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Environmental impacts on the ichnofossil diversity of the lower part of the Elika Formation (Lower Triassic), Moro Mountain, NW Iran

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Abstract

Early Triassic carbonate ramp sediments of the lower part of the Elika Formation are known as Vermicular limestone. In the Moro Mountain, northwest Iran, the Vermicular limestone includes bioturbated dolomitic mudstone, bioclastic packstone and grainstone, algal calcirudite and intraclastic grainstone. These sediments accumulated in their lower part in open marine subtidal and shoal environments, changing upward to lagoonal and intertidal environments. Heavily bioturbated gray mudstone formed under quiet water conditions in lagoon and lower intertidal environments. Storm processes and high salinity indicative of an arid environment influenced the activities and distribution of euryhaline and/or opportunistic trace-makers. The low biodiversity of the trace-maker community is reflected by the low ichno-diversity, the sole trace fossil being abundant *Planolites*.

Keywords*:* Trace fossil; Triassic; Elika Formation; carbonate ramp; NW Iran

1. Introduction

Lower Triassic sediments of the Alborz Mountains are represented by lower part of the Elika Formation (295 m; Glaus, 1964), which have been deposited on a carbonate ramp (Aghanabati, 1990). Two lithostratigraphic subdivisions are recognized in the type section of this formation in the central Alborz Mountains (Stöcklin and Setudehnia, 1991). The lower part (95 m)consists of thin- to medium-bedded gray limestones, crowded by worm-like trace fossils. These heavily bioturbated limestones are informally called Vermicular limestone (Delenbach, 1964; Brönnimann et al., 1972; Annelles et al., 1975; Bolourchi, 1979; Alavi et al., 1982). The upper part (200 m) includes thick-bedded light crystalline dolostones. In Damavand-Firuzkuh area, Central Alborz, the uppermost layers of the Elika Formation are, however, represented by 60–80 m of limestones and evaporates and has been named Veresk member (Steiger, 1966) or Aruh member (Seyed-Emami, 2003). This part crops out in sparse localities that have not been affected by the Early Cimmerian tectonic event (Aghanabati, 1990; Seyed-Emami, 2003).

The Elika Formation is Scythian to Ladinian in age (Zaninetti and Brönnimann, 1974; Aghanabati, 1990), and extends to northwest Iran, with lithofacies similar to the Alborz Mountains (Fig. 1; Szurlies and Kozur, 2004; Rhichoz et al., 2010). The formation gradually overlies on the Permian sediments of the Jolfa area, northwest Iran. As a consequence the Permo–Triassic boundary is continuous and the Elika Formation replaces the Jolfa Formation by Permo–Triassic transitional layers (Stepanov et al., 1969; Teichert et al., 1973; Partoazar, 1995; Kozur, 2007). The Elika Formation unconformably rests on the Nesen Formation (Median–Dzhulfian, Late Permian) in the Moro and Mishu Mountains, west Tabriz (Shabanian et al., 2007). The formation, has been strongly affected by the Tabriz fault system in the Moro Mountain (Fig. 1). The Tabriz fault is composed of several en-echelon right-stepping segments associated with pull-apart basins, the most important being the Tabriz basin where the city of Tabriz is located (Siahkali Moradi et al., 2011). Structural deformation of northwest Iran is characterized by movements along this fault (Masson et al., 2006).

Lower–Middle Triassic equivalents of the Elika Formation are known as Sorkh Shale Formation (red calcareous shales and terrigenous sediments; Lower Triassic) and as Shotori Formation (dolostones with the uppermost Espahak limestone member; Middle Triassic) in Central Iran (Stöcklin et al., 1965). The vermicular layers, however are a common feature in the lower part of the Elika Formation and in the Sorkh Shale Formation. It seems that the vermicular trace fossils have been

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made by a facies-crossing trace maker(s) with a wide distribution in the Alborz Mountains and Central Iran. Heavily bioturbated Lower–Middle Triassic carbonates are not confined to Iranian territory and the same lithofacies have been reported from the central to western Tethys; from Afghanistan (Boulin, 1988), Turkey (Baud et al., 2007, 2005), Oman (Richoz et al., 2010), Carpathians (Hips, 1998; Jaglarz and Uchman, 2010), Alps (Twitchett, 1999; Hofmann et al., 2011; Knaust and Costamagna, 2012) and Spain (Escudero-Mozo et al., 2014).

Ichnological investigations on the Vermicular limestone are limited to Okhravi et al. (2000), who used microfacies data for evaluation of the environmental distribution of trace fossils of this limestone in the central Alborz Mountains. Equivalent Middle Triassic vermicular carbonates from the Tatra Mountains, western Carpathians have been interpreted as a hypersaline ichnoassemblage (Jaglarz and Uchman, 2010).

This paper focuses on the paleoecology of the lower part of the Elika Formation and evaluates the effect of environmental factors on the trace fossils distribution in the Vermicular limestone of the Amand section, east of Moro Mountain, northwest Iran. In other words, this study investigates the impact of environmental factors on the biotic recovery, recorded in the ichno-diversity of a Lower Triassic carbonate ramp, after the end-Permian mass extinction. The studied section is located at the GPS coordinates N36˚ 14′ 20″ and E46˚ 09′ 27″ (Fig. 1).

2. Elika Vermicular limestone of Moro Mountain

Different rocks are crop out in the Moro Mountain as a result of overthrusting along the

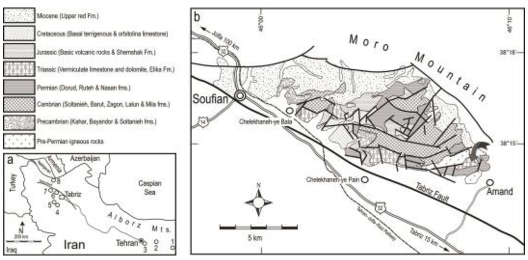

Fig. 1. a) Geographic location of Moro Mountain and Tabriz fault in the northwestern Iran. Localities mentioned in the text include Shahmirzad (1), Sarbandan (2), Bibi Shahrbano (3), Maragheh (4), Osku (5), Moro Mountain (6), Mishu Mountain (7) and Jolfa (8). b) Geological map of the Moro Mountain, (modified from Eftekhar Nezhad 1993). Arrow shows the section studied, northwest of Amand

Tabriz fault in northwest Iran (Eftekhar Nezhad, 1993). These rocks include strongly deformed metamorphic-igneous rocks of Precambrian to Miocene red beds (Fig. 1).

The Elika Formation is exposed at the southern flank of Moro Mountain, northwest of Amand, north of Chelehkhaneh-ye Pain and northeast of Chelehkhaneh-ye Bala villages. The Vermicular limestone measures 27 m in thickness, northwest of Amand (Fig. 2). It unconformably overlies the Nesen Formation and is followed by the dolostone part of the Elika Formation. No index fossils have been found in the studied section, but this part of the Elika Formation is attributable to Early Triassic, based on either stratigraphy position or age dating of adjacent areas such as Mishu, Osku and Maragheh in northwestern Iran (Baud et al., 1974; Alavi and Shahrabi, 1975; Eftekhar Nezhad, 1994, 1995; Seyed-Emami, 2003). Fifty-two oriented thin-sections have been prepared from sampled specimens. Studied samples have been classified by Dunham (1962) method. Microfacies of the Vermicular limestone in the studied section include brecciated dissolved calcirudite, marly gray-brown calcilutite, bioturbated well bedded calcilutite, dark gray bioclastic (mainly gastropod) dolocalcarenite, light brown thin-laminated dolocalcilutite, intraclastic calcirudite (tempestites), strongly bioturbated gray massive calcarenite, laminated calcilutite, and stromatolite calcirudite. Bedding features include planar parallel, convolute planar, discontinuous non-parallel wavy bedding. The bivalve *Claraia* is common in the Elika Vermicular limestone (Stepanov et al., 1969; Hirsch and Süssli, 1973; Seyed-Emami, 2003), but gastropods are the main bioclasts in the section studied. Algal thrombolitic and stromatolitic build-ups are known from Triassic carbonate ramps of Vermicular limestone (Gallet et al., 2000; Baud, 2005; Lasemi et al., 2012). One of the uppermost layers of the section contains 30-cm-thick circular to elongated stromatolites (max. diameter 5 cm). Intraclasts, the main lithoclast of calcirudite layers, are found in tempestite layers which are main lithoclast of calcirudite layers. Ooids, however, which are common lithoclasts in other sections have not been found (Okhravi et al., 2000). Ooids are the main lithoclasts of non-biogenic bars of carbonate ramps of Vermicular limestone (Lasemi et al., 2012). Gastropod grainstones/packstones formed bioclastic bars in Vermicular limestones of the Amand section.

3. Microfacies and ichnofacies

Table 1 shows a synopsis of microfacies encountered in the Vermicular limestone (Fig. 3). Bioclasts include gastropods, bivalve (thin shell debris of *Claraia*) and rare echinoderms.

Gastropods and bivalves are euryhaline and commonly show high tolerance towards salinity (Flügel, 2010). Bioclasts of stenohaline organisms are restricted to rare echinoderms. The Vermicular limestone has been dolomitized. The dolostones have been classified in seven petrographic groups based on early to late diagenesis processes (Okhravi and Rabbani, 1995). The dolostones of the studied section are categorized in three groups, all of which formed by early to late diagenesis processes (Fig. 3).

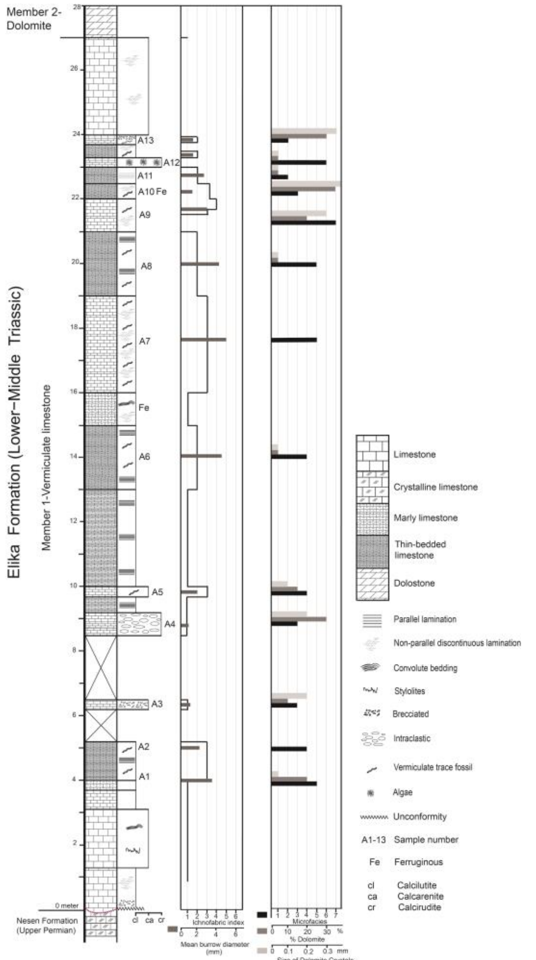

Fig. 2. Stratigraphic column and ichnofabrics, mean burrow diameter, microfacies, size and percent of dolomite crystals in the Vermicular limestone of the Elika Formation in the section studied

(1) Small crystals of dolomite formed in thin laminated mudstones. These crystals are euhedral to subhedral in shape, occur in microfacies (4) in the form of laminated calcilutite and are interpreted as early diagenetic origin. (2) Dolomite crystals replacing some gastropodshells and bioclasts include medium-sized euhedral cloudy core-clear rim rhombs. Microfacies (3) is host of this type of dolomitization. This dolomitization occurred in the mixed zone of fresh- and marine waters. (3) Cavity and fracture filling dolosparite cement is related to burial diagenesis. Samples show high early dolomitization and a low degree of bioturbation, which is related to a supratidal dolomitization environment.

Packing and sedimentary fabrics of litho- and bioclasts differ in the various microfacies. Tempestite deposits are recognizable by unsorted non-oriented intraclastic grainstones. Fair-weather sediments, in contrast, are characterized as fine-laminated calcilutite.

Bioturbation is limited to microfacies (1), (4) and (5). Ichnofabrics of bioturbated sediments differ from 10 to 90% (standard ichnofabrics indexes of Droser and Bottjer, 1989). Ichnofabric index change 2–4 in these microfacies, but bioturbation is strongly restricted to microfacies (5) in lagoonal environments (Fig. 2). The ichno-assemblage is near-monospecific. Only *Planolites* has been recognized on bedding planes (Figs. 4A–C), represented by *P. beverleyensis* and *P. montanus*. *P. beverleyensis* is a mostly horizontal, straight to slightly winding, smooth cylindrical burrow with a mean diameter of 5 mm. *P. montanus* is a small cylindrical, rarely branched burrow with a diameter of 2–3 mm. The burrows are filled with micritic sediment, similar to the host rock. The outer margin of the burrows is smooth but some of them have been deformed during compaction (Fig. 4A).

It is difficult to comment on the ichnofacies of the sediments, *Planolites* being the only trace fossil. This trace fossil has been reported from several of environments, which reflects its facies-crossing nature. Jaglarz and Uchman (2010) considered the *Planolites*-dominated vermicular Middle Triassic limestone of the Tatra Mountains as belonging to the Cruziana ichnofacies, also recording *Thalassinoides*, *Balanoglossites*, *Rhizocorallium*, *Helminthopsis*, *Phycosiphon* and *Taenidium*.

Table 1. Synopsis of microfacies (MF) data of the Vermicular limestone of the Elika Formation in the Amand section, Moro Mountain, northwest Iran

MF number	MF name	Lithology	Main components	Dolomitization	ichnofabrics	Environmental interpretations
1	Dolomicrite	Micrite/Mudstone	Thin, <10% of fine-grained shell debris	Aggregate of fine dolomite crystals	>10% bioturbated	Open marine (outer ramp)
2	Imbricated bioclastic grainstone	Biosparite/Grainstone	Gastropods (90%), bivalves, Echinoderms, sparse lithoclasts	Non- dolomitized	Non-bioturbated	Subtidal flank of bar (Mid ramp)
3	Gastropod dolobiomicrite	Dolomitic biomicrite/packstone	<70% gastropods, bivalves echinoids, rare intraclasts	Dolomitization restricted to gastropod shells	Non-bioturbated	Bioclastic bar (Mid ramp)
4	Laminated dolomitic calcilutite	Micrite/Mudstone	>10% molluscan shell debris	Partly dolomitized cement	>10% bioturbated	Subtidal lagoon (inner ramp)
5	Bioturbated calcilutite	Micrite/Mudstone	Rare shell debris (>5%)	Non-dolomitized	Heavily bioturbated (70–90%)	Lower intertidal–Subtidal lagoon (inner ramp)
6	Stromatolite rudstone	Biomicrite	Stromatolite, sparse pseudomorphs of evaporate minerals	Small crystals of dolomite 0–50%	Non-bioturbated	Lower intertidal, coastal plain
7	Dolointrasparite	Intrasparite/grainstone	Intraclasts	Strongly dolomitized cement	Non-bioturbated	Tempestite

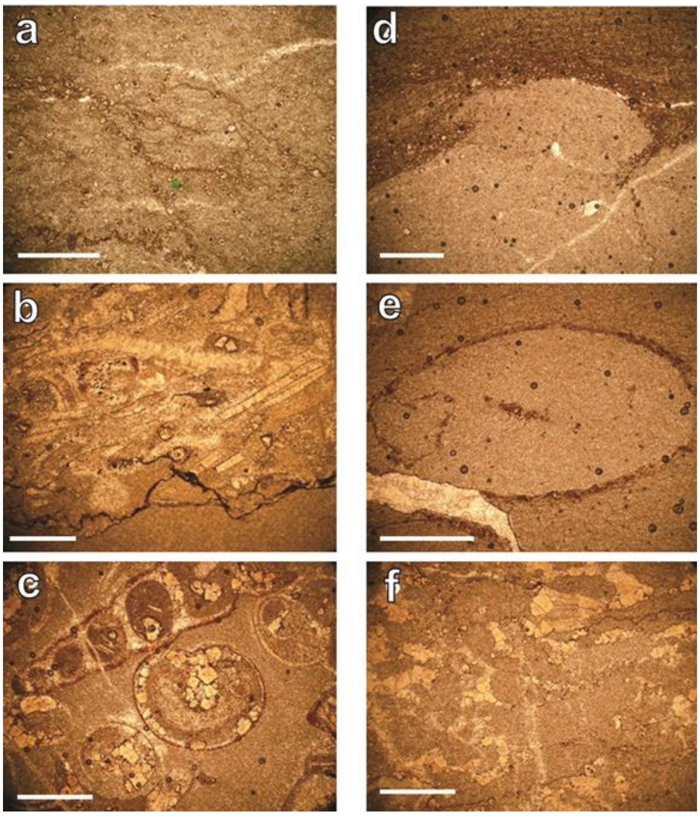

Fig. 3. Lithologies and microfacies of Vermicular limestone of Elika Formation. a) Bioturbated dolomicrite, b) imbricated bioclastic grainstone, c) gastropod dolo-biomicrite, d) laminated dolo-mudstone, e) bioturbated mudstone, f) dolo-intragrainstone. Scale bar equals 0.5 mm

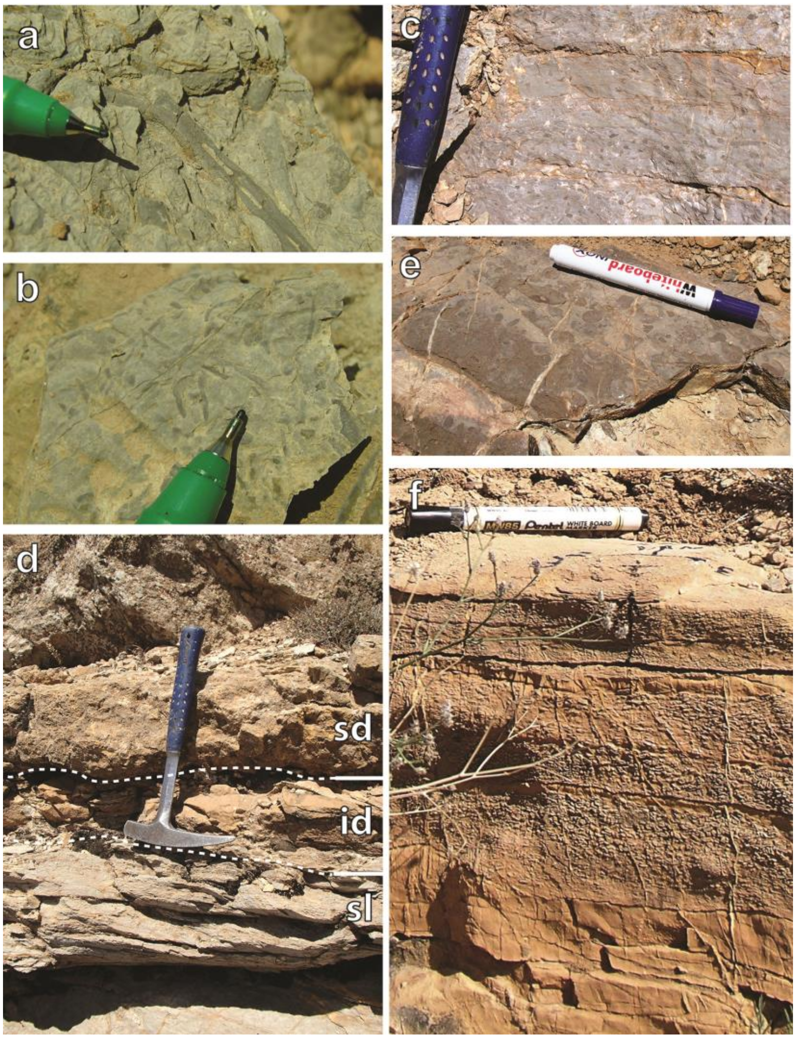

Fig. 4. Field photographs of rock units in the studied section of Vermicular limestone. a–c) Bioturbated gray mudstones with Planolites beverleyensis, silver end of pen is 1 cm in length, width of handle of hammer is 3 cm. d) Succession composed of bioturbated gray subtidal limestone (sl) overlain by light brown intertidal dolomitic mudstone (id), and brown supratidal dolostone (sd), length of hammer is 30 cm. e) Domal stromatolite structure of lower intertidal sediments, pen for scale is 14 cm long, f) succession of tidal flat intraclastic grainstone (storm bed) and intertidal dolomitic mudstone. Pen for scale is 14 cm long

4. Discussion

Approximately 80% of marine species became extinct in the end-Permian mass extinction (e.g., Stanley and Yang, 1994). As a result, Early Triassic marine communities have a low diversity and mainly include biotic recovery opportunists (Hallam and Wignall, 1997; Rodland and Bottjer, 2001). The consequence of this low diversity is visible in the ichno-diversity and ichnofabrics of Early Triassic substrates (Pruss et al., 2005). Regaining communities' biodiversity in the recovery period involves complex processes, mainly governed by environmental factors (Krassilov, 1996). The Vermicular limestone of the Elika Formation yields ichnological data that allow us to estimate the effect of environmental factors on the recovery process of the Early Triassic epoch. Environmental reconstruction of the Vermicular limestone shows that the sediments have been deposited on a carbonate ramp and consist of open marine subtidal and shoal facies in the lower part changing upward to lagoonal and intertidal facies (Fig. 5; Okhravi and Rabbani, 1995; Lasemi et al., 2012). Open marine sediments of the studied section include thin-laminated calcilutite with fine-grained molluscan bioclasts. These sediments are characterized by poor bioturbation. Gastropod and rare bivalve bioclastic packstone are interpreted to represent a bar. Two kinds of oolitic and bioclastic bars, however, have been recognized in the Elika Vermicular ramp that mostly accumulated by high-energy currents (Lasemi et al., 2012). Heavily bioturbated gray bioclastic peloidal lime mudstone-packstone with a restricted fauna are related to a lagoonal origin.

Flooding and a sea-level high stand in the Early Triassic epoch led to the development of ramps with growth of domal stromatolites, thrombolites and/or microbial mats in the western and central Tethys (Baud et al., 1993, 2002, 2005; Pruss et al., 2005). The stromatolite rudstone of the Elika Vermicular limestone with thin-laminated penecontemporaneous dolomitic mudstone has been deposited on a supratidal flat, sabkha-like environment (Figs. 4E, 5).

It seems that the trace maker(s) of Vermicular limestone was influenced by two environmental factors. Increasing salinity or current energy caused a decrease in biodiversity and bioturbation. Storms disturbed the floor of the basin, which is indicated by tempestites. Weidong et al. (1997) summarized sedimentological features of tempestites. These features are an erosional lower bedding plane, graded bedding texture, horizontal to low angle cross-lamination, kinds of particles, packing, and presence of intraclasts. In the section studied storm deposits have been found as non-bioturbated grainstone with imbricated packing and unsorted intraclastic grainstone (Fig. 4F). Fluctuations in salinity occurred in the lagoon and lower intertidal flat zone, where the arid condition led to penecontemporaneous precipitation of dolomite and evaporites (microfacies 6). This factor was mainly responsible of absence of stenohaline trace makers (Sugden, 1963; Gibert and Ekdale, 1999; Buatois et al., 2005). Gastropods are abundant bioclasts in the thin-sections and sparse bivalve and echinoderm bioclasts show low biodiversity in the Vermicular limestone. Thus, biotic recovery communities of the Elika Vermicular limestone include euryhaline gastropods and bivalves, which were affected either by storm or salinity. The arid environment of Vermicular limestone had profound and predictable effects on the ichno-diversity of these layers and the solely recorded ichnogenus *Planolites* was produced by opportunistic and euryhaline organisms.

An ichnological study of the Vermicular limestone of the Elika Formation indicated the presence of *Planolites* and *Palaeophycus* in the central Alborz Mountains (Okhravi et al., 2000). This low ichno-diversity reflects environmental stress, and only small opportunistic trace-maker(s). A common feature among these localities is the high bioturbation of the low-energy sediment.

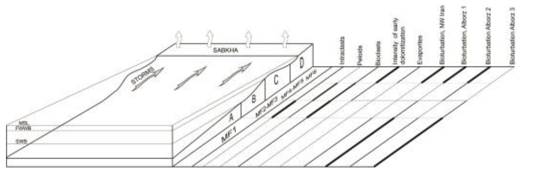

Fig. 5. Block diagram of Elika Vermicular ramp and distributions of particles and bioturbation in the Moro Mountain (NW Iran). Bioturbation of Alborz Mountains modified by Okhravi et al. (2000; Alborz 1, Shahmirzad; Alborz 2, Sarbandan; Alborz 3, Bibi Shahrbano). Letters and abbreviations: A, outer ramp; B, mid ramp; C, inner ramp; D, supratidal-sabkha; MSL, Main sea level; FWWB, Fair-weather wave base; SWB, storm wave-base; MF, microfacies

5. Conclusions

Lower Triassic sediments of the Moro Mountain, Northwest Iran, include thin- to medium-bedded gray limestones comprising 27 m. The thickness and lithofacies of this unit is the same as that of the lower part of the Elika Formation in other sections of northwestern Iran, known as Vermicular limestone. Although the Tabriz fault has controlled sedimentary basins of northwestern Iran since Devonian times, Triassic sediments around this fault have the same lithofacies. Dolomitic laminated mudstone, bioclastic packstone and grainstone, algal calcirudite and intraclastic grainstone are the main lithologies of the Vermicular limestone.

Sediments of the Vermicular limestones have been deposited on a carbonate ramp and consist of open subtidal and shoal facies in the lower part changing upward to lagoonal and intertidal facies. Some laminated gray mudstone layers contain cylindrical trace fossils and are heavily bioturbated. Trace fossils are restricted to a single ichnogenus, *Planolites*, with two ichnospecies *P. beverleyensis* and *P. montanus*. Based on microfacies data these layers have been deposited in a low-energy subtidal lagoon and lower intertidal flat. During early Triassic times biotic recovery of opportunists was controlled by environmental factors. Storm and salinity fluctuations are thought to be the two main stress factors controlling the distribution of euryhaline and/or opportunistic trace-maker(s). These factors differed, however, in their significance. Whereas storm events in the studied section were rare, rhythmically currents such as tidal currents influenced salinity fluctuations on the ramp. Hypersaline conditions led to high stress conditions for trace-maker organisms, which restricted their occurrence to the *Planolites* producer in the Vermicular limestone.

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