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Evidence of Neogene wildfires in central Chile: Charcoal records from the Navidad Formation

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ABSTRACT

Mediterranean-type climate (MTC) ecosystems are characterized by recurrent wildfires. Although the majority of wildfires are human-ignited, non-anthropogenic (i.e., natural) wildfires are common in all MTC regions except central Chile. The low frequency of natural wildfires in this Chilean region is explained by the scarcity of non-anthropogenic ignition sources, basically thunderstorm-induced lightning and volcanic activity. However, from a geological perspective, the current relative absence of non-anthropogenic wildfires in central Chile is a recent phenomenon. In the transition from the Early to Middle Miocene, the climate in the region was likely warm and seasonally dry. Such climate conditions would allow the growth of fuel during the spring, becoming flammable during the dry season. This fire-prone landscape would likely have been ignited by the high volcanic activity that concomitantly occurred with the orogeny of the Andes. To evaluate this hypothesis, we sampled rocks from the three locations at the Navidad Formation, considering the fossil plant evidence deposited during this warm and seasonally dry period. We found a high concentration of charcoal in Playa Navidad, coinciding with the global warming event reported between 17 and 15 Ma. The predominance of microscopic charcoal particles (between 125 and 250 μm) only allows us to infer the occurrence of Neogene fires at a regional scale. The fused cell walls preserved in the charcoal anatomy likely suggest that such fire events were highly severe. The presence of pumice associated with the high charcoal concentrations supports the hypothesis of volcanic ignition sources. Very little charcoal was found in Punta Perro (Late Oligocene – Early Miocene) or in Cerro Los Pololos (late Middle Miocene), where fire may have been limited by fuel humidity and ignition sources respectively, although changes in the depositional environment would also help explain differences in the fire record throughout the Navidad Formation. In conclusion, our results provide the first quantitative Neogene charcoal record for South America. The evidence of fire occurrence in central Chile during the Neogene will contribute to understanding the evolution of the Mediterranean-type flora.

1. Introduction

Regions with a Mediterranean-type climate (MTC) host sclerophyllous woody vegetation generally characterized by crown wildfires that occur every 10 to 60 years (Keeley et al., 2012). This fire regime is explained by the annual climate seasonality (Batllori et al., 2013), where the mild temperatures (12 °C) occurring during the rainy season (with a cumulative precipitation of 320 mm) provide the conditions for the growth of plant biomass that becomes highly flammable during the warm and dry summers (22 °C and 50 mm; Keeley et al., 2012). Currently, anthropogenic ignition is responsible for most of the wildfires in MTC regions, due to their high population density (Keeley et al., 2012). However, there are lightning-initiated wildfires in all MTC regions except for central Chile (30°–37°S), where they are practically negligible (1.3% for the 2003–2015 period cf. Chilean National Forestry Agency, CONAF; see also Montenegro et al., 2003). The scarcity of non-anthropogenic (i.e., natural) wildfires in central Chile is explained by the low regional thunderstorm-induced lightning activity, which is five times lower in central Chile than in California and almost 13 times lower than in the Australian MTC region (René Garreaud, com. pers., based on the World Wide Lightning Location Network for the 2009–2012 period). Despite the almost total absence of natural wildfires in the region, many plant species are able to regenerate after being burnt, mainly by resprouting (e.g., Montenegro et al., 2003). This has been used as an argument against the role of fire in the evolutionary origin of fire adaptive traits in the Chilean plants and, by

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extension, in species from other regions (Valiente-Banuet et al., 1998; Lloret et al., 1999; Bradshaw et al., 2011).

However, the current absence of recurrent natural wildfires in central Chile is a recent phenomenon at a geological time-scale (Heusser, 1990; Villa-Martínez et al., 2003). Specifically, periods of frequent fires have been recorded in Laguna Tagua-Tagua (34°30′S) at the end of the Pleistocene (between 53,800 and 28,500 year BP), before the arrival of humans to the region, which dates back to 11,380 year BP (Heusser, 1990 and references therein). Similarly, fires detected in Laguna Aculeo (33°S50′S) between 5500 and 2500 year BP are not necessarily attributable to human activity, considering that the oldest archaeological site in the Laguna Aculeo watershed dates from 2000 year BP (Villa-Martínez et al., 2003; Sanhueza et al., 2007). In both cases, the pollen record concomitant with fire occurrence indicates annual rainfall seasonality and warm conditions (Heusser, 1990; Villa-Martínez et al., 2003).

The current sclerophyllous flora of central Chile is derived from a Neogene Subtropical Paleoflora that through most of the Miocene occupied the central areas of Chile and Argentina, under a warm climate with high seasonal precipitation (Hinojosa and Villagrán, 2005; Hinojosa et al., 2011). Given such warm climatic conditions, with abundant vegetation growing during spring and becoming dry during summer, the landscape was probably highly fire-prone in the presence of an ignition source (e.g., see Pyne et al., 1996 and Pausas and Keeley, 2009 for a general discussion on fire drivers). In this sense, it has been proposed that both thunderstorm-initiated lightning and/or volcanism would have triggered wildfires in the past in central Chile (Fuentes and Espinosa, 1986; Keeley et al., 2012).

In this work, we hypothesize the occurrence of wildfires in the MTC region of Chile during the transition from Early to Middle Miocene, triggered by the warm conditions, the marked annual seasonality in precipitation and the co-occurrence of a variety of ignition sources. To test this hypothesis, we explored the existence of charcoal particles of the fossil record in the Navidad Formation, located on the west side of the Coastal Range in central Chile, considering the fossil plant evidence deposited here during this warm and seasonally dry period.

2. Geological and palaeontological setting

Several basins of differing size developed along the Chilean continental shelf between 33 and 45°S; they are filled with Cretaceous to Miocene sequences in discrete depocenters bounded by basements highs that segment individual basins (Melnick and Echtler, 2006). The northernmost of these sedimentary units is the Navidad Basin (Cecioni, 1980; Fig. 1). First described by Darwin (1846), its stratigraphic extent and subdivision has been controversial. For this study, we follow Encinas et al. (2006), who divided the sedimentary deposit between Valparaíso (~33°00′S) and Punta Topocalma (~34°30′S) into four Formations: Navidad, Licancheu, Rapel and La Cueva. The Navidad Formation extends from the mouth of the Rapel River (in Punta Perro beach) to the Matanzas locality, being 250 m thick on average

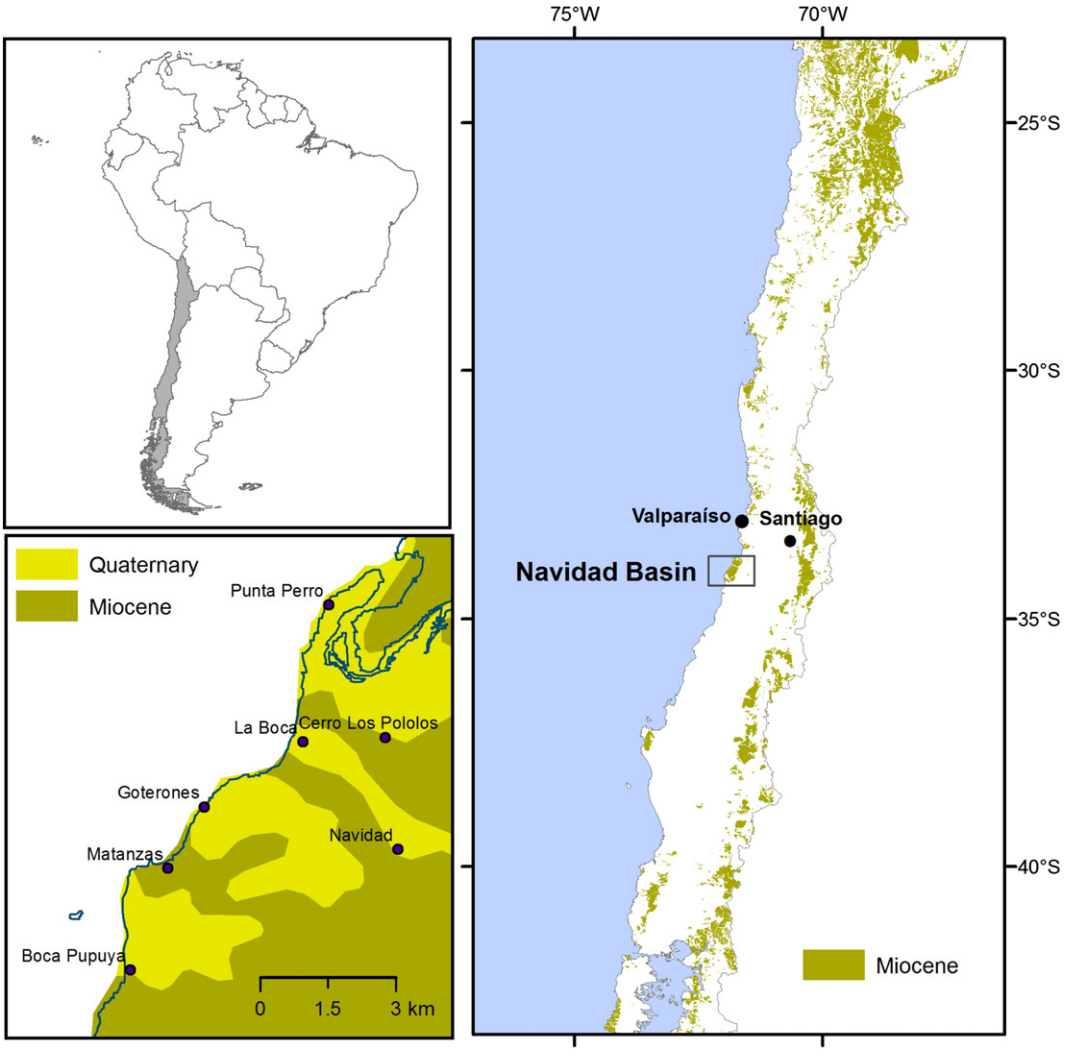

Fig. 1. Map of the geographical location of the study site. Upper left panel showing Chile in South America, right panel the Navidad Basin in Chile using the geological map from SERNAGEOMIN 1:1.000.000, and the down left panel the study site and references inside the text.