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Deep-marine structurally confined channelised sandy fans: Middle Eocene Morillo System, Ainsa Basin, Spanish Pyrenees

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ABSTRACT

The middle Eocene deep-marine Morillo System is up to ~260 m thick and is the penultimate deep-marine sand-prone system in the Ainsa Basin, Spanish Pyrenees. It comprises the proximal parts of three structurally confined, coarse-grained and channelised mid-slope/canyon to lower-slope submarine fans (designated the Morillo I–III fans). Their constituent channels appear to be low- to moderate-sinuosity channels with widths estimated in the range of 600 m to the order of 1 km, and depths typically several tens of metres or more. Locally, the presence of metre-scale gravel-rich and sandy barforms is consistent with either relatively sinuous thalweg channels or side- and mid-channel bars within a more braided-like channel complex. The abundance of pebble-rich deposits throughout the Morillo System is interpreted to reflect a response to increased gradients in the staging area for sediment gravity-flows and mass wastage, which also may have been linked to a fall in relative base level as the Ainsa thrust-top (piggyback) basin narrowed and was uplifted between the tightening Boltaña, Añisclo and Mediano anticlines (submarine growth structures). As the shallow-marine and non-marine source areas were degraded and the sandy fans were abandoned, up to several hundred metres of very fine- and fine-grained, thin- and very thin-bedded turbidites and hemipelagic sediments mantled the coarser-grained Morillo deposits. This change in depositional style is interpreted as a response to a reduction in seafloor gradients during a phase of increased tectonic shortening across the Ainsa Basin, thereby permitting the growth of the final structurally confined system, the Guaso System, as low-gradient submarine fans in the Ainsa Basin.

Contents

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1. Introduction

Many studies of modern (*e.g.*, Talling et al., 2007; Ercilla et al., 2008; Babonneau et al., 2010) and ancient deep-marine channelised slope and proximal basin-floor fan systems (*e.g.*, Payros et al., 1999; Gardner et al., 2000, 2003; Hodgson et al., 2006; Amy et al., 2007; Hubbard et al., 2008; Pickering and Bayliss, 2009; Sutcliffe and Pickering, 2009; Çelîk, 2013; Janocko et al., 2013; Stright et al., 2014) have shown the complexity of processes that influence their architectural elements and depositional styles. An understanding of the sedimentary and stratigraphic architecture of the Morillo System (for location and stratigraphic position, see Figs. 1 and 2 in Scotchman et al., this volume) is important in the application of this knowledge to other structurally-confined, coarse-grained submarine fans, particularly where gravel and sand barforms are present.

This study is based on nine separate localities and ~1110 m of measured section in a proximal (south) to relatively distal (north) transect over a distance of ~9 km. Here, we document the middle Eocene Morillo System in the Ainsa Basin (Fig. 1; also see Figs. 1 and 4 in Scotchman et al., 2014, this volume), which is stratigraphically significant because it represents the penultimate stages of deep-marine sedimentation in the thrust-top basin, and records an important tectonic regime of depositional confinement, changing seafloor gradient and overall shallowing of the bathymetry. It also contains locally abundant mass-transport deposits or "MTDs" (which where grouped are referred to as mass-transport complexes or "MTCs") and lateral accretion surfaces, the significance of which is critical to any environmental interpretations. Additionally, we also revise the sedimentology and stratigraphy of the Morillo System as described by Labourdette et al. (2008), Moody et al. (2012), and Pohl and McCann (2013), and propose an alternative interpretation of the depositional system.

The Morillo System is up to ~260 m thick and stratigraphically overlies the Ainsa System. Age dating of the Ainsa Basin suggests the deposition of the Morillo System occurred during the mid Lutetian (Payros et al., 1999; Pickering and Corregidor, 2000, 2005; Remacha and Fernández, 2003). The Morillo System was mapped using a combination of aerial photographs at a scale of 1:20,000 and topographic base maps at a scale of 1:40,000 with triacetate overlays used for interpretation. Sedimentological analysis included detailed bed-by-bed sedimentary logging, palaeocurrent measurements and lithostratigraphic correlations.

2. Sedimentary facies, facies-associations

In this paper, we adopt the facies terminology of Pickering et al. (1986, 1989), and the hierarchical terminology of Flint et al. (2008) and Sprague et al. (2008). Sediment gravity-flow (SGF) deposits define the second order hierarchical division in the Ainsa Basin and facies types define the fundamental units of a depositional body in architectural element analysis. A broad range of facies occurs in the Morillo System (Fig. 2), particularly a wide variety of MTDs and MTCs (Fig. 3). Fig. 4 shows the abundance of the principal facies classes in the Morillo fans, represented as the percentage of both the total number of beds and the total thickness measured. From this, it can be appreciated that there are a considerable number of beds in Facies Classes C, D and E, and that most of the cumulative thickness is represented by Facies Classes A, C and E.

The most common trace fossils in the lower-slope, sandy depocentres of the channelised Morillo fans are *Ophiomorpha*, a dwelling/*domichnial* trace; *Halopoa*, *Scolicia*, *Gordia*, grazing/*pascichnial* traces; *Megagrapton* and *Paleodictyon*, traps and gardening/*agrichnial* traces. The MI, MII and MIII fans are represented by a moderate diversity, low abundance trace-fossil assemblage; there is an increase in diversity and abundance with lateral distance from the channel axis-environments, and vertically, following a temporal trend of decreasing bed thickness and average grain size of sandstone beds (*cf.* Heard and Pickering, 2008; Heard et al., 2014).

Facies associations for the Ainsa Basin (including the Morillo System) are representative of the temporal and spatial arrangement of facies in the sedimentary record. Six facies associations are defined, which encompass the variety of deposits found in the Morillo System.

2.1. Facies-association 1

(FA1) is characterised by discontinuous, lens-shaped gravels, pebbly sandstones and MTDs (Facies A1.1, A1.2, A1.3, A2.1, A2.2, A2.3, F1 and F2). Many of the pebbles are very well rounded (fluvial processes) yet contain molluscan borings indicative of some residence time in shallow-marine environments. These deposits can be stacked to form thick MTCs, which typically reside at the base of sand-prone depositional units (referred to as fans in this paper) and form topography above which sandbodies accumulate. Alternatively, they may represent periods of bypass during channel development where erosive flows leave lag deposits. In either case, these deposits have irregular tops and are commonly erosive, with cumulative erosion of tens of metres. Internally, thin-bedded sandstones and marlstones are folded, attenuated and partially disaggregated with an abundance of incorporated and redeposited large benthic foraminifera such as nummulites. Thin- to thick-bedded, laterally discontinuous sandstone packages commonly occur between the gravelly deposits.

FA1 is interpreted to form from the collapse of upper- to lower-slope settings during the excavation of slope sediments and mark the onset of significant sediment supply to the basin. Transport mechanisms include concentrated density flows, hyper-concentrated density flows, MTD processes (slides, slumps, debris flow processes) and multiphase granular flows. The base of these deposits commonly represents sequence boundaries in the stratigraphic record. At outcrop, these deposits typically form prominent and mappable ridges, and in plan view they can extend for kilometres.

2.2. Facies-association 2

(FA2) comprises thick-bedded, very coarse-grained, amalgamated sandstones (Facies A1.1, A1.4, A2.1, A2.2, A2.4 and A2.5). These deposits are typically lens-shaped and laterally discontinuous. They are commonly erosive, creating irregular bases and convex-upward geometry. Groove casts and load structures are common. These deposits may contain conglomerates, which are typically well-stratified or graded, and rarely ungraded and disorganised. Internally, erosional surfaces commonly form inclined imbricated-clast horizons. This facies association is interpreted to represent the filling phase of channel-fill elements, with the deposition mainly from turbidity currents and concentrated density flows. This association of facies typically occurs stratigraphically above and temporally adjacent to FA1. Basal contacts could represent sequence boundaries where FA1 is absent. Downslope, this facies association becomes more laterally extensive and forms channel-mouth and/or proximal lobe deposits that comprise relatively unconfined, thick- to thin-bedded sandstones. At outcrop, these deposits are laterally more extensive in both cross-section and dip-section when compared to FA1. Where mapped in plan view, the outer boundary of these deposits appears to encompass FA1.