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Glacioeustatic cyclicity of a Pennsylvanian carbonate platform in a foreland basin setting: An example from the Bachende Formation of the Cantabrian Zone (NW Spain)

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ABSTRACT

By analysis of outcrop data, sequence stratigraphy was used to interpret the stratal architecture and evolution of a Moscovian (Pennsylvanian) carbonate platform (Bachende Formation) located in the Variscan foreland basin of the Cantabrian Zone (NW Spain). The Bachende Formation represents a delta-top carbonate platform developed in highly subsiding (average subsidence rate of 254 m/My) distal shelf areas of the basin. It reached a thickness of 650 m and covered an area of ~170 km^2 (after conservative palinspastic restorations). The platform interior succession is mostly composed of low-relief mound-shaped micritic boundstones, alternating with bioclastic mudstones/wackestones, peloidal–foraminiferal packstones/grainstones, calcareous algal bafflestones and skeletal and ooidal grainstones. Landwards (to the W), carbonate platform beds alternate and interfinger with deltaic sandstones and shallow marine shales.

The platform interior consists of three sequences (S1, S2 and S3), ranging from 180 to 230 m in thickness and from 1.3 to 0.5 My in age. These sequences are in turn subdivided into several meter-scale (10.6 m average thickness), high-frequency (110 to 15 ky), subtidal transgressive–regressive cycles. These cycles are bounded by subaerial exposure or marine flooding surfaces and are inferred to be laterally continuous across the platform-top. They vary from mixed carbonate-siliciclastic to carbonate-dominated cycles.

Cyclicity on the Bachende platform was strongly influenced by glacioeustatic sea level variations and changes in subsidence and sedimentation rates. Subaerial exposure surfaces capping high-frequency cycles are better developed in the sequence 1 (late Kashirian/early Podolskian), when subsidence was relatively low and glacioeustatic sea level fluctuations could have exposed subtidal deposits during base-level falls. On the basis of the conservative estimated duration of each cycle and spectral analysis of cycle thickness, the precessional (~20 ky) and obliquity (~40 ky) cycles were detected in all the sequences, the short eccentricity cycle (~100 ky) in the sequence 1, and the long eccentricity cycle (~400 ky) in the sequences 2 and 3 (Podolskian). Nevertheless, precessional and obliquity frequencies seem to dominate during sequences 2 and 3, which were deposited under significant higher subsidence and sedimentation rates. Additionally, spectral peaks at ~60–80 ky are randomly present across the whole succession, and they cannot be explained as a linear response of the climate system to the Milankovitch forcing.

1. Introduction

Wanless and Shepard (1936) first proposed that Carboniferous cyclothems recorded in the northern hemisphere of Gondwana could record the glacioeustatic changes caused by the waxing and waning of continental ice sheets. Over the past decades, many authors have provided evidence that icehouse conditions existed and that Milankovitch-driven glacioeustasy would have been responsible for late Paleozoic sedimentary cycles (Crowell, 1978; Heckel, 1986; Veevers and Powell, 1987; Goldhammer et al., 1991; Wiberg and Smith, 1994; Soreghan and Giles, 1999; Heckel et al., 2007; among others).

During icehouse periods, high-frequency carbonate cycles were commonly composed of thick (up to several meters) subtidal deposits, lacking peritidal lithofacies and capped by subaerial exposure surfaces (Wright, 1992; Read, 1995). Veevers and Powell (1987) and Algeo and Wilkinson (1988), proposed that frequency variations of 100 and 400 ky (short and long eccentricity periods of the Milankovitch parameters) were the dominant orbital controls over the Pennsylvanian, and many authors have suggested that the late Paleozoic icehouse glacioeustasy would have been similar in magnitude to the Pleistocene, with sea level changes that probably exceeded 100–120 m (Heckel, 1986; Soreghan and Giles, 1999; Joachimski et al., 2006).

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Nevertheless, depositional cycles in shallow-water carbonate settings are also strongly influenced by other combined factors, such as subsidence, sediment supply, the type of carbonate factory and environmental conditions (Schlager, 2003). The interaction of all these processes determines the distribution of depositional elements within a sedimentary system, as well as the larger-scale stacking patterns of depositional systems within a sedimentary basin (Catuneanu, 2006). Thus, flexural subsidence in active foreland basins, combined with glacioeustasy and the dispersal of siliciclastic sediments, could have exerted an important control over the architecture of carbonate platforms and their cyclicity (Klein and Willard, 1989; Dorobek, 1995; Della Porta et al., 2002, 2004).

Although distinguishing glacioeustatic from relative sea-level changes is fairly problematic, the complex interplay between different driving mechanisms can be unraveled using high-resolution sequence stratigraphy (Smith and Read, 2001). Here, the well-exposed cyclic successions of the Bachende Formation (Cantabrian Zone, NW Spain) were studied to determine the evolution and stratigraphic organization of a Pennsylvanian carbonate platform deposited in a foreland basin where subsidence rates were high (~254 m/My). The two main objectives of the present work are: 1) to describe the high-frequency cycles and their stacking pattern in a carbonate platform-top setting during icehouse Pennsylvanian times; and 2) to define the interplay between glacioeustatic and tectonic processes on the development of high-frequency cycles in a foreland basin context, using the sequence hierarchy and the estimated duration of high-frequency cycles; the role of subsidence as a control on high-frequency cyclicity is discussed.

2. Methodology

The stratigraphic study is based on a detailed geological mapping at 1:20,000 scale and the logging and sampling of eighteen stratigraphic sections (total thickness ~2100 m). Owing to the nearly vertical orientation of the bedding planes caused by tectonic rotation (Variscan orogeny), aerial photographs and orthophotos provide 2D cross sections of the Bachende Formation and reflect platform-top stratal patterns in discontinuous and faulted outcrops. A total of 400 thin sections were examined under a petrographic microscope to determine the composition, texture and biota assemblage of the samples. Bed sets were traced laterally in outcrops to determine facies relationships. Correlations of sections were made using distinctive stratigraphic markers, such as subaerial exposure surfaces and limestone beds with lateral continuity. Additionally, biostratigraphic data from the analysis of fusulinids (Alonso-Herrero, 1981; Barba et al., 1991; and samples collected during this research) were also used for the correlation of the sections. Two temporal and spatial scales of stratigraphic cyclicity, namely high-frequency cycles (HFC) and sequences (S), can be recognized in the study area. The duration of sequences and cycles was estimated using the Menning et al. (2006) Global Time Scale (7 My for the Moscovian).

Quantitative subsidence analysis was performed for a representative synthetic section, located in the Lois–Ciguera sector (see Fig. 1 for location). The thickness of decompacted units was calculated using the *backstripping* technique (Steckler and Watts, 1978), assuming Airy isostasy. Porosity reduction with depth was calculated using the methodology proposed by Schmoker and Halley (1982) and Vergés

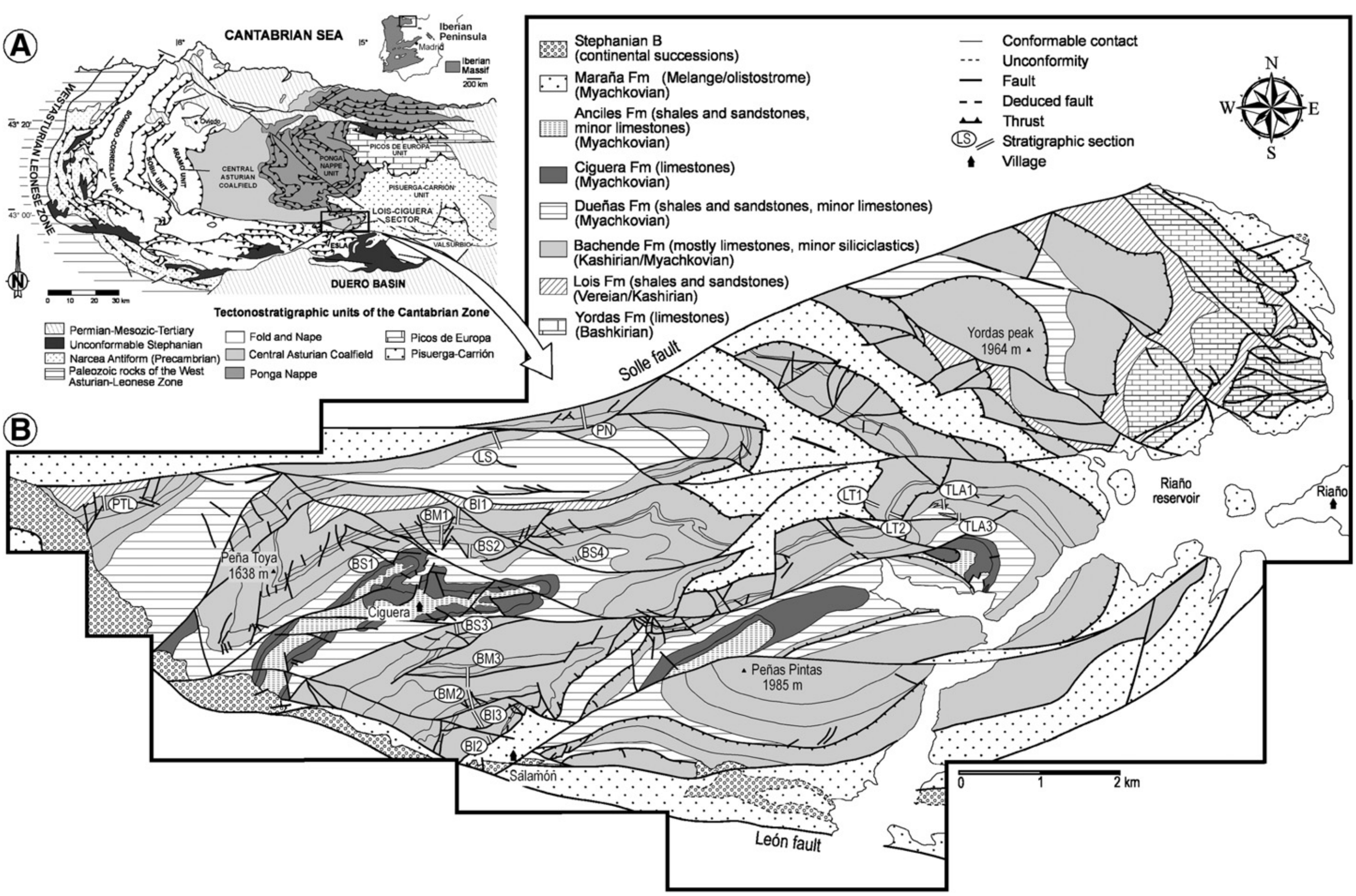

Fig. 1. A). Synthetic geological map of the Cantabrian Zone showing the main tectono-stratigraphic units and the location of the Lois–Ciguera sector. Modified from Pérez-Estaún et al. (1988) and Alonso et al. (2009). B). Geological sketch map of the Lois–Ciguera sector, showing the location of measured sections in the Bachende Formation.