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Research paper

Turbidite bed thickness statistics of architectural elements in a deep-marine confined mini-basin setting: Examples from the Grès d'Annot Formation, SE France

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ABSTRACT

Statistical analysis of bed thickness was performed for sampled turbidite successions from well-documented architectural elements of the Grès d' Annot Formation to characterize confined deep-water mini-basins of the Tertiary foreland basin of SE France. The purpose was to use advanced statistical processing techniques in order to evaluate whether a discrimination of different architectural elements is feasible through observed statistical signatures of bed thickness. Statistical methods were focused on: i) fitting of widely used non-normal theoretical distribution models using robust non-parametric goodness-of-fit statistical tests, and ii) detecting the possible presence of non-random bed thickness clustering using existing and new clustering estimation methods. Results indicate that the bed thickness data are best characterized by a multi-modal lognormal distribution model which probably reflects a background sedimentological process. Several datasets exhibit power law as well as exponential thick-bedded tails. The data also exhibit non-random clustering of bed thickness. Discrimination of architectural elements in this confined turbidite succession seems to be feasible based on the characteristics of the observed composite lognormal distributions such as number and variability of the detected components. The estimation of the degree of facies clustering has potential for the discrimination of architectural elements in confined basin settings if used in conjunction with alternative estimation methods (such as periodogram estimation). This methodology may now be applied to other confined turbidite successions, be they outcrops with less certain architecture, or subsurface datasets with borehole imaging.

1. Introduction

Statistical knowledge regarding the thickness and stratal patterns of deep-marine gravity flow deposits (turbidites) constitutes an important aspect of recent sedimentological research since turbidite deposits can host large hydrocarbon accumulations. Thus, information such as the thickness distribution of turbidite beds in a vertical section can be an important component in the creation of reservoir models and the estimation of reservoir volumes (e.g. Flint and Bryant, 1993; Drinkwater and Pickering, 2001; Sylvester, 2007). Therefore, a detailed statistical characterization and methodology is essential in order to better constrain reservoir modeling parameters for turbidite deposits. Furthermore, the characteristics of turbidite bed thickness distributions (Malinverno, 1997; Carlson and Grotzinger, 2001; Talling, 2001; Mattern, 2002; Sinclair and Cowie, 2003; Clark and Steel, 2006) or the degree of turbidite facies clustering (Chen and Hiscott, 1999) might prove useful in differentiating depositional settings, even when working with data of limited lateral extent, such as wells or isolated outcrops (Sylvester, 2007).

Previous studies have attempted to assess the possibility of characterizing turbidite depositional environments based on observed types of bed thickness statistical distributions (Carlson and Grotzinger, 2001; Talling, 2001; Sylvester, 2007; Prekopová and Janočko, 2009; Pantopoulos et al., 2013), and bed thickness clustering (Chen and Hiscott, 1999; Mukhopadhyay et al., 2003; Felletti, 2004; Felletti and Bersezio, 2010; Kötelešová, 2012; Pantopoulos et al., 2013).

This study presents the results of statistical analysis of turbidite bed thickness data from well-documented architectural elements in a confined mini-basin setting of the Grès d'Annot Formation, SE France (Fig. 1; Hilton, 1994; Amy et al., 2000; Amy et al., 2004; Puigdefàbregas et al., 2004; Amy et al., 2007), focusing on fitting of statistical distributions and quantitative recognition of facies clustering.

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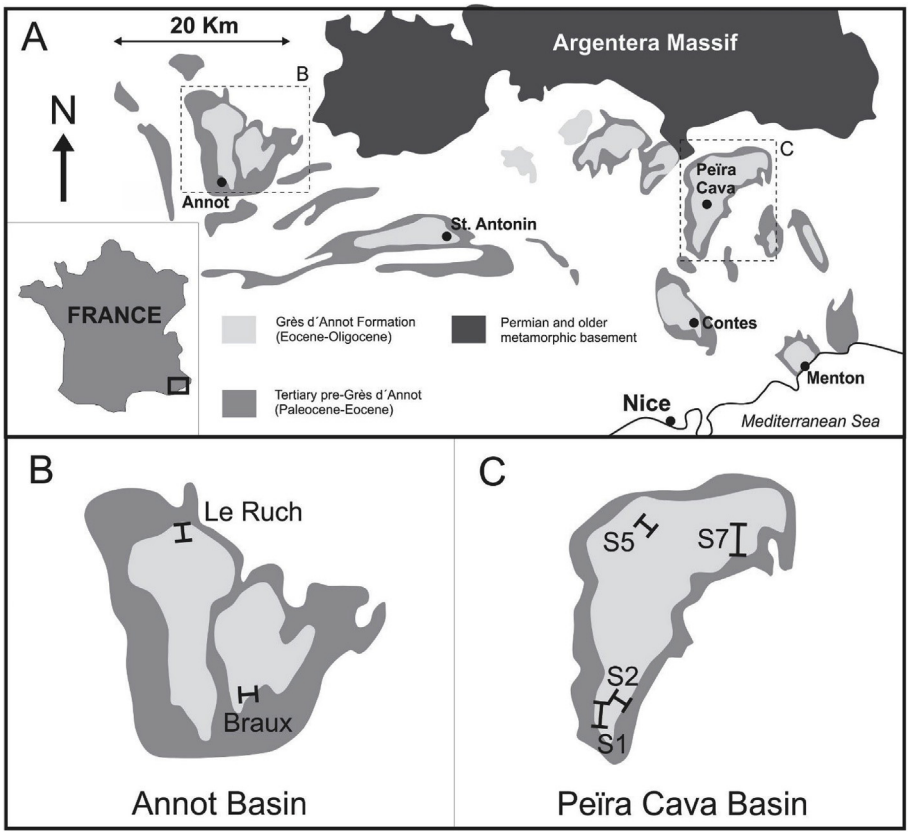

Fig. 1. A) Simplified geological map of southeastern France highlighting the outcropping remnants of the Grès d'Annot Formation. The locations of the studied outcrops at B) Annot and C) Peïra Cava sub-basins. Modified from Amy (2000).

The main objectives of this study are: a) to determine whether the empirical distribution of turbidite thicknesses of well documented architectural elements can be expressed by a specific theoretical distribution model using advanced statistical goodness-of-fit methods, b) to estimate possible discrimination of architectural elements based on the best fitting distribution model, where these elements have been previously defined, and c) to assess the usefulness of facies clustering techniques by combined testing of new and previously proposed methodologies on sampled bed thickness data.

2. Geological setting

The Grès d'Annot Formation was deposited during the late Eocene to early Oligocene (du Fornel et al., 2004) in the Tertiary Alpine foreland basin, and is a characteristic example of a confined sand-rich turbidite system, offering good quality exposures over a large area of SE France (Fig. 1; Joseph and Lomas, 2004). It occurs as a number of isolated remnants of what was a once a continuous basin (Apps et al., 2004).

The Cenozoic sequence rests with erosional unconformity on a Mesozoic basement. The oldest Tertiary deposits are conglomerates and sandstones, with gravel bars that are rarely capped by palaeosol and coally horizons (Argens Conglomerates). A regionally extensive shallow marine bioclastic limestone unit (Calcaires Nummulitiques Formation) consisting of a variety of bioclastic shallow marine environments commonly characterized by the presence of giant nummulite foraminifera, overlies the previous deposits (Apps et al., 2004). The Marnes Bleues Formation succeeds the Calcaires Nummulitiques and represents a deep-water, marl-dominated succession deposited during a phase of rapid subsidence and low sediment supply (Stanbrook and Clark, 2004).

The final phase of basin fill is dominated by deep-marine clastics derived from the Pyreneo-Provençal orogen to the south, and mass wasting deposits of the advancing Alpine Orogeny (Sinclair, 1997). Deep-marine deposits consist of turbidites of the Priabonian to Rupelian Grès d'Annot Formation which constitutes a 500–1500 m thick, sand-rich succession of turbidites and associated mudstones (Ravenne et al., 1987). At the time of turbidite deposition ongoing regional thrust tectonics created a province of piggy-back basins in which structural highs bounded confined sub-basins (Apps et al., 2004) with a general sediment transport northwards from the Corsica-Sardinia massif (Stanley and Mutti, 1978). As turbidite deposition progressed the basin floor topography was gradually buried as the turbidite fill onlapped and eventually filled the basin fill (Sinclair, 2000), although the thrust system continued to be active during turbidite deposition Apps (1987). The remaining accommodation space was filled by the overlying Schists à Blocs Formation (Apps et al., 2004) ending turbidite deposition in the late Rupelian (du Fornel et al., 2004).

The northern basin remnants of the formation are consisting of channelised, relatively "proximal", to non-channelised, relatively "distal" sand-rich systems, with rare, basin-wide, debris-flow conglomerates (Elliott et al., 1985; Ravenne et al., 1987; Ghibaudo, 1995; Hilton and Pickering, 1995; Sinclair, 1994). The outcrops north-northwest of Nice (Fig. 1) at Contes and Peïra Cava, comprise the southeastern part of the formation and probably form a part of an older, deeper-water system, though apparently more ponded (Amy et al., 2007). The Annot sub-basin (Fig. 1) was separated from those to the NE and bounded to the SW by palaeo-highs, which Elliott et al. (1985) related to ramps in the underlying thrust system.