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The Madrid Basin and the Central System: A tectonostratigraphic analysis from 2D seismic lines

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ABSTRACT

Data from deep boreholes, seismic surveys, and surface geology are used to reconstruct the sedimentary infilling of the Cenozoic Madrid Basin. Eight main depositional sequences and seismic units are recognised. From the Paleogene, the latter four of these sedimentary sequences were deposited in a continental environment, under the influence of tectonic activity in the Central System, the Toledo Mountains, the Iberian Chain, and the Sierra de Altomira. The sedimentary infill shows an overall coarsening-upward trend from upper Cretaceous formations to syn-tectonic conglomerate deposits, followed by a fining-upward sequence and moderate reactivation of some faults during the late Miocene–Pliocene. The syn-tectonic sediments are Oligocene–early Miocene in age. The foredeep is oriented northeast–southwest and shows a sediment thickness of up to 3800 m in areas close to the Central System.

Several types of tectonic structures are recognised, including imbricate thrust systems, thrust triangle zones, fault-propagation folds, back-thrust systems, and pop-up structures. The frontal thrusts were subjected to significant erosion, and late Miocene sediments onlap the anticlines of the onshore foreland. NW–SE-trending positive flower structures have been recognised in the eastern part of the basin. The total northwest–southeast shortening across the contact between the Madrid Basin and the Central System is approximately 5 km, of which 2–3 km occurred across the Southern Border Thrust. The simultaneous basement uplift of the Central System and the tectonic escape of the Sierra de Altomira have been interpreted as a consequence of constrictive deformation within the "Pyrenean" foreland of the Iberian microplate.

1. Introduction

The objectives of the present study are to establish a hierarchy of the stratigraphic higher-order sequences in the Cenozoic Madrid foreland basin of central Iberia and to investigate the coupling between basin infilling and tectonism. To accomplish this, we analyse tectonic, stratigraphic, sedimentological, geophysical and subsurface geological data in order to assess in detail the 3D structure of thrusting in the intraplate basement uplift of the Central System–Madrid Basin contact.

So far, data from seismic lines of the Madrid Basin have not been systematically studied, without any published migrated sections. Related structures, outcropping at the Central System, were either considered. Therefore, the Cenozoic deformation structural styles of central Iberia were not yet established. Although there are many works that deal with partial aspects of the evolution of the Madrid Basin and its related borders, with this synthesis we try to give a global view from multiple standpoints. Up to the moment, it was one of the missing pieces in the Cenozoic Iberian puzzle.

2. Geological setting

Within the Iberian microcontinent, the southern foreland basin of the Cantabrian Mountains–Pyrenees alpine deformation zone is known as the Duero–Ebro Basin (Fig. 1). This basin is bordered to the south by the Spanish–Portuguese Central System–Iberian Chain intraplate uplift. The area located south of the intraplate deformation comprises, from west to east, the Lower Tagus Basin at the Portuguese Atlantic margin, the Beira Baixa–Moraleja Basin at the Spanish–Portuguese border, the Madrid Basin (Civis, 2004; De Vicente et al., 1994; Friend and Dabrio, 1996), and the Loranca Basin (these latter two basins are also referred to collectively as the Tagus–Tajo Basin). The Madrid Basin is connected to the Loranca Basin (also known as the Intermediate Basin) to the NE, and to the shallow La Mancha Basin to the south (Pérez-González, 1982). The Madrid Basin is triangular in shape, except at its westernmost edge, where the linear Campoarañuelo subbasin trends E–W. All of these basins were filled and deformed during the Cenozoic (Fig. 2) in relation to folding of the Iberian lithosphere (Cloetingh et al., 2002).

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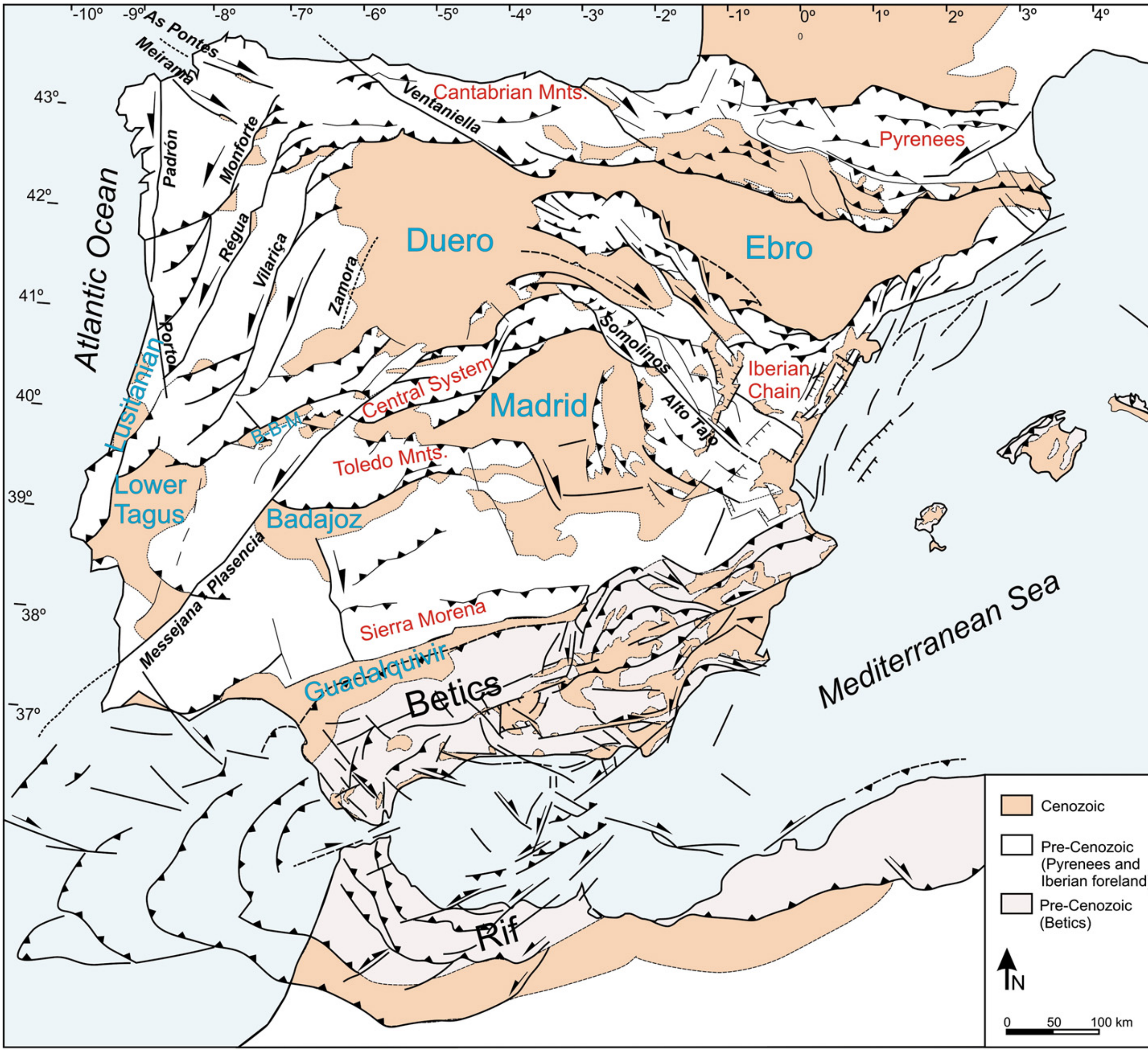

Fig. 1. Tectonic sketch of the three thrust-related ranges of continental Iberia (in the north: the Pyrenees–Cantabrian Mountains, in the centre: the Iberian Chain–Central System, to the South: Sierra Morena, in red). The main Cenozoic basins (marked in blue) and strike–slip faults (marked in black) are also shown. Shaded in light brown is the Betics–Rif area. B-B–M: Beira Baixa–Moraleja Basin.

The Madrid Basin is over 20,000 km^2 in area and has significant hydrological resources, as well as the potential for CO_2 storage and geothermal energy. An accurate assessment of the exploration potential of the Madrid Basin, in terms of these resources, requires a better understanding of its 3D structure, which is closely related to the tectonic evolution of the Central System and the Iberian Chain. An understanding of Cenozoic deformation in the region would also be useful in estimating the orientation of the present-day stress field, to ensure the safety of future infrastructure projects against acceptable levels of seismicity, and to mitigate seismic hazards.

3. Methodology

Stratigraphic records of the subsurface can be interpreted by analysing seismic facies. Such analyses have been of great utility in studies of the sedimentary filling and evolution of many basins (e.g., Herrero et al., 2010 for the Duero Basin). To investigate the tectonic structure of the Madrid Basin, it is necessary to study subsurface data, since Neogene sediments obscure older units in most of the region. Accurate geological cross-sections of the structure of the Madrid Basin–Central System can be obtained by fitting seismic lines to structural data. Such cross-sections would enable a better understanding of the 3D geometry of the basin and, consequently, represent a valuable tool in constraining the Cenozoic tectono-stratigraphic evolution of the basin.

Six main seismic investigations have been carried out across the Madrid Basin area by oil companies: CGG during 1968–1973 (27 seismic lines), Chevron during 1968–1973 (4 seismic lines), Delta in 1972–73 (30 seismic lines), Prakla in 1976 (22 seismic lines), Shell in 1978–79 (10 seismic lines), CGG in 1979 (14 seismic lines), and Shell again in 1980 (18 seismic lines). A total of 99 seismic sections were surveyed. For each section, the properties investigated included CDP (common depth point) on the horizontal axis and dynamic velocities. The results of the analyses and interpretations of these seismic sections have been presented in internal reports and scientific journals (e.g., Gómez et al.,