Journal of South American Earth Sciences 54 (2014) 109–119

Contents lists available at ScienceDirect

Journal of South American Earth Sciences

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

Revised timing of the South American early Paleogene land mammal ages

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ARTICLE INFO

Article history:
Received 2 November 2013
Accepted 24 May 2014
Available online 3 June 2014

Keywords:
Paleogene
Eocene
Itaboraian age
South America
Patagonia
Las Flores Formation

ABSTRACT

A new Ar/Ar date on the Las Flores Tuff (Río Chico Group, Las Flores Fm., central Patagonia, Argentina) yielded an age of 49.512 ± 0.019 Ma. This tuff, which stratigraphically overlies the mammal-bearing deposits that produced the Las Flores fauna, helps constrain the age of the Itaboraian SALMA [South American Land Mammal Age] to which that fauna is referred. The new data also have implications for the age of succeeding mammal biochrons, such as the Riochican and "Sapoan" which are revised to being somewhat younger than previously interpreted. Although closer in age than formerly interpreted, they still are biotically distinct. Concomitant evaluations suggest that the Itaboraian SALMA is perhaps more contemporary with the EECO (Early Eocene Climatic Optimum) than previously considered. The Riochican may be interpreted as post-EECO, with its cooler climate consistent in that regard. A recent reconsideration of the chronology of elements of the Salamanca Formation resulted in the downward revision of the ages of the Peligran SALMA and the *Carodnia* Zone biochrons. These operations, together with our results, reflect a 9 m.y. gap in the late Paleocene and early Eocene land mammal record in South America.

1. Introduction

The succession of South American Mammal Ages has been developed over several decades since the middle of the last century (Pascual et al., 1965; Simpson, 1971; Patterson and Pascual, 1972; Marshall et al., 1983). As summarized in Woodburne et al. (2014), those of the Paleogene are largely uncalibrated, with age estimations based on aspects of biochronology, stratigraphy and correlation to paleomagnetic scales.

Here we report on a new ^{40}Ar/^{39}Ar date on the Las Flores Tuff that crops out near the middle of the Las Flores Formation (Río Chico Group, central Patagonia, Argentina). The new date (49.512 ± 0.019 Ma) provides an upper boundary for the underlying mammal-bearing deposits referred to the Itaboraian SALMA. The results of the present work suggest that the Itaboraian SALMA likely ranges in age from about 53 – 50 Ma, somewhat younger than previously suggested (Woodburne et al., 2014), and also that the Riochican is no older than about 49 Ma. With the post-Riochican "Sapoan" fauna likely ranging from about 48.5 – 47 Ma (revised from Tejedor et al., 2009), it appears that the Riochican represents a relatively short interval of time, and that the "Sapoan" age may be revised as being somewhat younger than previously considered. Although not bracketed by calibrated dates, the new information provided in this work aids in narrowing the potential age range, and suggests a later beginning for the Riochican SALMA and the "Sapoan" local fauna. Geological investigations by Clyde et al. (2014) on the Salamanca Formation in the western part of the San Jorge Basin (from about CA – LF, with extension to about CH, Fig. 1b) results in a lowering of the Peligran SALMA and *Carodnia* Zone ages. The Tiupampan and Peligran SALMAs and the *Carodnia* Zone are contained within the Danian Stage. The result of these studies is that there now appears to be a nearly 9 m.y.-long, middle to late Paleocene, gap in the biochronology of the South American mammal fauna.

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http://dx.doi.org/10.1016/j.jsames.2014.05.003
0895-9811/

1.1. Definitions and abbreviations

BNI	Banco Negro Inferior (Lower Black Bank, Hansen Member; uppermost Salamanca Formation).
EECO	Early Eocene Climatic Optimum. This is the interval of highest mean ocean temperature of the Cenozoic Era (Wolfe, 1978; Zachos et al., 2001, 2008). It began about 53 Ma and persisted to about 50 Ma (Tsukui and Clyde, 2012), and occurred in the contexts of generally warm conditions that characterized the early Cenozoic Era from the Paleocene to about middle Eocene.
k.y.	A segment of geologic time one thousand years in duration or the age of an event (e.g., ten thousand years ago), without reference to a point or set of points on the radioisotopic time scale.
Ma	Megannum. One million years in the radioisotopic time scale (e.g., 10 Ma refers to the ten million year point on the time scale)
MAT	Mean Annual Temperature (as inferred from paleobotanical leaf margin and other data)
m.y.	A segment of geologic time one million years in duration or the age of an event (e.g., ten million years ago) without reference to a point or set of points on the radioisotopic time scale.
NALMA	North American Land Mammal Age (Woodburne, 2004); an interval of time based on North American mammalian biochronology. Use of NALMA indicates that the units are not formalized Ages of the International Stratigraphic Guide (Salvador, 1994).
NMGRL	New Mexico Geochronological Research Laboratory, Socorro, New Mexico.
PETM	Paleocene-Eocene Thermal Maximum. A short-term hyperthermal pulse of global warming at the Paleocene-Eocene boundary (Zachos et al., 2008; McInerney and Wing, 2011). This is the earliest Eocene hyperthermal event, calibrated at 56.33 Ma (Westerhold et al., 2009). It had a duration of 120–220 k.y. (Murphy et al., 2010), with an initial pulse of about 10 k.y. during which global sea surface temperatures rose 5–9 °C.
SALMA	South American Land Mammal age; comparable to NALMA; see Pascual et al. (1965), Simpson (1971), Patterson and Pascual (1972), Marshall et al. (1983), Dunn et al. (2013), Woodburne et al. (2014). Units discussed here include Tiupampan, Peligran, *Carodnia* Zone, Itaboraian, Riochican, and "Sapoan fauna." Units such as "Sapoan" are given (" ") due to their currently informal status. Nevertheless, both the *Carodnia* Zone and "Sapoan" are considered to represent distinct temporal intervals consistent with SALMA status.

2. Geological framework

The study area is located on the eastern margin of the San Bernardo fold belt, on the northern flank of the San Jorge Basin, Chubut Province, southeastern Argentina (Fig. 1a). This basin is an extensional intracontinental trough developed on a Paleozoic continental crust, linked to the Gondwana break-up and the opening of the South Atlantic Ocean during the Jurassic. The main deposits of the basin are pyroclastic and epiclastic sediments that range in age from Jurassic to the Miocene (Barcat et al., 1989; Fitzgerald et al., 1990). Several continental and marine successions from the Late Cretaceous to the middle Miocene are exposed in the north flank of the basin (Fig. 1b).

The San Jorge Basin record of the Salamanca Formation has been studied for over 70 years (Clyde et al., 2014). Bond et al. (1995) and Raigemborn et al. (2010) show that the formation occurs widely in the subsurface and outcrop from the Río Senguer in the west to the Atlantic Coast on the east (Fig. 1a, b). Clyde et al. (2014) focus on outcrops in the Sarmiento district from Palacio de los Loros (*PL*, Fig. 1b) to the vicinity of Las Flores (LF, Fig. 1b), but also extends to the east coast. Their discussion includes new paleomagnetic and radioisotopic data for the Salamanca and Peñas Coloradas Formations.

As upgraded by Clyde et al. (2014) the Salamanca Formation represents a shallow marine transgression composed mostly of sandstone, siltstone and mudstone. It ranges up to 150 m thick and unconformably overlies the Angostura Basalt, dated (Clyde et al., 2014) at 67.31 Ma (Fig. 2), with both units unconformably above the continental deposits of the Chubut Group (early Campanian; Fig. 2). As indicated in Fig. 2, the Fragmentosa unit of the Salamanca Formation is unconformably overlain by the Banco Verde, and followed by the Hansen Member, also known as the Banco Negro Inferior (Bond et al., 1995; BNI, Fig. 2), a widespread dark paleosol that marks the transition from the shallow marine Salamanca Formation to the following nonmarine units of the Río Chico Group, of ?late Paleocene – early Eocene age (Feruglio, 1949; Legaretta and Uliana, 1994; Raigemborn et al., 2010), but see below for an early Paleocene base for the Río Chico Group. Raigemborn et al. (2010) also reported a transitional unit above the BNI, where the beds change from marine to nonmarine strata (Transitional beds, Fig. 3), and characterized the overlying Las Violetas and Peñas Coloradas as part of the transitional succession. In that Raigemborn et al. (2010; 243, and Fig. 6a and b) indicate an unconformable relationship between the Peñas Coloradas and the Transitional beds of the Salamanca Formation at Cerro Abigarrado and a site 20 km southwest of Punta Peligro, the physical contact with the Peñas Coloradas Formation is shown as an unconformity in Figs. 2 and 3. As discussed below, the revised chronology of the BNI bears on the age of the Peligran SALMA.

The Río Chico Group consists of an epiclastic and pyroclastic continental succession composed of fluvial, lacustrine, and eolian facies (Legaretta and Uliana, 1994), with major outcrops extending in a northeast direction from Cerro Abigarrado, through the Las Flores region north of the Gran Barranca, and along the Río Chico and to the coast (CA – ELV, Fig. 1b). The Río Chico Group forms four units which, from bottom to top, are the Las Violetas (not shown on Fig 2), Peñas Coloradas, Las Flores, and Koluel-Kaike Formations (Raigemborn et al., 2010). The Río Chico Group is overlain by, and partly interfingers with, the middle Eocene – early Miocene loessic and fluvial Sarmiento Formation (Fig. 2) or is locally overlain unconformably by the early Miocene shallow marine Chenque Formation (Fig. 1b). A gradational relationship was observed between the units of the Río Chico Group on the north flank of the basin, with a lateral transition likely maintained between the Las Violetas and Peñas Coloradas Formations (see Krause and Piña, 2012: Fig. 2), and also partly between the Las Flores and Koluel-Kaike Formations (Raigemborn et al., 2010), as reflected in the stratigraphic relations shown in Fig. 2. For the purpose of this report we focus on the Peñas Coloradas, Las Flores and Koluel-Kaike Formations, with emphasis on the Las Flores.

2.1. Peñas Coloradas Formation

The Peñas Coloradas Formation is composed of fine-grained conglomerate, very fine to very coarse sandstone, and massive mudstone, of volcaniclastic as well as siliclastic composition, of gray to reddish color. This unit has an average thickness of 40 m and represents a fluvial system of low to moderate energy. Where studied by Clyde et al. (2014), the Peñas Coloradas unconformably overlies the transitional units of the Salamanca Formation (Figs. 2 and 3). Clyde et al. (2014) interpreted an early Paleocene age for the formation in the western part of the basin, with its base being about 62.4 Ma, and tuffs near the top of the unit assessed at 61.51 ± 0.88 Ma. The *Carodnia* Zone, which is defined (Simpson, 1935) at Bajo de La Palangana (Fig. 1b), is interpreted as being contained within these limits (Fig. 2). The implications of these data for the ages of the Tiupampan and Peligran SALMAs and the *Carodnia* Zone are discussed below. Clyde et al. (2014) also implied the presence of an unconformity at the top of the formation, with the overlying Las Flores Formation being correlated with chron C26n, or about 59.2 Ma. We arbitrarily (Fig. 2) use this as the base of the Las Flores Formation, so that the Peñas Coloradas extends upward to that date, past the upper boundary indicated by Clyde et al.