TECHNICAL COMMENTS

Miocene Deposits in the Amazonian Foreland Basin

In their report, Matti E. Räsänen et al. state that there is a tidal origin for the sedimentary sequences they studied in the western Amazon region (1). Their interpretation of these sequences in the Acre, Brazil, as tidal, on the basis of a relatively small data set, implies the existence of a marine connection between the Caribbean Sea and the southern Atlantic Ocean. Background information and earlier work suggests that this conclusion is not the best explanation of the sediments in Acre. The sedimentary history and paleogeography of this area are more complex than Räsänen et al. or S. David Webb, in his Perspective (2), suggest.

The outcrops studied by Räsänen et al. represent a small (areal) part of the Miocene stratigraphic level. The Solimões Formation (also Pebas Formation), to which these sediments belong, crops out in a vast area of Brazilian, Peruvian, and Colombian Amazonia. This formation is up to 980 meters thick and is part of the infill of several sedimentary basins. In the last 20 years, extensive geological studies (3-10) have shown that the Solimões Formation was mainly formed in a fluvio-lacustrine system of Andean origin, which was periodically affected by marine ingressions. This fluvio-lacustrine system originated during the Middle Miocene as a result of the uplift of the Eastern Cordillera, and was the ancestor of the present Amazon River. Contrary to what Webb suggests (2), "substantial evidence" concerning the marine influence during the Miocene in the area was published (7-10) before the Räsänen et al. report appeared.

The changes in drainage patterns caused by the genesis of the paleo-Amazon River system and the opening of the previously existing east-west-directed fluvial system had a major influence on the development of the ecosystem, the sedimentary history, and the paleogeography of Amazonia (8-11). Subsequently, when establishing a paleogeographic model for the Miocene history of Amazonia, both the fluvial dynamics as well as the tidal influence and marine ingressions should be included. Therefore, Webb's conception of an Amazon seaway as a cause of Amazonian floral and faunal diversity seems limited.

Räsänen et al. consider two possible depositional environments for the sediments they studied (p. 388); fluvial or tidal, and conclude that they are tidal. However, in a tropical fluvial environment such as that in which the Solimões Formation was deposited, periodical flooding of the overbank environment causes alternating mud and sand lenticles such as those described (1). Moreover, the north- to southeast-directed paleocurrents and the sediment composition of Andean origin coincide with the transport direction and the sediment composition reported for the paleo-Amazon River (9). Furthermore, Räsänen et al. relate the timing of the presumed seaway to the Late Serravallian, which is Middle Miocene (12), and not to Late Miocene, as the title of their report suggests. The base of the Late Miocene (~10.4 Ma [million years ago]) represents the largest drop in sea level in the entire Miocene; thus it is not likely that a marine ingress would occur. Moreover, during the Late Serravallian, the maximum sea level rise was estimated at about 50 m, whereas at the base of the Serravallian (~14.2 Ma), the maximum sea level rise was estimated at 150 m (13). If there was a marine ingress it would be thus more understandable if it occurred in this interval. Indeed, there is evidence elsewhere in Amazonia (8-10) of a base Serravallian marine ingress, on the basis of the presence of marine fossils and palynomorphs (14). In addition to this, the connection between the paleo-Amazon and the Atlantic was well established during the Late Miocene. The classic sediments on the Guyana shield and in the Amazon core are evidence of the Amazon-Atlantic connection (15-17). Therefore, a Late Miocene marine connection between the Caribbean and the southern Atlantic at this same time is highly unlikely.

The Late Miocene sediments studied by Räsänen et al. are most likely fluvial, not tidal, and were probably deposited by the ancestral Amazon River. There were marine ingressions in Amazonia during the Early and Middle Miocene, but not in the Late Miocene. Moreover, during the Early and Middle Miocene, the connection between Amazonia and the sea had a more modest character than the seaway postulated by Räsänen et al. Their model might be applicable to the Cretaceous (for which marine deposits are well known to exist in the eastern Andes and in the foreland basins), but it is not suitable for the Miocene paleogeography.

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3. Levantamento de Recursos Naturais (Radianbrazil), Brazilian Ministry of Mining and Energy, Department of Mineral Production, Rio de Janeiro, Brazil, 1977, vols. 13 and 14.
14. Microforaminifera (Protozoa), dinoflagellate cysts (Bryognathium and Spiniferites), mangrove pollen (Rhizophora type), mollusks (Cyma, Corbula and Nassarius), and fish remains (Caranchinidae and Chimaenidae).
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The Rio Acére formations studied by Räsänen et al. (1) are more compatible with a freshwater than with a tidal marine environment.

In addition to the absence of marine mollusks, the fish species Räsänen et al. list from the Rio Acére sediments (with the exception of the bullshark Carcharhinus leucas) are freshwater species typical of modern Amazonian flood plains: Osteoglossidae, freshwater stingrays, three families of freshwater catfishes, and the characid Colossoma (2). The latter genus consists of fruit-eating fishes typical of seasonally inundated forests (3). Carcharhinus leucas is euryhaline and is reported from freshwater habitats world-wide, including the upper Amazon (4). We know of no exclusively marine fish in the Rio Acére sediments.

There is insufficient sedimentological evidence to safely conclude that the channel lithosomes were deposited in a tidal environment. (i) Räsänen et al. assert that the coarsening upward sand and the sharp contact with the overlying mud are diagnostic of a tidal environment and rule out the possibility of their deposition during a fluvial flood event. This is not a valid argument. The flow velocity in a fluvial flood event would follow the same general pattern of increase followed by decrease as seen in tidal floods (5). The observed features are not uniquely indicative of a tidal environment. (ii) The scatter of palaeocurrent indicators within the units at Rio Acére is compatible with the effects of local channel and floodplain geometry within a meandering fluvial system. (iii) The apparent periodicity in sand-mud couplet thickness variation is unconvincing, given the number of maxima and minima in the data and the arbitrary choice of the starting point for the spring-neap cycles. The thickness variations could equally be a result of seasonal fluvial flood cycles. Also, even within a single flood cycle in the modern Amazon, river levels can oscillate by up to 2 meters over a few days; a phenomenon known locally as the "ripipuete." (6). (iv) Other features, such as desiccation cracks and bioturbation, are just as likely to occur in a fluvial setting. Mud flats exposed at low water or by "ripipuete" forms can desiccation cracks within a couple of days.

In sum, from a sedimentological viewpoint, a fluvial origin of the deposits seems equally if not more plausible than a marine-tidal origin. The deciding factor, we believe, is that freshwater fish are present while marine fish and mollusks are not. Both the fish fauna and many of the characteristics of the sediments are strongly reminiscent of the "várzea" flood plains of modern Amazonia. Perhaps a more detailed picture of the habitat could be determined through pollen analysis.

We agree with Webb (7) that the putative Amazonian sea requires more precise dating, Räsänen et al. state that the marine incursion occurs at the latest Serravallian highstand of global sea level shown on the chart by Haq et al. (8). The chart actually shows a pronounced low point at 10 Ma. The Miocene highstand is shown at approximately 15 Ma (Langhian). These conflicting dates and the still contentious nature of the chart by Haq et al. make it necessary to consider other mechanisms. It is possible that flooding of the South American continent to form the Amazonian sea was a result of tectonic mechanisms, such as lithospheric loading by the Andean orogenic wedge, or dynamic topography related to the Andean subduction, or both. More work is required to resolve the temporal and spatial boundaries of the Miocene Amazonian sea.

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Because the Pecasian and Paranáns (that is Paranaense) seas (Fig. 1) ingressed to large structural basins, the dynamic depositional history of these basins should be compared. Similarities of the basins include direct (though distal) connections with the marine realm, epicontinental settings, and restricted marine conditions in parts of both basins. Differences include that the Pecasian had a restricted connection with the Caribbean and a large watershed and was dominated by an estuarine-influenced setting, whereas the Paranáns had a broad connection with the South Atlantic and a smaller watershed and (south of Bolivia) was an epicontinental sea.

The sedimentary features used by Räsänen et al. (1) to establish estuarine conditions in their study area are rhythmites. Tidal rhythmites are found in a variety of modern low salinity or freshwater settings in contact with coastal waters which, with few exceptions, have tidal ranges of about 3 m (2). Under certain conditions, tidal energies can propagate hundreds of kilometers landward into freshwater settings. For this reason rhythms cannot be used to infer salinity.

Räsänen et al. (1) list four fish groups from the Solimões Formation as indicators of a marine setting in the southern part of the Pecasian Sea, but a detailed comparative description of these fossils is not referenced, and all other Miocene fish faunas from inland northern South America indicate freshwater habitats (3).

Webb (4) proposes in his Perspective that some modern fishes and mammals of South American rivers with marine affinities owe their origin to entrapment upon regression of seas. A proximate marine ancestry has long been inferred for several Neotropical fish and mammal species or small clades, but there is no compelling evidence that the ancestors of these groups.
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Editor's Summary

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