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Lutetian magnetostratigraphic calibration of larger foraminifera zonation (SBZ) in the Southern Pyrenees: The Isuela section

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ABSTRACT

In this paper, we present a chronostratigraphic calibration of the shallow benthic zones (SBZs) of larger foraminifera during Lutetian times based on new magnetostratigraphic data (Isuela section) and two new densely sampled biostratigraphic sections (Isuela and Gabardiella). These sections are located in the External Sierras (Southern Pyrenees) and represent an ideal location to avoid previous chronostratigraphic problems. 1) They belong to a shallow carbonate shelf environment with abundant larger foraminifera, which ensure the reliability of SBZ data. 2) The time span covers almost the entire Lutetian interval. 3) The profiles are sufficiently long to establish trustworthy local scales, both the SBZs (520 m and 760 m in Isuela and Gabardiella respectively) and the paleomagnetic local polarity sequence (LPS) (520 m). 4) The excellent outcropping conditions also permit a detailed paleomagnetic and biostratigraphic sampling to be performed.
The LPS at the Isuela section was built after sampling every 2.6 m. In total, more than 359 samples were thermal (244) and alternating field (115) demagnetized. Characteristic remanent magnetization (ChRM) usually dropped at 560 °C. Only 43% the samples (359 demagnetizations) gave reliable directions (high quality) for the LPS. A further short section (Gas line) was also cored (38 samples in 90 m) to obtain more detailed data for the upper part of the section. At the Isuela section, the results allow three pairs of trustable magnetozones to be assembled within the Lutetian. A further 255 samples were taken for biostratigraphic purposes, 55 sites at the Isuela and 52 at the Gabardiella sections being determinant. This density enabled a thorough study of changes in fossil associations to be performed. Assuming a constant accumulation rate within the chron boundaries, absolute ages have been estimated for the biostratigraphic boundaries. Combining all these data allows the previous calibration of SBZ during Lutetian times in the geological time scale to be refined. In particular, with this new data, we identify the SBZ 13/SBZ 14 boundary at 44.46 Ma reaching C20r; a boundary interval spanning from SBZ 14 to SBZ 15 (41.36 and 42.45 Ma) is found within C20n and C19n; and, finally, the top of SBZ 15 can be accurately located at 41.12 Ma (C19r).

1. Introduction

During recent years, the shallow benthic zones (SBZs) of Paleogene times have become recognized as a concise alternative chronostratigraphic framework allowing larger foraminifera to be used as biostratigraphic markers. The improvement in temporal resolution, especially in shallow marine shelf environments, is based on the abundance, diversity and high evolutionary rates of, in particular, alveolinids and nummulitids (Serra-Kiel et al., 1998a).

The biozonation described by Serra-Kiel et al. (1998a) for the Lutetian times (SBZ 13 to SBZ 16) was mostly based on Pyrenean data, where the paleontological record on planktic foraminifera (Canudo, 1990 and Canudo in Canudo et al., 1988), calcareous nannofossils (Sucunza in Canudo et al., 1988) and larger foraminifera (Schaub, 1981 and Serra-Kiel in Canudo et al., 1988) is well preserved and the anchoring to the geomagnetic polarity time scale (GPTS; Berggren et al., 1995; Cande and Kent, 1995) was based on magnetostratigraphic data from the Mediano and Esera valley sections of Bentham (1992) and Bentham and Burbank (1996).

However, these previous magnetostratigraphic profiles, which implied a great advance in the Pyrenean chronology at the time, can

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no longer be used for accurate calibrations for following reasons. 1) The magnetostratigraphic sampling of key profiles, in the Mediano and Esera valley sections, was low density (approximately one site every 30 to 50 m). This lack of resolution alone produces a high uncertainty in the correlation. 2) Some facies were not suitable; for instance, some of the data in the Mediano section was taken in turbiditic facies where reworking of the fossil record can be expected. 3) The correlation between the magnetostratigraphic and biostratigraphic data is not straightforward: the samples were collected by different authors in different studies and sections, and this adds to further uncertainties. 4) Finally, recent calibration of the GPTS (Gradstein et al., 2004) and especially the redefinition of the new global stratotype for the base of the Lutetian (Molina et al., 2011 and references therein) have to be considered to anchor the magneto-biostratigraphic record.

Suitable sections with a continuous succession of limestone from Early Lutetian to Late Lutetian can be found in the Betic ranges (Southern Spain), Espuña and Malvariche Fms. in the Espuña range. These sections offer extensive biostratigraphic data (Serra-Kiel et al., 1998b) but there is a lack of magnetostratigraphy to attach the local scales to the geological time scale. Trying to address these problems, some attempts have been made in different sections all around the Mesogea. 1) The Agost section in Southern Spain was recently proposed as a stratotype for the Ypresian/Lutetian boundary (Larrasoaña et al., 2008; Molina et al., 2011). This section provides magnetostratigraphic calibration and biostratigraphic data from planktic as well as small and larger benthic foraminifera. However, the section is very condensed (115 m), it has a weak magnetic signal, very few sampling points of benthic organisms and, due to the turbiditic environment, could include reworking of facies. 2) The Gorrondatxe and Otsakar sections (Northern Spain) with a clear magnetic record and abundant fossil content (Bernaola et al., 2006; Orue-Etxebarria et al., 2006; Payros et al., 2007, 2009a, 2009b, 2011; Molina et al., 2011) provide a partial record of the Lutetian time (C22r to C20r). On the other hand, the content of larger foraminifera (SBZ 12 to SBZ 14) is weakened by the absence of the nummulitid assemblage due to the pelagic environment.

Therefore, to date there has been no calibration between the SBZ biostratigraphic scale and the geomagnetic polarity time scale under the appropriate conditions to accurately determine the chronological time frame for the Lutetian age. The Isuela section, in the South-Central Pyrenees, is a perfect candidate to avoid the aforementioned problems and to build a reasonable chronostratigraphic calibration between SBZs and the GPTS. Isuela and Gabardiella sections, with their proper correlation, have ideal outcropping conditions and they represent extensive series (520 m and 760 m respectively). Finally, these sections represent a carbonate shelf; an ideal environment for benthic foraminifera in situ development, where the reworking of facies can be ruled out, hence allowing a detailed, continuous and reliable study of larger foraminifera to be performed. In this paper, we report new and extensive paleomagnetic and biostratigraphic data and we propose a recalibration of the Lutetian shallow benthic zones (SBZ 13 to SBZ 16).

2. Geological setting

The External Sierras are defined by an imbricate thrust system and associated detachment folds. This system developed during Middle Eocene time and laterally propagated to the West in more recent times reaching the Chattian–Aquitanian boundary (Puigdefábregas, 1975; Millán, 1996; Millán et al., 2000). The rotational activity of these thrusts produced several N–S structures perpendicular to the main Pyrenean trend: Boltaña, Balzes, Pico del Águila, and Gabardiella, among other anticlines. A second tectonic pulse during Oligocene–Miocene times re-located these structures in the hanging-wall dorsal-block (on the underlying thrust ramp) producing the north plunging that, nowadays, affects most of them. The Isuela and Gabardiella sections are located in the hanging-wall of the South Pyrenean sole thrust (basal thrust of the External Sierras), detached in the Triassic evaporites in the Central Zone of the Pyrenees (Fig. 1).

The very well exposed outcrop of the syntectonic Eocene marine deposits in External Sierras has been the target of numerous sedimentological studies (Puigdefábregas, 1975; Millán et al., 1994; Barnolas and Gil Peña, 2001; Castelltort et al., 2003; Barnolas and Pujalte, 2004), structural studies (Poblet and Hardy, 1995; Poblet et al., 1998; Millán et al., 2000; Pocoví et al., 2004; Vidal-Royo et al., 2012), and biostratigraphic studies (Canudo et al., 1988; Canudo, 1990; Samsó et al., 1994). Previous magnetostratigraphic studies have focused on the Bartonian–Chattian interval (Hogan, 1993; Hogan and Burbank, 1996; Pueyo et al., 2002; Kodama et al., 2010). Despite all this research, and the fact that the Isuela and Gabardiella sections of the Guara Formation exhibit excellent outcrops with layers rich in larger foraminifera, the Lutetian chronology has not yet been defined in detail.

3. Lithostratigraphy

For the studied area (Fig. 1 and Supplementary Material A), the stratigraphy in the External Sierras includes excellent Tertiary and very condensed Mesozoic outcrops. Above the level of detachment of the basal thrust, from base to top, a few hundred meters of limestones, dolomites, and gypsum clays outcrop as the Keuper facies (Triassic in age). Over the Keuper facies and separated by a hiatus, Late Cretaceous shallow marine limestones of the Adraén–Bona Fm. are exposed. Above these limestones, a thicker succession comprising continental sandstones, siltstones and lacustrine limestones are part of the Tremp Fm. and the so-called “Garumnian Facies” (Late Cretaceous–Paleocene, Mey et al., 1968). On these facies, there are a few meters of shallow marine limestones of the Boltaña Fm. and an almost complete record of Guara Fm. (Ypresian–Lutetian). Lying on the Guara Fm., there are the exposed marls, limestones and sandstones of the Arguis and Belsué–Atarés Fms. (Bartonian–Priabonian; Kodama et al., 2010). Finally, there is the outcrop of the fluvial-lacustrine deposits of the Campodarbe Fm. (Middle Priabonian to Middle Oligocene).

We studied the Eocene limestones of the western External Sierras in the Isuela section (along the Isuela river canyon [San Clemente Pass], located in the Arguis syncline) and in the Gabardiella section (15 km to the East of the Isuela section, in the hinge and western limb of in the Gabardiella anticline) (Supplementary Material A). In both sections, the Eocene limestones lie unconformably on the terrestrial red beds of the Tremp Fm. In the Gabardiella section, the lower part of the Eocene carbonates corresponds to the Boltaña Fm. of Barnolas et al. (1991). In that section, the lower part of the unit is represented by 50 m of silty limestones whereas the upper part is composed of 40 m of marls and bioclastic limestones containing larger foraminifera (*Alveolina*, *Glomalveolina* and *Orbitolites*) allowing the section to be assigned to the Upper Ypresian, or more specifically the Middle Cuisian as it is known locally (Samsó et al., in press). In the Isuela section, this unit is represented by 20 m of silty dolomitic limestones with no large foraminifera. Their correlation with the Gabardiella section is supported by geometrical criteria based on a 1:50,000 scale geological map (Samsó et al., in press).

The rest of the Eocene limestones in both sections correspond to the Guara Fm. (Puigdefábregas, 1975) as defined by Canudo et al. (1988, 1991), Barnolas et al. (1991), Samsó et al. (1994) and Samsó et al. (in press). In this part of the External Sierras, the Guara Fm. lies unconformably over the Boltaña Fm. (Samsó et al., in press) and shows regional thinning to the west. According to their lithology,