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Depositional environments and ichnology of the deep-marine succession of the Amiran Formation (upper Maastrichtian–Paleocene), Lurestan Province, Zagros Fold–Thrust Belt, Iran

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ABSTRACT

The paleoenvironmental significance of deep marine trace fossil assemblages in the upper Maastrichtian–Paleocene Amiran Formation has been done for the first time in Lurestan Province (NW Zagros) from the Zagros Fold–Thrust Belt. A semi-quantitative study of trace fossil abundance (bioturbation indices) in the Amiran Formation shows that trace fossil assemblages can be very powerful discriminators of deep-marine clastic fan and related environments. The Amiran Formation is a sand-rich, thick-bedded, and coarse-grained turbidite succession. Deep marine paleoenvironments from basin slope to basin floor settings are preserved. These strata contain a diverse and abundant pre- and post-depositional ichnofauna. Proximal and axial parts of the sandy systems show low-diversity and low-density trace fossil assemblages dominated by post-depositional trace fossils, but distal environments show a general increase in trace fossil diversity, abundance and number of pre-depositional trace fossils. The post-depositional association essentially consists of dwelling, feeding, and grazing traces. The pre-depositional assemblage is rich in graphoglyptids and grazing trails, and feeding structures also occur.

The ichnodiversity, composition, ethology, and morphologic complexity of the pre-depositional association of the heterolithic successions of thin to thick-bedded turbidite sandstone and inter-turbidite mudstone are characteristic of three ichnosubfacies of the *Nereites* ichnofacies. These ichnosubfacies are identified in Amiran Formation deposits, the typical succession of ichnosubfacies can express a bathymetric trend from shallower to deeper parts and from higher-to-lower hydrodynamic conditions. They are: (1) the *Ophiomorpha rudis* ichnosubfacies (the proximal and axial parts with thick bedded channel and lobe related environments), (2) the *Paleodictyon* ichnosubfacies (channel-lobe transition in the distal lobe facies), and (3) the *Nereites* ichnosubfacies (distal part of off-axis lobe or fan fringe–basin floor transition and overbank settings). There is also mixed *O. rudis* to *Paleodictyon* ichnosubfacies (channel–margin, lobe–fringe in the proximal lobe facies). The dominance of *Zoophycos* and *Chondrites* in poor-oxygen basin floor facies may represent *Zoophycos* ichnofacies. The number of graphoglyptids increases from distal (basin floor) to proximal (fan fringe–basin floor transition, fan fringe, lobe complex fringe/lobe complex off-axis) settings. They are absent in the most proximal/axial lobe environments due to increased volume, frequency, erosive power of turbidity current events and sedimentation rate, grain size, decreased preservation potential of shallow tier, and pre-turbidite trace fossils. The ichnosubfacies method used here, as utilized by other authors, has the potential to improve paleoenvironmental analysis of other deep marine depositional settings, and in outcrop investigation of turbidite systems.

1. Introduction

Commonly, a submarine fan system is characterized by a single feeder system and an overall fan-shaped geometry and consists mainly of channel–overbank deposits and sheet-like turbidite sandstones interbedded with hemipelagic mudstones (Walker, 1978; Reading and Richards, 1994). Submarine-fan models based on lithofacies successions

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of ancient deep-water deposits in outcrops and on morphological features of modern submarine fans (Mutti and Ricci Lucchi, 1972; Normark, 1978; Walker, 1978) have been widely used for the interpretation of ancient deep-water depositional systems. Considerable research into the characterization of the architectural elements of submarine fans has attempted to fully integrate ichnology and sedimentology (e.g. Crimes, 1973, 1976, 1977; Wetzel, 1991; Orr, 1995, 1996, 2001; Tunis and Uchman, 1996; Wetzel and Uchman, 1997, 2001; Tchoumatchenco and Uchman, 1999; Uchman and Demircan, 1999; Uchman, 2001, 2004a,b, 2007; Uchman et al., 2004; Heard and Pickering, 2008; Monaco and Checconi, 2008; Monaco et al., 2010; Giannetti, 2010; Cummings and Hodgson, 2011; Callow et al., 2013). Trace fossils and the ichnofabrics have many applications particularly for paleoenvironmental and stratigraphic studies (Taylor et al., 2003; McIlroy, 2004, 2008). The use of trace fossils stems from the fact that variations in trace fossil assemblages and average bioturbation in fan and related environments reflect changes in such environmental parameters, among others, as substrate consistency (e.g. sand:mud ratio), energy conditions, rates of sediment accumulation and oxygenation (Frey et al., 1990).

Flysch deposits of the succession of the Amiran Formation (upper Maastrichtian–Paleocene) in the Lurestan Province (NW Zagros) from the Zagros Fold–Thrust Belt host some of the most spectacular and diverse trace fossil assemblages. The sedimentary environments of the Amiran Formation are poorly understood and the potential of trace fossils as tools for reconstructing depositional conditions of these deposits has not been realized until now. Trace fossils of the Amiran Formation are very diverse, favoring comparisons with similar flysch sequences. Distribution of trace fossils and lithologies of the 'host' sediments was referred to the analysis of facies associations.

This paper develops a practical ichnosubfacies-based approach for the use of trace fossils in paleoenvironmental analysis of turbidite systems. The distribution of trace fossils and ichnosubfacies is determined from depositional constraints in the Amiran Formation. This method is based on the observation of bed thickness, grain size, burrow size, burrow depth and specific trace fossil association. The trace fossil content, diversity, abundances, and ethologies have been compared to other formations of similar age (Cretaceous–Eocene) and environments. It is considered that the trends in ichnology and ichnosubfacies determined from this case-study could be used as a basis for interpretation of slope–turbidite systems.

2. Geological setting

The NW–SE trending Zagros orogenic belt, which extends for about 2000 km from Turkey to south-eastern Iran, with its numerous supergiant hydrocarbon fields, is the most resource-prolific fold–thrust belt of the world, and it represents a large segment of the Alpine–Himalayan collisional system (e.g., Berberian and King, 1981). The Zagros Fold–Thrust Belt is an imbricated and simply folded belt that lies on the northeastern margin of the Arabian Plate and has been subdivided into NW–SE trending structural zones parallel to the plate margin separated by major fault zones such as the High Zagros and mountain front faults (Fig. 1). The Zagros Basin is filled by rocks ranging from the Cambrian to Holocene, which exhibit significant thickness and facies variations both along and across the belt (Fig. 2). The Zagros region was part of a passive continental margin, which was rifted between the Permo-Triassic and the Late Cenozoic collision (Stocklin, 1974; Berberian and King, 1981; Beydoun et al., 1992). According to Alavi (2007), the Zagros Fold–Thrust Belt is a result of the structural deformation of the Zagros (peripheral) proforeland system, whose present-day expression is the marine Persian Gulf basins (Baltzer and Purser, 1990), and underlying pre-proforeland, mostly shelf deposits. Following the Permo-Triassic rifting episode, the Zagros Basin was sub-divided into two main basins: the Lurestan Basin to the NW and the Fars Basin to the SE, with very different sedimentary successions (Setudehnia, 1978). During the Jurassic–Cretaceous, the Fars Basin to the SE part of the Dezful Embayment underwent slow and steady subsidence which resulted in the deposition of shallow marine sediments until the Late Cretaceous (Figs. 1, 2). Conversely, in the Lurestan Basin and NW part of the Dezful Embayment, the Lower Cretaceous contains deeper water sediments (Setudehnia, 1978; Berberian and King, 1981; Beydoun et al., 1992). In the Lurestan Province (NW Zagros), thrust sheet emplacement was associated with the formation of a flexural basin that was initially filled by calcareous deep-marine sediments (Gurpi Formation) followed by ophiolite- and radiolarite-derived clastic sediments (e.g., the "flysch" Amiran Formation and the conglomeratic Kashkan Formation; Fig. 2). Meanwhile, in the interior parts of the Zagros Fold–Thrust Belt, detrital units of the Amiran and Kashkan formations, which were derived from the ophiolite complexes (James and Wynd, 1965; Alavi, 1994) as a prograding siliciclastic wedge, grade laterally in a southwest ward direction. This gradation of alternating greenish-gray paralic siltstones, glauconitic sandstones, and dark gray shales ("flysch") interfingers with the Gurpi Formation. Farther to the southwest, the Amiran Formation pinches out, and *Globotruncana*-bearing calcareous mudstones of the Gurpi Formation, with deep-marine lithic and faunal characteristics, overlie the Sarvak Limestone (Alavi, 2004).

In the Lurestan Province, the exposed Mesozoic–Cenozoic stratigraphic record consists of ~4–5 km of pre-orogenic strata and 4–5 km of synorogenic deposits. The Mesozoic pre-orogenic succession is composed mainly of passive-margin carbonate units. The overlying synorogenic deposits include, from bottom to top, the Amiran–Kashkan detrital succession, the Shahbazan–Asmari shallow-marine carbonate platform, the evaporitic Gachsaran Formation, and the siliciclastic Agha Jari and Bakhtyari formations. Our study is restricted to the succession of the Amiran Formation (upper Maastrichtian–Paleocene; Fig. 2). Extensive outcrops of the succession of the Amiran Formation are exposed in the Lurestan Province (NW Zagros; Fig. 1). The lower contact with the Gurpi Formation is gradational; the upper contact is followed by the lenticular limestone of the Taleh Zang Formation. From the central Lurestan Province to the south and southwest, the beds of the Amiran Formation interfinger with marl of the Gurpi and Pabdeh formations. In the present study, three new surface sections have been measured and sampled, including the Maemolan (N33°10′46″, E48°3′21″), Pirshamsadin (N33°42′4″, E47°51′24″) and Khorramabad (N33°23′12″, E47°56′10″; Fig. 3) sections.

3. Methods

Representative outcrops and stratigraphic sections of deep-marine siliciclastic units of the Amiran Formation (upper Maastrichtian–Paleocene) in the Lurestan Province from Zagros Fold–Thrust Belt were logged (Figs. 3 and 4). Vertical exposure allows measurement of 800–1000 m continuous vertical sections through the complete stratigraphy. This permits facies distributions, geometries and depositional environments to be interpreted at scales from the individual architectural element to the complete slope–turbidite systems. Individual sedimentation facies and their internal divisions represent fundamental depositional processes which are grouped into mappable facies association (Table 1 and Fig. 4). Sedimentary bodies are defined collectively by thickness, grain-size, sedimentary structures, internal facies and nature of bedding contacts, cross-sectional (two-dimensional) geometry, bedding architecture, sandstone richness, and degree of amalgamation. However, the sedimentary environment of the siliciclastic facies Amiran Formation is poorly understood and the potential of trace fossils as tools for reonstructing depositional conditions and differentiation subenvironments of slope–turbidite systems has not been realized until now. The observed siliciclastic facies can readily be interpreted using existing deep-sea succession models (e.g. Normark, 1978; Mutti, 1985; Mutti et al., 1994; Johnson et al., 2001; Kane et al., 2007; Heard and Pickering, 2008; Prélat et al., 2009; Cummings and Hodgson, 2011). In this paper, ichnology is integrated with other lines of evidence as part of a multidisciplinary approach to