Frontiers in Earth Science

TYPE Opinion
PUBLISHED 10 July 2023
DOI 10.3389/feart.2023.1203667

OPEN ACCESS

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RECEIVED 11 April 2023
ACCEPTED 27 June 2023
PUBLISHED 10 July 2023

CITATION
Rivas JA (2023), The missing river.
Front. Earth Sci. 11:1203667.
doi: 10.3389/feart.2023.1203667

The missing river

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KEYWORDS

paleo-ecology, paleo-amazon, large rivers, marine incursion, marine derived lineages, pebas system, wetlands, *Eunectes*

Introduction

South America is the most diverse landmass in the world with highest diversity of species of multiple taxa of any other continent (Haffer, 2008; Rull, 2008; Pimm et al., 2014; Claramunt and Cracraft, 2015). South America's landscape has been very dynamic since the Cenozoic with abundant changes of major rivers, and developments of mega wetlands occupying substantial extensions of the existing continental areas (Albert et al., 2018). The flooding dynamic in the continent since the Andes started to raise, likely is responsible in large part for the high diversity of the continent (Ribas et al., 2007; Ribas et al.,2012; Rivas, 2020). The paleo-dynamics of South America landscape has been an area of interest in many very good recent studies reconstructing it. Unfortunately, on the interest of providing strong evidence-based reconstruction, some studies have proposed scenarios that fail to consider some of the basic laws of physics. In this contribution I review the literature of geological events and points out how some very good work that have been done recently adolesces consideration of some of the basic laws of physics, and often provides scenarios or explanation that are not the most parsimonious, or the most likely.

The lack of a river

When the South America separated from Gondwana it drained to the west by a major river located very much where the current Amazon is but running into the pacific (Lundberg et al., 1998). This river drained the same area that is now drained by the Amazon and Orinoco rivers. Currently these rivers, have a combined mean discharge of 246,600 (m^3/s^{-1}) (Latrubesse, 2015). Since this was a warmer period than the current one with no icecaps (Zachos et al., 2001) it is reasonable to assume that there was a lot more water circulating in the planet so this river would have been a true colossus. As South America moved west it collided with the Nazca plate initiating the rise of the Andes that ended up blocking the west drainage of the river some 30 mya (Lundberg et al., 1998). Blocking the flow of this mighty river with a 7,000 km mountain range would have produced the general flooding of the western part of the continent.

Early reconstructions of South America, showed the hypothetical location of this river and the consequences of the rise of the Andes (Lundberg et al., 1998). However, more recent reconstruction, while more advanced in data sources, fail to include this river (Hoorn et al., 2010b; Hoorn et al., 2022). This is quite an omission because the data shows that the continent was covered by rain forest throughout the Cenozoic (Colinvaux et al., 2000; Colinvaux and De Oliveira, 2002; Bush and Oliveira, 2006). A continent the size of South America receiving anywhere the amount of precipitation needed to sustain a rainforest (2,500–4,000 mm/year) (Holdridge, 1967) had to be drained by a very large river. Assuming that it did not have a river, defies the law of conservation of matter, or first law of thermodynamic since matter and energy are two sides of the same coin.

It is likely that the failure to include this large river has to do with the lack of an alluvial fan in the Pacific shore of South America. A river of this size would have produced a substantial alluvial fan in the ocean where it emptied its waters. Today the alluvial fan in the amazon stretches for 1200 KM from the shore (Pirmez et al., 1997; Mertes and Dunne, 2007). It stands to reason that this river would have had a comparable alluvial fan. What these argument fails to consider is that the Nazca plate, moves toward South America, at a speed of 68 mm/year (Norabuena et al., 1998) So, in the last 30 my, since the river stopped flowing, Nazca has moved 2040 km under South America which would have destroyed any alluvia fan that river had deposited. So the lack of the alluvial fan does not constitute evidence that there was not a river.

A mysterious mega-wetland

The failure to consider there that the Andes blocked a very large river has created controversies that could have been avoided from the beginning. One of the big questions about Pebas System was the source of its waters. It has been proposed that the weight of the Andes deformed the craton producing a depression below sea level that flooded the continent (Hoorn et al., 2010a). However, all the studies of the Pebas system describe it as a long-lived lacustrine or fluvial system of predominantly freshwater lakes and swamps that might have had episodic spots that had, at a maximum, short lived oligohaline patches (Wesselingh et al., 2002). Studies of stable isotopes (O/C and Sr) of ostracods and foraminifera provided compelling evidence that the water of the Pebas system was indeed fresh water (Wesselingh et al., 2002; Wesselingh et al., 2006; Vonhof et al., 2003), which mild salinity could derive from underwater aquifers (Gross and Piller, 2020). This explanation was dismissed in a later paper arguing the amount of water of Pebas was too large and it required a very large underwater aquifer to provide such amount of water. But no alternative explanation was provided other than the debunked possibility of ocean water (da Silva-Caminha et al., 2020).

What is missing in this debate is that fact that in South America's Cenozoic water, freshwater in particular, was not in short supply. Realizing that there was a mighty river that was dammed solves the problem in compliance with all the sedimentological and fossil evidence. The point that is missing in the debate is the realization that that Pebas was not a mysterious system that developed out of nowhere but just a big swamp created by a big dam (Rivas, 2020).

Discussion

Marine incursions in South America has been a dominant topic of discussion in the paleo-history of the continent; since as early as Darwin's observation of marine sea shells in the top of the Andes (Darwin, 1845). Data suggest that there were regular, but short lived, marine incursions constrained by forest and continental ecosystems (Uba et al., 2009). Despite numerous studies reporting marine incursions, there is considerable debate in how and where these marine incursions took place (Wesselingh et al., 2002; Wesselingh et al., 2006; Vonhof et al., 2003), or if they even took place at all (Díaz de Gamero, 1996; Vonhof et al., 2003; Gross et al., 2016; Gross and Piller, 2020; Rivas, 2020).

Part of the problem with these elusive marine incursions is that there has never been any evidence of a marine incursion *per se*. All that has been reported is *marine conditions*, based on presence of Marine Derived Lineages. If we go back to the basic scientific principle of parsimony, we would seek the simplest explanation for the data at hand. Marine incursions are often not the most parsimonious explanation or the one that better explains the data.

For starters, a true marine incursion would have brought a full assortment of marine organism, including stenohaline organism. However the data only shows the presence of Eurohaline organism such as Mangrove, ostracodes, other mollusks, foraminiferams, and Eurohaline fishes among others (Wesselingh et al., 2002; Wesselingh et al., 2006; Hoorn, 2006; Lundberg et al., 2010). All of these need only a very small level of salinity and are quite capable of dispersion through fresh water corridors connecting the Amazon with the Caribean (Gross and Piller, 2020).

An alternative, and simpler, explanation is that the water of the Big Dam could become oligohaline and back by local or regional weather changes (Furquim et al., 2010; Sepulchre et al., 2010; Rivas, 2020). If the contribution of rain from the Andes was very strong, it would bring eutrophic waters (Hoorn et al., 2022) that would have become oligo haline very quickly (Furquim et al., 2010). The development of marine conditions from freshwater bodies is far more parsimonious to explain the recurring mild marine conditions than continent wide flooding events such as marine incursion. In fact, the presence of haline environments today in Mato Grosso do Sul (Brazil), thousands of kilometers from the ocean shore (Furquim et al., 2010), provides irrefutable evidence that haline conditions are possible without marine influence.

Furthermore, one has to wonder if marine incursions were even possible. Díaz de Gamero (1996) provided compelling evidence that marine incursions from the Caribbean were not possible because of the flow of the big river which would have prevented the ocean from coming into the continent. Vonhof et al. (2003) points out this very phenomenon in Lake Maracaibo, Venezuela, pointing out that the southern part of the lake is fresh water despite having a direct connection to the ocean because the volume of its tributaries provide hydrostatic pressure to meet the ocean's. This would have been true with the waters of the Paleo-Orinoco/Amazon. The water already present in the continent would have prevented the ocean from coming in (Díaz de Gamero, 1996; Archer, 2005; Rivas, 2020).

Taking into consideration the continent was drained by a large river that was dammed by the Andes is important because of its consequences on the biodiversity of the continent. The flooding of the continent would have been a very slow process. Not only because it was lead by a geological process, such as the rise of the Andes, but also because of the flat and width of the basin. Every cm of depth that the river lost would have resulted in an imperceptible increase of the water level in its flood plains as its water spread over its wide basin. The very slow flooding perhaps did not produce a layer the sedimentological record we can recognize as a smoking gun of a flood but it would have produced a biological finger print on the diversity of species. The long time that took this change to occur would have given opportunity for natural selection to produce aquatic lineages adapted to the developing new conditions.

Looking at reptiles, we see the appearance of *Chelus*, an aquatic turtle specializing in small forest creeks around 70 mya (Wang et al., 2012). Also around 60 mya South American side-necked turtles (Podocnemidoidae) diversified into new lineages (Ferreira et al., 2018). At this time too, 60 mya, Alligatorids split into two lineages (Roberto et al., 2020), a larger one, Caiman that prefers rivers and lagoons, and *Paleosuchus* spp that is a smaller forest specialist living in small creeks inside the forest (Villamarín et al., 2021). Approximately 58 mya *Titanoboa* an aquatic lineages of snakes, split from terrestrial lineages (Head, 2009) and between 50–40 mya *Eunectes*, a group of aquatic snakes, diversifies from its terrestrial ancestors (Rivas et al. in prep). Also 40–35 mya Teidae a group of terrestrial lizards, diversifies producing two aquatic linages, *Crocodilurus* and *Dracaena* (Giugliano et al., 2007). Approximately, 40 mya, the caiman lineage had another split giving raise to the larger genus, *Melanosuchus*, which occupies large water bodies (Roberto et al., 2020). Last, approximately 49 mya we see the appearance of a strictly arboreal lineage of boids, *Corallus* (Colston et al., 2013). Specialization to living on the trees could be an evolutionary response of a flooded understory that was unavailable. While I have mentions only reptiles, we would have similar trend if we looked at Amphibians (Feng et al., 2017). Taken together, this scenario speaks of a generalized increase of habitat for aquatic lineages throughout the continent and supports the notion that the continent was flooding very slowly, consistent with the geological damming of a big river.

Ignoring that the continent had to have a big river, that was dammed by the Andes has created a lot of confusion and debate about the source of water of Pebas and perpetuated the believe in marine incursions, despite of abundant evidence to the contrary. Understanding that the discharge of the big river would have made marine incursions impossible help to put within context biogeographic processes in the continent. Applying basic principles of conservation of matter and seeking the most parsimonious explanations to the data would put most of these debates to rest.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Acknowledgments

I thank P. Roa-Morales for seeding my mind with questions about South America paleohistory. I thank NMHU ORSP for publication funding.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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