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Paleoenvironmental conditions in the late Paleogene, Sumatra, Indonesia

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ABSTRACT

A stratified paleosol sequence exposed in an open pit mine in central Sumatra provides a record of the paleoenvironmental conditions in the lower reaches of a large river system in the late Paleogene (latest Eocene or Oligocene). Morphological, geochemical, and stable isotope data suggest that the sequence represents a mosaic of local environmental conditions changing from estuarine to riverine up section. Weakly expressed soils formed on low-lying estuary surfaces, while more well expressed soils formed on higher, better drained surfaces. Peatlands (coal) with clayey subsoils were along the estuary margins. Well-expressed soils with evidence of clay translocation and chemical weathering become more common higher in the section where alluvial deposits associated with a meandering river are dominant. Stable carbon isotope ratios support a paleolandscape dominated by C_3 plants with input by C_4 vegetation limited to a few intervals. Finally, whole-rock geochemistry suggests moderate chemical weathering consistent with a tropical locality. This multi-proxy paleoenvironmental reconstruction suggests a highly productive lowland forest environment at this locality in the late Paleogene and provides the first direct examination of the terrestrial environment in Sumatra at this time. The limited fossil record in Island Southeast Asia during this time period is likely a result of poor bone and shell preservation in tropical forest environments combined with a general lack of systematic prospecting. However, our continuing work in this area has produced a relatively diverse assemblage of fossil vertebrates, now including fishes, amphibians, turtles, crocodiles, and mammals, as well as a growing diversity of fossil plants.

1. Introduction

The late Paleogene is a critical time period for the distribution of terrestrial vertebrates across Southeastern Asia as new landmasses emerged as the Indian and Australian plates collided with Asia (Hall, 2009). One consequence of this dynamic tectonic setting was dramatic changes in topography and relative sea level that significantly changed the distribution of land and sea across the eastern margin of the Sunda subcontinent (Fig. 1). Furthermore, changes in ocean temperature and salinity caused by the deep water closure of the Indonesian Throughflow at the beginning of the Neogene (between 25 Ma and 22 Ma) would have had an effect on rainfall, winds, atmospheric pressure, sea level, and temperatures, both in the Australia–Asia–Pacific region and globally, and may have directly influenced plant and animal distributions (Hall, 2009). These concurrent global and regional climate fluctuations likely influenced habitat availability and thus affected faunal radiations into what is today one of the most biodiverse regions on Earth.

The geographic changes that this region has undergone over the past 50 million years have led to the patterning of higher taxa due to ancient vicariance events (Lohman et al., 2011). In particular, the environment of Sumatra during this time period may have affected mammalian diversity throughout the late Paleogene and early Neogene (Hall, 2009). Central Sumatra was one of a few emergent parts of the Sunda Continent from the early Eocene through the

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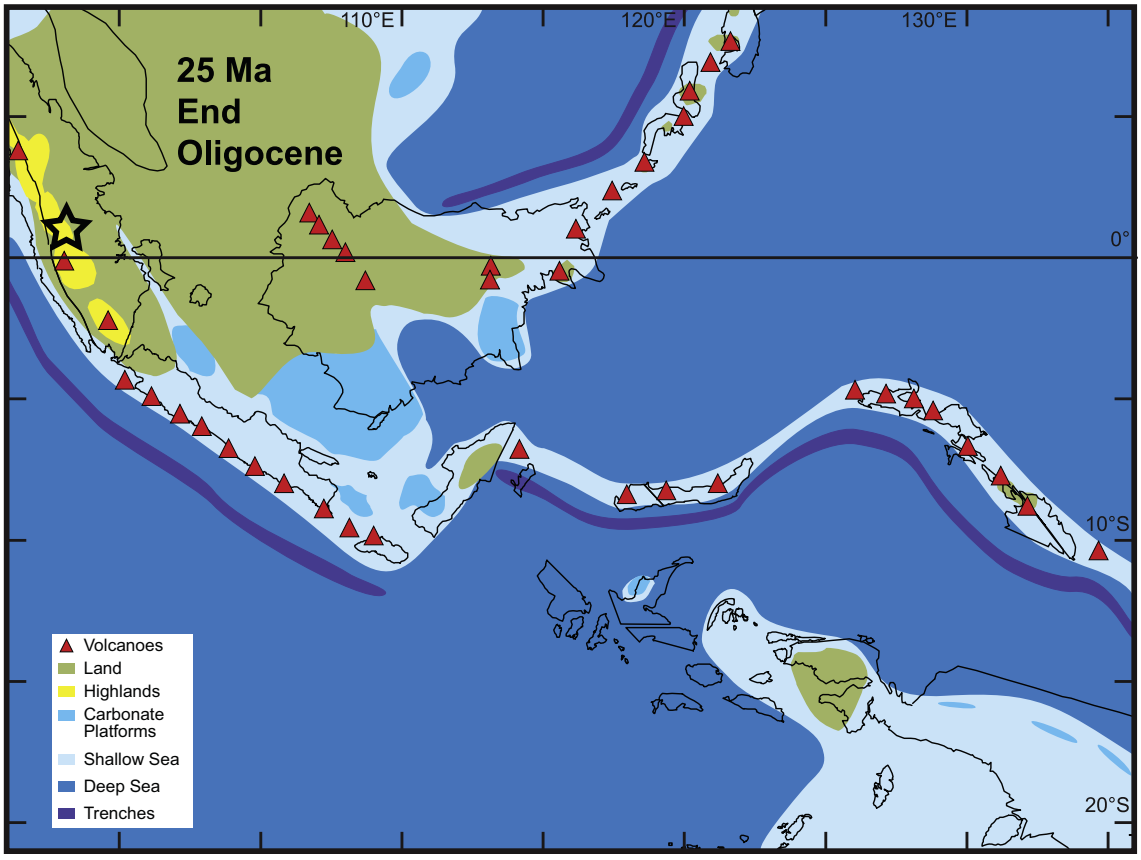

Fig. 1. Paleogeographic map of Island Southeast Asia. Map showing reconstructed submerged and elevated land surfaces in Sunda during the late Oligocene (reproduced with permission from Hall, 2009). Western Sumatra remained emergent during the late Oligocene (approximate study area marked with a black star).

early Miocene, making it an important location for investigating the distribution, evolution, and paleoecology of terrestrial vertebrates that existed in Island Southeast Asia during this time (Zonneveld et al., 2011). The complex geologic history of this region and its already well-documented evidence for complex patterns of biodiversity make Sumatra a good test bed for examining how the interplay of land availability and environmental changes may have affected faunal diversity in Island Southeast Asia.

Paleosols, positioned at the contact of the atmosphere and lithosphere, are a direct, but complex, terrestrial record of the paleoenvironmental and paleoclimatic conditions under which they formed. This makes paleosol-based proxies a powerful tool for reconstructing past environments (Sheldon and Tabor, 2009). In this study paleosol morphology, stable carbon isotope composition of bulk paleosol organic matter (POM), and bulk geochemistry provide multiple lines of evidence to help reconstruct the environment of the late Paleogene in western Sumatra. This research is the first examination of the Sumatran paleoenvironment from this largely unknown time period. These reconstructions provide critical baseline information about the paleoenvironment for assessing the development of biodiversity in Island Southeast Asia.

2. Geological setting

2.1. Structural setting

The paleosol sequences described in this paper occur within the Ombilin Basin, an intermontane sedimentary and structural basin located in the Barisan Mountain Range, West Sumatra (Fig. 2). The exposed segment of the basin is about 25-km wide and 60-km long, trends NW–SE and roughly parallels the Sumatran Fault System. The Sitangkai and Silungkang faults define the northern and southern boundaries of the basin, respectively (Koning, 1985; Situmorang et al., 1991). The Sumatran Fault System resulted from the oblique subduction of the Indo-Australian plate under the Eurasian plate (Situmorang et al., 1991). Tensional tectonics that resulted from the strike-slip movement of this collision produced the graben-like, pull-apart structure of the Ombilin Basin (Koning, 1985; Fatimah and Ward, 2009). The present study area is located within the Talawi syncline or Talawi Sub-basin in the northwestern section of the Ombilin Basin (Howells, 1997).

2.2. Stratigraphic setting

Despite the basin's small size it contains a relatively large amount of Cenozoic fill (~4600 m; Koning, 1985). The basin's Cenozoic fill overlies pre-Cenozoic basement rocks and includes in ascending order; the Brani Formation, the Sangkarewang Formation, the Sawahlunto Formation, the Sawahtambang Formation, and the Ombilin Formation (Fatimah and Ward, 2009; Koesoemadinata and Matasak, 1981; Whateley and Jordan, 1989). This study focuses on a small part of the late Paleogene Sawahlunto Formation. The oldest sediment in the Ombilin Basin, the Brani Formation, represents Eocene marginal fan deposition and consists of a sequence of breccias and polymictic pebble to cobble conglomerate in a muddy to sandy matrix that interfinger laterally and basinward with the Sangkarewang Formation (Fatimah and Ward, 2009; Whateley and Jordan, 1989). The Sangkarewang Formation is composed of dark bluish gray to black laminated shale that is commonly intercalated with greenish-gray feldspathic turbidite sandstone. These shale successions,

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