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Sedimentology and paleoenvironments of the Las Chacritas carbonate paleolake, Cañadón Asfalto Formation (Jurassic), Patagonia, Argentina

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ABSTRACT

The Las Chacritas Member is the lower part of the Cañadón Asfalto Formation (Jurassic). The unit is a completely continental limestone succession with volcanic contributions that were deposited during the development of the Cañadón Asfalto Rift Basin (Chubut province, Patagonia, Argentina). A detailed sedimentological analysis was performed in the Fossati depocenter to determine the paleoenvironments that developed in the context of this rift. The Las Chacritas Member represents a carbonate paleolake system with ramp-shaped margins associated with wetlands that were eventually affected by subaerial exposure and pedogenesis. This process is represented by three main subenvironments: a) a lacustrine setting sensu stricto (lacustrine limestone facies association), represented by *Mudstones/Wackestones containing porifera spicules* (F1), *Intraclastic packstones* (F6) and *Tabular stromatolites* (F10) in which deposition and diagenesis were entirely subaqueous; b) a palustrine setting (palustrine limestone facies association) containing *Microbial Mudstones* (F2), *Intraclastic sandy packstone with ostracode remains* (F3), *Oncolitic packstone* (F5), *Brecciated limestone* (F7) and *Nodular-Mottled limestone* (F8) representing shallow marginal areas affected by groundwater fluctuations and minor subaerial exposure; and c) a pedogenic paleoenvironment (pedogenic limestone facies association) including *Intraclastic limestone* (F4) and *Packstones containing Microcodium* (F9) facies displaying the major features of subaerial exposure, pedogenic diagenesis and the development of paleosols. The fluvial–palustrine–lacustrine succession shows a general shallow upward trend in which contraction–expansion cycles are represented (delimited by exposure and surface erosion). The variations in the successive formations reflect the responses to fluctuations in a combination of two major controls, the tectonic and local climatic variables. The predominance of the palustrine facies associations was determined by its accommodation space as well as the local climate conditions. The variations in the lacustrine limestone facies associations reflect differential patterns of subsidence within the sub-basin. The diagnostic features of the palustrine limestone facies associations (organic matter (OM) content, microinvertebrate fauna, abundant mud cracks, brecciation, presence of evaporitic minerals) frame the sub-basin in a climatic context intermediate between arid and subhumid conditions.

1. Introduction

Africa and South America separated from each other during the Early Jurassic period due to the dismemberment of Gondwana. This separation produced structural changes resulting from tensional strains deep in the basement faults and the transtentional reactivation of old structural systems related to the widespread extension (Kay et al., 1989). These processes originated rift basins in West Gondwana (Figari and Courtade, 1993; Cortiñas, 1996; Ramos et al., 2010) such as the Cañadón Asfalto Basin. This basin resulted from extensional forces that caused individual asymmetric graben sub-basins (Silva Nieto et al., 2002b) and is located in the center of Chubut province, Patagonia Extrandina, Argentina (Silva Nieto et al., 2002a) (Fig. 1).

The Cañadón Asfalto Basin possesses the most complete sedimentary transtensional tectonic sequences of the slip-strike or pull-apart variety (Silva Nieto et al., 2002a) or *prerift–synrif–postrift* deposits (Figari et al., 1996; Figari, 2005) and paleontologic record in the continental Jurassic in South America. This basin provides opportunities for studies of the evolution of the complete rifting in the western margin of Gondwana. In addition, this basin includes the thickest known sequences containing a record of the changes in the lacustrine and fluvial systems over time (Cabaleri and Armella, 1999; Cabaleri et al., 2005, 2010a) in a seasonal climate with a dry–wet regime (Rees et al., 2000; Volkheimer et al., 2011). Moreover, outcroppings are widely distributed throughout

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the basin, covering an area of 30,000 km^2, which allows for interpretation of coeval deposits in different sub-basins and provides the opportunity to establish regional correlations and perform paleogeographic reconstructions.

The stratigraphy of the unit was defined by Stipanicic et al. (1968). The paleontologic records of the Cañadón Asfalto Formation are numerous and include those of vertebrates (Bonaparte, 1986; López-Arbarello et al., 2002; López Arbarello, 2004; Rauhut, 2006) and invertebrates (Tasch and Volkheimer, 1970; Vallatti, 1986; Musacchio, 1989; Musacchio et al., 1990; Musacchio, 1995; Gallego et al., 2010, 2011), in addition to paleobotanic (Escapa et al., 2008) and palynologic (Volkheimer et al., 2008) records. Despite this, there are few sedimentologic reports, and these are focused on the Río Chubut Medio area (Cerro Condor sub-basin, Chubut province) (Cabaleri and Armella, 1999, 2005; Cabaleri et al., 2005, 2010a). Therefore, it is necessary to provide a detailed sedimentologic study of the unit in each sub-basin to establish the evolution of the continental sedimentary systems in each depositional setting.

The focus of this study is the carbonate succession at the Estancia Fossati locality (42°48′56″S and 68º24′58.28″W) situated northwest of the village of El Escorial (Fig.), which is part of the Fossati sub-basin. The aims of this investigation were to reconstruct the initial paleoenvironmental evolution of the carbonate lacustrine system of the Las Chacritas Member of the Cañadón Asfalto Formation at the Estancia Fossati locality (Fossati depocenter) and to determine the expansion and contraction sequences of the system to unravel the role of tectonism and climate in the development of the thick sedimentary sequences.

2. Geologic setting

The Cañadón Asfalto Rift Basin is formed by north-westerly oriented strike half-grabens that delineate three depocenters, namely the Fossati (south-west of Pampa de Gan Gan), Portezuelo–Llanquetrus (south-west of Pampa de Gastre), and Cerro Cóndor (Cerro Cóndor village) depocenters (Figari and Courtade, 1993; Figari et al., 1996). Homovc et al. (1991), Figari and García (1992), Figari et al. (1992, 1996), and Figari and Courtade (1993) determined the tectosedimentary evolution of the Cañadón Asfalto Basin and distinguished four megasequences for the different stages of the half-graben.

The Permian–Triassic (249.7 ± 5.3 Ma, radiometric K/Ar) (López de Luchi and Rapalini, 2002) basement in the Fossati sub-basin is represented by the Mamil Choique Formation (Ravazzoli and Sesana, 1997) (Fig. 2). This unit is unconformably covered by the Las Leoneras Formation (Hettangian–Toarcian) (Nakayama, 1973). The Las Leoneras Formation is covered by the Middle Jurassic volcanic rocks of the Lonco Trapial Formation (Lesta and Ferello, 1972) (K/Ar 173.1 ± 9.4 Ma; Silva Nieto, 2005). A regional unconformity separates the Lonco Trapial Formation from the volcano-sedimentary Cañadón Asfalto Formation (*synrift* stage). The Cañadón Asfalto Formation is unconformably overlaid with the continental deposits of the Los Adobes Formation and the Cerro Barcino Formation (Barremian–Santonian) of the Chubut Group (Lesta, 1968; Codignotto et al., 1979). The Chubut Group sequences developed during a stage of tectonic stability or thermal subsidence (*sag* stage) (Ranalli et al., 2011). In the eastern area (Ea. La Sin Rumbo, Fig. 1), the Cañadón Asfalto Formation is covered by the Paso del Sapo Formation (Campanian/Maastrichtian) (Lesta and Ferello, 1972) and the Lefipán Formation (Lesta and Ferello, 1972). The Paleogene period is represented by the Salamanca Formation and the Eocene–Miocene by basalts (Fig. 2).

The Cañadón Asfalto Formation (Stipanicic et al., 1968) is a thick sedimentary sequence that represents lacustrine and fluvial systems with olivine basalt flows and pyroclastic intercalations at its base (Stipanicic et al., 1968; Nullo, 1983; Turner, 1983; Cabaleri et al., 2010a). The complete volcano-sedimentary unit developed in the Toarcian–Aalenian to Tithonian ages (Salani, 2007; Cabaleri et al., 2010b). The Formation is composed of two members, the Las Chacritas (lower) and the Puesto Almada (upper) Members (Silva Nieto et al., 2003; Cabaleri et al., 2010a; Gallego et al., 2011). The radiometric age (K/Ar) obtained for the Las Chacritas Member at the Cerro Cóndor depocenter is 170 ± 4.4 Ma (Salani, 2007). Similar ages were obtained from radiometric dating (Ur/Pb) (Cabaleri et al., 2010a,b) and palynologic studies (Bajocian–Early Bathonian) (Volkheimer et al., 2008). Cabaleri et al. (2008, 2010b) described the stratigraphy of the Cañadón Asfalto Formation. Cabaleri and Armella (1999, 2005), Cabaleri et al. (2005, 2006, 2008) and Silva Nieto et al. (2007) presented a detailed study of the unit and its sub-basins, paleoenvironments and paleoclimates.

The type locality of the Las Chacritas Member is the Cerro Cóndor locality in the Cerro Cóndor sub-basin. There, the Member is represented by sedimentary rocks interbedded with pyroclastic deposits and basalt flows (Cabaleri and Armella, 1999). The lacustrine facies are brownish-gray homogeneous silicified limestone with chert nodules, planar stromatolites, algal boundstones, intraformational conglomerates and bituminous black shale. At the top of the Member, limestone with mud cracks and symmetric ripples are interbedded with shale containing conchostracans and bivalves. In addition, limestone containing ostracodes, coal remains and Brecciated limestone with evaporitic associations are often present. In some areas, fine-grained sandstone beds with planar cross-stratification and bioturbation features are interbedded with tuffite sandstone and yellowish-gray to white, very fine and massive siliciclastic tuffs. These tuffs are associated with fluvial channel deposits, angular limestone and chert intraclasts and tuff, tuffite, andesite and olivine basalt extraclasts. The olivine basalts correspond to flows and sills up to 20 m in thickness as well as dykes (Cabaleri et al., 2010a). In the upper section of the Las Chacritas Member, there are hyperconcentrated flows deposits containing vertebrate remains (Cabaleri and Armella, 1999).

3. Materials and methods

The study is based on detailed logs of two sections of the Las Chacritas Member of the Cañadón Asfalto Formation at the Estancia Fossati locality. The outcrops cover a belt 2700 m long and 300 m thick that has a stratigraphic thickness of 79 m. The field descriptions include the morphology, size, color, lithology, and relevant characteristics of the beds in vertical succession and lateral variations when there were changes in the sedimentation. A control profile was developed according to Flügel (2004), taking 74 samples on a cm scale. Then, 12 additional samples from each of the previously defined microfacies were taken. Polished slabs and standard thin sections (7.5 cm^2) were prepared from the samples at the Taller de Cortes y Secciones Delgadas, Instituto de Geocronología y Geología Isotópica (INGEIS). The polished slabs were observed using a low-magnification binocular microscope (Leica S8 APO, Switzerland). The thin sections were stained with Alizarin S Red to differentiate calcite from dolomite and were observed and photographed using a petrographic microscope (ZEISS Axioskop 40, Germany). The microfacies were designated F plus a correlative number.

4. Sedimentology of the Las Chacritas Member

The Las Chacritas Member is represented by different main categories of carbonate and associated siliciclastic and volcano-clastic facies (Table 1). Erosive surfaces are common in the carbonate sequence (Fig. 3). The main facies (Table 1) are described below.

4.1. Facies

Mudstones/Wackestones with porifera spicules (F1) (Fig. 4A). This facies occurs as strata overlying the Lonco Trapial Formation (volcanic breccia). The beds are nearly 0.50 m thick and 15 m wide. Thin sections reveal that they are composed of homogeneous micrite and microsparite