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Invited review

Temporal aspects of genetic stratigraphic units in continental sedimentary basins: Examples from the Ebro basin, Spain

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ABSTRACT

The utility of genetic stratigraphy lies with the fundamental relationship between genetic stratigraphic units and correlative intervals of geologic time. While high-resolution studies may reveal varying degrees of diachroneity that are associated with their bounding surfaces, genetic stratigraphic units are generally viewed as chronostratigraphic in nature, representing specific periods of basin fill. Despite the vast literature on basin analysis, an evaluation of the temporal character of the boundaries between genetic stratigraphic units, particularly in cases where they are conformable, has not yet been undertaken. The Cenozoic Ebro basin is a foreland basin on the north-eastern Iberian Peninsula that provides a case for assessing the temporal character of the boundaries between genetic stratigraphic units. These units are termed "tecto-sedimentary units", following the method of tecto-sedimentary analysis that is used in some continental basins. In the Ebro basin tecto-sedimentary analysis is based on direct field observations. In this work, magnetostratigraphic data from four tecto-sedimentary units (units T4 to T7) that span rocks of lower and middle Miocene age (ca. 1000 m thick) in the central and western areas of the basin are analysed. The study area contains alluvial, fluvial and lacustrine deposits that were sourced from Pyrenean and Iberian areas, whose catchments were structured during the collision of Iberia and Eurasia. New magnetostratigraphic data from this study and previously published magnetostratigraphic data enable us to determine the ages of these tecto-sedimentary unit boundaries throughout a 200-km-long, east–west transect that extends from the basin centre to the southwestern margin. The results indicate that the diachrony of the three boundaries between the Miocene tecto-sedimentary units through the central Ebro basin is less than 0.3 Ma where they are conformable. This low degree of diachroneity may be attributed to the effects of allogenic, largely tectonic processes that operate in the catchment areas and methodological inaccuracies. These results provide empirical support to the idea that genetic stratigraphic units are bounded by surfaces that exhibit low amounts of diachroneity where they are conformities.

1. Introduction

Basin analysis involves the division of basin-filling rocks into genetic stratigraphic units. Genetic stratigraphic units (cf., Embry, 2009) are important to study basin history because they are generally viewed as representative of specific periods of geologic time, irrespective of lithology. Such units are bound by key stratigraphic surfaces (e.g., sequence boundaries, maximum flooding surfaces) depending on the model that is employed (see Mitchum et al., 1977; Johnson and Murphy, 1984; Van Wagoner et al., 1987; Galloway, 1989; and Embry, 2009; Catuneanu et al., 2009, 2011 for a full discussion). In Spain, basin analysis with genetic stratigraphic units began with the with "tecto-sedimentary analysis" (TSA), which was used by Garrido-Megías (1973) to study Mesozoic and Cenozoic rocks in the South Pyrenean basin, and by Garrido and Villena (1977) to study the Germanic Triassic. TSA is based on the early work of Delfaud (1972, 1974), and its theoretical concepts were refined by Megías (1982).

Genetic stratigraphic units that were recognised via TSA were termed by Megías (1982) 'tecto-sedimentary units' (TSUs). Conceptually, a TSU is a three-dimensional body of sedimentary rocks that has a definite vertical trend, either fining or coarsening upward, and is bounded by regional unconformities and their correlative conformities. At the scale of the resolution of dating methods, the boundaries between TSUs should represent synchronous geologic timelines where they are conformable (Megías, 1982). Thus, each TSU that is characterised in a basin has chronostratigraphic significance, and successive TSUs do not overlap in time. In this respect, a TSU is partially equivalent to a depositional sequence that is established by seismic

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stratigraphy (Mitchum et al., 1977; Vail, 1987), as stated by Pardo et al. (1989), although the methods and data that are used in each case (i.e., direct field observations versus seismic interpretation) and the dominant allogenic controls at play may vary.

An early application of TSA was the study of Neogene marine, oil-bearing rocks in the western Mediterranean (Soler et al., 1986; Martínez del Olmo et al., 1986). In these works seismic profiles, continuous drilling cores and well-logs were used and compared with information from inland outcrops. The authors defined seven TSUs that were regressive in evolution and formed in relation to the Betic thrust that stacked in the Balearic Islands and synchronous extension in the western basin margin.

Despite the active development of sequence stratigraphy as a research topic by the late 1980s (see Bally, 1987; Wilgus et al., 1988), this theme did not greatly contribute to the analysis of continental basins, particularly basins whose evolution had no relation to sea-level changes. This case applies to most Neogene continental basins in the Iberian Peninsula, the stratigraphic studies of which have relied mostly on the outcropping record. Available core data, well logs and/or seismic profiles are rare, disperse and sometimes of insufficient quality. González et al. (1988) and Pardo et al. (1989) precisely defined the types and meaning of TSU boundaries in continental basins, compared TSA and sequence stratigraphy concepts, and used TSUs as a correlation tool in large continental basins with disconnected outcrops. Most scientists had accepted by the mid-1990s that factors other than sea-level changes, including climate change and regional tectonism, may play a key role in changes in accommodation, and hence in sequence architecture (Miall, 1995, 2010, 2016). A few works focused on sequence stratigraphy in continental basins (Catuneanu and Elango, 2001; Fanti and Catuneanu, 2010). After González et al. (1988) and Pardo et al. (1989), TSA was more extensively applied through the study of fully continental (endorheic) Cenozoic basins in Spain, such as the intermontane Ebro, Duero and Tagus basins and some intramontane continental basins in the Betic and Iberian Ranges (Mediavilla and Dabrio, 1988; Pérez, 1989; González, 1989; Alonso-Zarza et al., 1990; Viseras, 1991; Santisteban et al., 1991; Santisteban et al., 1996a; Santisteban et al., 1996b; Muñoz, 1992; Arenas, 1993; Villena et al., 1996a; Villena et al., 1996b; Mediavilla et al., 1996; Muñoz-Jiménez and Casas-Sainz, 1997; Luzón, 2001; López Olmedo et al., 2004; Pla et al., 2007; Ezquerro, 2017).

These basins were isolated from marine influence, so the primary allogenic control during filling was mainly tectonic activity in the basins' bounding mountain ranges. This tectonic activity consisted of thrusting and uplift 1) in the Pyrenees and Iberian Ranges for the Ebro basin (Muñoz-Jiménez and Casas-Sainz, 1997; Arenas et al., 2001), 2) in the Central System and Altomira Sierra for the Tagus basin (Calvo et al., 1989), and 3) in the Cantabrian and Iberian Ranges for the Duero basin (Mediavilla et al., 1996). An extensive tectonic regime occurred in the eastern Iberian Range, as with the Teruel basin (Ezquerro, 2017). In all these examples, the tectonic activity at the bounding ranges, alongside climate evolution, controlled the sediment supply and basin accommodation and produced sedimentary sequences that reflect the prograding or retrograding evolution of the related fluvial systems and the retraction or expansion evolution of the related lacustrine systems.

In the above-mentioned works, the correlation of TSUs throughout every basin was based on outcrop stratigraphic criteria and similarities between vertical sedimentary trends. However, these correlations may be imperfect, and the identification of key surfaces such as TSU boundaries may not be highly accurate, particularly in sequences that correspond to distal alluvial or lacustrine settings. Therefore, evaluating the temporal character of TSU boundaries requires a more accurate dating method to facilitate age correlation. In continental basins, magnetostratigraphy has proven to be one of the most suitable tools for this purpose (c.f., Krijgsman et al., 1996; Garcés et al., 2001; Pérez-Rivarés et al., 2002, 2004), although few published studies have been devoted to this goal. Relative to this subject, three Miocene genetic stratigraphic units have been defined and correlated throughout the Madrid basin in the central Iberian Peninsula (see Antunes et al., 1987; Alonso-Zarza et al., 1990; Calvo et al., 1989; López Olmedo et al., 2004). These units, which were termed lower, intermediate and upper, were first dated as Miocene based on their macro- and micro-mammal fossil contents. Montes et al. (2006) performed a magnetostratigraphic analysis of the lower and intermediate units in the central sector of the Madrid basin and established the age of the boundary between these two units to be 14.4 Ma. However, Abels et al. (2010) estimated the age of the same boundary in the north-eastern sector of the same basin to be 15.6 Ma, and concluded that this boundary is diachronous because the different sectors of the basin evolved separately.

In the Ebro basin, eight TSUs (T1 to T8) that range in age from Thanetian to the middle Miocene have been identified based solely on measured stratigraphic sections (Villena et al., 1996a; Muñoz et al., 2002; Pardo et al., 2004). Several magnetostratigraphic studies that span the Miocene series have been conducted in the central (Pérez-Rivarés et al., 2002, 2004; Larrasoaña et al., 2006) and northern (Oliva-Urcia et al., 2016) sectors of the Ebro basin. This work attempts to build upon these previous works with new magnetostratigraphic data from the central and western areas of the Ebro basin. The combined datasets represent the Miocene record across a large extent of the basin and thus provide an excellent opportunity to analyse the temporal character of the genetic stratigraphic unit boundaries that have been established by the TSA methodology. This work focuses on a 200-km-long east–west transect that extends from the basin centre to its southwestern margin and compares the results to previously published data from the northern basin's margin.

2. Methods

2.1. Tecto-sedimentary analysis (TSA)

TSA is a method of basin analysis that was first developed during the early 1970s (Garrido-Megías, 1973) to study a portion of the South Pyrenean foreland basins. The active tectonic context in which the basin evolved involves the use of the prefix "tecto" in the nomenclature of units and methodology. The basis of TSA is the division of a sedimentary basin's fill into successions of strata that are characterised by a definite vertical sedimentary trend (Fig. 1). Each of these rock successions was deposited "during a specific interval of geologic time, under a tectonic and sedimentary dynamic of definite polarity" (translated from Megías, 1982). These successions, which are generally hundreds of meters thick, were termed 'tecto-sedimentary units' (TSUs) and the boundaries between TSUs were termed "sedimentary breaks". Sedimentary breaks are surfaces of basinal extent (see González et al., 1988 and Pardo et al., 1989) that separate successions of strata that exhibit either of the following (Fig. 1):

a) different vertical sedimentary trends; the sedimentary break is defined by either a change from coarsening upward to fining upward (type-1 sedimentary break) or a change from fining upward to coarsening upward (type-2 sedimentary break), or
b) similar vertical sedimentary trends that are separated by a sharp shift in grain size or lithology (type-3 sedimentary break).

A type-2 sedimentary break can be difficult to recognize when it occurs within uniform distal facies (e.g., alluvial or lacustrine facies). Thus, this type of break is not commonly used to differentiate TSUs, and such retrogradational–progradational successions are treated as complex TSUs (Fig. 1).

Sedimentary breaks are generated by inflections or sharp changes in the rate or intensity of the allogenic process that controlled the basin-fill dynamics (Pardo et al., 1989; Villena et al., 1996a). When the tectonics are the operating allogenic factor, these boundaries are 1) syntectonic or angular unconformities along the basin's margins or zones