



Magnetostratigraphy and cyclostratigraphy of the Tithonian interval from the Vaca Muerta Formation, southern Neuquén Basin, Argentina

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ARTICLE INFO

Keywords:

Jurassic
Tithonian
Vaca Muerta
Cyclostratigraphy
Magnetostratigraphy

ABSTRACT

A cyclostratigraphic and paleomagnetic study was carried out in the lower part of the Vaca Muerta Formation, Los Catutos Member (Lower to lowermost Upper Tithonian) at the southern region of the Sierra de la Vaca Muerta, Neuquén Basin, west-central Argentina. The Vaca Muerta Formation is known for its unconventional resource potential and its exceptional behaviour as a world-class source rock. The studied section is c. 90 m thick and is characterized by decimetre-scale rhythmic alternations of marls, mudstones and limestones, showing a well-ordered hierarchy of cycles. Elementary cycles, bundles and superbundles were recognized with frequencies within the Milankovitch spectrum band. A total of 280 standard specimens collected from 35 paleomagnetic sampling horizons, dated with ammonites, were analyzed. The quality and primary origin of the characteristic magnetization was proved through the corresponding reversal test. A magnetostratigraphic scale was thus constructed that comprises 5 reverse and 4 normal polarity intervals, spanning the Andean *Virgatosphinctes andensis* (*ex mendozanus*) (Lower Tithonian) to *Windhausenicerias internispinosum* (lowermost Upper Tithonian) ammonite Zones. Polarities were correlated with the GPTS 2016 using the equivalences between the Andean and Standard ammonite zones which, allowed to interpret that Los Catutos section was deposited between M22r to M20n Subchrons. By means of the correlation between the cyclostratigraphic and magnetostratigraphic scales, it was possible to date the Tithonian succession with unprecedented precision. Rock magnetic studies indicate that the remanence is carried by titanomagnetite.

1. Introduction

The marine Tithonian in the Neuquén Basin (Fig. 1), is characterized by a rhythmic succession of mudstones, marlstones and limestones, included in the Vaca Muerta Formation (Weaver, 1931 *emend.* Leanza, 1973). This unit is known as a world-class source rock for its unconventional resource potential (e.g., Uliana and Legarreta, 1993; Desjardins et al., 2016). It also shows exceptional outcrops of hundreds meters-thick with an excellent biostratigraphic resolution (e.g. Leanza and Hugo, 1977; Leanza, 1981; Riccardi, 2008, 2015).

Given that there is still no full agreement in the correlation between Andean and Standard ammonite zones for the Tithonian (e.g. Riccardi, 2015; Vennari et al., 2014), the calibration of this stage requires the use of dating tools other than ammonites. Recent cyclostratigraphic, magnetostratigraphic and biostratigraphic studies conducted in the Vaca Muerta Formation in southern Mendoza (Arroyo Loncoche) by Kietzmann et al. (2015), Iglesia Llanos et al. (2017), Kietzmann (2017),

and Ivanova and Kietzmann (2017), improved the correlation between the Andean and Standard Tethyan ammonite zones. In particular, Iglesia Llanos et al. (2017) using magnetostratigraphy, and Ivanova and Kietzmann (2017) from calcareous dinocysts biostratigraphy concluded that the base of the Vaca Muerta Formation would be somewhat older than interpreted from ammonites.

The main goals of this study were on the one hand, to obtain detailed cyclostratigraphic and magnetostratigraphic scales at Los Catutos (southern area of Sierra de la Vaca Muerta) and on the other hand, to confront the results with those from Arroyo Loncoche in the stratigraphic interval corresponding to the Tithonian, given that both sections yield considerably different sedimentation rates. Sedimentological data from Los Catutos section (Scasso et al., 2002, 2005; Kietzmann et al., 2014a) indicate a low-energy dysaerobic open-marine environment accumulated in a distal but shallow gently-dipping ramp system, with high sedimentation rates resulting in high productivity at the sea-surface, and incoming plumes of suspended sediments. On the other

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<https://doi.org/10.1016/j.jsames.2018.05.010>

Received 7 March 2018; Received in revised form 14 May 2018; Accepted 14 May 2018
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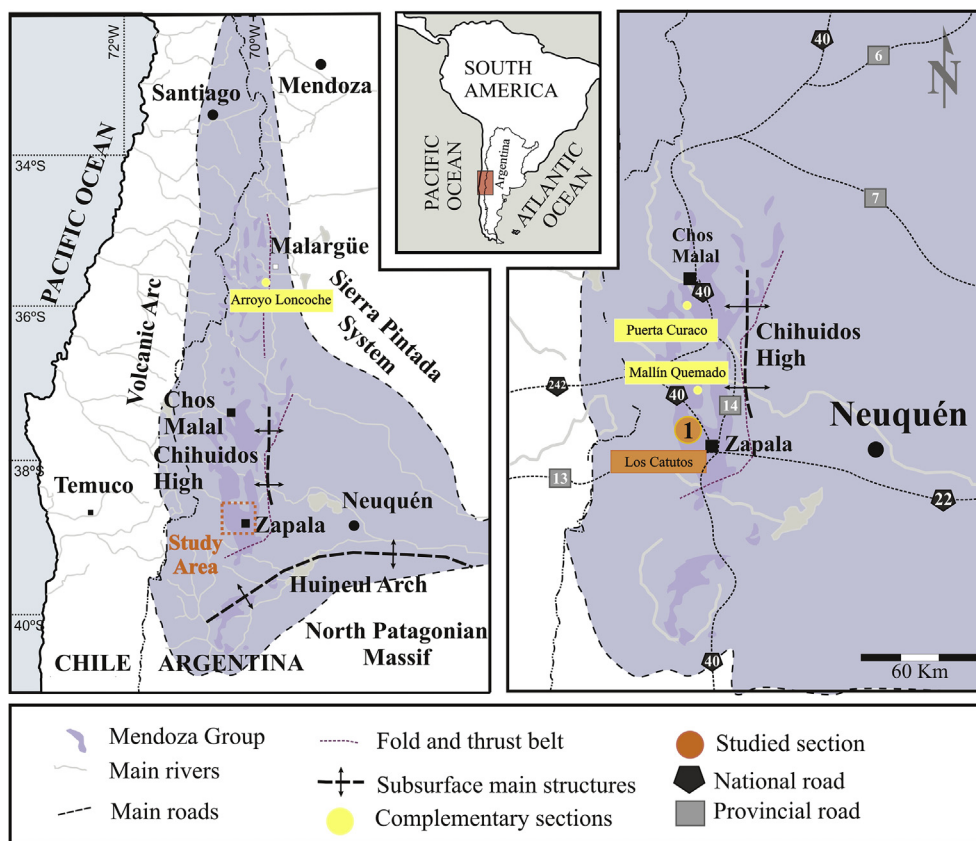


Fig. 1. Sketch map of the Neuquén Basin, showing main geological features and the studied locality.

hand, the Vaca Muerta Formation at the Arroyo Loncoche section is detailed analyzed by Kietzmann et al. (2008, 2014a,b), Kietzmann and Palma, 2011 and interpreted as a basinal to middle carbonate ramp deposit, described in four facies associations (FA-1 to FA-4), Iglesia Llanos et al. (2017). The possibility of developing such stratigraphic multidisciplinary studies in different sections will allow the construction of an increasingly robust chronostratigraphic scheme for this stage in the Andean region.

2. Geological setting

The Neuquén Basin is a retro-arc basin that began to develop in the Triassic in the Pacific margin of South America (Legarreta and Uliana, 1991, 1996) (Fig. 1). The stratigraphic framework was first defined by Groeber (1946); Groeber et al. (1953) and Stipanovic (1966), who recognized three sedimentary cycles: Jurásico, Ándico and Riogránico. Later, Legarreta and Gulisano (1989) updated this scheme and highlighted the importance of eustatic changes in the development of depositional sequences.

The Jurassic-Cretaceous in the basin is made up of marine - continental successions of at least 7000 m thick that covers c. 120.000 km². The succession was affected by the interaction and entailment of different tectonic regimes that exerted a first order control in its development and sedimentary evolution during Mesozoic times (Legarreta and Uliana, 1991, 1996). During the Late Triassic - Early Jurassic, an extensional regime was established which gave rise to isolated depocenters controlled by large transcurrent faults that got filled with deposits of the Precuyano Cycle (Gulisano, 1981; Manceda and Figueroa, 1995; Vergani et al., 1995; Llambías et al., 2007; Giambiagi et al., 2008; Arregui et al., 2011). From the Early Jurassic to the Late Cretaceous the onset of thermal subsidence with episodic tectonic events took place, leading to the filling of depocenters with continental and marine sediments from the Cuyo, Lotena and Mendoza Groups (Vergani et al.,

1995; Legarreta; 2002; Leanza, 2009). From the Late Cretaceous and throughout the Cenozoic, a compressive regime prevailed (Mosquera and Ramos, 2006; Ramos and Folguera, 2005; Ramos, 2010). A series of N-S oriented fold and thrust belts, produced by the Andean deformation, exposed the Mesozoic successions along the Neuquén Basin (e.g. Giambiagi et al., 2003; Zapata and Folguera, 2005; Ramos and Folguera, 2005; Yagupsky et al., 2008; Ramos, 2010).

3. The Vaca Muerta Formation at the Los Catutos area

The studied section is located in the southern part of the Neuquén Basin, and crops out in the Los Catutos area, 13 kilometers northwest of Zapala, Neuquén province. It is made up of c. 90 m rhythmic alternation of marlstones, mudstones and limestones (Figs. 1 and 2).

The Vaca Muerta Formation is part of the Mendoza Group (Stipanovic, 1966) (Fig. 3). This group consists of three shallowing-upward sedimentary cycles or subgroups (Leanza, 2009): i) Upper Kimmeridgian - Lower Valanginian: Lower Mendoza Subgroup (see also Vergani et al., 1995), ii) Upper Valanginian - Lower Hauterivian: Middle Mendoza Subgroup, and iii) Upper Hauterivian - Lower Barremian: Upper Mendoza Subgroup. The beginning of the Lower Mendoza Subgroup is characterized by the continental deposits of the Tordillo Formation of fluvial and aeolian origin (Kimmeridgian - Lower Tithonian?) overlaid by marine deposits of the Vaca Muerta Formation (Tithonian - Valanginian).

The Los Catutos Member was defined by Leanza and Zeiss (1990) in the southern part of the Sierra de la Vaca Muerta, who identify lithographic limestones plenty of off-shore vertebrate and invertebrate marine fossils, intercalated between the lower and upper parts of the Vaca Muerta Formation. Parent et al. (2013) formally proposed the Portada Covunco and Pichi Moncol Members, respectively, to refer to these parts of the Vaca Muerta Formation. However, we interpret that both the Lower and Los Catutos Members show a clinofom pattern that

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