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Integrated ichnological and sedimentological analysis of a Late Cretaceous submarine channel-levee system: The Rosario Formation, Baja California, Mexico

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ABSTRACT

The sedimentology and ichnology of the Late Cretaceous Canyon San Fernando channel-levee system (Rosario Formation, Baja California) have been used to generate an ichnofabric model that may be used to enhance facies characterization and improve palaeoenvironmental interpretation in slope-channel systems. The Canyon San Fernando system consists of conglomerate-dominated channel axes, with thalwegs that may be bound by small confined levees. Laterally, away from the channel axis, the system consists of overbank/terrace environments with isolated conglomerate bodies and thinly bedded heterolithic turbidite sediments. The central channel belt is confined by a major channel-bounding levee composed of sandstone and siltstone turbidites. This sedimentological and ichnological model is based upon a composite lateral transect of facies from proximal (channel axis) to distal (levee) facies. Five ichnofabric associations are recognized: 1) The *Ophiomorpha* ichnofabric association characterizes the innermost channel and terrace settings; 2) the *Scolicia* ichnofabric association is typical of outer terrace and inner levee palaeoenvironments; 3) the *Nereites* ichnofabric association dominates the channel-bounding levee; 4) an aff. *Ilmenichnus* ichnofabric is found to be characteristic of bypass surfaces at the base of submarine channels; and 5) a phycosiphoniform ichnofabric association is found across almost all studied depositional environments. The distribution of ichnofabric associations and their constituent ichnofabrics provide a framework that can be used to compare turbidite channel systems in outcrop, as well as in core. The ichnofabric method used here has the potential to improve palaeoenvironmental analysis of other deep marine depositional settings, and in subsurface investigation of turbidite-hosted petroleum reservoirs.

1. Introduction

Ichnological data are used routinely in palaeoenvironmental and stratigraphic analysis of shallow marine rocks, as well as for intra-regional correlation and studies of petroleum reservoirs at parasequence and inter-well scales (e.g. Martin and Pollard, 1996; Pemberton et al., 2001; McIlroy, 2004b; MacEachern et al., 2007a; Gingras et al., 2007). In contrast, trace fossil distributions of continental slope to deep basin floor depositional environments have historically been largely restricted to discussions of the *Nereites* and *Zoophycos* ichnofacies and the *Paleodictyon* and *Ophiomorpha rudis* ichnosubfacies (Seilacher, 1967, 1974; Frey and Seilacher, 1980; Frey et al., 1990; Uchman, 2001, 2009). Despite recent refinements of the archetypal ichnofacies models (MacEachern et al., 2007a,b), and a number of recent reviews (e.g. Buatois and Mángano, 2011; Uchman and Wetzel, 2011), ichnology has only recently begun to be directly related to progress and developments in deep marine sedimentology (e.g. Heard and Pickering, 2008; Phillips et al., 2010; Hubbard et al., in press).

In detail, the distribution of trace fossils in continental slope and basin floor deposits is found to be complex and strongly facies-controlled. For example, ichnological data have been used to help distinguish between proximal (coarse-grained) and distal (fine-grained) turbidites on broad spatial scales (e.g. Crimes, 1970a,b; 1973, 1974, 1977; Książkiewicz, 1970; Wetzel, 1991, 2008; Wetzel et al., 2007; Kane et al., 2007). More recent studies have begun to place ichnological observations within a detailed turbidite facies architectural context (Shultz and Hubbard, 2005; Kane et al., 2007; Wetzel et al., 2007; Heard and Pickering, 2008; Hubbard and Shultz, 2008; Knaust, 2009; Phillips et al., 2010; Hubbard et al., in press). In addition, the ichnofabric approach (e.g. McIlroy, 2004a),

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which has been predominantly used to refine palaeoenvironmental interpretations of shallow marine facies (e.g. Martin and Pollard, 1996; McIlroy, 2004b), has rarely been applied to deep marine successions deposited by sediment gravity flows and associated mass transport deposits (cf. Knaust, 2009).

Turbidites are widespread in deep marine settings, within canyons that are incised into the slope, in erosional and aggradational channel systems, and in the fans, basin plains and ponded sheet systems into which channels pass distally (Whitaker, 1976; Stanley and Kelling, 1978; Pickering et al., 1989; Richards et al., 1998; Piper and Normark, 2001; Posamentier, 2003; Schwenk et al., 2005; Gamberi and Marani, 2007; Brunt et al., 2013; Etienne et al., 2013; Figueiredo et al., 2013; Macauley and Hubbard, 2013). Given the economic importance of turbidite plays, there is a surprising lack of data regarding trace fossil distributions within the architectural elements of turbidite systems. This study is focused upon ichnological study of ichnofabrics in a turbidite channel-levee system. Submarine channel-levee systems are of particular interest because they are host to many important hydrocarbon reservoirs (see Mayall et al., 2006).

Within submarine channel systems, background pelagic deposition of fine-grained siliciclastic and biological material is punctuated by deposition of turbidites. Fine-grained siliciclastic material in such depositional systems includes a combination of pelagic, hemipelagic and turbiditic sediment sources, which may be reworked by a variety of clear-water bottom currents, including thermohaline flows and internal tides (e.g. Dykstra, 2011). The colonization of turbidite and inter-turbidite sediments by infaunal and epifaunal organisms commonly leaves a rich ichnological record, which is most commonly reported from material preserved on the soles of turbidite sandstones (e.g. Książkiewicz, 1970, 1977; Uchman, 1995, 1998; Heard and Pickering, 2008).

The distribution of modern benthic communities, and by extrapolation their ancient counterparts, is controlled by physical and chemical factors including variations in hydrodynamic energy, sedimentation rate, seawater oxygenation and nutrient supply (e.g. McIlroy, 2004a). These physiochemical parameters are strongly controlled by seafloor topography and geomorphology, especially within submarine channel or canyon systems (e.g. Garcia et al., 2007; de Leo et al., 2010). Since the modern seafloor shows variability in endobenthic ecology that is environmentally controlled, it is considered that improved ichnological characterization of turbidite depositional systems should be possible.

This paper develops a practical ichnofabric-based approach (see McIlroy, 2004a, 2008) for the use of trace fossils and ichnofabrics in palaeoenvironmental analysis of turbidite channel-levee systems. The distribution of trace fossils and ichnofabrics is determined from sedimentologically constrained depositional settings in the Rosario Formation. It is considered that the trends in ichnology and ichnofabrics determined from this case-study could be used as a basis for interpretation of slope-turbidite systems in subsurface, core-based studies (cf. Knaust, 2009).

2. Materials and methods

2.1. The Rosario Formation

The Rosario Formation is the uppermost unit of the Late Cretaceous Peninsular-Ranges fore-arc basin complex (see Gastil et al., 1974; Morris and Busby-Spera, 1990; Morris, 1992). It overlies the non-marine El Gallo Formation in the west of the basin, and onlaps Cretaceous volcanic rocks of the Alisitos Group in the East (Gastil et al., 1974; Morris and Busby-Spera, 1990; Morris and Busby, 1996; Busby et al., 1998). Shallow marine and non-marine Palaeocene and Eocene rocks unconformably overlie the Rosario Formation. In the El Rosario area, the continental slope deposits of the Rosario Formation consist of a number of submarine canyon and channel systems (Morris, 1992; Morris and Busby-Spera, 1988, 1990; Dykstra and Kneller, 2007).

Over 600 m thickness of Rosario Formation is exposed in the late Campanian-early Palaeocene Canyon San Fernando turbidite channel system to the South of El Rosario (Fig. 1). The geology and stratigraphy of the Canyon San Fernando system has been extensively documented and described elsewhere (see Dykstra and Kneller, 2007, 2009; Kane et al., 2007; Thompson, 2010). Due to its oblique orientation to the dip of the continental slope, the Canyon San Fernando depositional system evolved stratigraphically from a fully confined submarine canyon, to a system that was confined by an erosional contact with continental slope mudstones (canyon wall) to the southeast, and by a channel-bounding levee to the northwest (see Dykstra and Kneller, 2007; Kane et al., 2007, 2009; Thompson, 2010). The succession displays an overall upward fining trend, and consists of a number of distinct channel-complex sets (*sensu* Sprague et al., 2002). Each channel-complex set consists of coarse-grained, amalgamated conglomerate bodies at the base, passing upward through isolated conglomeratic channel bodies separated by heterolithic sediments, which are capped by grey siltstones and mudstones (Dykstra and Kneller, 2007; Thompson, 2010). The facies architecture in this area is well constrained (see Morris and Busby-Spera, 1988, 1990; Dykstra and Kneller, 2007; Kane et al., 2007, 2009; Thompson, 2010). The depositional environments studied comprise a lateral trend from the channel axis, through overbank-terrace settings with confined levees, and across a major channel-bounding levee which grades into the continental slope (Fig. 2; Dykstra and Kneller, 2007; Kane et al.,

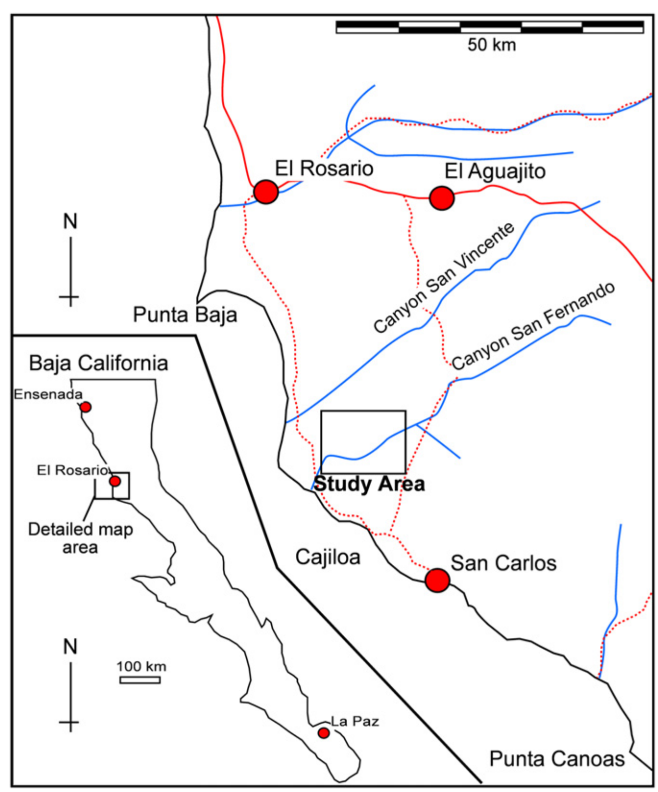

Figure 1. Map showing the location of the Canyon San Fernando system on the Pacific coast of Baja California, Mexico. Major roads are marked in red, dirt roads are dashed red and dry river valleys are shown in blue. Adapted from Bednarz and McIlroy (2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)