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Research paper

Integrating traditional field methods with emerging digital techniques for enhanced outcrop analysis of deep water channel-fill deposits

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ABSTRACT

The development of emerging digital technologies that allow the collection and analysis of field data represents a significant innovation in field-based geological studies. The integration of these digital techniques with traditional sedimentological field methods facilitates considerable improvements in outcrop characterization. An example of this integrated modern approach for geological data collection is employed for the detailed characterization of a turbidite channel-lobe system of the Gorgoglione Flysch Formation in Southern Italy. The study area, exposed above the village of Castelmezzano, has been measured and described in detailed stratigraphic sections, providing data for both sedimentological analysis and correlation of the stratigraphy. In order to gain a complete perspective on the exposure and stratigraphic elements, analysis of physical outcrop data was enhanced by the use of high-resolution Gigapixel imagery and 3D photogrammetric outcrop reconstructions. The Santa Maria section has been assessed in terms of vertical and lateral facies stacking arrangements and subdivided into two component facies associations separated by a prominent concave-up erosional boundary. The lower facies association, interpreted as a frontal lobe complex, consists of tabular, thick-bedded coarse sandstones interbedded with persistent heterolithic packages of thin-bedded sandstones and mudstones, and minor soft-sediment deformed strata. The upper facies association represents the infill of a channel-form and consists of a basal conglomerate, passing gradually upwards into massive amalgamated sandstones overlain by large-scale cross-laminated sandstones. The excellent exposure of the Santa Maria section records the complete evolution of a channel-lobe system, transitioning from frontal lobe deposition through channel incision and bypass, to progressive backfilling. This study shows how facies characterization, stratigraphic correlations and reconstruction of the depositional architectures have been substantially enhanced by the use of emerging digital techniques for geological data collection.

1. Introduction

The improved capabilities of Gigapixel imagery systems and 3D photogrammetry software suites in recent years provide useful tools that can strengthen traditional stratigraphic field data. Gigapixel imagery systems are able to record very high resolution photomosaics, which allow an unprecedented level of inspection of outcrops, while photogrammetry software, such as Agisoft Photoscan allows 3D outcrop reconstructions from ground-based or aerial photos to be manipulated and viewed from multiple angles. These tools can fill critical gaps in stratigraphic data by permitting the inspection of both bed-scale and outcrop-scale details from distances and angles unachievable in person.

Turbidite channels are one of the most important pathways for sediment transport into ocean basins and their sedimentary infill has proven to be one of the most common types of hydrocarbon reservoirs found in deep water settings (e.g. Mayall et al., 2006). Seismic stratigraphy applied to conventional and high-resolution three-dimensional (3D) data sets offered a compelling method to understanding their internal stratal and architectural complexity (Mayall and Stewart, 2000; Posamentier and Kolla, 2003; Deptuck et al., 2007). However, a high degree of spatial variability of

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reservoir properties is associated with differences in the nature of channel fill and their stacking patterns occurring at scales below the resolution of 3D seismic datasets. Over the past years, to improve the sub-seismic characterization of submarine channel fills, numerous studies have focused on the details of suitable outcrop analogues, greatly improving our knowledge of distribution of sedimentary facies, grain size, and small-scale architectural elements and factors that may control the observed changes in stratigraphic architecture (e.g. Mutti and Normark, 1987; Posamentier et al., 1991; Pickering et al., 2001; Camacho et al., 2002; Brunt and McCaffrey, 2007; Schwarz and Arnott, 2007; Navarro et al., 2007; Kane et al., 2009; Pyles et al., 2010; McHargue et al., 2011; Di Celma et al., 2011; Figueiredo et al., 2013; Hubbard et al., 2014; Bain and Hubbard, 2016). Field methods for data collection, however, have remained the same for nearly the last two hundred years. Considering the rapid state of improvement and increased availability of digital technologies, there is a need to update the traditional techniques by integrating emerging digital field methods (e.g. McCaffrey et al., 2005; Wynn et al., 2005; Thurmond et al., 2006; Nieminski and Graham, 2017).

For this study, we consider a well exposed channel-lobe system from a key stratigraphic interval of the Upper Miocene Gorgoglione Flysch Formation (GFF), a coarse-grained siliciclastic turbidite succession that crops out in the Southern Apennines of Italy (Fig. 1). The study area, informally named the Santa Maria section, is of primary importance in the interpretation of the stratigraphic evolution of the whole GFF, since it represents one of the best-preserved isolated channels characterizing the upper portion of the turbidite succession (Casciano et al., 2017). This section was analyzed using standard field methods integrated with new digital field methods using a GigaPan imagery system and 3D photogrammetry. The goal of using these additional tools is to develop new methodologies for creating digital outcrop reconstructions that can supplement physical data for enhanced facies characterization of bed-scale architecture and facies distribution. The methods for creating GigaPan and 3D outcrop reconstructions, as well as their utility for research are described in this text. However, they are best seen in their digital format and can be found at a permanent online location at www.geode.net as part of a larger collection of digital geologic materials.

2. Geologic and depositional setting

The Southern Apennine Chain is a fold-and-thrust belt developed from late Oligocene to Pleistocene within the general framework of Africa-Europe major plate convergence on an eastward-retreating, W-dipping subduction zone (Doglioni, 1991; Patacca and Scandone, 2007 and references therein). The resulting north-eastward migration of the thrust front determined the progressive involvement in the thrust belt of several intervening Meso-Cenozoic basin and platform successions covering the Adria passive margin and adjacent Tethyan ocean. Accordingly, the structure of the Southern Apenninic orogenic wedge is configured as a thick thrust pile of heavily deformed rootless nappes, tectonically overlying the subducted Apulian platform carbonates and associated foredeep deposits (Vezzani et al., 2010 and references therein). Thrust-top clastic successions of upper Eocene to Plio-Pleistocene age unconformably cover the whole thrust-pile (Patacca and Scandone, 2007). Among them, one of the better preserved units is the late Burdigalian – early Tortonian GFF (Selli, 1962; Ciaranfi, 1972; Giannandrea et al., 2016). This ~1950 m thick siliciclastic turbidite succession consists of coarse sandy turbidites and mudstones with subordinate conglomerates, filling a narrow and NNW-SSE oriented wedge-top basin (Boiano, 1997). Primary exposures of the GFF occur along the eastern edge of the former basin, in a 25 km wide outcrop belt, between the towns of Castelmezzano and Gorgoglione, 25 km SE of Potenza (Fig. 1). In this area, the GFF unconformably overlies the Cretaceous - Eocene mud-rich succession of the Argille Varicolori Fm. (Fig. 1; Boiano, 1997). Deposition of the GFF was strictly controlled by the contractional tectonic deformations affecting the Apenninic accretionary wedge (Patacca et al., 1990; Boiano, 1997; Giannandrea et al., 2016). Provenance data shows that the GFF was sourced from a crystalline basement terrane located within the growing orogen to the West (Critelli and Loiacono, 1988). However, paleocurrent data document a prevalent paleoflow direction from NNW to SSE, along the longitudinal axis of the basin (Loiacono, 1974). Consequently, many authors invoked a palaeogeographic scenario with sediment gravity flows initiated from an inferred shelf in the orogenic hinterland, which were directed down a NE-facing paleoslope and were successively deviated toward SSE along the basin axis near the base of slope (Pescatore and Senatore, 1986; Boiano, 1997).

In the Castelmezzano – Pietrapertosa area, the lower ~1200 m of the succession are characterized by the occurrence of amalgamated sandbodies up to 25 m thick, systematically stacked to form extensive channel complex sets. A ~700 m thick clay-prone succession incised by isolated arenaceous-conglomeratic channels constitutes the topmost part of the basin-fill succession, where the studied section is located. The vertical architectural and grain-size evolution of channel types documented in the upper 1000 m of the turbidite succession (from amalgamated sand-filled channels to isolated conglomerate-rich channels), together with the gradual upward change in the background sedimentation (from sand-prone to clay-prone heterolithic deposits), likely reflects a shift along the depositional profile, passing from a near base-of-slope to a slope setting as a result of slope progradation (Casciano et al., 2017).

3. Methodology

The Santa Maria section was recorded and measured using both a traditional sedimentary facies analysis approach and emerging digital field techniques for outcrop mapping and data collection. Traditional methods included bed-scale characterization of sedimentological and stratigraphic elements and a paleoflow analysis. Stratigraphic data were collected in 8 measured sections logged at centimeter resolution recording grain size distribution, bed thickness, internal bedding divisions, and bounding surfaces. Paleoflow data were recorded from 361 basal paleoflow indicators, such as flutes and grooves, and cross bed stratification. Additional digital data collection methods included the construction of ultra-high resolution outcrop panoramas produced by the GigaPan® imagery system and 3D outcrop models obtained from aerial and ground based imagery using structure-from-motion (SFM) 3D photogrammetry to aid in identification of key surfaces and the depositional architectures of stratigraphic units. The GigaPan image system is a tripod mounted robotic device, which functions with both point-and-shoot or DSLR cameras, and guides the camera through precise photo grid with each photo at the maximum zoom level. The resulting photo set is stitched together using GigaPan Stitch® software to render a massive photomosaic image built from hundreds of individual photos (Fig. 2). The resulting images are viewed in the GigaPan® viewer or on their online site, www.gigapan.com, as "tiled" dynamic images in which the resolution increases at deeper levels of zoom. The GigaPan® device was used at four key locations for recording the section, two medium-range positions to record outcrop sections and two close-range positions to record detailed bed-scale features of two basal surfaces showing large numbers of scour structures (Fig. 2A). Our methods for creating 3D outcrop models involved large numbers of overlapping photos acquired from multiple positions and angles from