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Tectonic inversion events in the western San Jorge Gulf Basin from seismic, borehole and field data

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ABSTRACT

The San Jorge Gulf Basin, located in Central Patagonia, has been interpreted as a Jurassic-Cretaceous rift basin that was later inverted mainly in its western sector. Consequently, the Bernardides System formed as a set of foreland contractional structures that constitute the core of the Patagonian broken foreland, exhuming continental deposits of the Cretaceous Chubut Group, 500 km away from the Pacific trench. In spite of the intense research done in the San Jorge Gulf Basin many aspects remain under discussion, particularly those regarding the age of uplift of the Bernárdides System. In order to unravel the tectonic evolution of the western San Jorge Gulf Basin (Río Mayo Sub-Basin), we analyzed subsurface information (2D and 3D seismic lines and oil wells) located in the western area of the basin and compared this with surface data of the southern Bernárdides System. Based on our interpretation, the western part of the basin could have been uplifted in a series of deformational events that began as early as late Early Cretaceous, related to the initial uplift of the Patagonian broken foreland, during the early stages of South Atlantic opening. Subsequent stages of tectonic reactivation identified in this system have selectively inverted previous extensional structures according to the variable direction of the greatest horizontal stress ($\sigma 1$) acting at each time.

1. Introduction

The San Jorge Gulf Basin (SJGB), located in Central Patagonia of Argentina, is a major hydrocarbon producer basin known worldwide due to its paleontological content, especially for its dinosaurs and Cenozoic land mammals. The origin of this basin is closely related to the breakup of Western Gondwana and consequently involves several episodes of crustal stretching. Its western sector known as Río Mayo Embayment/Sub-Basin or Aysén Basin constitutes the oldest part of the basin. This sector is characterized by shelf deposits related to a marine to mixed back-arc setting (Fig. 1) (Aguirre Urreta and Ramos, 1981; Clavijo, 1986; Suárez et al., 2009a). The Río Mayo Sub-Basin was associated with several intra-arc and retroarc depocenters, that developed contemporaneously to a westward jump of the arc front between 150 and 140 Ma (Late Jurassic to Early Cretaceous) (Rolando et al., 2002, 2003).

Tectonic inversion of the western sector of the SJGB has been classically considered as a direct aftermath of the Andean deformation (Peroni et al., 1995; Homovc et al., 1995). Hence, numerous depocenters were inverted at varying degrees depending on their orientation respect to the main Andean stress field (Homovc et al., 1995). As a result of these deformational events, an intraplate orogenic system known as the Bernárdides System developed about 300 km east of the Andes in the west central part of the SJGB, east of the study area (Fig. 1). The most prominent topographic feature of this system is the Sierra de San Bernardo, where extensive deposits of the late Early to Late Cretaceous Chubut Group crop out (Lesta, 1968). The Bernárdides System is currently considered as part of the broad Patagonian broken foreland that extends from the western flank of the North Patagonian Massif to the core of the Deseado Massif (Folguera and Ramos, 2011; Bilmes et al., 2013; Gianni et al., 2015a, b). Despite intense research in the SJGB, the age of the initial uplift of the Bernárdides System remains somehow controversial: Even though the most accepted contractional event had been considered as late Miocene for decades (Peroni et al., 1995; Homovc et al., 1995), a few works pointed out to earlier uplift events: In this line, Paredes et al. (2006) described locally,

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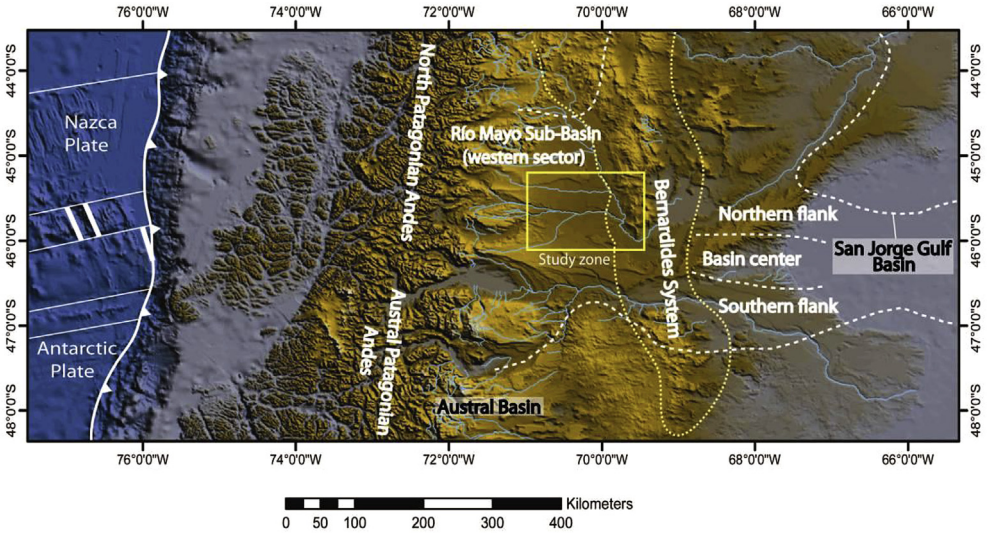

Fig. 1. Location of the study area in the Central Patagonian foreland region in the western sector of the San Jorge Gulf Basin. Regions analyzed in this work, based on the dominant structural style and orientation, are indicated. The location of the study zone shown in Fig. 2 is also indicated.

thickness variations in the late Paleocene Río Chico Group in the subsurface area of the Bernárdides System near the orogenic front of the broken foreland system. Interestingly, early works of Feruglio (1949) and Lesta et al. (1980) had suggested an even earlier uplift event in Late Cretaceous times to explain the lack of transgressive marine deposits of the Salamanca Formation (Danian) over the Chubut Group in the Sierra de San Bernardo area. In this line, Barcat et al. (1989) posed stages of tectonic inversion contemporaneous to the deposition of the Chubut Group (late Early to Late Cretaceous), after which Homovc et al. (2011), through the analysis of subsurface seismic data in the Rio Mayo Sub-Basin, showed direct evidence of late Early Cretaceous contractional deformation (Fig. 1). More recently, synorogenic deposition in all units belonging to the Chubut Group has been described from surface and subsurface data over the Sierra de San Bernardo (Gianni et al., 2015a). In the northern sector of the Bernardides System, Marquez and Navarrete (2011) proposed an even older contractional event affecting the foreland zone based on the description of an angular unconformity between the Chubut Group and the Early to Middle Jurassic Lonco Trapial Group. A similar tectonic event has been described in the Deseado Massif, south of the San Jorge Gulf Basin (Fig. 1), where Neocomian deposits were folded and unconformably covered by sedimentary sections equivalent to the lower section of the Chubut Group (Giacosa et al., 2010).

To the west, in the North Patagonian Andes where the Río Mayo Sub −Basin filling is partially exposed, an angular unconformity between the Neocomian deposits and the volcanic rocks of the Divisadero Group (120–100 Ma) has been interpreted as a consequence of the early uplift of this belt in the late Early Cretaceous (Suarez and De la Cruz, 2000; Folguera and Iannizzotto, 2004; Suárez et al., 2009a, b). In this sense, Iannizzotto et al. (2004) concluded that most of the contractional structure exposed in this region developed prior to 90 Ma.

Cretaceous contraction affecting Central Patagonia has been either explained by high convergence rates during fast westward motion of South America after the initial stages of formation of the South Atlantic ocean (Somoza and Zaffarana, 2008) as well as the shallowing of the subducted slab (Barcat et al., 1989), evidenced by an eastward arc migration at that time (Gianni et al., 2015a). The latter authors proposed that such slab shallowing may have occurred by a combination of high convergence rate and fast overriding of young lithosphere attached to two consecutive mid-ocean ridges that subducted beneath Central Patagonia in late Early Cretaceous times.

This work focuses in a broad subsurface sector of the retroarc area of the Río Mayo Sub-Basin, where Neocomian depocenters have been identified and in the adjacent southern Bernárdides System (Clavijo, 1986; Strelkov et al., 1994; Figari et al., 1996; Homovc et al., 2011) (Fig. 1). The main objective of this study is to characterize and determine the age of the contractional deformation of the western sector of the SJGB (Río Mayo Sub-Basin) from seismic and field information, through identification of growth strata associated with tectonic inversion. Then, Danian paleogeography characterized by a widespread Atlantic marine transgression through Central Patagonian is discussed. Finally, variable orientation of the contractional stress field through time is evaluated through the degree of inversion of the recognized structures, determined from seismic information, considering their different strike.

2. Location of the study area, material and methods

The study area is located at the central sector of Patagonia in Argentina, as part of the San Jorge Gulf Basin (Fig. 1). This basin has been usually divided by the oil industry into five regions depending on the dominant structural style: on the Atlantic passive margin the North and South flanks and Basin Center, and to the west next to the Andean front the Bernárdides System and the Western Sector (Fig. 1). This work focuses on the last two areas analyzing subsurface and field information.

In order to study the subsurface area of the Río Mayo Sub-Basin, 2200 km of 2D and 200 km^2 of 3D seismic data, mainly recorded in the past decades by the YPF oil company, have been analyzed. Currently, this area is operated by the Energial SA Company, which has generated valuable information through the acquisition of additional 3D seismic images that are also inspected in this work. Moreover, we used information obtained from 46 drilling wells, drilled since the 1960's to the present (Fig. 2). The seismic information was analyzed using the software Kingdom Suite version 8.6, for all the interpretations and grilled.

3. Geological framework

The SJGB is the result of extensional stresses that affected the