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Research paper

Middle Eocene dinoflagellate cysts from Santa Cruz Province, Argentina: Biostratigraphy and paleoenvironment

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ABSTRACT

The upper member of the Río Turbio Formation is a well-exposed marine Eocene unit at high latitudes in Patagonia, Argentina. It holds important information helpful to reconstruct regional climate and oceanographic patterns in an area adjacent to the Drake Passage. Knowledge on the paleoenvironmental and paleoceanographic evolution of the southwestern Atlantic Ocean during the Paleogene is hindered by the lack of precise tools to date and correlate the sedimentary units. In this paper we present the dinoflagellate cyst assemblages from the upper member of the Río Turbio Formation and compare the stratigraphic distribution of their species with the ranges proposed in the Paleogene Southern Pacific Ocean dinoflagellate cyst zonation. The abundance of *Enneadocysta dictyostila*, the first occurrence of *Impagidinium parvireticulatum* and the presence of *Vozzhennikovia apertura* all allow us to propose a mid-Lutetian to mid-Priabonian age (44.6 to 34 Ma) for the upper member of the Río Turbio Formation. The study section is characterized by a middle Eocene endemic-Antarctic dinocyst assemblage. According to the dinocyst assemblages the analyzed section can be divided into four zones. Zone I is dominated by *E. dictyostila*, which points to a distal setting in an inner shelf environment. Zone II exhibits a high abundance of *V. apertura*, thus suggesting high trophic levels and cool waters in a shallow-marine, coastal environment. Zone III is dominated by *I. parvireticulatum* and a lower abundance of *E. dictyostila*, both species indicating a possible deepening of the depositional area with increasing influence of oceanic waters. Finally, Zone IV is dominated by *V. apertura*, indicating shallow marine waters. Our data suggest that *V. apertura* could have been produced by a stress-tolerant dinoflagellate species. Toward the top of the section, the samples are dominated exclusively by sporomorphs and zygospores of fresh-water green algae, which indicate a transition from a tide-dominated deltaic to a continental environment.

1. Introduction

The Paleogene (~65–35 Ma) was a period of substantial climate change, involving the Earth's transformation from a greenhouse to an icehouse state, a transition which was not gradual, but was characterized by warming intervals, e.g. the Middle Eocene Climatic Optimum (Zachos et al., 2001, 2008; Bohaty and Zachos, 2003; Bohaty et al., 2009). During this period, there occurred significant tectonic changes, including the opening of deep Southern Ocean gateways (Tasman Gateway and Drake Passage), leading to the initiation of the Antarctic Circumpolar Current (Stickley et al., 2004a; Scher and Martin, 2006; Lagabrielle et al., 2009).

Paleoclimatic and paleogeographic data can be inferred from marine microfossil assemblages. Specifically, organic-walled dinoflagellate cysts (dinocysts) have been proven to be useful in reconstructing marine paleoenvironments for the Paleogene (Sluijs et al., 2005 and the references therein). These microfossils are found in large quantities in high-latitude shelf sediments, where carbonate is generally not well-preserved and less abundant. Dinoflagellates are susceptible to sea surface temperature and salinity fluctuations and depend on deep water fluctuations. They are also sensitive to slight changes in nutrient availability (e.g., Dale, 1996), and thus represent a valuable tool in determining surface-water productivity. The availability of nutrients in surface waters is directly related to upwelling and runoff, surface current patterns and water-mass mixing (e.g., Berger et al., 1989; Bertrand et al., 1996).

During the middle and late Eocene an endemic-Antarctic dinocyst assemblage, called "Transantarctic Flora" by Wrenn and Beckman (1982), has been recognized at sites with a paleolatitude south of 60°S (Sluijs et al., 2005). This assemblage is dominated by endemic and bipolar taxa that are clearly differentiated from assemblages rich in cosmopolitan and low-latitude species (Lentin and Williams, 1976; Wrenn

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and Hart, 1988; Brinkhuis et al., 2003a, 2003b; Sluijs et al., 2003; Bijl et al., 2011, 2013a, 2013b; Houben et al., 2013). Thus, our dinocyst assemblages, located off the southwestern Atlantic Ocean, can be biostratigraphically correlated with cores drilled in eastern Antarctica (Tasman Sea, Ross Sea) (Bijl et al., 2013a).

The middle Eocene in Patagonia is characterized by one of several Atlantic transgressions (Malumián, 1999). This transgression is represented by the upper member of the Río Turbio Formation in the westernmost part of the Austral Basin (Fig. 1). Due to the proximity of the Río Turbio Formation type area to the Drake Passage, whose opening leads to major ocean circulation and climate changes during the Paleogene, these marine deposits are a highly valuable source of information for the assessment of paleoenvironmental and paleoclimatic changes (Huber et al., 2004; Lagabrielle et al., 2009). However, paleoenvironmental reconstructions of the Paleogene in this area are prevented by the lack of biostratigraphic tools to date and correlate the sedimentary units. Earlier dinocyst studies of the Río Turbio Formation had been carried out by Archangelsky (1968, 1969) on cores drilled by the Argentine company Yacimientos Carboníferos Fiscales. Recently, Rodríguez Raising (2010) proposed a paleoenvironmental model based on sequence stratigraphy of sections outcropping in the Río Turbio Formation type area, which states that the processes responsible for transport and sedimentation during the deposition of the Rio Turbio Formation were generated by density flows with episodes of tidal diffusion processes. This model provides the stratigraphic framework for the present study.

This paper characterizes middle Eocene dinocyst assemblages from the upper member of the Río Turbio Formation in a composite section outcropping close to the Rio Turbio locality, southern Santa Cruz Province. Its aim is to provide a detailed biostratigraphic framework for the upper member of the Río Turbio Formation, taking as reference the dinocyst ranges determined by Brinkhuis et al. (2003b) and Bijl et al. (2013a) from cores drilled by the Ocean Drilling Program (ODP) on the East Tasman Plateau (Site 1172) and Integrated Ocean Drilling Program (IODP) at the Wilkes Land Antarctic Margin (Site U 1356). These records have magnetostratigraphically and biostratigraphically calibrated age models. We also reconstructed the paleogeographic and paleoceanographic conditions in the southwestern Austral Basin during the middle Eocene in order to critically assess and potentially improve the paleoenvironmental model proposed by Rodríguez Raising (2010).

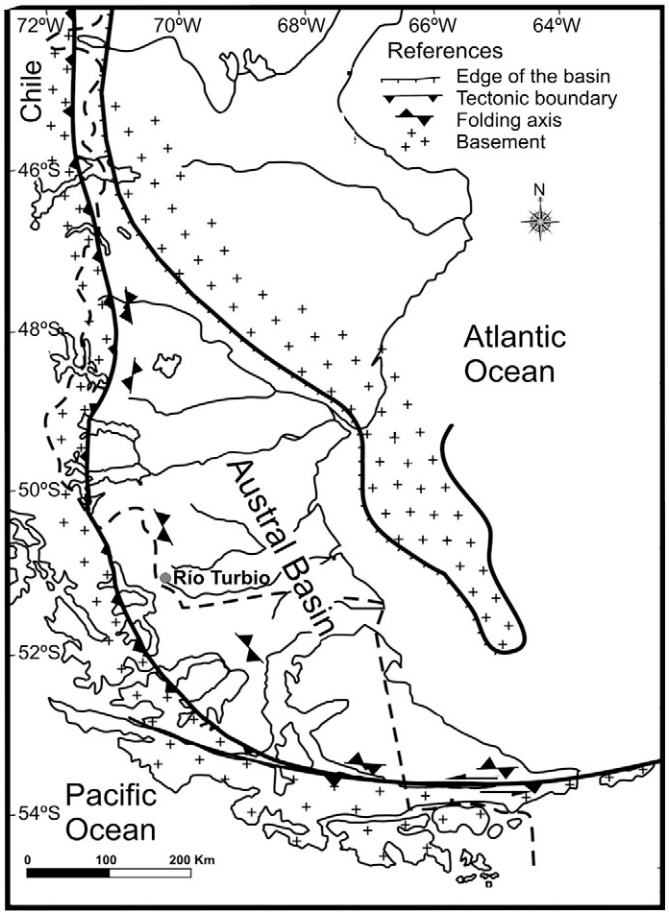

Fig. 1. Map of the south of Patagonia, Argentina with the Austral Basin and the Río Turbio study area identified.
Modified from Nullo et al. (1999).

2. Geological setting

The Austral Basin is located on the South American Plate south of 47°S and underlies the island of Tierra del Fuego, southern Patagonia, and the adjacent continental shelf of Argentina (Fig. 1). During the Late Cretaceous, a retro-foreland basin started to develop in response to the compression caused by the subduction of the Farallon, Aluk, Nazca and Antarctic plates beneath the South American Plate (Ramos, 2005; Somoza and Ghidella, 2005).

The upper member of the Río Turbio Formation is characterized by the presence of a glauconitic horizon widespread within the Austral Basin (Calegari et al., 1993) (Fig. 2). This horizon allows for the correlation with the Man Aike Fm. in Santa Cruz Province (Casadío et al., 2009), the Leticia Fm., the lower section of the Cerro Colorado Fm., the subsurfer Glauconítico B in Tierra del Fuego Province and the Ballena Fm. in Chile (Malumián, 2002; Olivero and Malumián, 2008).

Along the southwestern margin of the Austral Basin in Santa Cruz Province, outcrops of the upper member of the Río Turbio Formation have been assigned a late middle Eocene to early late Eocene age (Malumián et al., 2000). The lower member is separated from the underlying Paleocene Cerro Dorotea Formation by a disconformity. The upper member of the Rio Turbio Formation is separated from the overlying fluvial Río Guillermo Formation considered to be of late Eocene to early Oligocene age, by a gentle angular unconformity (Arguijo and Romero, 1981; Ramos, 2005). Based on a detailed ichnologic, sedimentologic and sequence stratigraphic study in the Río Turbio Formation type area, Pearson et al. (2012) interpreted the upper member as being deposited from multiple cycles of fall and rise of the relative sea-level forming a compound incised-valley system.

3. Materials and methods

The studied sections crop out in southwestern Santa Cruz Province along National Highway 40, south of the Rio Turbio locality (51°31′13″S, 72°15′11″O; Fig. 2). Two stratigraphic sections in the type area of the Rio Turbio Formation were measured using a Jacob's staff. The two sections belong to Sequences VI, VII and VIII of Rodríguez Raising (2010) (Fig. 3) and are up to 255 m thick (with 38 m of overlapping). The analysis of bed geometry, bounding surfaces, lithology, texture and sedimentary structures led to the distinction of three facies associations (FA) (Fig. 2). Sequence VI includes FA 1 and FA 2; Sequence VII constitutes FA 1 and Sequence VII includes FA 3. FA 1 is interpreted to represent deposits of distal zones of hyperpycnal lobe systems. FA 2 is explained as sediments accumulated in tidal plains, inter- to subtidal channels and abandoned channel systems. FA 3 is interpreted as intertidal alluvial deposits.

A total of 23 samples were processed for palynological analysis using hydrochloric and hydrofluoric acids. The residues were sieved through screens of 10, 25 and 180 μm and stained with Bismarck C. Strew mounts were prepared using gelatin–glycerin as a mounting medium. The palynological samples were processed at the Museo Argentino de Ciencias Naturales, Bernardino Rivadavia, Buenos Aires, and the slides are stored at the Laboratorio de Palinología, Instituto Geológico del Sur, Bahía Blanca. The field and laboratory numbers are shown in