Geomorphology 204 (2014) 502–509

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The origin of oriented lakes: Evidence from the Bolivian Amazon

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ARTICLE INFO

Article history:
Received 7 March 2013
Received in revised form 22 August 2013
Accepted 24 August 2013
Available online 31 August 2013

Keywords:
Oriented lakes
Rectangular lakes
Llanos de Moxos
Bolivian Amazon

ABSTRACT

The presence of hundreds of rectangular and oriented lakes is one of the most striking characteristics of the Llanos de Moxos (LM) landscape in the Bolivian Amazon. Oriented lakes also occur in the Arctic coastal plains of Russia, Alaska and Canada and along the Atlantic Coastal Plain from northeast Florida to southeast New Jersey and along the coast of northeast Brazil. Many different mechanisms have been proposed for their formation. In the LM, Plafker's (1964) tectonic model, in which subsidence results from the propagation of bedrock faults through the foreland sediments, is the most accepted. However, this model has not been verified. Here, we present new results from stratigraphic transects across the borders of three rectangular and oriented lakes in the LM. A paleosol buried under mid-Holocene sediments is used as a stratigraphic marker to assess the vertical displacement of sediments on both sides of the alleged faults. Our results show that there is no vertical displacement and, therefore, that Plafker's model can be ruled out. We suggest that, among all the proposed mechanisms behind lake formation, the combined action of wind and waves is the most likely. The evidence from the LM provides new hints for the formation of oriented lakes worldwide.

1. Introduction

Geometric and oriented lakes are intriguing geomorphological features that are still poorly understood. They occur along the coast of northeast Brazil (Bezerra et al., 2001) in the Arctic coastal plains of Russia, Alaska and Canada; in the Atlantic coastlands of Maryland, Georgia and the Carolinas, where the well-known Carolina Bays are found; and in the Llanos de Moxos (LM), in north-eastern Bolivia (Burn, 2004). The LM (Fig. 1) is a seasonally inundated savannah landscape (Hamilton et al., 2004; Mayle et al., 2007) interspersed with several hundred perennial lakes (Plafker, 1964; Hanagarth, 1993; Dumont and Fournier, 1994). Many of these lakes have been noted for their rectangular shape and markedly uniform SW–NE orientation. Although they vary considerably in size, they are characterized by being very shallow, usually less than two meters deep, and having a flat bottom. Many different mechanisms have been proposed for their formation. These potential mechanisms fall into two categories: i) those that involve one mechanism explaining both the formation of the lakes and their morphological characteristics, and ii) those that invoke a two-step process, with the first step forming the lake basins and the second accounting for their shape and orientation.

The first group of hypotheses include the following: 1) tectonic movements resulting from the propagation of bedrock faults through the foreland sediments (Plafker, 1964, 1974; Allenby, 1988); 2) water erosion caused by large-scale flooding in the Llanos de Moxos after Andean deglaciation (Campbell et al., 1985); 3) wind deflation during the dry Last Glacial Maximum (LGM) (Clapperton, 1993); and 4) anthropogenic origin (Barba, 2003; Belmonte and Barba, 2011) in line with other well-documented pre-Columbian earthworks (see Erickson, 2006; Mann, 2008; Lombardo et al., 2011). A two-step model was proposed by Dumont and Fournier (1994) suggesting that the lakes developed in mid- to late Holocene deflation areas and were later shaped by waves. Similarly, Langstroth (1996) suggested that deflation during dry periods may have initiated the formation of the lakes and that the shorelines and lake beds were later modified by wave action during wet phases.

The wide range of hypotheses about the processes behind lake formation is a function of the lack of field data and limited studies, which, so far, have been largely based on the interpretation of aerial photography or first-generation Landsat imagery.

However, the most accepted hypothesis to date is that of tectonic control, as proposed by Plafker almost 50 years ago (Plafker, 1964; Price, 1968; Plafker, 1974; Allenby, 1988; Gonzales and Aydin, 2008). A small cluster of oriented lakes in the northeast of Brazil which resemble the LM lakes has also been interpreted as resulting from tectonic control (Bezerra et al., 2001). According to Plafker, the lakes' rectangular shape results from the propagation of bedrock fractures through unconsolidated sediments (Fig. 2). Plafker suggested that the lakes are the projection on the surface of subsiding (Fig. 2A) or vibrating (Fig. 2B) basement blocks. The basement blocks would be the result of a system of orthogonal faults with a northeast–southwest and a northwest–southeast orientation. This system of faults would be the result of the re-activation of old fractures linked to those outcropping in the Brazilian Shield. The major northwest–southeast and northeast–southwest trending lineament sets are interpreted to be the expression of 'tension' fractures.

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http://dx.doi.org/10.1016/j.geomorph.2013.08.029

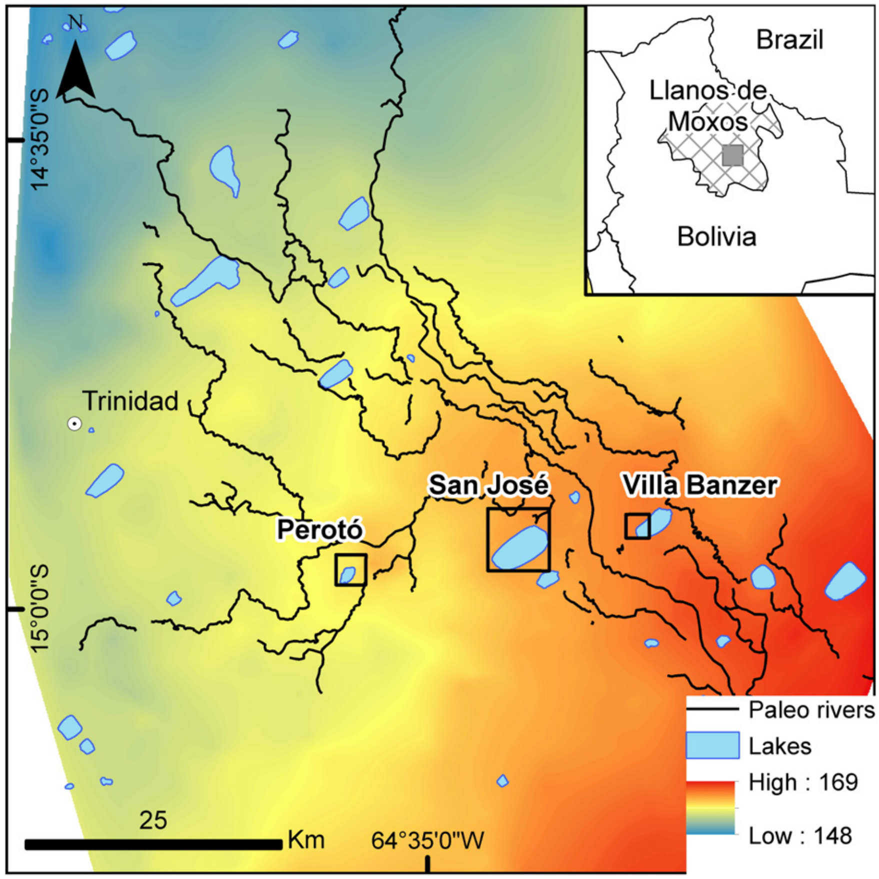

Fig. 1. Digital Elevation Model of the southeastern part of the LM, including the mid-Holocene Río Grande paleo-rivers and location of the three lakes studied (detailed in Fig. 5.).

The debate about the origins of rectangular and oriented lakes is not confined to the LM. While there is a general consensus that oriented lakes in the Arctic coastal plains initially form as thermokarst lakes (French, 2007), why they share the same orientation is a highly debated question (Hinkel, 2006; Pelletier, 2006). The most accepted explanation for their similar orientation is that wind induces a differential erosion

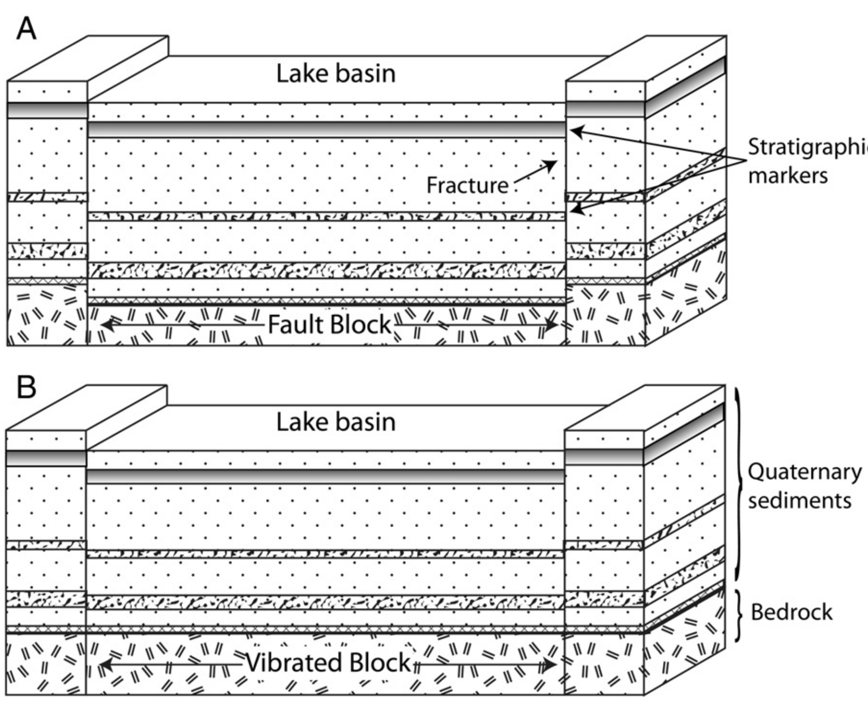

Fig. 2. The sinking/vibrating basement blocks model. Bedrock faults propagate through the overlying Quaternary sediments and create oriented and rectangular lake basins in the surface. In A the subsidence is due to a sinking basement block; in B the subsidence is due to a vibrating basement block. Regardless of the underlying cause, in both cases the effect on the surface is the same. Adapted from Plafker (1964).