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Long-period eccentricity control on sedimentary sequences in the continental Madrid Basin (middle Miocene, Spain)

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ABSTRACT

The middle Miocene Valdearenas–Muduex section in the internally-drained, continental Madrid Basin (central Spain) is dated bio-magnetostratigraphically between 15.2 Ma and 11.5 Ma. The section contains two formation-scale, sedimentary sequences, that both consist of a siliciclastic lower part and a calcareous upper part. Siliciclastic sedimentation took place in distal floodplain and fluvial environments, while limestones resulted from carbonate precipitation in calcic soil profiles and in ephemeral lacustrine water bodies. Spectral analysis of the L^* colour time series points to the influence of the ~405-kyr and 0.97-Myr eccentricity cycles, while the bases of the two calcareous intervals correlate to successive minima of the 2.4-Myr eccentricity cycle. The 405-kyr cycle lags maximum eccentricity, whereas the 0.97 and 2.4-Myr cycles lag minimum eccentricity, each by approximately a quarter of a cycle. No obliquity forcing is detected. The observed orbital configuration of 2.4-Myr minima at the base of limestone-dominated intervals is similar to a previously documented Late Miocene shift in the Teruel Basin of northeast Spain. Our results indicate that long-period eccentricity climate forcing may well be a significant player on long, tectonic time scales in continental basin fill.

1. Introduction

Orbital forcing of paleoenvironments is increasingly documented in well-dated, continental sediment records. The impact of precession, obliquity, and ~100-kyr and ~405-kyr eccentricity cycles is shown in lacustrine, palustrine, and floodplain successions around the Mediterranean Sea (Abdul Aziz et al., 2003, 2004; Abels et al., 2009a,b). Besides these relatively high-frequency orbital cycles, eccentricity and obliquity also include low frequency cycles, with periods of 0.97 Myr and 2.37 Myr for eccentricity and 172 kyr and 1.2 Myr for obliquity (Varadi et al., 2003; Laskar et al., 2004). These long-period cycles are more often linked to major Cenozoic climate events of Cenozoic age recorded in marine settings (Beaufort, 1994; Lourens and Hilgen, 1997; Shackleton et al., 1999; Wade and Pälike, 2004; Abels et al., 2005; Pälike et al., 2006; Holbourn et al., 2007). A similar impact in continental settings is thus likely. Long-period variability is shown in the lithological cyclicity of the Triassic continental Newark Basin, that was related to long-period eccentricity forcing (Olsen, 1986; Olsen and Kent, 1999). The lack of reliable astronomical target curves for the Triassic however hampered calibration of the Newark results to calculated eccentricity curves. The impact of long-period cycles has also been recognized in Neogene mammal assemblage records of Spain (Van Dam et al., 2006). Eccentricity minima of the 0.97-Myr and 2.37-Myr cycles are held responsible for cooler and more humid climate conditions, resulting in increased small-mammal turnover rates and supposedly in lake expansions. Renewed turnover acceleration took place during cooler and drier conditions at times of 1.2-Myr obliquity minima, suggesting that obliquity played a role in the termination of lake phases.

The Miocene infill in the largely endorheic continental Madrid Basin is characterised by formation-scale sequential units that are composed of a dominant siliciclastic lower and carbonate-rich upper part. These units are occasionally bounded by sedimentary disconformities. The cause of this sequential arrangement is enigmatic, although a tectonic origin has been suggested (Calvo et al., 1989a; Alonso Zarza et al., 1990, 1992a; Calvo et al., 1996). Poor age calibration hampers detailed comparison of these sequences with tectonic records or orbital target curves. Intra-basinal correlations depend on lithostratigraphic patterns substantiated by low-resolution biostratigraphic age constraints (Sesé et al., 1990; Montes et al., 2006). Here, we try to substantiate the role of long-period eccentricity and obliquity in this continental basin fill. Therefore, a composite section in the northeastern segment of the basin containing two siliciclastic-carbonate sequences is studied. A detailed magnetostratigraphy is established to

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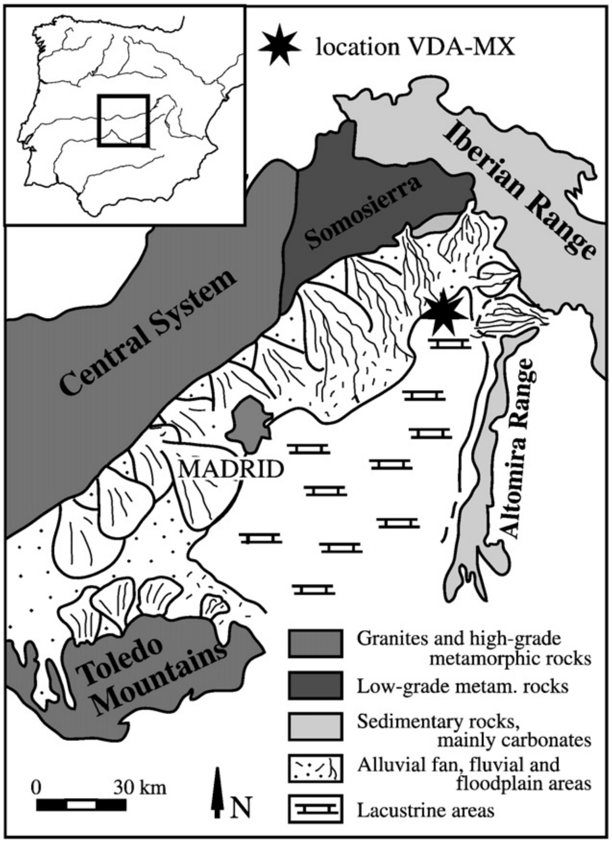

Fig. 1. Geological and paleoenvironmental map of the Madrid Basin during the deposition of the Intermediate Unit, modified after Alonso Zarza et al. (1992a,b). The location of the Valdearenas (VDA) and Muduex (MX) sections is indicated.

achieve accurate age control. High-resolution colour reflectance time series are generated and statistically analysed to detect orbital forcing of the sedimentary cycles. Finally, the sequential units are compared with orbital target curves and their intra- and inter-basinal significance was evaluated.

1.1. Geological setting

The ca 10,000 km^2 large Madrid Basin is located in central Spain, locked between the Central System in the northwest, the Iberian Range in the northeast, the Altomira Range in the east, and the Toledo Mountains in the south (Fig. 1; Calvo et al., 1989b). The basin originated from Alpine tectonics. The main tectonic phase started in the Late Oligocene as compressional and ended in the Late Miocene as extensional in ENE–WSW direction (Alonso Zarza, 1990). Miocene sediments unconformably overlie Paleogene and older rocks (Alonso Zarza et al., 1990). The total thickness of the Miocene sediments varies between 300 and 800 m from the margin to the centre of the basin. Small-mammal biostratigraphic control is poor, but indicates that sedimentation took place from 19 Ma to ~5 Ma (Alonso Zarza et al., 1990; Sesé et al., 1990; Pelaez-Campomanes et al., 2000). The Miocene basin infill is characterised by at least four to five sedimentary sequences that are found in three locally defined Units; one sequence in the Lower Unit, two or three sequences in the Intermediate (or Middle) Unit, and one in the Upper Unit (Calvo et al., 1989a,b; Alonso Zarza et al., 1990, 1992a; Cañaveras et al., 1996; Alonso Zarza and Calvo, 2002; Montes et al., 2006). Magnetostratigraphic data indicated a middle to Late Miocene age for the Lower and Intermediate Units in the central western and southern parts of the basin (Montes et al., 2006). In the north-eastern segment of the basin, the Intermediate Unit consists of two sequences both with a dominant siliciclastic lower part and carbonate-rich upper part. In the following, we refer to these two sequences as the lower and upper sequences.

1.2. Biostratigraphy

The biostratigraphic age constraints for the north-eastern segment of the basin available from scarce fossil mammal findings suggest a middle Miocene age for the Intermediate Unit. An overview of the most important mammal sites is given. The Pajares site is located east of our sections and is placed in the siliciclastic part of the lower sequence (Sesé et al., 1990). The site reveals small-mammal fauna that belongs to local zone D and lower MN5 (Sesé, 2006). The corresponding age is early middle Miocene, between 16 and 15 Ma according to the time scale of Daams et al. (1999). To the east of Guadalajara, near the village of Lupiana, the largest small-mammal association has been found in the siliciclastic part of the second sequence (Sesé et al., 1990). This association is characteristic of local sub-zone G3 that corresponds to a late middle Miocene age, between 12.8 and 11.1 Ma (Daams et al., 1999; Sesé, 2006). The Ledanca mammal site is closest to our section and located in the very top of the upper sequence, most probably just below the paleokarst surface (Sesé et al., 1990). The site yields fossil mammals related to local mammal zone H and lower MN9 that has an early Late Miocene age between 11.1 Ma and 10.4 Ma (Daams et al., 1999; Sesé, 2006).

2. Sections and lithology

The Valdearenas–Muduex composite section (VDA–MX) is composed of the Valdearenas section (VDA) that covers the lower sequence and the Muduex (MX) section that covers the lower and middle part of the upper sequence. Together they cover almost the entire Intermediate Unit. Poor outcrops of the upper sequence in the VDA section necessitated the 2.2 km NE lateral shift to the MX section. The correlation between the two sections cannot be done physically, and mainly depends on characteristics of limestone beds such as induration and stratigraphic pattern (Figs. 2 and 3). Both sections are located along the western flank of the Badiel river valley, close to the two villages after which the sections have been named. The sections have been part of earlier sedimentological studies (Alonso Zarza, 1990; Alonso Zarza et al., 1990; Sanz et al., 1995).

2.1. Valdearenas section

Siliciclastic sediments with limestone intercalations at meter scale dominate the basal 61 m of the 114 m thick VDA section (Figs. 2 and 3). Red and red-brown sandy mudstones display light-grey mottling and mm-size to cm-size carbonate nodules. Darker clay-rich and lighter sand-rich intervals occur. Few sandstone and gravel beds are present as sheet-like tabular beds, especially in the lower part of the siliciclastic interval, while some have a shallow channel-like geometry. Paleocurrent directions point to a S to SW transport direction (Alonso Zarza et al., 1990). Nodular and few prismatic, mottled, light-red calcareous beds intercalate at meter scale and occur at a fairly regular basis in the upper part of the siliciclastic interval (approximately every 3 to 5 m; limestone beds J to Q; Figs. 3C and 2).

The siliciclastic sediments have been interpreted as floodplain deposits of terminal fluvial systems (Alonso Zarza et al., 1990; Sanz et al., 1995), where sandstones relate to occasional enhanced fluvial activity and carbonate nodules are interpreted as of pedogenic origin. Intercalating calcareous levels have been interpreted to be related to carbonate precipitation in calcic paleosols that developed during times of low clastic input (Alonso Zarza et al., 1990; Sanz et al., 1995).

The siliciclastic interval is followed by a 43 m thick carbonate-rich interval of thick limestone beds with intercalations of marls and red mudstones (Fig. 2). This carbonate-rich interval represents the top part of the lower sequence (Fig. 2; Alonso Zarza et al., 1990). The