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Is the current stress state in the Central Amazonia caused by surface water loading?

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ABSTRACT

We present new fault data for the region of the Manaus, Central Amazonia, Brazil. Field measurements concentrate on the Miocene–Holocene sedimentary deposits exposed on the Amazonas River Basin, in order to investigate the development of this region in this time-interval. Two faulting events are distinguished since the Miocene. The oldest one is related to NW–SE extension during Miocene times and associated with paleoseismicity, while the younger is associated with NE–SW extension direction and seems to persist today. These two deformational events may be thereby considered Neotectonic. Moreover, the second extensional pulse with NE–SW orientation can be explained by the surface hydrological loading, which induces the Central Amazonia flexural subsidence and may promote extensional stresses in the upper crust.

1. Introduction

Central Amazonia is located within the Amazonas River basin, which occupies approximately 6.1 million km^2 and yearly discharge 5.5×10^9 m^3 year^{-1} of water (Guyot et al., 2007). At Manaus, located in this region, the Solimões and Negro rivers combine to form the Amazonas River (Fig. 1a). A GPS station in Manaus, near this confluence, manifests an annual cycle of vertical displacement of 100 mm (Guimarães et al., 2012), which is developed within ~200 km of the GPS station (Bevis et al., 2005). This vertical ground displacement is strongly anticorrelated with the local stage height of the Amazonas and suggests a purely elastic response to changes in the weight of a flowing river system (Bevis et al., 2005).

Studies in other parts of the world have examined the effect of the vertical surface deformation in response to water load on stress changes (e.g. Luttrell et al., 2007; Brothers et al., 2011). This response to hydrologic level changes occurs either by direct response of elastic stress following loading or by delayed increase of pore pressure and decrease of effective normal stress (Simpson et al., 1988; Luttrell et al., 2007).

In this context, the present-day SHmax orientation in Central Amazonia ranges from NW–SE to N–S (Assumpção, 1992). Apparently, this SHmax occurs throughout the crust, as suggested by the analysis of well bore break-outs (Lima et al., 1997) and focal mechanism solutions of two earthquakes (Assumpção and Suárez, 1988), which occurred in 1963 and 1983, with magnitudes of 5.1 and 5.5 mb, at depths of 45 and 23 km, respectively (Fig. 1a). This compressional regime is presumed to be a consequence of the flexural effect caused by a dense mass in the lower crust beneath the Amazonas Basin Paleozoic Rift (Zoback and Richardson, 1996) and/or tectonic forces acting on South-American plate boundaries (Assumpção and Suárez, 1988).

Although SHmax data estimated from two earthquakes and borehole break-outs in the region are consistent throughout the crust, this is not true for the stress regime. Indeed, while the earthquake data indicate the prevalence of a compressional regime (Assumpção and Suárez, 1988), here we show that data from normal faults collected in outcrops of sedimentary deposits from Miocene to Holocene age in the Manaus neighborhood (Fig. 1b)

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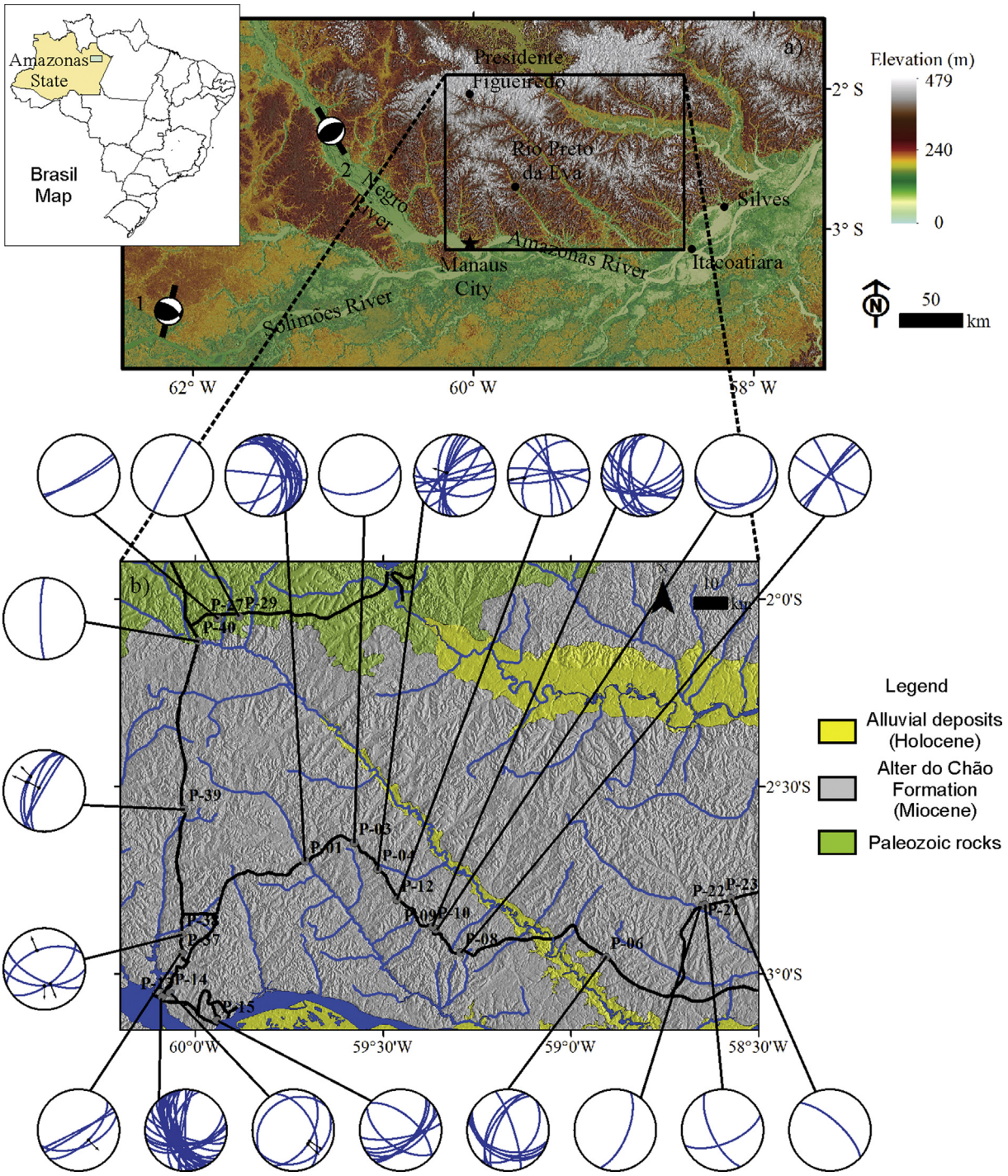

Fig. 1. Study area location map of Central Amazonia (northern Brazil). a. Shaded relief map derived from the Shuttle Radar Topography Mission (SRTM) 90 m data, where 1 and 2 refer to the focal mechanism and orientation of SHmax for the 1983 and 1963 earthquakes (Assumpção and Suárez, 1988), respectively. b. Study area geological map (CPRM, 2004) and equal area/lower hemisphere stereogram plots of the field measured fault planes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

characterize two extensional regimes with subvertical σ_1. The first regime with NE–SW SHmax (σ_2 in this case) was active during Miocene times, while the second shows NW–SE SHmax (also σ_2) and is apparently active today. Thus, in contrast to compressional regime, the current extensional regime may be due to water loading that would be able to change the σ_1 direction from NW–SE to vertical and hence cause extension in the upper crust.

2. Background

In the investigated area (Fig. 1b), the sedimentary deposits of the Amazonas Basin belong to the Cretaceous Alter do Chão Formation, which are overlain by the Miocene Novo Remanso Formation and, along the main river valleys, by Pleistocene to Holocene alluvial deposits (Cunha et al., 2007). However, a recent discussion