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Ecosystem responses to climate and disturbances in western central Mexico during the late Pleistocene and Holocene

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ABSTRACT

Central Mexico is a complex area with late Quaternary volcanic activity, climatic diversity and a long history of human occupation. Pollen, microcharcoal and magnetic susceptibility analyses of two sedimentary sequences from Lake Zirahuen in western central Mexico spanning the last 17,000 years provide evidence of a highly dynamic environment. During the late glacial *Pinus* forest developed around the lake, indicating cold and dry conditions. During the last deglaciation climatic amelioration was recorded at 13.5 ka, driving a strong and rapid change in vegetation composition and increase in lake levels. From the latest Pleistocene to early Holocene a hiatus, probably related to an erosive event, is recognized in the northern sequence. The central sequence spans the entire Holocene and reveals three periods of important ecological changes during the early Holocene. A first episode between 9.5 and 9.0 ka with a decrease in pine forest seems to have been associated with summer insolation increases. A second peak of forest change at 8.2 ka and was probably associated with the cold oscillation documented in the North Atlantic. A third abrupt change was evident from 7.5 to 7.1 ka with an anomalous plant community related to wetter Holocene climates and possible to a volcanic event. An episode of dry conditions was recorded from 4.5 to 4.2 ka, which was related to an increase in ENSO activity. Human influence over the landscape was evident from 3.5 ka to the present. The Zirahuen records offer a complex history of a landscape characterized by short and long term vegetation changes associated with factors ranging from global climate to local disturbances.

1. Introduction

The Transmexican Volcanic Belt (TMVB) is an E–W geological province that crosses Mexico at around 20° N. The volcanic and tectonic activity of the TMVB started during the early Neogene (~19 Ma) and continues to the present (Gómez-Tuena et al., 2005; Ferrari et al., 2011). Gradual development of the TMVB led to significant physiographic changes such as uplift (most of the region lies between 1500 and 3000 m a.s.l.) and the appearance of intermontane basins, some with water bodies. Active volcanism of the TMVB has produced up to 8000 volcanic structures in this province (Ferrari et al., 2011), including the highest elevations in Mexico (>4000 m a.s.l.). This major volcanic activity transformed the relief multiple times, causing hydrographic changes, altering edaphogenetic processes and promoting the development (or disappearance) of microhabitats. These environmental changes have actively modified the distribution and composition of the montane plant communities of the TMVB.

Besides volcanism, climate change has been a significant factor in promoting transformations of the landscape and changes in the plant communities during the Quaternary. Paleoclimatic studies carried out in central Mexico have documented variations in temperature and humidity during the late Pleistocene. For instance, changes in the equilibrium line altitude of glaciers suggest a 6 to 8.5 °C decrease in temperature during the Last Glacial Maximum (LGM) in central Mexico (Lachniet and Vázquez-Selem, 2005; Caballero et al., 2010). In relation to moisture availability, a gradient from the Pacific and Gulf coasts towards the interior of the TMVB has been reconstructed for the LGM based on the multiproxy synthesis from existing records (Caballero et al., 2010). Human occupation has been another important factor promoting environmental changes in the area during the last few millennia. Agricultural activities have induced deforestation and frequent fires, changing the composition of plant communities (Lozano-García et al., 2010a). Many of the pre-Hispanic settlements were developed in the central highlands, near lakes, where many types of resources were available. In fact, today, some of the largest cities in Mexico are located in this same region, with 60% of the country's population living there, causing environmental degradation and increasing pressure for water availability, and strong impact on the water bodies. Drier climates related to anthropogenic-driven climate change are projected for the coming decades in southwestern North America (Seager et al., 2007). These anthropogenic changes

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will be superimposed on natural climatic variability, making the central highlands of Mexico a highly vulnerable area.

The distribution and abundance of plants closely track shifts in climate at centennial and millennial timescales, with fossil pollen records providing information on climate change (Williams, 2009). Vegetation composition responds to abrupt environmental changes at decadal to centennial scale (Tinner and Lotter, 2001; Correa-Metrio et al., 2012b) and palynomorphs preserved in sediments of central Mexican lakes have been widely used to reconstruct past environmental conditions (Caballero et al., 2010). The late glacial and Holocene vegetation history in west central Mexico (Michoacan state) has been documented analyzing the pollen records (Watts and Bradbury, 1982; Xelhuantzi-López, 1994; Velázquez-Durán et al., 2004; Correa-Metrio et al., 2012a) (Fig. 1). Some of these records (Patzcuaro and Cuitzeo) lack good chronological control of the key periods of major Holocene climatic change or have low pollen counts, leading to weaker interpretations. Despite these efforts, some questions remain open, and information on montane ecosystem responses to the rather abrupt changes and climatic variability that took place during the last deglaciation and during the transition to the early Holocene is scarce. Evidence of human impact has been documented in several palynological records from the Mexican highlands (Watts and Bradbury, 1982; Lozano-García and Ortega-Guerrero, 1998; Metcalfe and Davies, 2007) although ecosystem responses to human activity during events of variable rainfall have not been widely explored.

Here we present paleoecological data from a sedimentary sequence from the central part of Lake Zirahuen, spanning the last 11,500 years. The record provides evidence of vegetation change

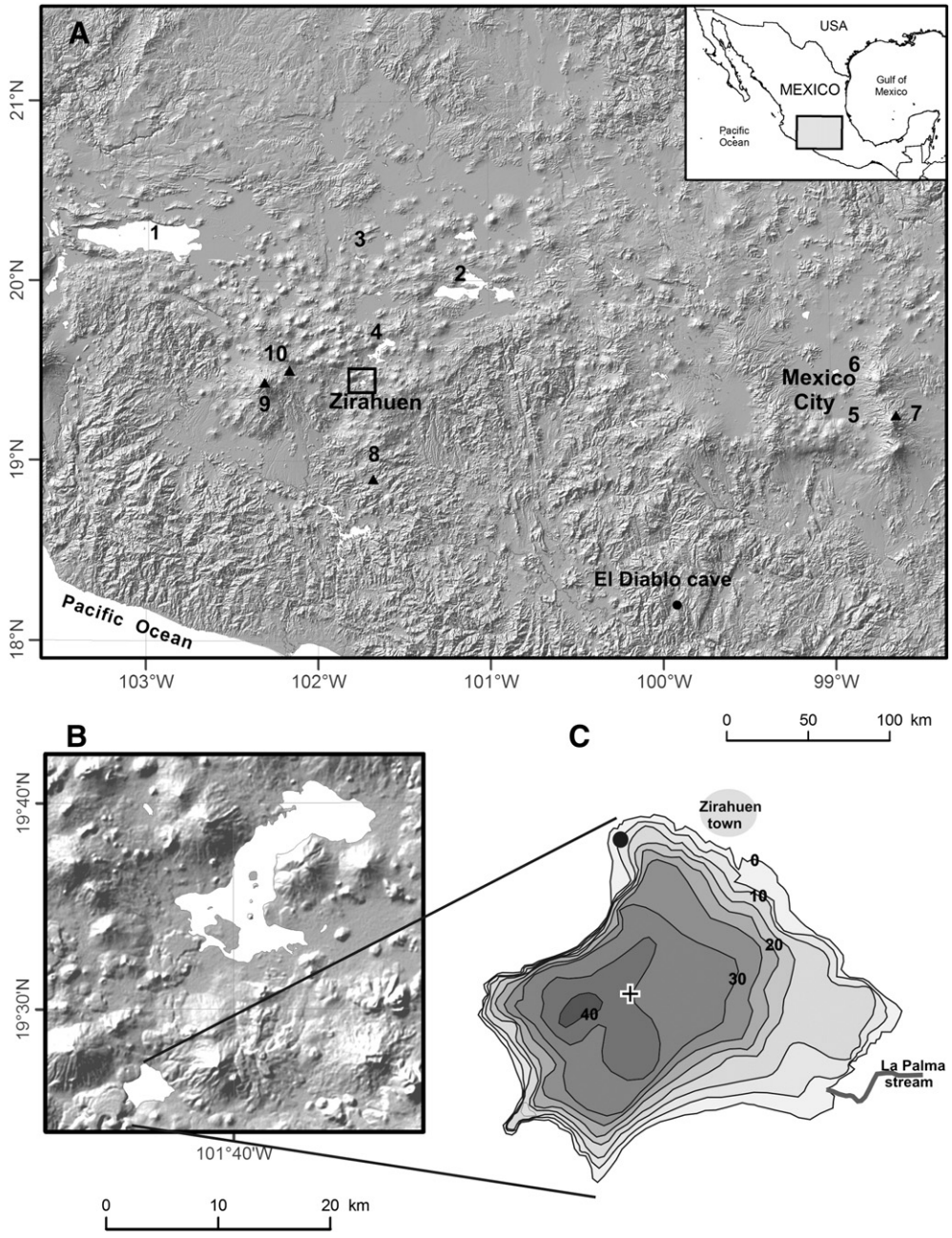

Fig. 1. Location maps. A. Western-central Mexico showing the sites mentioned in the text: 1. Lake Chapala, 2. Lake Cuitzeo, 3. Lake Zacapu, 4. Lake Patzcuaro, 5. Lake Chalco, 6 Lake Texcoco, 7. Iztaccihuatl volcano, 8. Jorullo volcano, 9. Tancitaro volcano, 10. Paricutin volcano and 11. Cueva del Diablo. B. Lake Zirahuen and Lake Patzcuaro. C. Lake Zirahuen bathymetry from Bernal-Brooks and MacCrimmon (2000) (meters) and location of the coring sites: (+) MOLE-ZIR03 central core and (•) ZIR03-I northern core.