Sociedad Geológica de España

GEOGACETA, 77, 2025

Paleogeographic imprint of a piggy-back basin rotation. The Ainsa Basin (South-central Pyrenees)

Huella paleogeográfica de la rotación de una cuenca piggy-back: La Cuenca de Aínsa (vertiente sur del Pirineo central)

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ABSTRACT

Sedimentary geometries and paleocurrent distribution from the Ainsa basin support the paleomagnetic data about its rotation and chronology. The Ypresian foreland platform margin, folded in the Boltaña anticline, predates thrusting and related piggyback basin transport. An early Lutetian initiation for the thrust–fold of the Boltaña – Balces system is consistent with the onlap geometries on the east limb of the Boltaña anticline. In the mid Lutetian, growth strata followed by an angular unconformity in the carbonate west limb of the Balces anticline postdates the fault-propagation folding in the Boltaña-Balces system. The forced deltaic progradation that filled the Ainsa basin following the syncline geometry during the mid to late Lutetian (Sobrarbe Fm) track this mid-Lutetian unconformity. The Campodarbe Group, including the Escanilla Fm (Bartonian – middle Priabonian), is connected to the hinterland tectonic uplifting by the Gavarnie thrust with a new palaeogeography and basin configuration. Sedimentary data reinforce a post-Lutetian (Bartonian – middle Priabonian) main event of rotation.

Key-words: *Rotation, Paleomagnetism, Piggy-back basin, Sedimentary Basin, Pyrenees.*

RESUMEN

La geometría sedimentaria y distribución de paleocorrientes en la Cuenca de Aínsa, son coherentes con los datos paleomagnéticos de la rotación y su cronología. El margen de la plataforma de antepaís Ypresiense, plegado por el anticlinal de Boltaña, es anterior al cabalgamiento y emplazamiento de la cuenca piggyback asociada. Un inicio del cabalgamiento y pliegues asociados del sistema Boltaña-Balces para el Luteciense inferior, es coherente con la geometría en onlap en el flanco oriental del anticlinal de Boltaña. La discordancia progresiva y angular de las calizas del Luteciense medio del flanco occidental del anticlinal del Balces postdata el sistema de pliegues de propagación de falla de Boltaña-Balces. La progradación deltaica forzada del Luteciense medio y superior que rellena la cuenca de Ainsa siguiendo la geometría del sinclinal es posterior a la discordancia del Luteciense medio. El Grupo Campodarbe, incluida la Fm Escanilla (Bartoniense - Priaboniense medio) está relacionado con el levantamiento tectónico del margen activo por el cabalgamiento de Gavarnie, con una nueva configuración paleogeográfica de la cuenca. La información sedimentaria apoya una edad post-Luteciense (Bartoniense – Priaboniense medio) para el evento principal de rotación.

Palabras clave: *Rotación, Paleomagnetismo, Cuenca piggyback, Cuenca sedimentaria, Pirineos.*

Geogaceta, 77 (2025), 39-42
https://doi.org/10.55407/geogaceta108867
ISSN (versión impresa): 0213-683X
ISSN (Internet): 2173-6545

Fecha de recepción: 22/07/2024
Fecha de revisión: 30/10/2024
Fecha de aceptación: 29/11/2024

Introduction

A thin-skinned foreland-ward sequence of thrust sheets is recognised lateral to the western oblique ramp of the South-Central-Pyrenean structural unit (Séguret, 1972). This sequence is detached on the upper Triassic saline deposits and includes a progressively thin and incomplete Mesozoic cover, with transitional Mesozoic-Cenozoic red beds on their top. Westwards, a progressively younger Paleocene and Eocene section overlaps the Mesozoic sequence. The overlapping sequence involves basal backstepped shallow carbonate platform units deposited at the foreland basin margin, which were successively drowned and buried in onlap by hinterland-sourced terrigenous sediments wedging forelandwards. The Eocene succession shows a general classic underfilled to overfilled trend from deep marine (canyon fill) to terrestrial sedimentation. Later, this sequence engaged in the Oligocene South-Pyrenean Frontal thrust sheet. The present erosional level provides an excellent outcrop exposure with a sequence of near N to S trend ramp anticlines along the External Sierras (Séguret, 1972).

Early studies assumed that this sequence represented a westward progradation of the deformation, whereas the sin-sedimentary infill accommodates the growing structures during Middle Eocene times (Dreyer *et al*., 1999; Millán *et al*., 2000; Michael *et al*., 2014). Paleomagnetic studies (Dinarès, 1992; Pueyo, 2000; Mochales *et al*., 2012a; Muñoz *et al*., 2013; Rodriguez-Pintó *et al*., 2016) show that these folds grew and were rotated clockwise progressively after the main stage of its structural emplacement.

This work focused on the eastern part of this fold sequence, the Boltaña anticline and its piggyback syncline, the Sobrarbe syncline, commonly known as the Ainsa Basin. The present research focuses on how the sedimentary geometries and tectonic-sedimentary evolution of the Ainsa Basin agree with the rotational chronology obtained from paleomagnetic research.

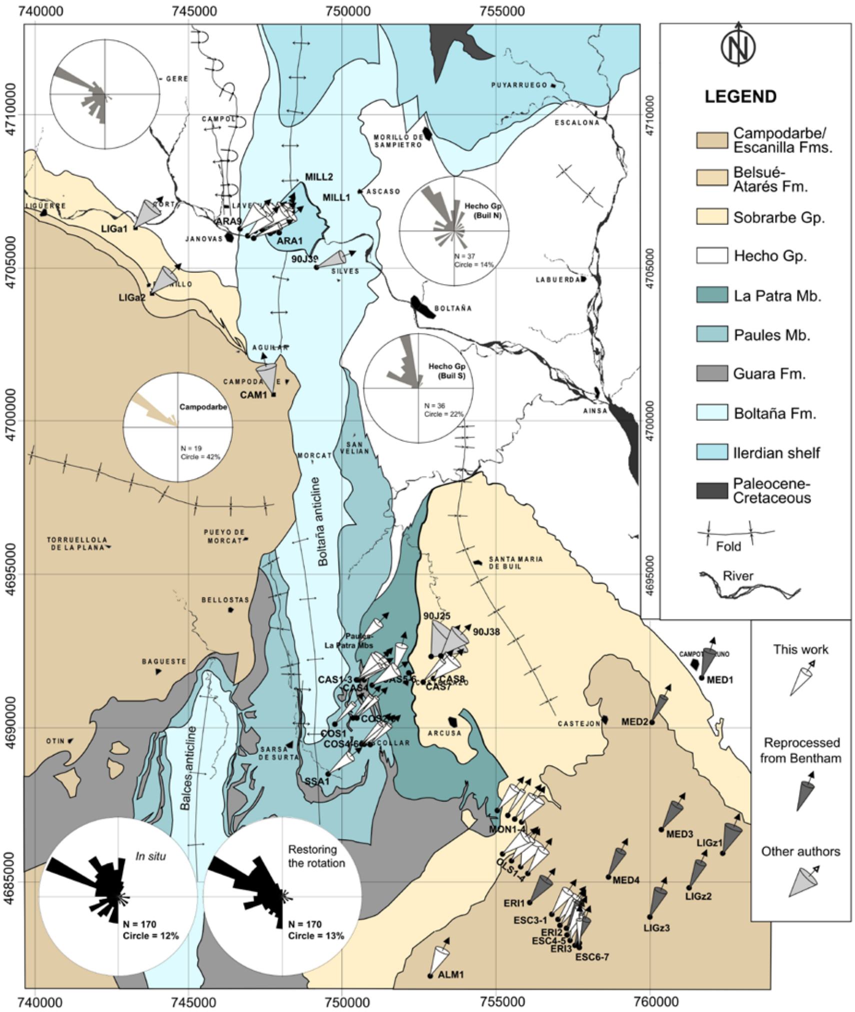

Figure 1.- Simplified geologic map of the Ainsa Basin, including cones and magnetic declination and compiled paleocurrents. Bottom left diagrams: Left) Paleocurrents with bedding restoration. Right) Paleocurrents *in situ* and restored using VAR value for each point. After restoring the rotation, a better grouping is observed (modified from Mochales *et al.*, 2012a). See the colour figure on the web version.

Figura 1. Mapa geológico simplificado de la cuenca de Ainsa incluyendo los conos de declinación magnética y la recopilación de paleocorrientes. Diagramas de la parte inferior izquierda: Izquierda) Paleocorrientes con la restitución del buzamiento. B) Paleocorrientes in situ restituidas usando el valor VAR en cada punto. Se observa un mejor agrupamiento después de la restitución de la rotación (modificado de Mochales et al., 2012a). Ver figura en color en la versión web.

The Ainsa Basin

The Ainsa Basin (Fig. 1) expands between the top of the Boltaña–Balces anticline system until the footwall of the blind lateral ramp of the Montsec thrust sheet (in the sense of Soto et al., 2002, and Muñoz et al., 2013), where the slope transition between the terrigenous shelf facies of the Tremp-Graus Basin and the deeper Hecho Group facies occurs (Barnolas et al., 2019, and references therein).

The late Ypresian–Priabonian succession predates, was highly influenced, and postdates the tectonic evolution of the Ainsa Basin. It includes five main facies groups (Fig. 2): 1) Shallow carbonate platform facies (Boltaña and Guara Fms) deposited in the foreland margin of the basin. 2) Calcareous marls and carbonate breccias of the distal ramp and slope settings related to the foreland carbonate platforms (Paules and Patra Mbrs, of the San Vicente Fm; Mochales *et al*., 2012b, and references therein). 3) Deep-marine terrigenous facies, including slope mudstones, mass wasting deposits and siliciclastic turbidites from the slope and hinterland provenance (known locally as San Vicente Fm, but formally the Hecho Group); this sequence onlaps the foreland carbonate facies in recurrent onlapping wedges. 4) A shallowing-up sequence of deltaic facies (Sobrarbe complex) that concludes the marine sedimentation in the Ainsa Basin. 5) Terrestrial red beds (Escanilla - Campodarbe Fms), which are slightly unconformable on the basin trough (Sobrarbe syncline) and unconformable on the Boltaña – Balces anticlines high.

The basin asymmetry, inherited from its un-detached basin phase, remained up to the Mid Lutetian. The sedimentation of Sobrarbe Fm (Middle to upper Lutetian) postdates this moment, filling the basin following the piggyback syncline axis.

Rotational evidence and chronology

A comprehensive paleomagnetic database, along the entire stratigraphic succession, has provided a chronological framework for vertical axis rotations (VAR) (Mochales *et al*., 2012a, and references therein) (Fig. 1). The rotational kinematics of the Boltaña anticline and the Ainsa Basin were established through variable magnitudes of clockwise rotations, ranging between +52 and non-significant rotation, showing a decreasing pattern with time.

Only early Lutetian, non-significant basin rotation exists. At a subsequent stage, early to middle Lutetian (49 Ma to 42 Ma), at the time of the San Vicente Fm and Sobrarbe Fm sedimentation, sync-folding, pre-rotation, or rotation with a low rotational rate was produced. The rotational turning point trend was detected from the late Lutetian succession onward when the obtained rotational rates started to rise, suggesting the onset of the main rotational event. At this stage, late Lutetian-middle Priabonian (42 Ma to 35 Ma) (uppermost Sobrarbe Fm and Escanilla Fm), the thrust-propagation fold culminated, whereas the rotation rate started to increase. The rotation values shift from a 2.6 º/m.y rate, from 42 to 38 Ma (late Lutetian-Bartonian), to a 10 º/m.y rate, from 38 Ma to 35 Ma (Bartonian-Priabonian boundary to mid-Priabonian) when rotation abruptly ceased reaching the definite configuration (Mochales et al., 2012a).

Sedimentary overview

The Boltaña carbonate platform drowned in the late Ypresian (mid-Cuisian) at the uppermost part of C22r near the boundary with C22n (Mochales *et al*., 2012b). The drowning unconformity includes a complex pattern of drowned surfaces with condensed sections or car-

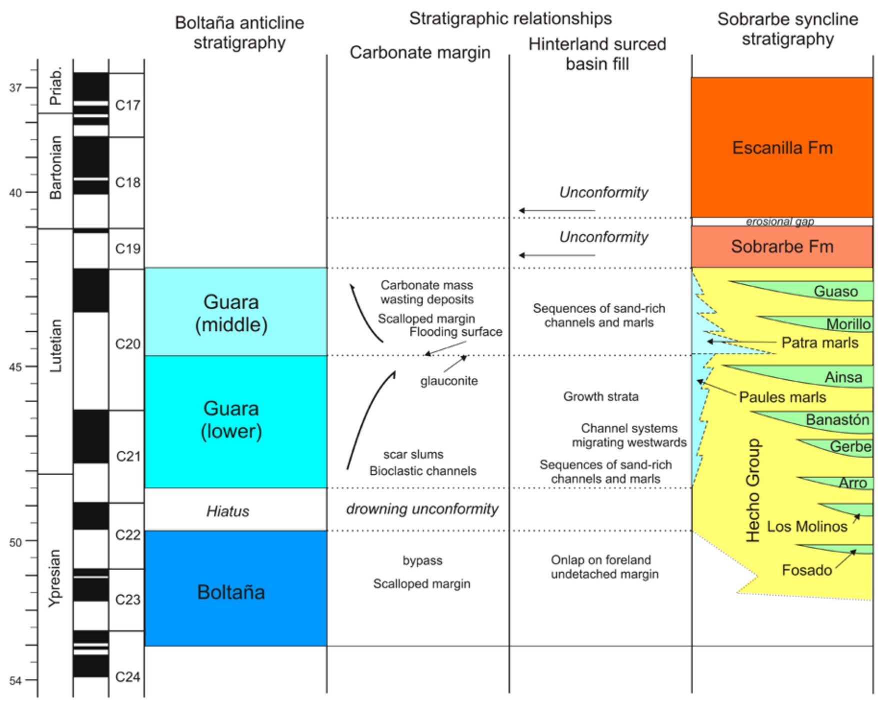

Figure 2. Simplified stratigraphic chart for the Ainsa Basin (Modified from Mochales *et al*., 2012b and Barnolas *et al*., 2019). See the colour figure on the web version.

Figura 2. Esquema estratigráfico simplificado de la Cuenca de Ainsa (Modificado de Mochales et al., 2012b y Barnolas et al., 2019). Ver figura en color en la versión web.

bonate biogenic corrosion. Condensed sections are exceptionally preserved and include sandy marl layers with abundant glauconite followed by marls where the C22n (late Cuisian) was registered (Mochales *et al*., 2012b). Furthermore, erosional gullies and scours due to sediment bypass are also present with significant stratigraphic gaps comprising the entire late Cuisian (C22n and the lower part of C21r).

The overlying marls and marly limestones (Paules marls) include channels of shallow water bioclastic sands and carbonate breccias with lower Lutetian-attributed forms (C23r, SBZ13; Mochales *et al*., 2012b) and are related to the lower Guara carbonate platform. The Guara platform margin, exposed south of Sarsa de Surtra village (Fig. 1), has a lower progradational trend followed by a retrogradational one, marked by a scalloped margin collapse geometry with huge carbonate breccias in the slope marls (Patra marls). A glauconitic flooding surface preludes the margin collapse (C20r, SBZ14; Mochales *et al*., 2012b; Barnolas *et al*., 2019). Scour lineation in the collapse surface shows a N38º direction. The Hecho Group hinterland sourced facies, which consist of marls and sand-rich channel systems, thin southwestwards overlapping the carbonate margin interfingering with the carbonate slope deposits. Paleocurrents from the sand-rich channel systems (see Pickering and Hiscott, 2016 and references therein) stand in Fig. 1.

A sudden sedimentation change occurred in the Mid Lutetian (C20n, near the boundary with the C19r, SBZ15). This event, pointed out by a widespread dark double marl level, the Anoxic level of Mochales *et al*. (2012b), is related to the end of the slope sedimentation and the shift to a deltaic progradation of the Sobrarbe Fm (Barnolas *et al*., 2019 and references therein). The progradation follows the syncline geometry of the piggyback basin northwards, turning slightly to the northwest in the later progradational stages. In the delta top transitional facies (Mondot marls), the C19n was registered (Mochales *et al*., 2012b).

The Escanilla Fm corresponds to alluvial plain facies (fluvial channels and floodplain deposits) with finning-up sequences of low- to high-accommodation channels (Labourdette, 2011). The main level of amalgamated channels corresponds to the Olson conglomerate in the lower part of C18n (Bentham and Burbank, 1996). North provenance paleocurrents are documented (Bentham *et al*., 1993; Dreyer *et al*., 1993; Labourdette, 2011).

Discussion

The late Ypresian platform margin, folded by the Boltaña anticline, predates the fault-propagation fold system and the associated development of the Ainsa Basin.

The drowning of the Boltaña platform displaced the platform margin forelandwards at least 19 km, assuming the subsequent clockwise rotation of the Boltaña anticline (Barnolas *et al*., 2019). The erosional geometry of the platform margin, exposed at the north limbs of the Boltaña anticline, and backstepping support the pre-rotational restoration and its undetached basin history.

During early Lutetian, the Boltaña-Balces fault-propagation folds started growing as it was detected by near-field kinematic indicators (Mochales *et al*., 2010). Growth strata at the shallow platform facies of Guara Fm (middle Lutetian) in the west limb of the Balces anticline (Barnolas and Gil-Peña, 2001; Rodríguez-Pintó *et al*., 2016) and the Jánovas fold fan of the west limb of Boltaña anticline (Mochales *et al*., 2016) indicate a slowdown of thrust displacement and the anticlinal growth. In the east limb of the Boltaña anticline, the instability in the mid-Lutetian carbonate slope, with huge carbonate breccias, is coeval with this event.

The geometry of the Lutetian carbonate margin (Guara Fm, Paules and Patra marls) results in the Balces – Boltaña anticlines growth, which collapses in mid-Lutetian without any significant backstepping. The mid-Lutetian angular unconformity on the Balces anticline postdates the anticline growth. Later, the Sobrarbe deltaic complex accommodates its progradation through the piggyback syncline filling the basin trough. The slightly anticlockwise shift in the direction of upper sequences progradation means still from low rotational values of the basin.

Accordingly, the sedimentary target by the paleomagnetic studies was in Bartonian to middle Priabonian (Escanilla – Campodarbe units) when the abrupt rotation occurred (Mochales *et al*., 2012a). This rotation followed abrupt basin geometry and sedimentation changes on the Sobrarbe Fm - Campodarbe Group transition. The uplift in Central Pyrenees, with a sudden input of hinterland provenance coarse alluvial sediments, led to a significant shift in the South-Pyrenean basin configuration.

Conclusions

During the Ypresian, the succession included in the Ainsa Basin was part of the Jaca undetached foreland basin.

Thrust displacement and growth folding started in the early Lutetian. Paleocurrents and migration patterns in the channel-fill systems towards the Boltaña anticline reflect a non- or low-rotational trend.

Mid-Lutetian growth folds mark the end of thrust propagation folding in the Balces – Boltaña system. The mid-Lutetian angular unconformity on the Balces anticline postdates this event.

During the mid-to late Lutetian, the Ainsa Basin was filled with the Sobrarbe complex, ending its depositional history. Younger sediments reflect new basin geometries and structural constraints.

Up to late Lutetian, Hecho Group, and Sobrarbe Fm paleocurrents maintain similar northward dominance with a secondary dominance from east and west (hinterland and foreland direct provenance). Applying rotational corrections, they are coherent with an originally non-rotated south-Pyrenean E-W trend basin. The persistence of paleocurrents through time agrees with the proposed rotational chronology of low rotational rates before late Lutetian and sudden rotation increase by Bartonian to middle Priabonian times.

The rotation postdates and follows the fault-propagation fold emplacement.

Authors contribution

Data acquisition and research (TM), article structure, methodology, writing and edition (AB and TM), figures (TM and AB).

Acknowledgements

The original data acquisition was sponsored by a PhD IGME fellowship (T. Mochales), a 2015 Research Grant from the Sobrarbe Geopark (GEO/3.2.1.3), and financial support of CGL-2006-2289-BTE MEC and CGL2008-00809/BTE MICINN research projects. This work is supported by projects PID2020-114273GB-C22 and PID2019-108753GB-C22.

The contribution of A. Barnolas to this work is supported by PID2021-122467NB-C21 and PID2021-123917OB-I00 Projects (Agencia Estatal de Investigación).

We acknowledge Antonio Teixell (UAB) and two anonymous reviewers who helped to improve our manuscript.

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