The Lutetian Ainsa Sequence: an Example of a Small Turbidite System Deposited in a Tectonically Controlled Basin

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Introduction

Relatively small and lenticular sandstone bodies encased in a predominantly mudstone succession crop out in the Ainsa region in the South-Central Pyrenees. These Ainsa sandstones, of late Lutetian age, were first mentioned by Mutti and Ricci Lucchi (1972, Figs. 15 and 16) and interpreted as slope features thought to represent the main feeder channels of the thick and laterally extensive basinal turbidite succession which developed west of the Boltaña anticline (the Hecho Group). Subsequent studies (Mutti, 1974, 1977; Mutti et al., 1981; Mutti and Normark, 1987, 1991; Schuppers, 1995; Clark, 1995; Clark and Pickering, 1996; Cronin et al., 1998; Pickering and Corregidor, 2000) have contributed to a better understanding of the sedimentological characteristics and depositional setting of the Ainsa sandstones, emphasizing in particular the channelized nature of the deposits. There remains, however, the need to frame the Ainsa sandstone bodies within their local stratigraphic framework and to consider the lateral and vertical stratigraphic relationships of these deposits all across their outcrop area (extending for roughly 10 km within the Santa Maria de Buil syncline). Because these sandstones have become increasingly known in recent years as potential analogs of similarly lenticular and hydrocarbon-bearing sandbodies commonly found in many slope basins of divergent continental margins, it is clearly important that these sandstones be re-examined within their context.

In this paper, we describe and discuss some of the characteristics of the Ainsa sandstone bodies over their entire outcrop area and, based on detailed mapping and high-resolution correlations (see also Benevelli, 2002), attempt to show that their deposition was mainly related to synsedimentary basin-modifying tectonics.

Geologic Setting

The Ainsa sandstones form the lowermost portion of an approximately 3000-m-thick sedimentary succession that lies unconformably on a highly deformed substratum following a phase of dramatic tectonic and paleogeographic reorganization of the South-Central Pyrenean basin during Late Lutetian (Mutti et al., 1985, 1988). This succession is preserved within the Santa Maria de Buil syncline and records the progressive infilling and shoaling upward of this sector of the South-Central Pyrenean Basin concomitantly with the main phase of growth of the Mediano and Boltaña anticlines to the east and west, respectively. The ancestral Santa Maria de Buil syncline can thus be seen as a piggyback basin, herein termed the Ainsa Basin *sensu stricto*, located between the NNW-stretching oblique ramp anticlines of the Mediano and Boltaña thrusts (Figure1).

The Ainsa basin fill is initially recorded by relatively small and poorly-efficient turbidite systems overlain by deltaic strata (the Sobrarbe delta of Puigdefábregas, 1975; see also Dreyer et al., 1999) and eventually by upper Eocene fluvial sandstones (the Escanilla Formation).

Based on published data (Puigdefábregas, 1975; Mutti et al., 1988; Dreyer et al., 1999) and the results of this study, the infilling of the Ainsa basin took place under strong synsedimentary structural control. In a S-N (dip) section, the basin suffered a marked differential subsidence recorded by a dramatic stratigraphic expansion toward the north, which resulted from the progressive uplift and erosion of the southern margin of the basin (Sierras Marginales) and the concomitant thrust-related subsidence in the north.

The synsedimentary westward propagation of the Mediano thrust system and the concomitant growth of the thrust-related Boltaña anticline affect the architecture of the Ainsa basin fill, generating a highly complex depositional pattern essentially characterized by sediment entry points in the south (the Sobrarbe Delta), a dispersal pattern controlled by structurally-induced submarine topography and a divergent onlap stratal pattern on the NNW-stretching basin margins. Deposition of the Ainsa sandstones records the early phases of the infilling of the basin.

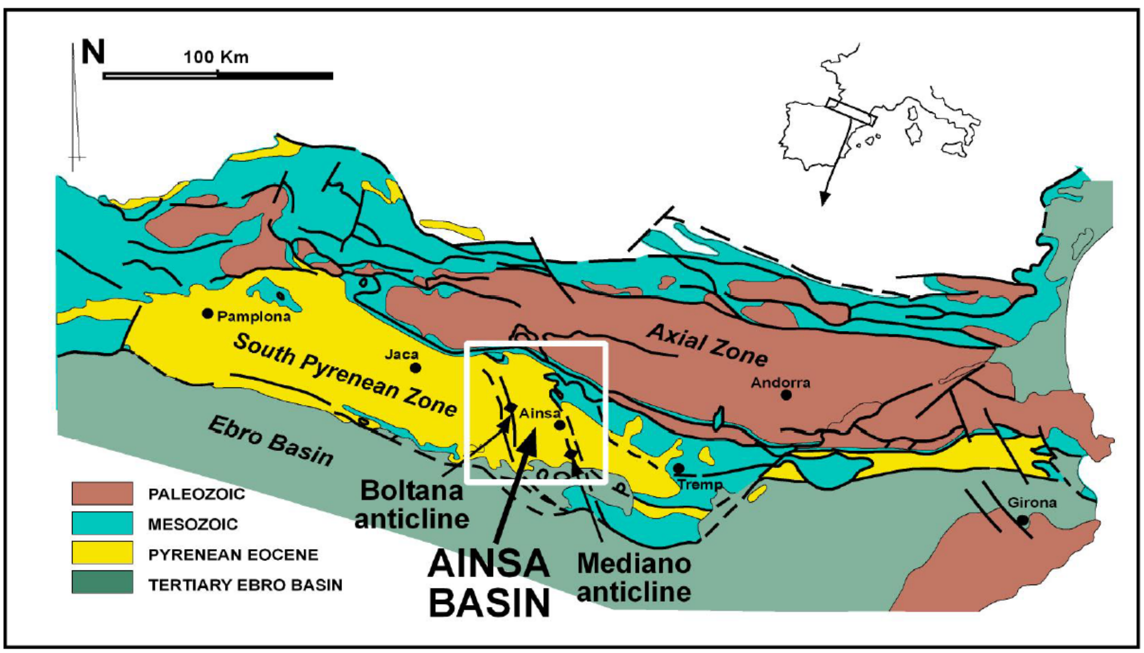

Figure 1: Simplified sketch map of the Southern Pyrenees highlighting the geologic setting of the Ainsa Basin.

Stratigraphy and Facies Distribution

Careful mapping of the study area, both in the field and on aerial photographs, and the correlation of 18 measured sections for a total of 5.5 km have allowed us to establish the preliminary map and stratigraphic cross-section of Figures 2 and 3, respectively. As shown in these figures, we introduce herein the term "Ainsa Sequence" to denote an approximately 1000-m-thick succession, which unconformably overlies a severely folded and thrusted substratum and is erosionally overlain by the Morillo system. In the axial portion of the basin, the Ainsa Sequence can be further subdivided into five smaller-scale depositional sequences, herein termed A1, A2, A3, A4, and A5 units, each clearly bounded by a basal unconformity surface locally identified by either angular stratigraphic relationships with the underlying deposits or an abrupt basinward shift of coarse-grained facies. Each of these sequences is characterized by a distinct overall thinning- and fining-upward facies trend.

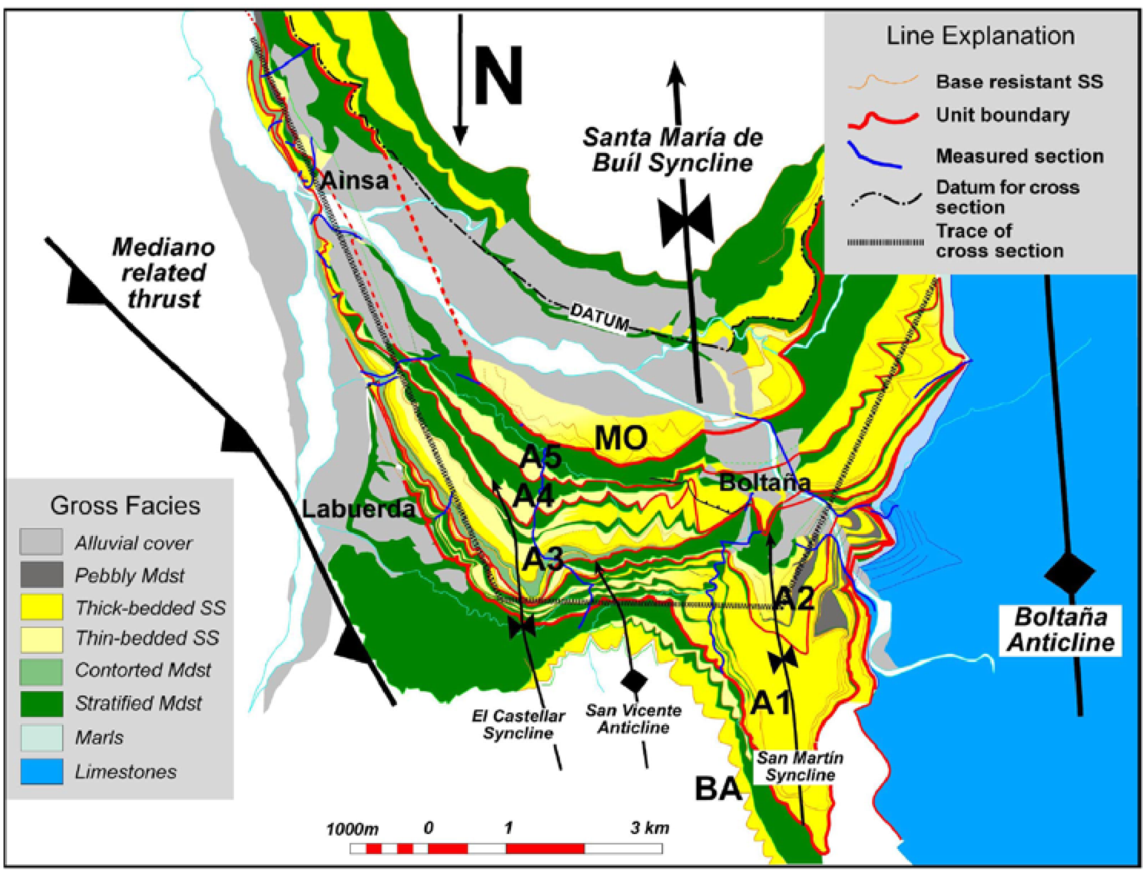

Figure 2: Geologic map of the Ainsa Sequence.

The Ainsa Sequence is made up of a limited number of lithofacies which are partly intergradational. These include: (1) pebbly mudstones and pebbly sandstones, (2) thick-bedded sandstones, (3) thin- to very thin-bedded sandstones, (4) mudstones (with the limited occurrence of packets of thin-bedded sandstones) and (5) contorted mudstones (Figures 2 and 3).

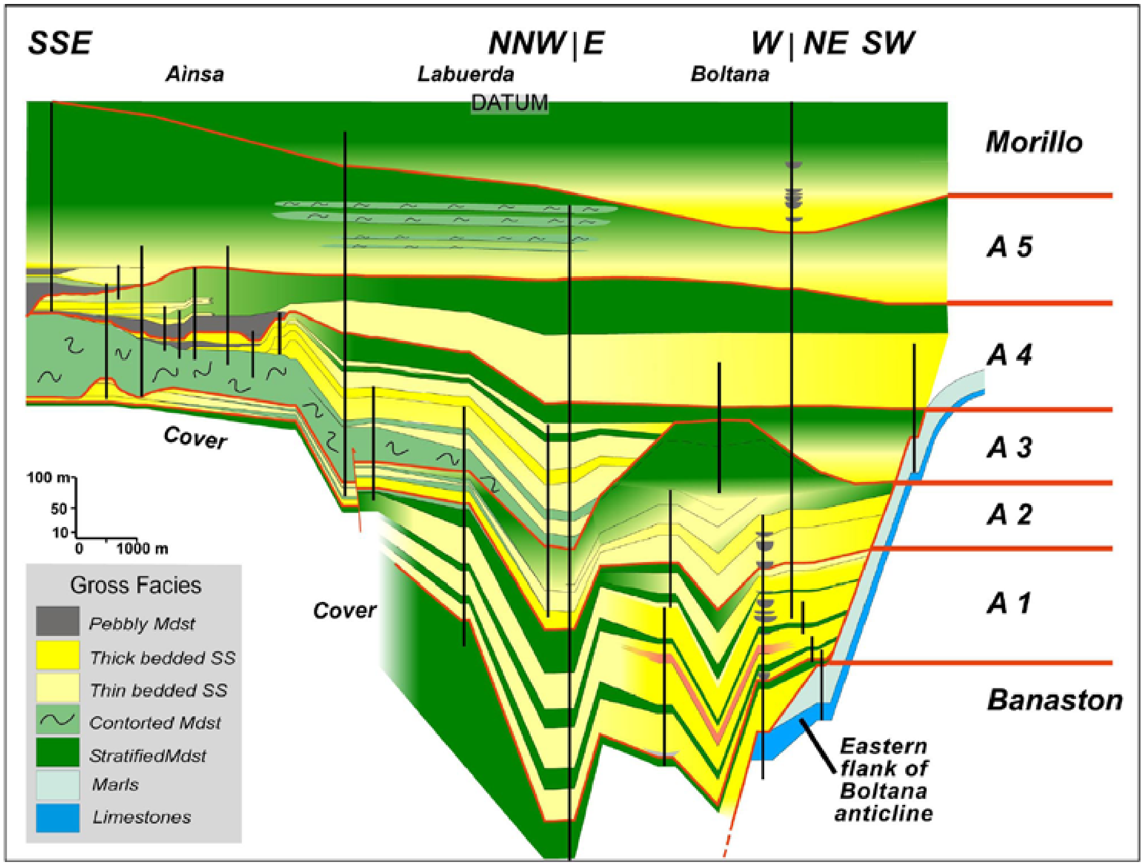

Figure 3: Stratigraphic cross-section of the Ainsa Sequence. See the trace in Figure 2 for orientation.

A1, which is preserved only in the northernmost outcrop of the study area, forms the infill of a highly asymmetric basin; its depocenter coincides with a narrow syncline, termed San Martin syncline, located between the San Vicente and Boltaña anticlines (Figure 2). In this depocenter, the unit reaches a thickness of some 400 m and mainly consists of thick-bedded sandstones, pebbly sandstones, and occasional pebbly mudstones that terminate abruptly to the west against the eastern flank of the Boltaña anticline; the unit thins and wedges out to the east and southeast concomitantly with a dramatic facies change, whereby the basal coarser grained facies are replaced by a laterally equivalent mudstone-dominated succession containing m-thick packets of thin-bedded coarse and fine sandstones.

A2 is still partly affected by the presence of the same depocenter, which was infilled with sandstone lobes overlain by a 100-m-thick succession of mudstones. At least in their upper and receding part, these sandstone lobes correlate with those that form the sandy infill of the well known “channel” exposed in the quarry south of Ainsa. Careful facies studies of this classical exposure cast serious doubt about a “channel” interpretation (Mutti et al., in preparation).

The uppermost 3 sequences (A3 to A5) developed after an important phase of deformation and are each composed of small channel-lobe systems, where relatively tabular sandstone lobes capped by mudstone lithofacies in the north can be traced upcurrent; i.e., to the southeast, in small channels (up to 1 km wide and up to 10 m deep). These channels and their related lobes, which are well exposed north of the town of Ainsa, abruptly overlie a thick section of chaotic mudstones (herein included in the A3 unit), which can be interpreted as a slump unit derived from the inversion and uplift of the San Martin depocenter and from the concomitant uplift of the western limb of the Mediano anticline. The lack of substantial accumulations of F3 facies indicates that these systems were poorly efficient and therefore not indicative of an important sediment bypass. The lobes of the A4 and A5 units were deposited progressively more westward, onlapping onto the eastern flank of the Boltaña anticline.

Summary and Conclusions

The upper Lutetian Ainsa sequence cropping out in the Santa Maria de Buil syncline in the south-central Pyrenees formed during the early phase of infilling of a piggy-back basin associated with westward thrust propagation. Deposited after a phase of severe structural deformation, the Ainsa sequence is bounded below and above by two unconformity surfaces. Five distinct smaller-scale sequences can be recognized within the Ainsa Sequence. Each of these units is also bounded below and above by unconformity surfaces produced by structurally-induced modifications of the basin, creating new depocenters and intrabasinal “highs”.

Within this highly mobile tectonic setting, both the down- and cross-current facies changes observed appear to have been mainly controlled by structurally-induced basin topography; i.e., by the shifting, with time, of intrabasinal “lows” and “highs,” which interfered with the path of SSE-derived sediment gravity flows. An early depocenter, located in the present San Martin syncline, controls the deposition of the A1 and, to a lesser extent, the A2 units. Following a phase of structural deformation, this depocenter was inverted and progressively smoothed off, giving way to a succession of relatively small channel-lobe systems (A3 to A5) with relatively tabular geometry. The asymmetric cross section of the depocenters, with a steep western flank and a gentler eastern flank, generates a characteristic cross-current facies distribution pattern. The denser and faster moving parts of the flow moved along the deeper and steeper portion of the depocenter, whereas the more dilute and turbulent part of the flow tended to climb the more gentle slope bounding the depocenter to the east, generating characteristic cross-current facies tracts.

In such settings, the local flow pattern must be very complex, but detailed facies observations suggest that turbulent flows rework and move as bed load away, from their original site of deposition, the coarse-grained deposits which formed along the margins of the dense flow because of dewatering and frictional freezing. These sediments comprise very distinctive facies produced by the migration of megaripple and ripple fields (F6 of Mutti, 1992; Facies E of Mutti and Normark, 1987; for details see Mutti and Tinterri, 2004).

Despite the very different geodynamic setting, the Ainsa Sequence is a potential analog for the fill of slope basins of divergent margins, where salt tectonics plays a fundamental role in controlling the architecture and facies of small and confined channel/lobe turbidite systems.

References

Benevelli, 2002, Stratigrafia fisica ed analisi di facies dei sistemi di Ainsa 1 e Ainsa 2, dei canali di Fosado e di Fuendecampo (Eocene dei Pirenei centro-meridionali) e stratigrafia fisica di un volume 3D nell'offshore dell'Africa occidentale: Ph.D. Thesis, University of Parma, Italy, 144 p..

Clark J.D., 1995, A detailed section across the Ainsa II channel complex, south-central Pyrenees, Spain, *in* Pickering K.T., R.N. Hiscott, N.H. Kenyon, F. RicciLucchi and R.D.A. Smith, eds., Atlas of Deep Water Environments: Architectural Style in Turbidite Systems: Chapman and Hall, London, p. 212-215.

Clark J.D., and K.T. Pickering, 1996, Architectural elements and growth patterns of submarine channels: Application to hydrocarbon prospectivity. AAPG Bulletin, v. 80, p. 194-221.

Cronin, B.T., D. Owen, A.J. Hartley and B. Kneller, 1998, Slumps, debris flows and sandy deepwater channel systems: Implications for the application of sequence stratigraphy to deep water clastic sediments. Journal of the Geological Society, v. 155, p. 429-432.

Dreyer T., G. Corregidor, P. Arbues,l and C. Puigdefabregas, 1999, Architecture of the tectonically influenced Sobrarbe deltaic complex in the Ainsa Basin, northern Spain. Sedimentary Geology, v. 127, p. 127-169.

Mutti E.,1974, Turbiditas de suprafan en el Eoceno de los alrededores de Ainsa (Huesca). VII Congreso del Grupo Español de Sedimentologia, 23-28 Settembre 1974, Bellaterra-Tremp, Resumenes, Sesion 7a, Dia 26, p.68-72.

Mutti E.,1977, Distinctive TBT facies and related depositional environment in the Eocene Hecho Group (south-central Pyrenees, Spain): Sedimentology, v. 24, p. 107-131.

Mutti E.,1992, Turbidite Sandstones: Agip and University of Parma.

Mutti E., and F. Ricci Lucchi,1972, Le torbiditi dell'Appennino Settentrionale : introduzione all'analisi di facies: Mem. Soc. Geol. It., v. 11, p. 161-199.

Mutti E., and W.R Normark, 1987, Comparing examples of modern and ancient turbidite systems: Problems and concepts, *in* Legget J.K., and G.G. Zuffa, eds.: Marine Clastic Sedimentology: Graham and Trotman, London, p.1-38.

Mutti E., and W.R Normark, 1991, An integrated approach to the study of turbidite systems, *in* Weimer, P., and M.H. Link, eds., Seismic Facies and Sedimentary Processes of Modern and Ancient Submarine Fans: SpringerVerlag, New York, p. 75-106.

Mutti E., and R. Tinterri, 2004, Cross-stratified coarse-grained sandstone beds: Evidence of flow-margin deposition and reworking in confined turbidity currents (abstract): AAPG Bulletin, v. 88, no. 13 (AAPG Annual Convention [CD-ROM]; also Search and Discovery Article #90026 (2004) (www.searchanddiscovery.net/documents/abstracts/annual2004/Dallas/Mutti02.htm)).

Mutti E., F. Fonnesu, G. Rampone and M. Sonnino,1981, Channel fill and associated overbank deposits in the Eocene Hecho Group, Ainsa-Boltaña region (south-central Pyrenees): IAS 2nd European Regional Meeting, Bologna, p. 113-116.

Mutti E., E. Remacha, M. Sgavetti, J. Rosell, R. Valloni, and M. Zamorano, 1985, Stratigraphy and facies characteristics of the Eocene Hecho Group turbidite systems, South Central Pyrenees, *in* Mila, M,D., and J. Rosell, eds., Excursion Guidebook of the 6th European Regional Meeting of the International Association of Sedimentologists, Lerida: IAS, p. 521-576.

Mutti E., M. Seguret, and M. Sgavetti, 1988, Sedimentation and deformation in the Tertiary sequences of the Pyrenees: AAPG Mediterranean Basin Conference, Special Publication, University of Parma, Field Trip, 7, p. 153.

Mutti E., R. Tinterri, E. Remacha, N. Mavilla, S. Angella and L. Fava,1999, An introduction to the analisys of ancient turbidite basins from an outcrop perspective: AAPG Course Notes 39, p.93.

Pickering K.T., and J. Corregidor, 2000, 3D reservoir-scale study of Eocene confined submarine fans, South-Central Spanish Pyrenees: GCSSEPM Foundation 20th Annual Research Conference Deep-Water Reservoirs of the Word, Houston, December 3-6, 2000, p. 776-781.

Puigdefabregas C.,1975, La sedimentacion molasica en la Cuenca de Jaca: Pireneos, v. 104, p. 1-188.

Schuppers J..D., 1995, Characterization of deep-marine clastic sediments from foreland basins: Ph.D. Thesis, Delft University of Technology, Holland, 272 p.