Geomorphology 230 (2015) 1–12

Contents lists available at ScienceDirect

Geomorphology

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

Geomorphology, internal structure and evolution of alluvial fans at Motozintla, Chiapas, Mexico

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ARTICLE INFO

Article history:
Received 26 December 2013
Received in revised form 28 September 2014
Accepted 5 October 2014
Available online 12 October 2014

Keywords:
Alluvial fans
Alluvial plain
Radiocarbon geochronology
Stratigraphy
Chiapas

ABSTRACT

Alluvial fans and terraces develop in diverse regions responding to different tectonic and climatic conditions. The Motozintla basin is located in the State of Chiapas, southern Mexico and has an E–W orientation following the trace of the left-lateral Polochic Fault. The evolution of the Motozintla basin and the alluvial plain is related to several factors, such as fault movement, intense erosion by hydrometeorological events, and anthropogenic activity. This study presents the geomorphology of the alluvial plain that between the villages of Motozintla and Mazapa de Juárez exposes 31 alluvial fans, 5 hanging terraces and 13 ramps. Fourteen of these alluvial fans have been truncated by the Polochic fault, exposing maximum uplifts of ~12 m. The internal structure of truncated fans consists of single massive beds (monolithologic fans) or stacked beds (polygenetic fans). The fans' stratigraphy is made of debris flow deposits separated by paleosols and minor hyperconcentrated flows, fluviatile beds, and pyroclastic fall deposits. The reconstruction of the stratigraphy assisted by radiocarbon geochronology suggests that these fans have been active since late Pleistocene (25 ka) to the present. This record suggests that at least 10 events have been recorded at the fan interior during the past ~1840 years. One of these events at 355 ± 65 ^{14}C yrs. BP (cal yrs. AD 1438 to 1652) can be correlated across the fans and is likely associated with an extreme hydrometeorologic event. The presence of a 165 ± 60 ^{14}C yrs. BP (cal yrs. AD 1652–1949) debris flow deposit within the fans suggests that movement along the Polochic fault formed the fans' scarp afterwards. In fact, a historic earthquake along the fault occurred east of Motozintla on July 22, 1816 with a M_w of 7.5–7.75. Recent catastrophic floods have affected Motozintla in 1998 and 2005 induced by extreme hydrometeorological events and anthropogenic factors. Therefore, scenarios for Motozintla involved several types of mass movement processes that pose a serious hazard and threat to the inhabitants of the region.

1. Introduction

Alluvial fans and terraces develop in diverse regions responding to their tectonic and climatic conditions and often reflect high-energy environments with high sediment transport (Gomez Villar, 1996). Alluvial fans are generally defined as semi-conical depositional landforms along mountain piedmonts (Saito and Oguchi, 2005). They have a morphology that consists of three main parts: inner fan (short extension and coarse granulometry of deposits), mid fan (smaller grain-size of particles and bedded deposits), and outer fan (largest area made by fine-grained bedded deposits) (Blair and McPherson, 2009). These features reflect the facies architecture of fans developed during their evolution, which can be modified by endogenous and exogenous processes, as has been described on the eastern side of Death Valley (Staley et al., 2006), north Venezuela (USGS, 2002) and Panamint Range piedmont, California (Blair, 1999a). However, some alluvial fans have been emplaced under low energy conditions, such as the Okavango fan in Botswana (Blair and McPherson, 2009).

Fluvial terraces, in contrast, are formed by rapid sedimentation during floods along fluvial valleys and are frequently associated to hydrometeorological events in which intense precipitation triggers debris remobilization driven by water. Several studies (Al-Farraj and Harvey, 2000; Michels and Peña-Monné, 2006; Miránda-Aviléz et al., 2007) of different regions around the globe have shown that terraces formed in tectonic environments may result in overhanging terraces along the

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http://dx.doi.org/10.1016/j.geomorph.2014.10.003
0169-555X/

sides of fluvial valleys. The alluvial plain of Motozintla in Chiapas is a unique place because it stands at the trace of the Polochic fault showing considerable evidence of tectonic activity. In a distance of 12 km between the towns of Motozintla and Mazapa de Madero, the basin holds 31 alluvial fans, 5 hanging terraces, and 13 ramps. Of the 31 fans, 14 of them have truncated forms. The truncated fans and terraces at Motozintla represent an excellent opportunity to study their morphology and internal architecture. The deposit features and composition helped us to understand their origin and their relationship with their modern analogues deposited in 1998 (Caballero et al., 2006; Sánchez-Núñez et al., 2012) which were caused by tropical storm Earl in the Atlantic and hurricane Stan in the Pacific, respectively. Therefore, in this study, we describe the morphology of the alluvial fans and their internal stratigraphy aided by radiocarbon dating of paleosols.

2. Methods

The geologic and geographic data of the area were collected and synthesized in a spatial database. To produce digital elevation models (DEM) 20 × 20 m of resolution, we used the 2007 digital topographic maps scale (1:50,000) from Instituto Nacional de Estadística, Geografía e Informática (INEGI, 2007). The DEM was used to prepare thematic models (hypsometric, slope, hillshade and drainage pattern) previously presented by Sánchez-Núñez et al. (2012). The photo-interpretation of the area was carried out on six aerial photo lines of INEGI (1:75,000), orthophotos (1:37,500), and panchromatic (5 m)/color SPOT images at 10 m of resolution. The compiled information included main lithologic contacts, faults, fractures, drainage patterns, and mass movement processes. The morphologic features were identified following the scheme proposed by Van Zuidam (1985). All this information was processed with a range of diverse commercial software, such as ILWIS 3.3 and ArcGIS 9.0. The preliminary map was used during fieldwork and modified to produce the final map (Fig. 3). In order to reconstruct the stratigraphic record of deposits on the alluvial plain, 53 stratigraphic columns were reconstructed, identifying different deposits and paleosols forming the alluvial fans.

3. The study area

Motozintla is found at an elevation of 1240 m asl (above sea level) in the Xelajú Grande, at the confluence of La Mina and Allende rivers (Fig. 1). This is the main city of the municipality with the same name. The Motozintla basin has an approximate area of 298 km^2, of which only 1.42 km^2 has been used for urban infrastructure.

The alluvial plain of Motozintla is characterized by the presence of overhanging terraces and tectonic fans because it coexists with the trace of the left-lateral Polochic fault that belongs to the Polochic–Motagua fault system. This fault represents the tectonic boundary of the North American and Caribbean plates close to the Mexico–Guatemala border. The movement along this fault has produced V-shaped valleys in Motozintla with steep (>30°) unstable slopes made of highly fractured metamorphic and intrusive rocks. Such conditions have produced hundreds of mass movement processes (–) such as rock falls, flows, avalanches and landslides (Sánchez-Núñez et al., 2012).

The alluvial plain of the Motozintla belongs to the largest Grijalva–Usumacinta basin, located in the hydrologic region called Frontera Sur (Carabias et al., 2005; CONAGUA, 2007). The Motozintla basin has an E–W orientation and extends for 12 km from Xelajú Grande village in the west, to Mazapa de Madero village in the east. The alluvial plain is up to 120-m wide, although it is wider (up to 300 m) where higher overhanging terraces occur. The alluvial plain of Motozintla corresponds to a low energy cumulative type C plain (Allen, 1970; Gutiérrez-Elorza, 2008) with slopes under 15°, where sediment deposition is permanent occurs during long periods of time (Fig. 3). The plain has recorded both channel and overflow sediments that have undergone sorting by transport processes and vertical accretion (Trenhaile, 2007). At least 31 alluvial fans were identified, 5 levels of terraces and 13 ramps that attest to the evolution of the basin.

4. Tectonic setting and local geology

Motozintla is located at the western tectonic boundary between the North American and the Caribbean plates (Fig. 2). These plates are

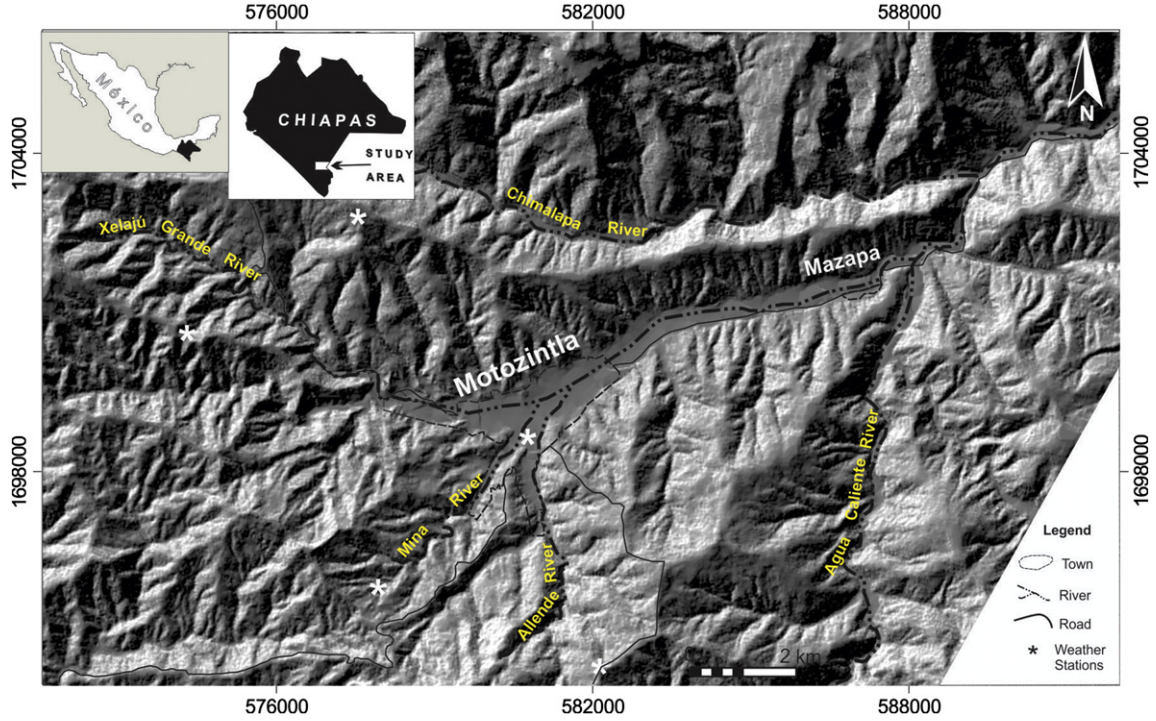

Fig. 1. Location of the Motozintla basin in the State of Chiapas in southeastern Mexico (insets). The shaded relief map of the study area shows the strongly dissected topography and the main settlements located on the alluvial plain of Motozintla. Motozintla connects to the east with Frontera Comalapa and to the west to Huixtla through Road 211.