, shaping and reshaping South American landforms and ecosystems.

One of the more significant Andean mountain building phases took place in the Early and Middle Miocene, which probably shut down most Pacific influences on South America, and established the wet Atlantic climate system which still dominates the area today. As a result, the Amazon Basin in the Middle and Late Miocene knew widespread wetland environments, the fossiliferous sediments of which are now known as the Pebas Formation. Good chronostratigraphy of the Pebas Fm long remained problematic. Since the 1990's it has become clear from the work of Nutall (1990) and Hoorn et al. (1993, 1994a, 1994b) that the Pebas Fm is of late Early to early Late Miocene age.

PEBAS FM SEDIMENT CHARACTERISTICS

Pebas Fm sediments are remarkably similar over large distances in Western Amazonia, in Peru, Colombia and Brazil. Sediments consist of smectitic clays, immature silts and sands (mostly from Andean sources) and numerous lignite layers. A rich and well preserved fossil fauna occurs throughout the Pebas Fm, which includes teeth and bones of fishes, mammals and reptiles, shells of molluscan bivalves and gastropods as well as microfossils of ostracods and (very rare) foraminifera. Lignites commonly contain complete fossil plants and tree trunks, often with rootzones preserved, testifying of the probable swamp environment in which many of these lignites formed. Grain size analyses of samples from one of the larger outcrop groups in the Pebas Fm (at Los Chorros, Colombia; Fig 1) show distinct coarsening upward cycles (Fig. 2) that we interpret to be a stack of 8 prograding coastal lobes in a shallow fresh water lake. The top of each cycle is formed by a rooted lignite representing the (back) swamp at zero meter water depth. A cycle thickness of between 3 and 7 meters, suggests the lake was not very deep at this location. Wave ripples in these sediments are absent in the bottom part of the cycles and clearly increase in amplitude towards the top, which appears to support our decreasing water depth interpretation from the bottom to the top of the cycle. Similar cycles have been observed in, for example, the outcrops in older strata of the Pebas Fm near Indiana (Peru).

Figure 1: Photograph of part of the Los Chorros outcrop near the town of Puerto Nariño (Colombia) at the Amazon River. 3 persons in the photograph are standing in one of the coarsening upward cycles between two lignites; one lignite is ~2m below their feet and best visible in the right part of the photograph. The second lignite is best visible in the left part of the photograph, ~1m above their heads. The total sequence outcropping at los Chorros in 1998 comprised 8 of these cycles.

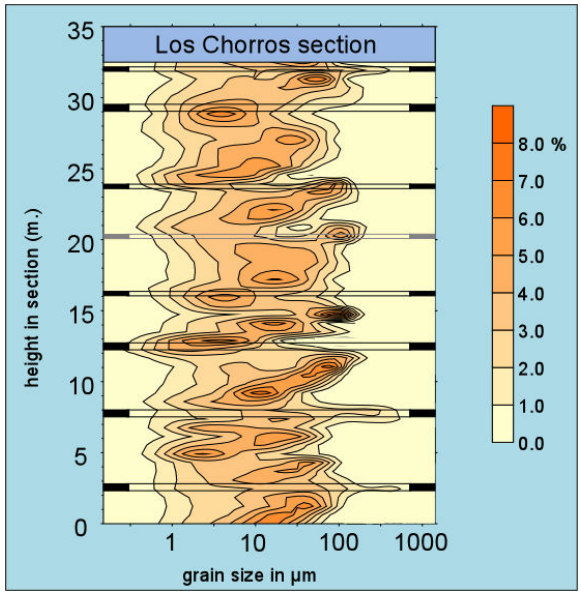

Figure 2: Grain size distribution of the composite section at Los Chorros (Colombia). Over the total height of the section samples were analyzed at 50 cm stratigraphic intervals. Grain size distributions per sample were contoured to produce this representation of shifting grain size distribution with stratigraphic height. Lignite layers are marked by black horizontal bars; The grey bar at 20m in the section is not a lignite but a bone bed with large amounts of plant fossils. Grain size distribution between lignite beds clearly shows coarsening-upwards trends, interpreted to reflect deposition of prograding coastal lobes.Occasional shifts to much finer grain size at ~50cm below the lignites is interpreted to reflect shielded shallow water (lagoonal?) deposition. These fine grained zones generally have a mottled appearance.

SR-ISOTOPE SIGNATURES OF PEBAS FM BIVALVES

Strontium isotope analyses on well-preserved fossil molluscan shells from various outcrops of the Pebas Fm are used as a powerful tool to reconstruct the paleohydrology (i.e. run off patterns) of Western Amazonia. This can be done because fresh water Sr isotope chemistry of rivers from the cratons is very different from Andean rivers, which is recorded in the isotope compositions of modern and fossil shells (Fig 3; Vonhof et al., 2003).

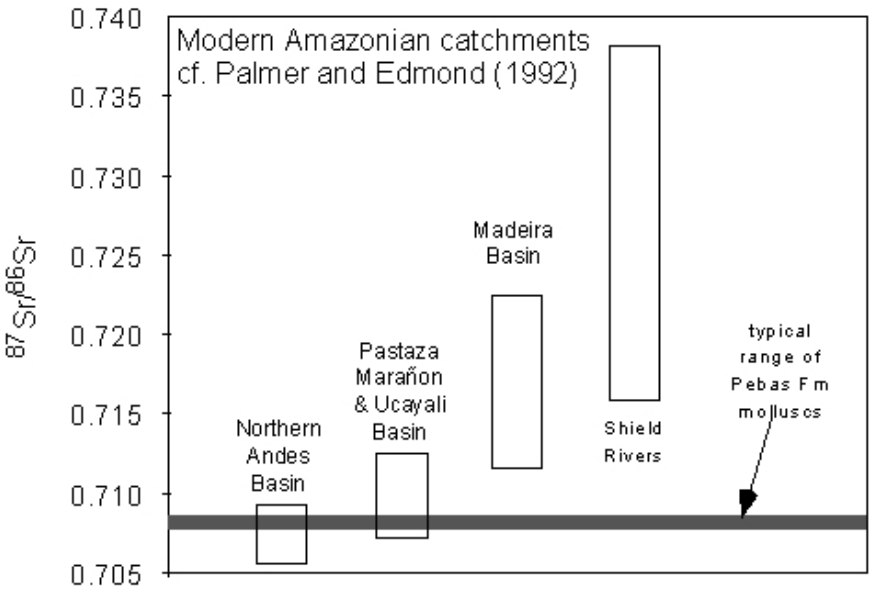

Figure 3: adapted from Vonhof et al. (2003). Vertical bars represent modern riverine $^{87}Sr/^{86}Sr$ ranges of the Amazonian sub-basins (c.f. Palmer and Edmond, 1992). The general isotopic difference between cratonic and Andean catchments is believed to have been similar in the Miocene. Horizontal grey bar indicates the typical $^{87}Sr/^{86}Sr$ range of the majority of Pebas Fm mollusks, which is in accordance with the $^{87}Sr/^{86}Sr$ ratios of the two Andean sub-basins. The large $^{87}Sr/^{86}Sr$ difference between Andean and Cratonic catchments makes this technique a strong diagnostic tool for the reconstruction of past run-off patterns in Western Amazonia.

The Miocene seawater $^{87}Sr/^{86}Sr$ signature is very different from both freshwater sources, so that molluscan $^{87}Sr/^{86}Sr$ ratios can be used to determine paleosalinities as well (Fig 4; cf. Vonhof et al., 2003). Miocene Amazonian molluscs from several well known outcrop groups are shown to have lived dominantly in fresh water from Andean catchments (Fig 4). Through the Pebas Formation stratigraphy, Sr-isotope shifts to higher $^{87}Sr/^{86}Sr$ values are interpreted to reflect tectonic reorganization of catchment areas, or, in some strata in the top of the Pebas Fm, influence of Caribbean Seawater in the heart of the Amazon Basin (Vonhof et al., 1998; Vonhof et al., 2003).

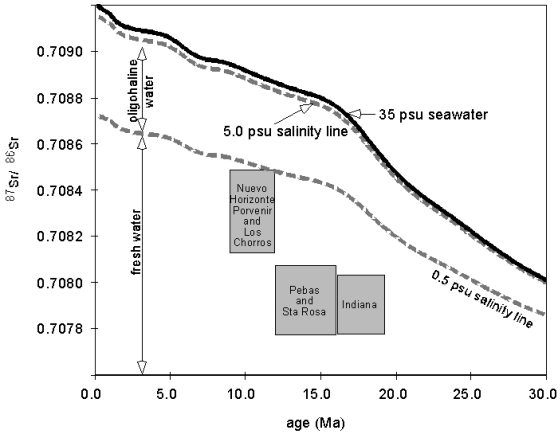

Figure 4: after Vonhof et al. (2003). Molluscan $^{87}Sr/^{86}Sr$ ranges of Pebas Formation outcrops plotted over their full palynostratigraphic range. Superimposed are the paleosalinity fields for this part of the Neogene calculated with the Sr-isotope-based binary mixing model from Vonhof et al. (2003). The black line marked "35 psu seawater" is the marine $^{87}Sr/^{86}Sr$ reference curve for this time interval. This plot shows that Pebas Fm molluscan $^{87}Sr/^{86}Sr$ data all plot in the fresh water field of the model (<0.5 psu salinity).

STABLE ISOTOPE SIGNATURES OF PEBAS FM BIVALVES

With computer operated microsample techniques we have produced very detailed isotope and trace element records of single molluscan shells, allowing us to sample time series of molluscan $CaCO_3$ with a resolution of one week shell growth. These growth incremental oxygen isotope ($\delta^{18}O$) and carbon isotope ($\delta^{13}C$) data from modern and Pebas Fm mollusks show distinct seasonal environmental change recorded in the chemical composition of consecutive growth increments of $CaCO_3$ shells. Observed high amplitude cyclic variation of $\delta^{18}O$ appears to represent wet-dry season cyclicity (Fig 5; Kaandorp et al., 2003).

These data demonstrate that the South American monsoon system was in place already in the late Early Miocene, which appears to be in good agreement with paleogeographic interpretations based on palynological data (Hoorn 1993, 1994a, 1994b, 1995). This early emplacement of the Monsoon climate may have been of key-importance for the development of the rich Amazonian biodiversity, since it created the flood plain biotope in which specialized flora and fauna have evolved.

MARINE OR FRESH WATER ENVIRONMENT?

The combination of molluscan Sr- and stable isotope data strongly suggest that the molluscan bivalves from the Miocene Pebas Fm represent dominantly freshwater conditions. Not only their Sr-isotope signature rules out seawater influence, also the high amplitude of the seasonal $\delta^{18}O$ signal and the relatively low $\delta^{13}C$ values (very similar to modern Amazonian fresh water bivalves) do not occur in seawater. Furthermore, paleoecological.

analyses of Pebas Molluscs also points towards freshwater conditions (Wesselingh et al., 2002). Only in a single outcrop from the top of the Pebas Fm (Buenos Aires outcrop, Colombia; Vonhof et al., 1998) we have found Sr-isotope evidence for brackish water influence, together with a clearly more marine character of the fossil flora and fauna (*Balanus* sp., euryhaline benthic Foraminifera, mangrove pollen). Although this indicates that marine environments were nearby, our data do notcomply with earliersuggested brackish – marine signatures of the Pebas Fm deposits (e.g. Gingras et al 2002; Räsänen et al., 1995)

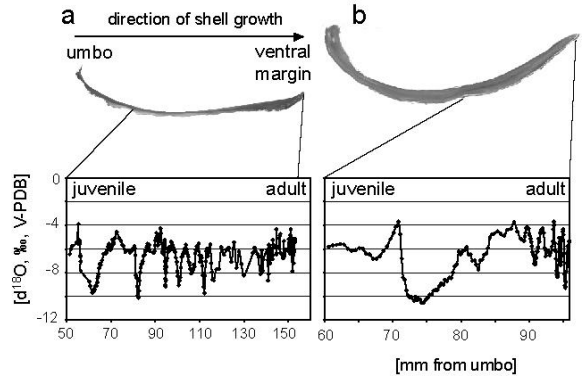

Figure 5a (left panel): Oxygen isotope data through consecutive growth increments of the modern molluscan bivalve *Triplodon corrugatus* from the Itaya River near Iquitos (Peru). Clear cycles in the $\delta^{18}O$ data represent wet-dry season cyclicity in rainwater $\delta^{18}O$; lowest values represent wet season and highest values dry season. This specimen had a lifespan of more than 10 years (Note decreased growth rates in the adult stage). Figure 5b (right panel): Oxygen isotope data through consecutive growth increments of the Pebas Fm molluscan bivalve *Diplodon* aff *longulus* from the Mazan outcrops near Indiana (Peru). Amplitude and absolute values of $\delta^{18}O$ cyclicity for modern and fossil (~17 Ma) specimen is remarkably similar, suggesting that the modern monsoon climate of Western Amazonia was in place already in the late Early Miocene.

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