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Provenance of sands from the confluence of the Amazon and Madeira rivers based on detrital heavy minerals and luminescence of quartz and feldspar

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ABSTRACT

Source-to-sink systems are poorly known in tropical rivers. For the Amazonian rivers, the majority of the provenance studies remain focused on the suspended load, implying a poor understanding of the processes governing production and distribution of sands. In this study, we perform heavy mineral and optically stimulated luminescence (OSL) analysis to cover the entire spectrum (heavy and light minerals fraction) of 29 sand samples of the Lower Madeira river region (Amazon and Madeira rivers), of which the main goal was to find provenance indicators specific to these rivers. Despite the tropical humid climate, the sands of the Amazon and Lower Madeira rivers are rich in unstable heavy minerals as augite, hypersthene, green hornblende and andalusite. The Madeira river is highlighted by its higher content of andalusite, with source attributed to the Amazon Craton (medium-to-high grade metamorphic rocks), while the Amazon river, upstream of the Madeira river mouth, has a signature of augite and hypersthene, that suggests an Andean provenance (volcanic rocks). Sands from the Madeira river can be tracked in the Amazon river by the increasing concentration in andalusite. OSL analysis of the light minerals fraction was used as an index of feldspar concentration and sedimentary history of quartz grains. Lower feldspar concentration and quartz grains with longer sedimentary history (higher OSL sensitivity) also point to a major contribution of cratonic sources for the sands in the Madeira river. While the sands from the Lower Madeira would be mainly supplied by cratonic rocks, previous work recognised that suspended sediments (silt and clay) are derived from Andean rocks. Therefore, we interpret a decoupling between the sources of sand and mud (silt and clay) under transport in the Madeira river. Andean sands (rich in augite and hypersthene) would be trapped in the foreland zones of the Beni and Mamoré tributaries. In the Amazon river sands, the low OSL sensitivity of the quartz, higher content of feldspar and unstable heavy mineral assemblage dominated by augite and hypersthene suggest both a fast transport from Andean sources with fine sediment bypass over foreland areas.

1. Introduction

There is great debate about the evolution of the Amazonian river system, especially with regard to its onset to a transcontinental west to east drainage (Campbell et al., 2006; Figueiredo et al., 2009; Shephard et al., 2010; Sacek, 2014). Provenance questions are in the core of this debate because Andean sediments reaching the present Amazon river mouth could be the fingerprint for the development of a transcontinental river. Using sediment characteristics to deduce changes in a river system requires the understanding of factors controlling the production (source), transport and accumulation (sink) of sediments. Under this approach, sediments and sedimentary rocks are products of a source-to-sink system (Allen and Allen, 2005) operating on different temporal and spatial scales. Determining sediment provenance and reworking (i.e., number of burial-erosion cycles during sediment transport) can be considered two fundamental tasks to describe the Amazonian river system under a source-to-sink perspective (Blatt, 1967; Pettijohn et al., 1972; Pettijohn, 1975; Everett and Rye, 2003; Allen, 2008; Carter et al., 2010; Marsaglia et al., 2010; Wolinsky et al., 2010).

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Sediment provenance and reworking are mutually related and are essential to define proxies able to record spatial and temporal variations in production, transport and deposition of sediments.

Large rivers from tropical settings such as the Amazon are part of the major active source-to-sink systems around the world. The Amazon watershed and its subaqueous fan represent the biggest active source-to-sink system in terms of sediment load in South America (Latrubesse et al., 2005). The Amazon river accounts for more than 70% of the sediment load reaching the South Atlantic ocean (Meade et al., 1985). In this context, the Madeira river stands out as one of the major tributaries of the Amazon river, from which approximately 2.76×10^9 tonnes/year of suspended sedimentary load is delivered to the Amazon river (Meade et al., 1985; ANA, 2014). The Madeira river drains terrains with distinct elevation, climate, vegetation cover and land use and it supplies around 15% of the Amazon river waters (Latrubesse et al., 2005). Factors such as catchment size and intense channel migration dynamics (i.e., meandering, avulsion) make large rivers subjected to complex changes in sediment sources, storage and reworking through time (i.e., Stouthamer and Berendsen, 2001; Slingerland and Smith, 2004). Temporary sediment storage in stabilised bars and floodplains can promote mixing of sediments from different sources and produced under distinct climate or tectonic conditions. Sedimentary reworking within the fluvial system can occur, for example, by means of erosion of ancient bars and abandoned meanders. In large rivers, the control in sediment mixing and reworking goes beyond the action of autocyclic phenomena of meandering or channel avulsion. Allocyclic factors, such as tectonics and climate changes, are also important, especially on millennial timespans (Stouthamer and Berendsen, 2007). Therefore, the study of sediment provenance, mixing and reworking in large tropical rivers is necessary to understand how sediment properties may record allocyclic changes. This is still poorly understood for Amazonian rivers, especially with regard to the sand supply. Most previous studies of the Amazonian rivers focus on the suspended load using geochemical approaches (Martinelli et al., 1993; Meade, 1994; Filizola, 1999; Bouchez et al., 2011; Govin et al., 2014). This paper investigates provenance and sedimentary reworking of sands of the Madeira river supplied to the Amazon river. For this, we performed heavy mineral analysis (Morton and Hallsworth, 1994, 1999) combined with optically stimulated luminescence (OSL) sensitivity (Pietsch et al., 2008; Sawakuchi et al., 2011, 2012) for provenance and sediment reworking analysis of sand from bars and the bottom channel in the confluence of the Madeira and Amazon rivers.

2. Physiography, geology and fluvial hydrology of the Amazon and Madeira rivers

The Amazon river, in its portion upstream of the Madeira river mouth, is formed by the coalescence of numerous drainages sourced in the Andean region of Peru, Ecuador and Colombia and flowing to the Amazonian plains (mainly in Brazil) (Meade et al., 1985), covering an area of about 3 million km^2 (Fig. 1). In turn, the Madeira river has a drainage area of nearly 1.4 million km^2, being one of the major tributaries of the Amazon river (Latrubesse et al., 2005). The upstream waters of the Madeira river are located in the Bolivian Andes, and it is formed by the coalescence between Beni and Mamoré rivers on the Bolivia-Brazil border (Hoorn, 1994; Hoorn et al., 1995).

The Amazon and Madeira rivers' watersheds present a wide variation of climatic and geomorphologic features. The climate varies from semi-arid (as in the La Paz river, mean precipitation of 200 mm/year) to hyper-humid tropical (as in the Yungas valleys, mean precipitation of 6000 mm/year) and common tropical (mainly in the Amazonian plains, precipitation of 1700–2000 mm/year) (Guyot et al., 1999; Latrubesse et al., 2005; Silva et al., 2011). The general altitudes vary from 120 to 6500 m (altitudes of the catchment areas of the Madeira river ranges 3000–4000 m; Guyot et al., 1999), locally exerting strong influence in the heavy orographic rains at the foot of the Andean Cordillera (Latrubesse et al., 2005). The precipitation is heavily seasonal, with dry and wet seasons controlled by the migration of the Intertropical Convergence Zone (ITCZ) (Vera et al., 2006; Grimm, 2011). The rainy season starts at the ITCZ moves southward at the end of Spring, with

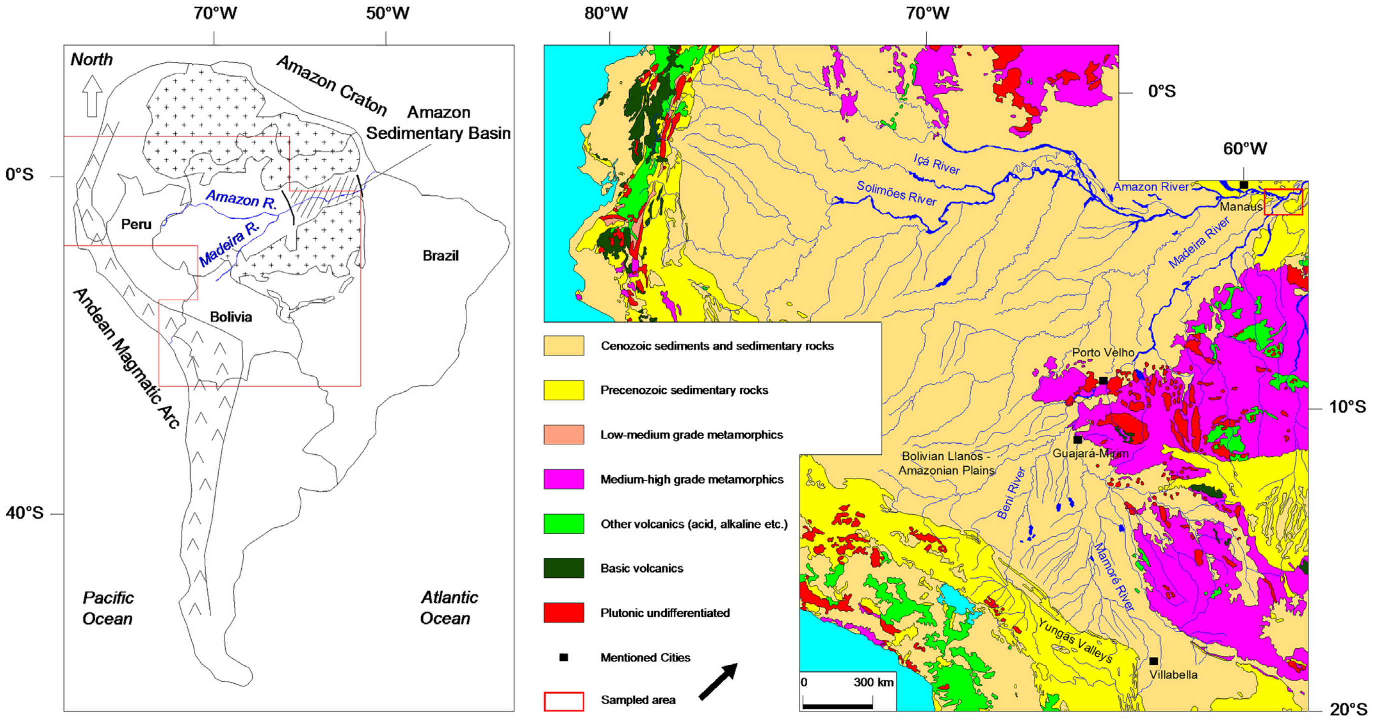

Fig. 1. Location and geology of the study region. Adapted from Schobbenhaus and Bellizia (2001).