Climatic changes recorded during the Jenkyns Event (Early Jurassic) in the lacustrine sediments of the Sichuan Basin (China)

Registro de los cambios climáticos durante el Evento Jenkyns (Jurásico Inferior) en los sedimentos lacustres de la Cuenca de Sichuan (China)

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ABSTRACT

The Toarcian lacustrine deposits of the Sichuan Basin (China) are represented mainly by silty marlstones and bivalve-rich limestones disposed in decametric-scale thickening upwards sequences. Dense accumulations of bivalve shells are related to episodes of mass mortality under oxygen depleted conditions in the bottom waters. The geochemical detrital proxies indicate a climatic turnover during the Toarcian. The lower part of the Toarcian succession is characterized by high values of Zr/Rb and Sr/Cu that point to warm and arid conditions, whereas the upper part is characterized by low values of Zr/Rb and Sr/Cu and enhanced C-value related to relatively more humid conditions.

Key-words: *Toarcian, microfacies, geochemistry, climatic change*

RESUMEN

Las rocas sedimentarias lacustres del Toarciense de la Cuenca de Sichuan (China) son principalmente margas limolíticas y calizas de bivalvos organizadas en secuencias decamétricas estrato-crecientes. Los packstones de bivalvos se relacionan con episodios de mortalidad masiva por condiciones hipóxicas en el fondo del lago. Los indicadores geoquímicos de detritismo muestran un cambio climático en el Toarciense. La parte inferior de la sucesión estudiada presenta valores altos de Zr/Rb y Sr/Cu que indican condiciones áridas y cálidas, mientras que la parte superior muestra valores bajos de Zr/Rb y Sr/Cu, así como un aumento del índice-C propios de un clima más húmedo.

Palabras clave: *Toarciense, microfacies, geoquímica, cambio climático.*

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Introduction

The Sichuan Basin, located in South China, includes Toarcian (Lower Jurassic) lacustrine continental rocks consisting of limestones, sandstones and siltstones of the Da'anzhai Member of the Ziliujing Formation (e.g. Liu *et al*., 2020). The study of these materials is relevant for better understanding the impact of the Jenkyns Event (early Toarcian) in emerged areas. The early Toarcian was characterized by a global warming trend parallel to a perturbation of the carbon cycle, the development of oxygen depleted conditions in the marine basins (Toarcian Oceanic Anoxic Event) and a biotic crisis that resulted on a second order mass-extinction that affected marine and continental ecosystems (e.g. Reolid *et al*., 2020). The aim of this work is to interpret the climatic fluctuation in the Sichuan Basin from the analyses of facies and geochemical proxies.

Geological setting

The Sichuan Basin is located in the central part of China and palaeogeographycally was situated in the SE of Eurasia close to the boundary between Tethyan Ocean and Panthalassa Ocean (Fig. 1). The Sichuan Basin sedimentation was marine from Late Sinian to Middle Triassic and continental from Late Triassic to Eocene. During the Early Jurassic the Sichuan Basin developed a freshwater lacustrine-delta depositional system (Liu *et al*., 2021). The Da'anzhai Member was deposited in a time interval with high subsidence rate that favoured the deepening of the basin and the conditions for accumulation and preservation of organic matter (Cui *et al*., 2023).

The Dacao D section is located in the NE of the Sichuan Basin. This is constituted by a 132 m thick succession of siltstones, sandstones and limestones, and includes the uppermost 12 m of the Ma'anshan Member (Pliensbachian) and 92 m of the Da'anzhai Member (Toarcian) corresponding to the Ziliujing Formation. The uppermost 28 m of the studied section correspond to the Lianggaoshan Formation (Middle Jurassic).

Materials and methods

Of the total of 56 samples, 31 correspond to silty marlstones to siltstones, 23 to limestones and 2 to sandstones. Thin sections were prepared for limestones and sandstones, and studied for microfacies under microscope (Olympus SZ-PT) at the University of Jaén (Spain).

Whole-rock analyses of the major elements were carried out using a PANalytical (Zetium) wavelength dispersive X-ray fluorescence spectrometer at the Centro de Instrumentación Científica (CIC) of the University of Granada (Spain). Trace

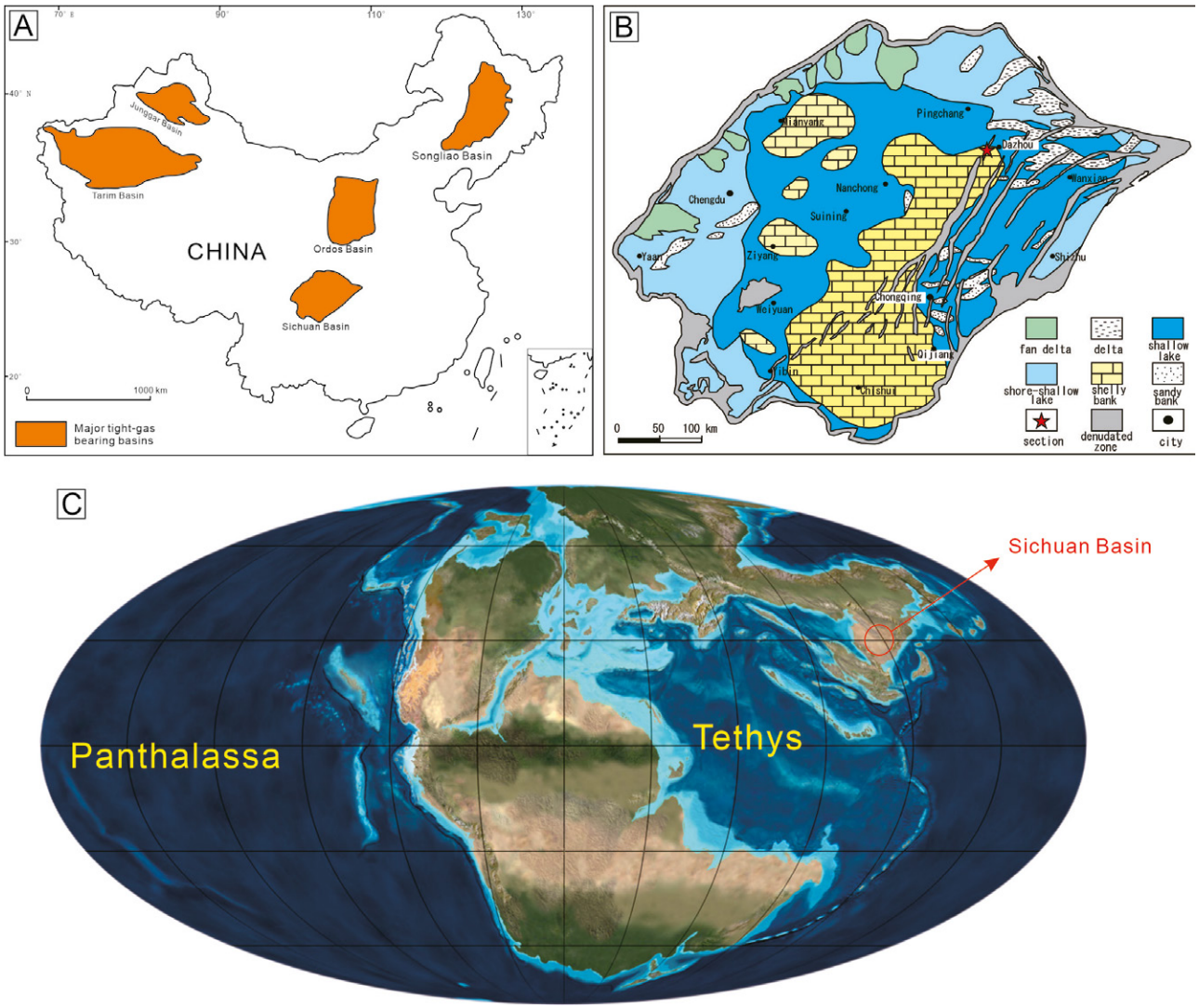

Fig. 1.- Geological setting. A. Location of the Sichuan Basin and other lacustrine Mesozoic basins in China. B. Distribution of Early Jurassic palaeoenvironments in the Sichuan Basin and position of the Dacao D section. C. Palaeogeographic location of the Sichuan Basin during the Toarcian. See color figure in the web.

Fig. 1.- Localización geológica. A. Ubicación de la Cuenca de Sichuan y otras cuencas lacustres mesozoicas de China. B. Distribución de paleoambientes en el Jurásico inferior de la Cuenca de Sichuan y ubicación de la sección Dacao D. C. Localización paleogeográfica de la Cuenca de Sichuan durante el Toarciense. Ver versión en color en la web.

elements were analysed using a NexION 300D inductively coupled plasma-mass spectrometer at the CIC. Palaeoclimatic conditions were approach using geochemical proxies (Sr/Cu and Zr/Rb ratios). In addition, the C-value relates elements typically enriched under moist conditions (Fe, Mn, Cr, V, Ni, and Co) and elements relatively enriched under arid conditions (Ca, Mg, K, Na, Sr, and Ba) (Moradi *et al*., 2016).

Results

Lithofacies and microfacies

The lower part of the section (top of the Pliensbachian) is composed by siltstones and silty marlstones with some medium to coarse sandstones (Fig. 2A). The beginning of the Toarcian is characterized by the record of an alternance of bivalve-rich limestones and silty marlstones in a thinning upwards trend (around 10 m). The next 50 m are constituted by a stratigraphic interval dominated by dark siltstones and silty marlstones with thin layers of bivalve-rich limestones, the last ones organized in a thickening upwards sequence. The microfacies are packstones of densely packed shells and shell fragments of bivalves, and secondarily gastropods and ostracods (Fig. 2B). The degree of packing, fragmentation and recrystallization of bivalve shells is variable among layers.

The subsequent 30 m constitute a new thickening upward sequence with around 14 m poorly exposed in the outcrop, and the top composed by thick bedded bivalve-rich limestones with packstone microfacies.

The Lianggaoshan Formation overlies the Da'anzhai Member, and its lower part is constituted by sandstones with thin siltstone interlayers.

Geochemical proxies of climatic conditions

For avoiding the lithological effect on the geochemical proxies we have separated the data obtained from limestone and those from siltstones and silty marlstones. The Zr/Rb ratio shows a relative increase from the top of Pliensbachian to the mid part of the Da'Anzhai Member (around meter 53), mainly observed in the silty marlstones. From here to the top of the member there is a decrease of

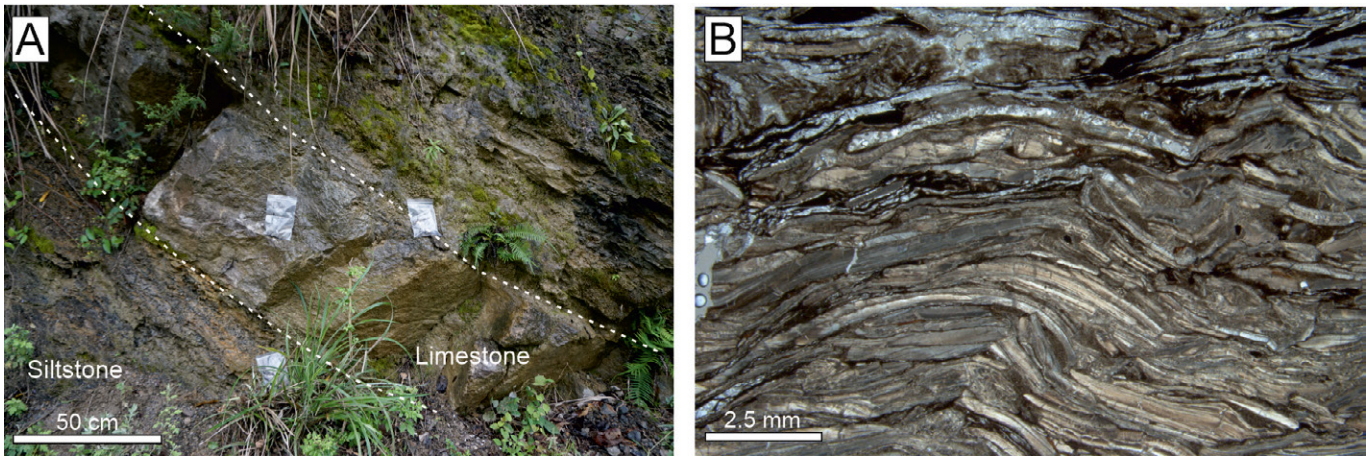

Fig. 2.- Lithofacies and microfacies. A. Field view of the lower part of the Da'Anzhai Member at the Dacao D section. B. Packstone of thin-shelled bivalves of the lithofacies of bivalve-rich limestones from the lower part at the Da'anzhai Member.
Fig. 2.- Litofacies y microfacies. A. Vista de afloramiento de la parte inferior del Miembro Da'Anzhai en la sección de Dacao D. B. Packstone de conchas de bivalvos correspondientes a la litofacies de calizas de bivalvos procedente de la parte inferior del Miembro Da'Anzhai.

the Zr/Rb ratio observed both in limestones and silty marlstones. Values of Zr/Rb newly increase in the boundary between Ziliujing and Lianggaoshan formations.

The Sr/Cu ratio shows abrupt fluctuations in the lower part of the section in both signals from limestones and silty marlstones (Fig. 3). After the meter 53 (middle part of the Da'anzhai Member), the Sr/Cu decreases to very low values without fluctuations. Both Zr/Rb and Sr/Cu show significant peak in the base of the Da'anzhai Member.

The C-value is higher in the silty marlstones than in limestone samples. The curve from silty marlstones shows high values except for a significant decrease in the lower part of the Da'anzhai Member, coincident with the peak of Zr/Rb and Sr/Cu. The curve of C-value from limestones shows an important increase in the mid part of the Da'anzhai Member, where Zr/Rb and Sr/Cu begin the decrease of values.

Interpretation

Different studies in the Toarcian lacustrine deposits of the Sichuan Basin have identified oxygen depleted conditions as well as high total organic carbon (Liu *et al*., 2022). In this context, the presence of dense accumulations of benthic macroinvertebrates, mainly bivalves, could be related to episodes of colonization of the bottom after oxygenation events, and subsequent mass mortality when anoxic conditions returned. The main calcareous component of the limestone beds are bivalve shells. Therefore, the thickening upwards carbonate sequences are related to more common occurrences of bottom colonization and mass-mortality cycles.

Over imposed to these sequences observed according to litho- and microfacies, there is a clear climatic fluctuation in the mid Da'anzhai Member.

The Zr/Rb ratio is a proxy of silt/clay ratio (Kylander *et al*., 2011) considering that Zr is normally enriched in medium and coarse silt and linked to heavy minerals such as zircon, whereas Rb present a very strong sorption to clay minerals. In addition, Zr content is typically used as an eolian detrital proxy and Rb as a fluvial detrital proxy (Rodríguez-Tovar and Reolid, 2013). Relatively high Zr/Rb values in the lower part of the section indicate enhanced arid conditions in the lower part of the Da'Anzhai Member, and the subsequent decrease.

High Sr/Cu ratio in lake sediments is interpreted as weathering proxy under warm conditions (Cao *et al*., 2015; Moradi *et al*., 2016). Therefore, the lower part of the Da'anzhai Member represents warmer conditions than the upper part.

The C-value curve for silty marlstones shows high values except in the lower part of the Da'anzhai Member where is a significant decrease coincident with the peak of Zr/Rb and Sr/Cu curves for limestones (Fig. 3). This is related to an episode of arid conditions in the beginning of the Toarcian. The curve of C-value for limestones shows an important increase in the mid part of the Da'anzhai Member just above the high values of Zr/Rb and Sr/Cu pointing to relatively moist conditions. The C-value increases newly in the Lianggaoshan Formation where sandstones are related to more humid climate.

Conclusions

The Toarcian lacustrine deposits of the Dacao D section in the Sichuan Basin (China) were deposited in a subsiding basin dominated by siltstones and silty marlstones and secondarily bivalve-rich limestones. The limestones are constituted almost exclusively by bivalve shells and form decametric-scale thickening upwards sequences. The dense accumulations of bivalve shells are related to episodes of colonization of the lake bottom and subsequent mass mortality under oxygen depleted conditions.

The Da'anzhai Member shows two parts according to geochemical detrital proxies that evidence a climatic turnover during the Toarcian. The lower part characterized by warm and arid conditions according to high values of Zr/Rb and Sr/Cu, whereas the upper part (from meter 62) is characterized by lower Zr/Rb and Sr/Cu, and relatively higher C-value, pointing to more humid conditions.

Author contributions

Reolid: design of the work, microfacies and geochemistry, writing and figures. Ayadi: geochemistry and figures. Jin: design of the work, field work, writing and figures. Abad: writing. Baranyi: writing. Franceschi: field work, writing. Preto: field work, writing. Shi: Field work, writing.

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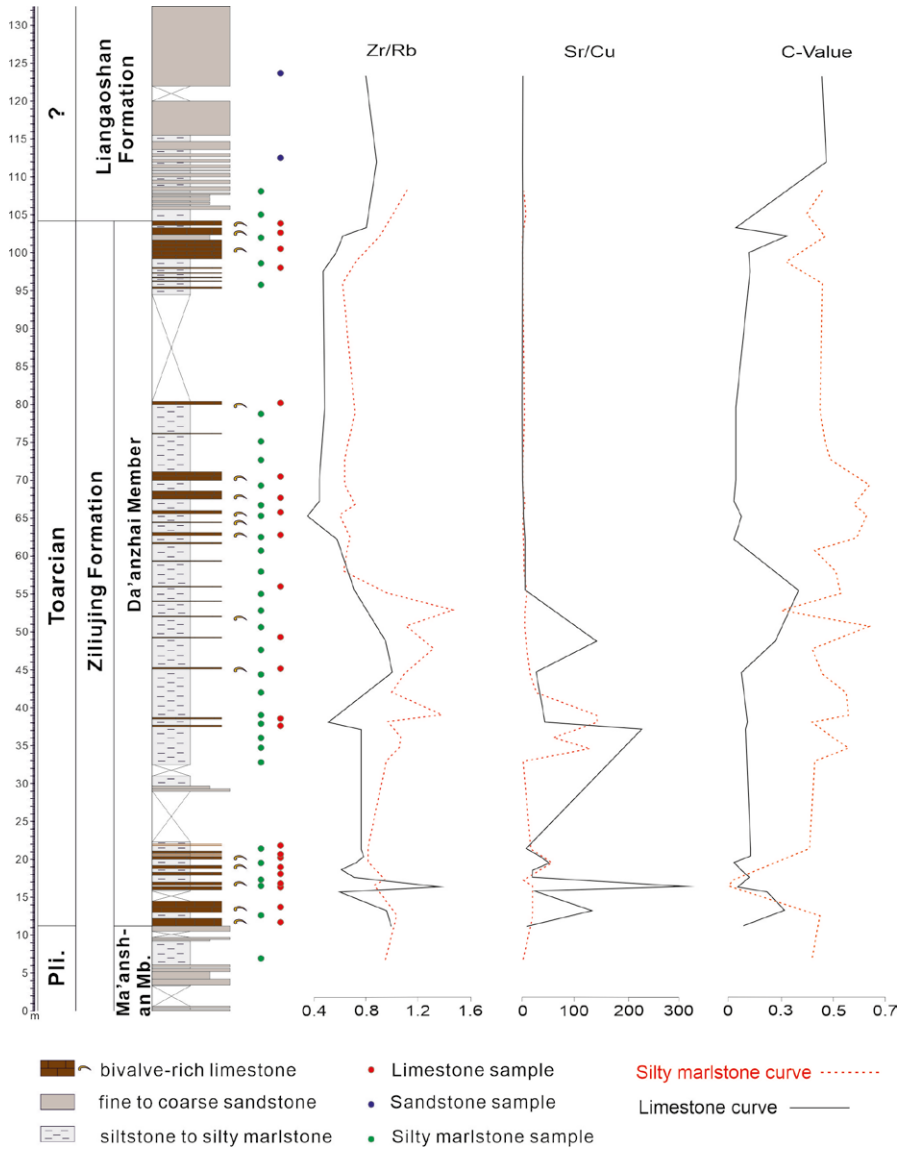

Fig. 3.- Dacao D section with indication of the studied samples and curves of the geochemical detrital proxies for limestone and silty marlstone samples. See color figure in the web.
Fig. 3.- Sección de Dacao D con indicación de las muestras estudiadas y curvas de indicadores geoquímicos de detritismo diferenciados para muestras calizas y de margas limolíticas. Ver versión en color en la web.

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