STRATIGRAPHIC CHARACTERIZATION OF AREQUIPA BASIN FROM SEDIMENTARY STACKING PATTERN AND AMMONITES BIOZONES

Aldo Alván [1], Audrey Decou [1] & Mirian Mamani [2]

[1] University of Göttingen, Geoscience Center, Department of Sedimentology and Environmental Geology, Goldschmidtstrasse 3, D-37077, Germany. E-mail: aalvand@gwdg.de

[2] University of Göttingen, Department of Geochemistry, Goldschmidtstrasse 1, D-37077, Germany.

1. INTRODUCTION

Characterizing sedimentary stacking patterns and depositional sequences associated with standard ammonite biozones, is crucial to understand the geodynamic evolution of Arequipa basin during Jurassic period in southern Peru and northern Chile (14°S to 20° S, in Fig. 1). Arequipa basin consists of Triassic, Jurassic and Cretaceous rocks that are currently part of Coastal, Western and Eastern Cordilleras, and Central Andean Altiplano. These rocks were deposited in a rift context, creating enough sedimentary accommodation space as well as in central and northern Peru (Jacay et al., 1999; Sempere et al., 2004). Several of the pre-orogen tectonic elements coincide either correspond to the actual ones, such as Ica-Islay-Ilo Fault System (SFIII, Spanish abbreviation) (Acosta et al., 2010), Cincha-Lluta-Incapuquio Fault System (SFCLLI), Cusco-Lagunillas-Mañazo Fault System (SFCLM) and Urcos-Sicuani-Ayaviri Fault System (Sempere et al., 2004; Carlotto et al., 2009). Above these alignements, both sedimentary and volcanic materials were deposited (Carlotto et al., 2009; Acosta et al., 2010). By mean integration of these Fault Systems and sedimentary facies analysis, a new geodynamic model is suggested for Arequipa basin. Such results support to understand how relative sea level changes contrast or interact with subsidence, refining previous sea level curves (Vicente, 2005, 2006; Alván & Acosta, 2010).

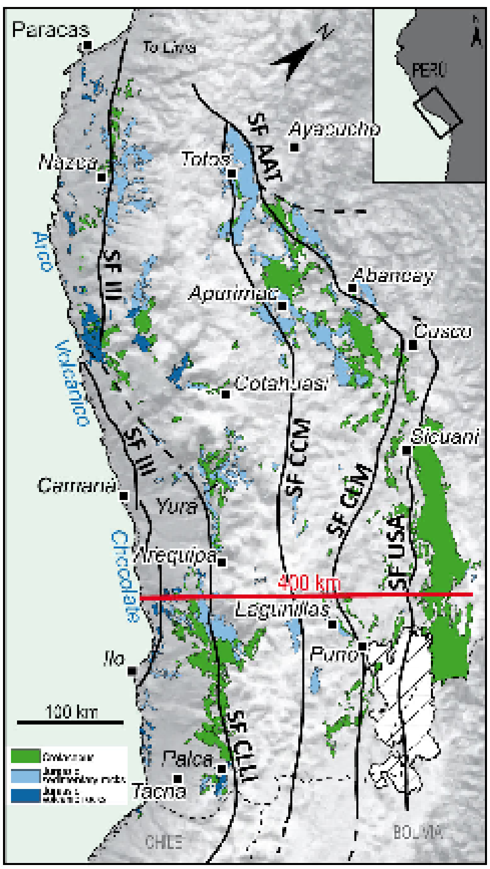

Fig. 1. SFAAT: Abancay-Andahuaylas-Totos Fault System, SFCLLI: Cincha-LLuta-Incapuquio Fault System, SFIII: Ica-Islay-Ilo Fault System, SFCCM: Condoroma-Caylloma-Mollebamba Fault System, SFCLM: Cusco-Lagunillas-Mañazo Fault System, SFUSA: Urcos-Sicuani-Ayaviri Fault System (Vicente, 1989; Jacay et al., 2002; Carlotto et al., 2009; Acosta et al., 2010).

RELATION BETWEEN DEPOSITIONAL PATTERNS AND TECTONIC SYSTEMS IN AREQUIPA BASIN

In Arequipa basin are described Jurassic sedimentary deposits with sequence boundaries, regressive and transgressive system tracts (Vicente, 2006; Alván & Acosta, 2010), possibly related to tectonoeustasy (Fig. 2). For instance, tectonic domains activity (Carlotto et al., 2009; Acosta et al., 2010) during sedimentation are highlighted, because they played an important role to define accommodation space (Figs. 1 and 3). Prosser (1993) interpreted linked depositional systems since seismic reflectors of rift tectonic signatures, noting that several active fault systems that bounded the basin are linked with sedimentary input. Eustatic fluctuations of Vail et al. (1977) cannot be applied in this context (Prosser, 1993), because corresponds to an active tectonic setting (Sempere et al., 2004).

For instance, each depositional system is linked to a *tectonic system tract* (Prosser, 1993; Kuchle et al., 2008). Prosser (1993) define four main stages: (1) *Rift Initiation system tract*, (2) *Rift Climax system tract*, (3) *Immediate Post-Rift systems tracts* and (4) *Late Post-Rift systems tracts*. These concepts characterize most of sedimentary piles in Arequipa basin; however, this abstract only refers to *Rift Climax system tract* (Fig. 3), which in southern Perú corresponds since Toarcian to Callovian age.

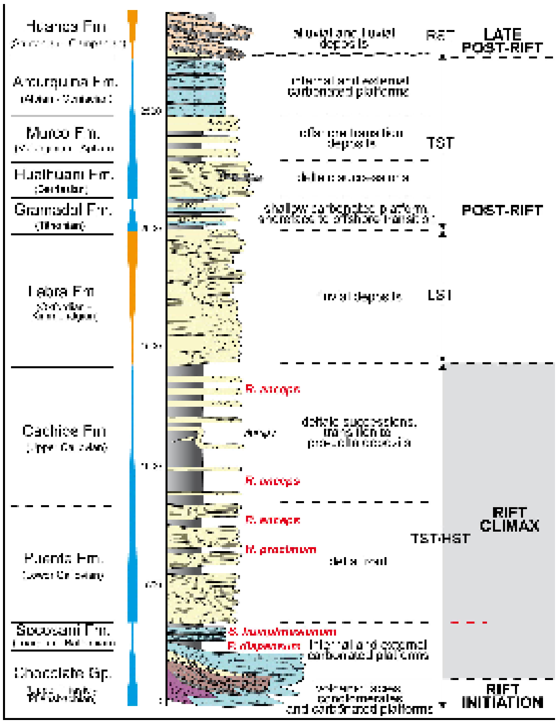

Fig. 2. Generalized stratigraphy of Arequipa region, Jurassic ammonite biozones.

1. Toarcian to Bathonian: Rift Climax system tract (early stage). Depositional features of this tectonic system are related with differential deposition due to the irregular topography of the basement, created by the activity of the SFIII, SFCLLI, SFCCM, SFCLM y SFUSA (Fig. 1). The interval Upper Toarcian to Bathonian is considered for Socosani Fm. carbonated platforms in Arequipa and San Francisco Fm. in Tacna (Benavides, 1962). These units are aligned following the SFIII y SFCLLI (Fig. 1). The Unidad Calcárea Inferior of Lagunillas Group outcropping in Puno, corresponds from Sinemurian to Bajocian (Jaillard & Santander, 1992), and occurs along the NW-SE striking SFCLM and SFUSA (Fig. 1). These system faults are thought to be developed individually during this stage, triggering conglomeratic fans (Prosser, 1993) coexisting with shallow marine facies (Fig. 3-1), as seen in the base of Socosani Fm. in Yura, Alto del Meadero (Moquegua) and in La Yarada (Tacna). A marine ingression is suggested to occur due because subsidence exceeded eutatism; however, some similarities with eustatic global curves of Hardenbol et al. (1998) and Hallam (2001) are noted. Also, sedimentary signature in Lagunillas (Unidad Calcárea Inferior of Lagunillas Gp.), located between SFCLM and SFUSA, suggest a less active tectonic than in Arequipa. This unit is comparable with the carbonated platforms in central Peru described as Pucara Gp. (Megard, 1979; Rosas et al., 2007; Carlotto et al., 2009).
These limestones are constrained in age from Toarcian to Bathonian, by the Toarcian biozones *D. tenuicostatum, D. hoelderi, P. largaense, P. pacificum, C. chilensis, P. copiapoense, P. tenuicostatum, P. fluitans* (von Hillebrandt, 1987) in southern SFCLLI, by the aalenian biozones *B. manflasensis*, *Z. groeberi*, *P. malarguensis*, *bajocianas P. singularis*, *E. giebeli*, *S. humphriesianum*, *M. rotundum* (Westermann et al., 1980; von Hillebrandt & Westermann, 1985), and some bathonian ammonites, outcropping from Nazca until Tacna following the W-E striking SFAAT until SFCLLI further south. One of the features of a rift climax initiation is that the basin can contain several isolated synsedimentary faulting triggering “isolated sub-basins”, with important consecutives displacements (Prosser, 1993). This differentiation in accommodation space can explain the variations either absences of sedimentary facies between Arequipa, Moquegua and Tacna. Therefore, a differential topography might exist between the SFIII and SFCLLI from Nazca to Tacna, and between the SFCLM and SFUSA from Abancay to Puno, where outcrops corresponding to carbonated platforms with variation in thickness and often with conglomerated base are observable.

2. Callovian: Rift climax systems tracts (mid and late stage). Callovian sedimentary rocks correspond to Puente-Cachíos Fm. in Arequipa region (Acosta et al., 2011), and Unidad Lutácea of Lagunillas Gp. in Puno (Jaillard & Santander, 1992). Middle stage of a rift climax is associated with the onset of fault scarp formation, due to the extensional stresses in the basin (Fig. 3-3). According to the thickness seen in stratigraphic sections in southern Peru, is thought that the main accommodation space was placed in Arequipa, represented in Puente-Cachíos Fm. beds (~1100 m), and also in Puno, with the Unidad Lutácea of Lagunillas Gp. (~500 m, Jaillard & Santander, 1992). Mentioned thick strata are located between the SFIII and SFCLLI, and between the SFCLM and SFUSA (Fig. 1). Between SFIII and SFCLLI, the bases of these lithological units are represented by fluvial-deltaic deposits containing plants fragments, with erosive channels affecting the fault scarp bases (basal part of Puente Fm. in Yura), with some sporadic marine ingression. Later, black shales in significant thicknesses were deposited with abundant slumps (Vicente, 1989; Jacay, 2005) and containing reineckeids corresponding to *H. proximum* (= *M. gracilis*) and *R. anceps* biozones of Lower and Middle Callovian. Between the SFCLM y SFUSA in Lagunillas, black shales are also described, with slumps and reineckeids linkable with the one described in Puente Fm. (Jaworski, 1915; Jaillard & Santander, 1992).

According to the thicknesses, a major extensive activity during Callovian in SFCLLI is suggested; having in Yura a main depocenter, then between the SFCLM y SFUSA in Lagunillas (Fig. 1), and also the SFCCM might trigger partially emerged zones, as suggested in Carlotto et al. (2009). During these ages in Arequipa, turbidites, megaturbidited and slumps and in different scales (Jacay, 2005), S-SE directed, characterizing the extensive continuity of the rift, meanwhile there are consecutives occurrences of *R. anceps* biozone (en Alván et al., 2010). Coastal sedimentary facies can be deposited in the rift borders, either the fault scarp crests as submarine coarse grained fans, and might be aligned to the SFCLLI (cerro Gramadal, Yura). In spite of showing a eustatic sea level during Callovian (Hardenbol et al., 1998), a major influence of subsidence exceeding eutatism is interpreted during this age.

PALEOGEOGRAPHY OF JURASSIC AND AMMONITE BIOZONES

Interpretations based on stratigraphic signatures, sedimentary lithofacies and ammonite occurrences; redefine the paleogeographical scheme for Arequipa basin. The continuous rifting process during Jurassic included simultaneously fault systems perpendicular to the actual coastal line (Jaillard & Sempere, 1989; Carlotto et al., 2009; Acosta et al., 2010) giving way to consecutives sedimentary accommodation spaces episodes. In this context, tilting and falling blocks occurs along the SFIII and SFCLLI in the west and the SFCLM y SFUSA to the east of the basin (Fig. 1), allowing marine ingression in differential manner and possibly triggering "sub-basins", with conspicuous stratigraphic signatures. In southern Peru, late Lower Jurassic and Middle Jurassic are constrained in area by two main tectonic belts, the first in the west, represented by outcrops from Pisco until the Chilean border, and the other in the east, represented by outcrops in Puno (Westermann et al., 1980) and Apurimac further north. The western belt comprises the SFIII and SFCLLI, showing beds that were deposited during the early stage of the *Rift Climax system tract* (Socosani Fm., Toarcian to Bathonian) with reports of ammonites of the families Hammatoceratidae, Dactylioceratidae, Hildoceratidae, Stephanoceratidae, Sphaeroceratidae and Macrocephalitidae.

Analyses made in actual *Nautilus* chambers (Westermann, 1987) suggest that these ammonite families could reach depth of 50 m. While on the east side, between the SFCLM and SFUSA outcrops large carbonated platforms of the Unidad Calcárea Inferior of Lagunillas Gp., with Sinemurian ammonites (Westermann et al., 1980). In Puno region (NW Titicaca lake), the only fossil evidence of Middle Jurassic is the equinoid *Diademopsis*, which reach Bajocian (Sempere et al., 2004), and could be equivalent in age with Sipin and Socosani Fms. (Sempere et al., 2004; Carlotto et al., 2009). Also, in the further north SFAAT, in Pucará basin, there are many outcrops with reports of Aalenian, Bajocian and Bathonian ammonites included in Cercapuquio, Chunumayo and Chaucha Fms. beds (Westermann et al., 1980; von Hillebrandt & Westermann, 1985), suggesting a vertical continuity in carbonated deposition since Aalenian. Currently these strata are lying above a structural high defined as Totos-Paras (Carlotto et al., 2009) aligned with the SFAAT, which mentioned authors described that during Lower Jurassic age were separated by this high, and there Roperch et al. (2006) suggest a strong rotation since Jurassic age (-90°).

During Callovian age, between the SFIII and SFCLLI, between the SFCLM y SFUSA, and surrounding areas, ammonites of the *H. proximum* y *R. anceps* biozones are present, comprising the families Oppeliidae and Reineckeiidae. Between the SFIII and SFCLLI in Yura, are described Callovian biozones repeatedly in several layers of ~1000 m thickness (Puente-Cachíos Fm. in Fig. 2), together with sedimentary structures that reflects tectonic instability (Vicente, 1989). Similarly, between the SFCLM and SFUSA, the Unidad Lutácea of Lagunillas Gp. contains beds with ammonites of the same Callovian families. Westermann (1987) suggest that these families could reach up to 250 m depth. According to the genetic characterization of the Arequipa basin, this stage corresponds to the middle and late *Rift Climax system tract*, and coincides with the major basin opening and marine ingression in Callovian age (Sempere et al., 2004), both in Arequipa, Puno and Apurimac regions, and western Abancay. During Callovian, tectonism is attributed as major element of marine ingression in Arequipa basin, exceeding eutatism, and being a stronger process than Toarcian-Bathonian range.

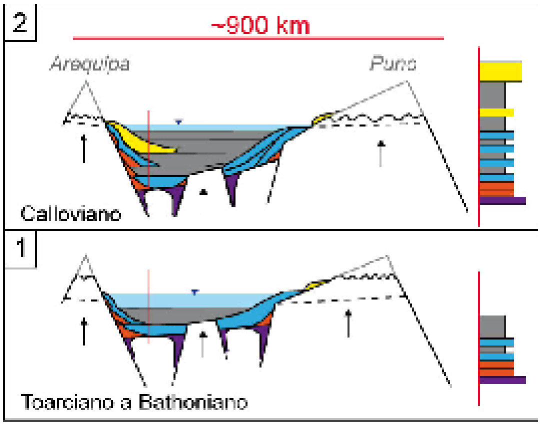

Fig. 3. Schematic representation of Arequipa basin evolution Turing Middle Jurassic, inspired in Kuchle et al. (2008). The more active edge corresponds to the left side of the diagrams, and the less active in the opposite side. Spatial and chronological rates of the depositional systems in a basin bounded by normal faults are attributed mainly to tectonics. Displacement of faults during a basin develop, controls the erosive potential and sediment input rate (Prosser, 1993). (1) *Rift Climax system tract* (early stage), (2) *Rift-Climax system tract* (mid and late stage). Adean shortening was calculated in ~900 km, ~70 Ma ago (Yang & Liu, 2003).

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