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The role of sediment supply in large-scale stratigraphic architecture of ancient Gilbert-type deltas (Pliocene Siena-Radicofani Basin, Italy)

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ABSTRACT

Aggradation, progradation and retrogradation are the main patterns that define the large-scale architecture of Gilbert-type deltas. These patterns are governed by the ratio between the variation in accommodation space and sediment supply experienced during delta growth. Sediment supply variations are difficult to estimate in ancient settings; hence, it is rarely possible to assess its significance in the large-scale stratigraphic architecture of Gilbert-type deltas. This paper presents a stratigraphic analysis of a Pliocene deltaic complex composed of two coeval and narrowly spaced deltaic branches. The two branches recorded the same tectonic- and climate-induced accommodation space variations. As a result, this deltaic complex represents a natural laboratory for testing the effects of sediment supply variations on the stratigraphic architecture of Gilbert-type deltas. The field data suggest that a sediment supply which is able to counteract the accommodation generated over time promotes the aggradational/progradational attitude of Gilbert-type deltas, as well as the development of thick foreset deposits. By contrast, if the sediment supply is not sufficient for counterbalancing the generated accommodation, an aggradational/retrogradational stratigraphic architecture is promoted. In this case, the deltaic system is forced to withdraw during the different phases of generation of accommodation, with the subsequent flooding of previously deposited sub-horizontal topset deposits (i.e., the delta plain). The subsequent deltaic progradation occurs above these deposits and, consequently, the available space for foresets growth is limited to the water depth between the base-level and the older delta plain. This leads to the vertical stacking of relatively thin deltaic deposits with an overall aggradatational/retrogradational attitude.

1. Introduction

Gilbert-type deltas have been extensively described in many tectonically active and quiescent basins (e.g., Ethridge and Wescott, 1984; Colella, 1988; Nemec and Steel, 1988; Leren et al., 2010) and have attracted the attention of sedimentary geologists predominantly for their importance as indicators of the infill history of basins. This is particularly relevant for coarse-clastic basin margins, where biostratigraphic age control is generally poor and the stratigraphic arrangement of Gilbert-type deltas has been used as a tool for refining the reconstruction of basin fill patterns and basin subsidence kinematics (Postma, 1995).

The large-scale architecture of Gilbert-type deltas is defined by three main patterns: progradation, aggradation and retrogradation (e.g., Postma, 1995; Marzo and Steel, 2000). These patterns are generally identified by the trajectory of the topset/foreset transition point (also called "topset breakpoint path" by some authors, e.g., Backert et al., 2010) along the sedimentary succession (Helland-Hansen and Martinsen, 1996; Mortimer et al., 2005). These stratigraphic patterns are essentially governed by two allocyclic driving factors: i) the accommodation space variations, and ii) the type and amount of sediments supplied to the deltaic systems by rivers (Posamentier and Allen, 1993; Dorsey et al., 1995; Postma, 1995; Bijkerk et al., 2014). Autocyclic processes (e.g., delta-lobe switching) may secondarily influence the architecture of deltas, although they generally do not dramatically modify the overprint given by allocyclic driving factors to the final stratigraphic architecture.

The creation/degradation of accommodation space results from the combination of global sea-level variations and vertical movements within the basin. In turn, the combination of global sea-level variations, basin subsidence and sediment supply define the stratigraphic architecture of sedimentary successions and the shoreline trajectory pattern (cf., Posamentier and Allen, 1999; Coe et al., 2002; Catuneanu, 2002). Global sea-level variations are easily predictable from the Pliocene to present (Haq et al., 1987; Miller et al., 2005) and the basin subsidence history can be deduced by micropalaeontological, structural, seismic and geophysical data. On the contrary, the type and amount of sediment supplied to deltas are difficult to estimate in ancient settings, even though they play a crucial role in the formation and growth of deltas

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(López-Blanco et al., 2000; Marzo and Steel, 2000; Carvajal et al., 2009; Bijkerk et al., 2014). Variations in sediment yield can be connected for several factors, such as climatic changes, tectonics, geology of the drainage basin, inherited basin relief, etc. (cf., Schumm and Lichty, 1965), which often act unpredictably.

The aim of this paper is to understand the role of sediment supply on the stratigraphic architecture of ancient Gilbert-type deltas. For this purpose, a Pliocene Gilbert-delta complex located in the Siena-Radicofani Basin (Tuscany, Italy) has been investigated in accordance with sedimentological and stratigraphic criteria. The delta complex is composed of two different branches, situated ~300 m apart, and supposed coeval based on the lateral tracing of two key stratigraphic surfaces that mark the beginning and the end of the Gilbert-type related deposition. The two branches show an overall similar stratigraphic evolution, with basal shoal-water delta deposits passing upward to Gilbert-type delta deposits, which are in turn abruptly overlain by shoal-water delta deposits. However, the Gilbert-type delta deposits in the two branches display a marked difference in their stratigraphic arrangement.

The coeval timing of the two delta branches ensures that climate-induced base-level fluctuations influenced the delta complex built up in the same way. Moreover, the shoal-water delta deposits at the base and top of the succession narrowly constrain the accommodation space experienced during Gilbert-delta build-up, suggesting that subsidence acted uniformly in the area during deposition. Consequently, it is considered that the observed differences in the stratigraphic architecture are only attributable to differential sediment supply feeding the different delta branches.

2. Geological setting

The study area is located in the central part of the Siena-Radicofani Basin, close to the traditionally accepted boundary between the Siena and Radicofani sub-basins (southern Tuscany, Italy; Fig. 1A, B). These sub-basins have been considered as independent basins for a long time. Recently, however, Brogi (2011) demonstrated that they belong to the same tectonic depression and for this reason the term “sub-basins” is adopted. The Siena-Radicofani Basin (which also includes the Casino sub-basin to the north) is one of the most important post-collisional basins of the inner Northern Apennines (Costantini et al., 2009). Post-collisional basins correspond to a series of NNW-SSE trending tectonic depressions developed since the middle Miocene (Jolivet et al., 1998; Brunet et al., 2000), in which continental and marine sediments accumulated since the Miocene until the Quaternary.

The Siena-Radicofani Basin is traditionally interpreted as having developed in extensional settings and records a basin-and-range structural architecture (Martini and Sagri, 1993; Carmignani et al., 1995; Jolivet et al., 1998; Pascucci et al., 1999; Carmignani et al., 2001). Brogi (2011) proposed a more complex history, which sees the basin originating due to the activity of Serravallian/late Messinian staircase extensional detachments. These produced a bowl-shaped structural depression, which is partially modified by high-angle normal fault systems active during the Pliocene. Other authors interpreted the Basin as a thrust-top basin developed in a compressional tectonic setting (Finetti et al., 2001; Bonini and Sani, 2002).

2.1. Neogene sedimentation

Sedimentation in the Siena-Radicofani Basin starts in the late Miocene when deposition of a fluvio-lacustrine succession occurred. Miocene deposits unconformably overlie pre-Neogene bedrock and are presently exposed in limited areas. These sediments are in turn overlain unconformably by Pliocene deposits (Costantini et al., 2009) which accumulated since the early Zanclean until the late Piacenzian/earliest Gelasian (Bossio et al., 1992; Martini et al., 2011, 2013, 2016; Arragoni et al., 2012; Martini and Sandrelli, 2015).

The Pliocene succession is mainly represented by nearshore marine deposits close to basin margins, which pass basinwards to offshore fines. Episodes of continental sedimentation have been reported in the lower part of the Pliocene succession close to the Siena sub-basin margins (Bossio et al., 1992, 1993; Aldinucci et al., 2007; Manganelli et al., 2010, 2011; Martini et al., 2011; Bianchi et al., 2013). Individual sub-basins recorded different infilling histories, generally related to the time intervals when deposition occurred. Synthetic stratigraphic columns of the sedimentary successions exposed in the central sectors of the Siena and Radicofani sub-basin are proposed in Fig. 1C. Fig. 1C also reports the stratigraphic column of the sedimentary succession exposed in correspondence to the bedrock high that marks the traditionally accepted Siena/Radicofani sub-basins boundary (i.e., the so called “Pienza high”, data derived from Marini, 2001; Antoni et al., 2005). Among the several and marked differences in the depositional infilling history of these areas, it is important to highlight that marine settings persisted in basinal areas during the Pliocene. A low-magnitude intra-Pliocene base-level fall (occurred within the MPl3 biozone) is recorded only in the surrounding of the “Pienza high”, where lacustrine limestones and fluvial conglomerate occur within the Pliocene succession. Continental settings in which these deposits accumulated have been interrupted by a relative sea-level rise occurred at top of the Zanclean (MPl4 biozone) that restored marine settings (Marini, 2001).

Marine settings ended due to a regional uplift which affected southern Tuscany since the Piacenzian (Marinelli, 1975; Bossio et al., 1993). Quaternary deposition is documented by discontinuous outcrops of sandy-gravelly alluvial deposits (Aldinucci et al., 2007; Bianchi et al., 2013; Brogi et al., 2014).

The investigated area is located close to the “Pienza high” and previous stratigraphic studies have been performed in this area adopting lithostratgraphic criteria (Bonini and Sani, 2002; Antoni et al., 2005). The succession deposited during the Zanclean (MNN14/15 biozone of nannoplancton biostratigraphy; Martini et al., 2015) and according to Bonini and Sani (2002) and Antoni et al. (2005) it is mainly composed of coarse-grained and steeply inclined (up to 30°) conglomerate beds overlain by sub-horizontal sandstone. Bonini and Sani (2002) interpreted the angular unconformity between the conglomerate and the sandstone as connected to an intra-Pliocene uplifting pulse.

3. Methods

The study uses conventional geological field methods, including: i) mapping based on facies association concepts (at 1:5000 scale); ii) bed-by-bed sedimentological logging of twelve sections (about 320 m of measured succession); iii) collection of palaeocurrent indicators; and iv) line-drawing of architectures on photomosaics of four selected outcrops (up to 400 m long and 80 m high). The location of measured sections, as well as of the outcrops selected for line-drawings, is reported on Fig. 2. The area is vegetated by tall trees, thus offering limited opportunities to take good photographical records of extensive outcrops. In order to overcome this problem, large outcrops are featured as line-drawings and important features are detailed in close-up photos.

The sedimentological analysis is based on the concept of facies association, i.e., assemblages of spatially and genetically related facies that are the expression of different sedimentary environments (Walker and James, 1992). The descriptive sedimentological terminology is from Harms et al. (1975, 1982) and Collinson et al. (2006).

The term “flooding surface” is used in accordance with its classical meaning (cf., Van Wagoner et al., 1988), i.e., the surface connected to a transgressive pulse that separates shallower-water strata below from deeper-water strata above. However, in deltaic settings, autocyclic factors (i.e., not connected with base-level fluctuations) can produce vertical facies superimposition that resembles those typically connected to flooding surfaces. The term “deactivation surfaces” has been