Palaeogeography, Palaeoclimatology, Palaeoecology 459 (2016) 365–380

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Ichnology of a subaqueously prograding clastic wedge, late Pliocene Morne L'Enfer Formation, Fullarton, Trinidad: Implications for recognition of autogenic erosional surfaces and delineation of stress factors on irregular echinoids

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ARTICLE INFO

Article history:
Received 8 August 2015
Received in revised form 27 June 2016
Accepted 18 July 2016
Available online 20 July 2016

Keywords:
Autogenic
Trace fossil
Paleo-Orinoco
Hyperpycnal–hypopycnal
Irregular sea-urchin
Marine erosion

ABSTRACT

The Morne L'Enfer Formation outcrops near Fullarton, Trinidad, expose an erosional surface between the shelf deposits below and a prograding clastic wedge of the late Pliocene paleo-Orinoco system above. The surface exhibits similarities as well as dissimilarities with examples of Regressive Surfaces of Marine Erosion (RSMEs) in wave-influenced shelf settings and also with incised valleys inherited from fluvial incision of shelf during a forced regression episode. However, detailed ichnological studies reveal that the surface is a subaqueous, autogenically controlled, erosional surface on a shelf dominated by the hyperpycnal and hypopycnal discharges with transient wave influence. Integration of ichnological and sedimentological characteristics also suggests complicated interrelationships among different stress factors affecting the infauna in different subenvironments, especially the irregular echinoids. The delta prograded subaqueously through autogenically establishing its lobe on the open shelf without stratigraphically significant erosional removal of sediments. In the subaqueously prograding clastic wedge, the fluvial influence pertains high stress conditions not only for the adult infauna, but also for their larvae within the water column, especially in and near the subaqueous distributary channels.

1. Introduction

Identification and characterization of erosional discontinuity surfaces is an essential component of sequence-stratigraphic analysis in evaluating basin evolution (see Plint and Nummedal, 2000; Embry, 2002; Catuneanu, 2006; Zecchin and Catuneanu, 2013). Trace fossils commonly provide important diagnostic information in recognizing an erosional discontinuity surface and its stratigraphic implications (MacEachern et al., 1992, 2012; Pemberton et al., 2001; Buatois and Mángano, 2011) and also in distinguishing an erosional surface from an apparent tectonic contact (*e.g.*, Dasgupta and Buatois, 2012, 2015). In a succession, where the shallow-marine sediments overlie the relatively deeper-water deposits along a sharp/erosional surface, the surface can conventionally be related to two sequence-stratigraphic scenarios unless the change-over is completely autogenic.

The first scenario takes place during a forced regression (*i.e.*, an episode of regional relative sea-level fall irrespective of the sediment supply), during which the pre-existing sediments deposited in a relatively deeper marine setting get eroded and occasionally incised. Then, the shallower marine sediments are deposited on top of the erosional surface. Such a surface is called a Regressive Surface of Marine Erosion (RSME) or Regressive Wave Ravinement Surface in wave-dominated shelf settings (Plint, 1988, 1991; Plint and Nummedal, 2000; Galloway, 2001, 2004). The erosion is commonly attributed to the zone or locus of wave action along the depositional strike, while the locus of erosion moves basinward. In this scenario, the erosion surface is characterized by the abrupt occurrence of proximal (*i.e.*, relatively landward) trace-fossil assemblages, which contrastingly overlie the more distal (*i.e.*, relatively basinward) assemblages across the surface (Pemberton and MacEachern, 1995; Buatois and Mángano, 2011). As a result, the extensively bioturbated muddy sediments, deposited on the shelf in deeper water settings (*e.g.*, offshore/offshore-transition and/or distal prodelta and/or open shelf) and containing either archetypal or distal *Cruziana* or *Zoophycos* Ichnofacies, are sharply overlain across the surface by the coarser-grained sediments. These younger sediments are deposited at a shoreface and/or delta-front and/or proximal prodelta belonging to either the *Skolithos* Ichnofacies or proximal *Cruziana* Ichnofacies. The exhumation of a semi-consolidated firmground substrate results in preservation of the *Glossifungites* Ichnofacies suite at the surface (MacEachern et al., 1992; Pemberton et al., 1992; Chaplin, 1996; Buatois et al., 2002; Buatois and Mángano, 2011).

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http://dx.doi.org/10.1016/j.palaeo.2016.07.018

In the second scenario, valleys can be incised by fluvial erosion during a forced regression episode into the pre-existing shelf deposits. The subaerial incision surfaces can be modified during the ensuing transgression and a 'coplanar surface of Lowstand and Transgressive Erosion' is generated (Zaitlin et al., 1994; Pemberton et al., 1992; MacEachern and Pemberton, 1994; Buatois and Mángano, 2011). The incised valleys are commonly filled with the fluvial sediments during the later stage of forced regression and lowstand normal regression and can be inherited by an estuarine valley setting during the subsequent transgressive phase. The older fluvial deposits are commonly not preserved. The depositional stacking and distribution patterns in the incised valley scenario, however, are manifestations of geomorphic equilibria of the sedimentary environments involved and functions of the degree of incision, sediment supply, relative sea-level changes, and so forth. Compared to the RSME scenario, therefore, an incised valley can occur either in a relatively shallower bathymetric position or in the case of higher magnitude relative sea-level fall during the forced regression episode. The latter situation allows the locus of fluvial erosion to move farther towards the open shelf. Because the incision surfaces exhume either the semi-consolidated (or firm) or consolidated/cemented (or rocky) older marine sediments, respectively, either suites of the *Glossifungites* Ichnofacies or the *Trypanites* Ichnofacies are emplaced at the incision surface during the marine transgression (Pemberton et al., 1992; MacEachern et al., 1992; de Gibert and Martinell, 1992, 1993, 1996; Martinell and Domènech, 1995; MacEachern and Pemberton, 1994; Uchman et al., 2002; Carmona et al., 2006, 2007).

In SW Trinidad near Fullarton outcrops of the Morne L'Enfer Formation expose an erosional surface that has apparent similarities with both the above scenarios. A pervasively bioturbated muddy sedimentary unit, which was deposited in a shelf setting belonging to the *Cruziana* Ichnofacies, has a sharply eroded and intermittently incised top surface. The overlying unit consists of a thick coarsening-up interval of sediments deposited as laterally accreting incised channel-fill sandstones and conglomerate/breccia and overbank deposits consisting of sandstone and heterolithic lithology and also as the wave-modified swaley–hummocky cross-stratified (SCS–HCS) tabular sandstone lithosomes. Although this succession is a candidate for the two sequence-stratigraphic scenarios described above, there are also differences that are discussed in this paper. These differences distinguish the erosional surface from either an RSME or an incised valley, which are known to be scoured respectively by the wave-action or fluvial erosion during a falling relative sea-level. Therefore, the erosional surface requires scrutiny through integration of sedimentological and ichnological variations across the contact. The objectives of this paper are: (1) to evaluate the nature of the erosional surface, (2) to determine the depositional settings in which the bioturbating infauna either thrived or struggled to survive, and (3) to postulate the causes behind the distribution and intensity of bioturbation by irregular sea-urchins (Spatangoida). Furthermore the varying influences of the stress factors on sea-urchin ethology and trophic types are discussed that arose from the interaction of fluvial and nearshore processes, in particular spatial and temporal variations of salinity, turbidity, and nutrients.

2. Geologic setting

The Southern Basin in southern Trinidad along with the neighboring Columbus Basin in the eastern offshore evolved as a large and structurally complex depocenter filled with the Neogene–Pleistocene clastic sediments delivered by the paleo-Orinoco River (DiCroce et al., 1999; Wood, 2000; Garciacaro et al., 2011a). Prograding sand-dominated clastic wedges over the Neogene muddy shelf are known to host prolific petroleum reservoirs in the Southern Basin. The tectonic–stratigraphic evolution of the Southern Basin, its depositional settings, and the structural geology have extensively been documented in the literature (*e.g.*, Kugler, 1956, 2001; Saunders and Kennedy, 1965; Donovan and Jackson, 1994; Dunham et al., 1996; Algar, 1998; Pindell et al., 1998; Babb and Mann, 1999; DiCroce et al., 1999; Wood, 2000; Bowman, 2003; Osman, 2006; Winter, 2006; Pindell and Kennan, 2009; Garciacaro et al., 2011a, 2011b; Gibson et al., 2012; Bowman and Johnson, 2014; Chen et al., 2014). The Southern Basin initially developed as a transpressional foreland basin since the late Oligocene in response to the oblique convergence between the Caribbean and South American Plates along the Serranía del Interior–Central Range system, thereby creating the NEE–SWW trending anticlines. A thin-skinned pull-apart stage followed during the Pliocene along with the extensional growth faulting phenomena due to the rapid sedimentation in the paleo-Orinoco delta–estuarine system. At the end of Pliocene, the transpression tectonics restarted.

With the eastward prograding rivermouth of the paleo-Orinoco towards the shelf-break, four grossly regressive cycles of sedimentation took place, which were preceded and followed by transgressive intervals and shelf-wide flooding (Fig. 1). Therefore, there were four phases of sedimentation of the delta–estuarine sand-dominated clastic wedges, which were deposited by the paleo-Orinoco River system developed across the shelf with overall transit of the system towards north and east during the late Miocene to late Pliocene (Fig. 1A–B) (Wach et al., 2003; Vincent et al., 2007; Vincent, 2008; Wach and Vincent, 2008; Osman, 2006; Winter, 2006; Steel et al., 2007; Chen et al., 2014: Bowman and Johnson, 2014). These phases are separated by three flooding episodes and corresponding transgressive deposits, namely the Lower Forest Clay, the Upper Forest Clay, and the Lot 7 Silt members. The third and fourth phases of clastic wedge deposition were first described together as the Morne L'Enfer Formation by Macready (1921) from the Pitch Lake–Point Fortin–Morne L'Enfer area. Later, Kugler (1956, 1959) delineated its constituent members, from bottom to top, the Upper Forest Clay Member, the Morne L'Enfer Silt, the Lower Morne L'Enfer Member, the Lot 7 Silt, and the Upper Morne L'Enfer Member (Figs. 1A–B, 2A). Therefore, apart from the basinal flooding related deposits of the Upper Forest Clay and Lot 7 Silt members (Fig. 1B), all the other members of the Morne L'Enfer Formation were deposited during the dominantly regressive or deltaic and the minor retrogradational or estuarine cycles across the shelf (Chen et al., 2014).

3. Sedimentological and ichnological observations at the Fullarton section and their interpretation

The Fullarton section is exposed along the *ca.* 2000 m shoreline of the western end of Cedros Bay (part of the Gulf of Paria) at Fullarton (Fig. 2A–B). The section has been poorly studied (except in unpublished proprietary field guidebooks and in the older literature; *e.g.*, Kugler, 1959; Saunders, 1997) and comprises the westernmost outcrops of the Morne L'Enfer Formation in Trinidad. The outcrop exposes deposits of the Morne L'Enfer Silt and the Lower Morne L'Enfer members (Fig. 2A). The outcrop has been marked with several reference points (Fig. 2B; Table 1). Between the terminal reference points FL01 and FL15, outcrops are disrupted into three fault-blocks by the two steep, westerly dipping, NNE–SSW-trending normal faults. The outcrop is subparallel to the strike of the erosional contact between the lower (*i.e.*, facies association A) and the upper units (*i.e.*, facies associations B–E; see below). Hence, the contact has repeatedly been exposed along the outcrop traverse (almost continuously between reference points FL04 and FL08, and locally at FL14). Because the paleo-shelf-margin defined by the earliest basin-bounding growth faults in the adjacent Columbus Basin was far eastward (Fig. 12 in Bowman and Johnson, 2014; Fig. 1A) during Pliocene and early Pleistocene, the study area therefore was on the continental shelf at the time of deposition of the Morne L'Enfer Formation.

While placing the Morne L'Enfer Silt and Lower Morne L'Enfer Member within a sequence stratigraphic framework, Wach et al. (2003); Osman (2006) and Chen et al. (2014) have adopted the scheme of categorizing (i) both siltstone-dominated prodelta and shelf deposits and sandy delta-front deposits as the Morne L'Enfer Silt and (ii) the tidally