Shallow-marine trace fossils from the Callovian-Oxfordian Tuwaiq Mountain limestone and Hanifa Formations, central Saudi Arabia

1El-Hedeny, M., 2Hewaidy, A. and 3Al-Kahtany, Kh.

1Department of Sciences, College of Teachers, King Saud University, Kingdom of Saudi Arabia.
2Geology Department, Faculty of Science, Al-Azhar University, Egypt.
3Department of Geology, College of Science, King Saud University, Kingdom of Saudi Arabia.

Abstract: The Callovian-Oxfordian Tuwaiq Mountain Limestone and Hanifa formations of Central Saudi Arabia contain an assemblage of abundant trace fossils, including Chondrites intricatus Brongniart, 1828; Chondrites stellaris Uchman, 1999; Curvolithus simplex Fritsch, 1908; Hillichnus agrioensis Pazos and Fernández, 2010; Palaeophycus cf. tubularis Hall, 1847; Phycodes cf. palmatus Hall, 1852; Thalassinoides horizontalis Myrow, 1995; Thalassinoides suvicus (Rierh, 1932) and Thalassinoides isp. This assemblage is considered to belong to the Cruziana ichnofacies. Traces of this assemblage have been described for the first time from this interval of the present area. Ethologically, the trace makers reflect a wide range of behaviours with Chemichnia (Chondrites), domichnia (Palaeophycus), complex mining "domichnia/fodinichnia" (Thalassinoides), Fodinichnia (Phycodes), Repichnia (Curvolithus) and pascichnion and possible chemichnion (Hillichnus). The trace fossil association is comparatively rich in the Hanifa Formation than those recorded in the Tuwaiq Mountain Limestone Formation. The ichnogenus Thalassinoides is the dominant trace fossil and well distributed in the whole section. On the other hand, Chondrites is predominant in the marly limestone bed at the base of the Hanifa Formation. In the studied area, The Cruziana ichnofacies reflects moderate to relatively low energy in infilalitral to shallow circalitral substrates and below the fair-weather wave base, but not storm wave base environments.

Key words:

INTRODUCTION

Trace fossils are recognized to be excellent tools for reconstructing ancient environments, especially when trace fossil assemblages are analysed (Seilacher, 1953, 1967; Frey, 1975; Eldale et al., 1984; Curran, 1985; Pemberton et al., 1992; McIlroy, 2004; Miller, 2007).

In Saudi Arabia, the Jurassic sediments have attracted the attention of many workers (Steineke, 1937 (in Powers et al., 1966); Arkell, 1952; Steineke et al., 1958; Powers et al., 1966; Powers, 1968; Okla, 1983, 1986, 1987; El-Asa'ad, 1989; Vaslet et al., 1991; Hughes, 2004; Dabbagh, 2006). Particularly, the Callovian – Oxfordian sediments are well exposed and easily accessible in this region. They represent two famous formations, the Tuwaiq Mountain Limestone (Callovian) and the Hanifa (Oxfordian) formations. The Tuwaiq Mountain Limestone Formation (total thickness in the type section is 184 m) consists mostly of shallow-marine lagoon and stromatoporoid carbonates of Middle to Late Callovian age. At the type locality, the Hanifa Formation is 100m thick (Powers et al., 1966) and made up of alternating aphanitic and calacarenitic limestone.

Although high abundant macrotaxa (mollusk, brachiopods, echinoderms, colonial coral and sponges) have been documented from sediments of both formations in the studied area, trace fossils have not been recorded well. Data obtained from trace fossil assemblage of the studied formations, in association with body fossils and lithologic information can provide excellent clues to parameters of ancient environments.

The purpose of this paper is to describe and interpret the new trace fossil material recorded from central Saudi Arabia (Fig. 1) and to determine their environmental significance.

2- Stratigraphic context:

The succession of the Jurassic basin in central Saudi Arabia is divided into the Lower Jurassic Marrat Formation, the Middle Jurassic Dhruma Formation and the Tuwaiq Mountain Limestone and the Upper Jurassic Hanifa Formation, Jubaila Limestone, Arab Formation and Hith Anhydrite.

The Middle Jurassic Tuwaiq Mountain Limestone Formation was first introduced into Saudi Arabian lithostratigraphy by Steindke (1937, cited in Powers et al., 1966) for the Callovian-Oxfordian limestone exposed in Jabal Al Tuwaiq, central Arabia. He initially described the formation as Tuwaiq Mountain Member of the Tuwaiq Formation. Later, Bramkamp (1945, cited in Powers et al., 1966) raised the member into the Tuwaiq Mountain Limestone Formation. The newly defined Tuwaiq Mountain Limestone Formation lies unconformably on the Dhruma Formation and consists mostly of shallow-marine lagoon and stromatoporoid carbonates of
Middle to Late Callovian age with a combined thickness of 295 m. The sediments were laid down in low-energy of a carbonate shelf in the lower part and grades upward into moderate-energy deposits in water ranging from 20 to 30 m, as indicated by abundant corals and algae.

Fig. 1:

Several microfacies can be distinguished in carbonates of the Tuwaïq Mountain Limestone Formation. Mudstone, wackestone and packstone are the most common microfacies. Grainstone is less encountered and floatstone and boundstone are rare. The formation lies disconformably upon the Dhruma Formation (Bajocian-Callovian) and is followed unconformably (minor) by the Hanifa Formation (Oxfordian).

On the other hand, the Hanifa Formation was named after Wadi Hanifa (or Hanifa valley) near the city of Riyadh, Saudi Arabia. In 1937 Max Steineke (in Powers et al., 1966) defined the Hanifa as a member of the Tuwaïq Mountain Limestone. The member was raised to a formational status by R.A. Bramkamp in 1945 (see Powers, 1968). It was then included in the Tuwaïq Mountain Group. In 1952, the Tuwaïq Mountain Group was discarded as stratigraphic term and the Hanifa was retained as formational name (Steinake and Bramkamp, 1952). The Hanifa Formation, of Oxfordian age, is separated from the Tuwaïq Mountain Formation by a minor unconformity.

It composed of limestones interbedded with marly limestones that are mostly low-energy, laminated, dark, organic-rich lime mud deposited under anoxic bottom-water conditions. The Hanifa carbonate lithofacies indicate that the formation is essentially composed of various limestone types of wackestone, packstone, grainstone, lime mudstone and boundstone.

Sediments of the Tuwaïq Mountain Limestone and Hanifa formations are well exposed (Fig. 2) and easily accessible in studied area.

**MATERIAL AND METHODS**

The data were collected during three field works during 2010-2011. Most of the information on Callovian-Oxfordian trace fossils comes from sections of Wadi Dirab, Khashm Al Gedya, Seduse and Mâshâba (Fig. 1). Trace fossils are restricted mostly to limestone and marly limestone beds. Most of them were recorded and
analysed in the field, as only a limited number of specimens could be collected and brought back to the laboratory. These specimens are housed in the collections of the College of Teachers (King Saud University) under the prefix TFCSA.

Fig. 2:

4. Vertical Distribution of Trace Fossils:

Generally, all trace fossils recorded in this study (Fig. 3) are of the same composition (Cruziana ichnofacies). Obviously, the Hanifa Formation contains relatively frequent ichnotaxa than the Tuwaiq Mountain Limestone Formation. Their diversity and abundance fluctuate significantly throughout the section (Fig. 3). It is noticed that *Chondrites* ichnogenus is restricted in the marly limestone bed directly above the last limestone of the Callovian Tuwaiq Mountain Formation. In addition, the ichnogenus *Thalassinoides* is well distributed in both formations and is confined, like all ichnotaxa (except *Chondrites*) to limestone facies. In addition there are some trace fossils that are confined to particular formation than other e.g. *Curvolithus* and *Palaeophycus*.

4. Systematic Description of Ichnofossils:

A variety of trace fossils are present in the Tuwaiq Mountain Limestone and Hanifa formations at central Saudi Arabia. Most observations were made in the field as only a very limited amount of material was collected. Thus, some ichnotaxa are only determined at ichnogenus level. They are listed here in alphabetical order.

The assemblage is considered to belong to the Cruziana ichnofacies. The fossils traces recorded in this study belong to three main ichnological structures: Chemichnia (*Chondrites*), domichnia (*Palaeophycus*), complex mining (domichnia/fodinichnia) (*Thalassinoides*), Fodinichnia (*Phycodes*), Repichnia (*Curvolithus*) and pascichnion and possible chemichnion (*Hillichnus*).

For the present study, ichnogenera and ichnospecies are named according to I.C.Z.N. Rules, using the binomial system of nomenclature and described alphabetically.
Ichnogenus *Chondrites* Sternberg, 1833
*Chondrites intricatus* Brongniart, 1828

**Fig. 4A (C1)**

**Material.** Four specimens, TFCSA 12-15.

**Description.** A system of regularly unlined branching tree-like flattened tunnel, number of bifurcations rarely exceeds two. Branches are fine (0.3-1.0 mm in diameter) with acute angle (commonly less than 45°), rarely cross or intersect each other. In many specimens, only branched or unbranched fragments of the tunnels are visible. Tunnels are filled with lighter material than the host rock.

**Discussion:** The present ichnospecies has very clear and distinct features. It exhibits the remarkable phenomena of its fine branches and acute angle of branching. Taking branching pattern into consideration, Fu (1991) have revised the ichnogenus *Chondrites* and reduced over 170 existing ichnospecies to only four distinguished ichnospecies (*C. targionii, C. intricatus, C. patulus* and *C. recurvus*). Among others, Fu (1991), Uchman (1999) and Pemberton et al. (2001) mentioned that this trace is produced by chemosymbiotic (most probably sipunculids and vermiform) organisms penetrating periodically into sediments of the anoxic zone but considered worms to be the most likely producers. It may have been able to live at the aerobic/anaerobic
The ichnogenus *Chondrites* is present in a wide stratigraphic range [Tommotian (e.g., Crimes, 1987) to Holocene strata (e.g., Werner and Wetzel, 1981)].

*Chondrites stellaris* Uchman, 1999

**Fig. 4(A) C2**

**Material:** Two specimens, TFCSA 16-17.

**Description:** Small, straight, flattened, branching tunnels, 0.4-0.6 mm wide, up to 5 mm long, radiating from a central point. Number of radials from 4 to 6. The tunnels are light in contrast to the dark background. In one specimen, the present ichnospecies is found together with the ichnospecies *Chondrites intricatus*.

**Discussion:** The specimen described show most of the morphological characters of the holotype of *Chondrites stellaris* as described and illustrated by Uchman (1999) from the Tristel Formation (Upper Barremian – Lower Aptian) of the Rhenodanubian Flysch, in the Bavarian Alps. The present specimens is characterized by a narrow range of morphometric parameters (width of tunnels and width of the burrow system) (Uchman, 1999), which fits well to the described specimens.

*Chondrites* characteristically appear as a well developed pattern of branching burrows with numerous bifurcations. Small size burrow systems are not diagnostic of changing environmental parameters since more than one size burrow system can occur in the same rock slab (Simpson 1957 pl. XXI). However the degree to which the system of branching is developed may be significant. In the Rock Lake Shale, *Chondrites* branches have the characteristic acute angle of the *Chondrites* network but the number of bifurcations rarely exceeds two (Hakes, 1976; pl. 4 fig 2b). This is partially explained because of the thin bedded approximately 5 mm thick lenticular sediments where intricate burrow patterns do not have sufficient space to develop along discontinuous surfaces.

Ichnogenus *Curvolithus* Fritsch, 1908

*Curvolithus multiplex* Fritsch, 1908

**Fig. 4(B-D)**

**Material:** Six slabs, TFCSA 18-23, containing approximately 20 specimens and additional specimens studied in the field.

**Description:** Straight to slightly curved, ribbon-like or tongue-like structures; horizontal, subhorizontal to rarely oblique burrows flattened, unbranched a positive trilobate epirelief and a positive bilobate hyporelief; trilobate epirelief consists of a broad median ridge and two narrower lateral ridges, similar to type 1 of Heinberg (1970); hyporelief is generally poorly preserved and consists of two narrow ridges separated by a broad flat groove; 14-23 mm in width and 3-6 mm in thickness.

**Discussion:** The ichnogenus *Curvolithus* has been usually interpreted as a locomotion trace (Repichnia) of endostral carnivorous (Heinberg and Birkelund, 1984; Lockley et al., 1987; Buatois et al., 1998). It was first created by Fritsch (1908) on the basis of fragmentary specimens from the Bohemian Upper Ordovician. Lockley et al. (1987) support this hypothesis by taking into account the absence of structures indicative of deposit-feeding. Inferred tracemakers include gastropods (Heinberg and Birkelund 1984), polychaetes, nemerteans, holothurians (Lockley et al. 1987) and flatworms (Seilacher 2007). According to Heinberg (1973), the *Curvolithus*-producer transported sediment from front to rear while digging into the sediment. As reported by Buatois et al. (1998), *Curvolithus* commonly occurs within shallow-marine deposits, either of normal or slightly brackish salinity. It is frequently associated to delta or fan delta settings, especially related to slightly brackish water conditions. Lockley et al. (1987) proposed a subset of *Cruziana* ichnofacies - *Curvolithus* ichnofacies – corresponding to deltaic-influenced nearshore environments subject to rapid deposition exceeding physical reworking.

Buatois et al. (1998) distinguished two ichnospecies of *Curvolithus*: *C. multiplex* Fritsch 1908, with a convex quadrlobate lower surface, and *C. simplex*, with a uni- to trilobate concave or convex lower surface. *Curvolithus* differs from similar trace fossils, such as *Psammichnites*, *Aulichnites* and *Gyrochorte*, by its trilobate upper surface. It occurs from Precambrian to Miocene (Buatois et al., 1998).

*C. multiplex* has been recorded from several stratigraphic intervals throughout the Middle and Upper Jurassic shelf deposits of East Greenland (Heinberg, 1970, 1973; Fürsich and Heinberg, 1983; Heinberg and Birkelund, 1984; Surllyk and Clemmensen, 1983) and is carefully described and interpreted by Heinberg (1973).

Ichnogenus *Hillichnus* Bromley et al., 2003

*Hillichnus agrioensis* Pazos and Fernández, 2010

**Fig. 5A**

**Material:** Three slabs (TFCSA 24-26).

**Description:** Spreiten or feather-like structures arise alternately on either side of the basal segmented structure. The general course of the trace fossil is horizontal, straight to curving or rarely looping. Concentric structures sometimes appear beside the spreiten structure.
Fig. 5: Discussion: The ichnognus Hillichnus is a three-dimensionally integrated trace fossil from shallow-marine deposits (Bromley et al., 2003). Pazos and Fernández (2010) found that Hillichnus agrioensis is composed of 4 characteristic levels of exposure. They stated that the feather-like structure (level 2) is the most characteristic feature of the ichnospecies. This structure is well developed in our specimens. It is interpreted as a bivalve resting, locomotion, and feeding trace fossil. Hillichnus is preserved as endichnia to positive-relief hypichnia. Excursions of the animal’s inhalent siphon have created feather-like and spreite-like structures to either side of a basal axial tube complex (Bromley et al., 2003).

Ichnogenus Palaeophycus Hall, 1847
Palaeophycus cf. tubularis Hall, 1847

Fig. 5B

Material: Three slabs (TFCSA 27-29) containing approximately 15 specimens.

Description: Simple, thinly lined, horizontal to slightly inclined burrows, unbranched with diameters ranging from 0.8 cm to 1.0 cm, filled with sediments essentially identical to host rock.

Discussion: Palaeophycus is interpreted as a dwelling trace (Domichnia) Palaeophycus was reviewed by Pemberton and Frey (1982), Keighley and Pickerill (1995), and Buckman (1995). Palaeophycus tubularis is distinguished from the other ichnospecies of Palaeophycus by its thin wall and the absence of ornamentation. It is distinguished from Planolites another unbranching burrow, which is not lined and is filled with sediment distinctly different from surrounding sediment. Palaeophycus tubularis was probably a feeding trace of a worm-like creature living in water-saturated sediment (Pemberton and Frey, 1982). Although widely considered marine, P. tubularis is also known from non-marine rocks (Morrissey and Braddy, 2004; Ekdale et al., 2007). In addition to lake and sea bottom habitats, the occurrence of this ichnospecies deep within Upi palaeosols opens the possibility of life in saturated soil below the water-table (Retallack, 2008).

Ichnogenus Phycodes Richter, 1850
Phycodes cf. palmatus Hall, 1852

Figure 5(C-D)

Material: Three slabs (TFCSA 30-32) containing three specimens and an additional specimen studied in the field.

Description. Horizontal branching burrow system, consisting of a few tubes (3 to 4) apparently branching from nearly the same point in a proximal position. Burrow diameter is 2-4 mm. Maximum burrow system length observed is 38 mm. Burrows filled with lighter materials than the surrounding matrix.

Discussion: Ichotaxonomy of Phycodes at the ichnospecies rank is based on ethological and morphological features, so that trace maker behavior influences the diverse morphology of Phycodes (Abbassi, 2007). The common feature of Phycodes is a master tunnel that is used by the tracemaker for the formation of other tunnels (Marintsch and Finks, 1982). Ichnospecies of Phycodes differ in pattern, size, nature, style and rank of bifurcation and the presence or absence of spreite (Abbassi, 2007). It was formerly thought that Phycodes occurs exclusively in relatively consolidated sediments of low energy shallow marine environments. However, it is also less frequently found in deep-marine and non-marine conditions (Han and Pickerill, 1994). Phycodes is

Ichnogenus *Thalassinoides* Ehrenberg, 1944

*Thalassinoides horizontalis* Myrow, 1995

**Fig. 6:**

Fig. 6(A-B)

*Material:* Five slabs (TFCSA 33-37) and additional specimens studied in the field.

*Description:* Horizontal, branching framework of smooth-walled, unlined burrows, forming polygonal networks, lacking vertically oriented offshoots. Burrow diameter consistent within individual specimens at 7 and 10 mm; constrictions or swellings at both junctions and inter-junction segments are notably lack.

*Discussion:* The present ichnospecies is characterized by an extremely regular burrow diameter, and a strictly horizontal orientation. Myrow (1995) discussed the four commonly occurring ichnospecies, namely *T. saxonicus* (Geinitz) (characterized by its large form with tunnels; Kennedy, 1967), *T. ornatus* (Kennedy) (consisting of smaller ovate, horizontal to gently inclined burrows; Kennedy, 1967); *T. Paradoxicus* (Woodward) (that branches forming complex boxwork patterns, generally irregular in geometry; Howard and Frey, 1984); and *T. suevicus* (Rieth) (which is predominantly a horizontal form consisting of enlarged Y-shaped bifurcations; Howard and Frey, 1984); and formulated fifth, *T. horizontalis* Myrow (a strictly horizontal form). The remaining ichnospecies of *Thalassinoides*, and not discussed by Myrow (1995), namely *T. tandoni* Badve and Ghare, *T. minimus* Aron and *T. foedus* Mikulas, are not worthy of ichnospecific distinction (Keighley and Pickerill, 1997).

*Thalassinoides suevicus* (Rieth, 1932)

**Fig. 6(C-D)**

*Material:* Four slabs (TFCSA 38-41) and additional specimen studied in the field.

*Description:* Straight or slightly winding, horizontal to oblique, flattened cylinders, 7-20 mm wide, showing Y to T-shaped bifurcations in horizontal system, more or less regularly branched, essentially cylindrical large burrow systems; dichotomous bifurcating common. They are filled with homogeneous dark clayey material. The cylinders are at least 30 mm long and join horizontal systems at different levels. Burrow walls distinct and smooth, burrow fills structureless and sharply different from host sediment. Typically bulbous enlargement at points of branching and burrow ends.

*Discussion:* *Thalassinoides* Ehrenberg, 1944 is a domichnial and fodinichnial structure produced by crustaceans, mostly decapods (Frey et al., 1984). It occurs in a great variety of marine environments, yet is most typical of the shelf Cruziana ichnofacies. Many authors (e.g., Fürsich, 1973; Ekdale, 1992; and Schlirf, 2000) have discussed this ichnogenus and its ichnotaxonomy.

The present specimens are fairly identical to *Thalassinoides suevicus*, originally described as *Cylindrites suevicus* and *Spongites suevicus* (Rieth, 1932). The only difference is typical swelling at the burrow ends of this material. The *suevicus* is distinguished from other ichnospecies of this ichnogenus by predominantly horizontal, more or less regularly dichotomous. *Thalassinoides suevicus* occurs in a wide range of facies, from ferruginous oolites to fine, medium and coarse sandstone, silt, marl, wackestone, packstone, and grainstone (Fürsich, 1998).

*Thalassinoides isp*
Material: Six slabs (TFCSA 42-47) and additional specimens studied in the field.

Description: Cylindrical to elliptical burrows, smooth-walled. Branches are Y- to T-shaped, usually enlarged at the bifurcations points. A horizontal branching polygonal network is dominant. Diameters range from 10 to 50 mm (long diameter) and 5 to 20 mm (short diameter) in the vertical plane.

Discussion: *Thalassionoides* burrow systems have been described many times in various types of marine depositional systems. They are usually interpreted as the work of deposit feeders or as domiciles in well-oxygenated sediments, and are attributed by most workers to endobenthic crustaceans (Bromley and Frey, 1974; Ekdale et al., 1984; Ekdale, 1992; Savrda, 1992; Bromley, 1996).

Unlike *Ophiomorpha*, *Thalassinoidea* has smooth walls. *Thalassinoidea* is interpreted as a combined feeding and dwelling burrow, but has been observed as a boring in some cases. The probable tracemaker was an arthropod.

*Thalassinoidea* is usually interpreted as a fodinichnial structure (i.e., Ekdale, 1992; Bromley, 1996), but a domicinial burrow (i.e., Myrow, 1995; Buatois et al., 2002), passively filled, and occasionally anagrichnial behavior have been also proposed (Bromley, 1996; Ekdale and Bromley, 2003).

Classification of the ichnogenus *Thalassinoidea* is essentially based on the presence of horizontal elements and branching characteristics. *Thalassinoidea* isp. as described herein does not exhibit any of well known ichnospecies, which therefore precludes definitive ichnospecific identification.

*Polychaetes Tubes*

Material: Eleven specimens (TFCSA 48-58).

Description: solitary, short, straight, nonbranching cylindrical to subcylindrical tube preferentially runs parallel to the bedding plane. Maximum observed length is up to 30.0 mm and diameter varies from 5.0 to 6.0 mm. Burrows are unusually preserved as full relief, having quite distinct prominent wall-like external structure, which is made up of calcium carbonate. Burrow walls are constructed to form growth ring, which are prominent and symmetrical in outline and unequally spaced, while some burrow tubes display faintly developed and widely and unequally spaced rings. Few tubes show smooth exterior surfaces. Internal materials of the burrow fills are massive and structureless and identical to surrounding material. Sometimes these tubes appear as protruding circles or hollow tubes on the bedding planes.

5. Discussion and Conclusions:
The present study of the Jurassic (Callovian-Oxfordian) sequences of central Saudi Arabia indicates the presence of abundant and diverse assemblage of body and trace fossils in their strata. Assemblages of trace fossils, in association with body fossils and lithologic information, provide excellent clues to parameters of ancient environments. In General, shallow water environment indicative of low to intermediate water energy is widespread in the studied sequence.
A detailed paleoecological analysis of the macrofaunal assemblages (brachiopods, mollusks, echinoderms colonial corals and sponges) recorded throughout the studied sections has revealed shallow marine water body association (in preparation). The abundance macrofossils in carbonates of the Callovian-Oxfordian Tuwaiq Mountain Limestone and Hanifa formations suggest that deposition occurred within the photic zone which favored benthic macrofossils.

Lithologically, the Callovian-Oxfordian Tuwaiq Mountain Limestone and Hanifa formations are composed mainly of carbonate rocks (pure limestone interbedded, particularly in the Hanifa Formation, with marly limestone). Within the carbonate regime, they are represented by wackestones to packstones and silty marl, only rarely interrupted by thin beds of grainstone produced by storm flows.

The Tuwaiq Mountain Limestone Formation is represented by carbonates which are characterized by mud-supported fabrics including the lime-mudstone and wackestone microfacies. The dominance of calcareous micritic matrix, the fine-grained nature of the bioclasts and other carbonate allochems, the dominance of low diversity of benthonic foraminifera (miliolids), ostracods, calcispheres and the lack of wave- and current-reworking features support its deposition in quiet water below wave base. The sediments of wackestone facies may be deposited in shallow inner shelf and lagoon area behind skeletal barriers while the lime-mudstone facies were deposited in the intertidal area. In addition, the Tuwaiq Mountain Limestone Formation comprises coral bournemouth microfacies that is well developed in quiet to moderately agitated water condition.

The trace fossils from the Callovian-Oxfordian Tuwaiq Mountain Limestone and Hanifa formations are typical elements of the Cruziana ichnofacies. The occurrence and distribution of this assemblage are controlled by the various environmental parameters such as energy level, substrate, light, salinity, oxygen level and bathymetry. These parameters have controlled the distribution of trace producers during the deposition of the Callovian limestone of the Tuwaiq area. Seilacher (1963) stated that the interpretation of salinity cannot be done solely by the study of trace fossils because the activities which control trace morphology are related to sedimentary facies and not to salinity.

Analysis of biogenic structures of the Tuwaiq Mountain Limestone and Hanifa formations exhibits the bathymetric control trace fossils assemblages which display the Cruziana ichnofacies type of setting which mainly characterized by the horizontal grazing and feeding forms. The Cruziana Ichnofacies is most characteristic of permanently subtidal in shallow marine settings typified by uniform salinity. Conditions typically range from moderate energy levels lying below fair-weather (minimum) wave base but above storm wave base, to lower energy levels in deeper, quieter waters. Such conditions were prevailed during deposition of the Callovian-Oxfordian sediments in central Saudi Arabia.

Strata of the Hanifa Formation are intensely bioturbated and represented by number of trace fossils. The association is dominated by the horizontal forms like P. tubularis, Phycode palmatus, Thalassinoides suevicus, Th. horizontalis and Th. isp. that are indicative of low energy environmental condition below fair weather wave base. C. intricatus, and C. stellaris are opportunistic burrows preserved in similar environmental condition. The crustacean burrows of Thalassinoides are fairly abundant, occurring in near shore environment and often form large networks preserved as positive hyporelief.

On the other hand, the trace fossil assemblage from the Callovian Tuwaiq Mountain Limestone Formation is mainly composed of Curvolithus multiplex, Thalassinoides suevicus, Th. horizontalis and Th. isp. Curvolithus multiplex is a component of the Cruziana ichnofacies in shallow-marine facies, either of normal salinity or slightly brackish (Buatois et al. 1998).

Generally, Thalassinoides is not a direct indicator of water depth, but is mainly related to other ecologic and sedimentologic factors, especially substrate character (Ekdale, 1992). Since its erection, the ichnogenus Thalassinoides has been recorded from a variety of environmental settings. Thalassinoides is mainly marine, ranging from tidal flat and shoreline environments to offshore outer shelf facies and deep-sea fans (Myrow, 1995; Kim et al., 2002). Moreover, Thalassinoides (T. paradoxicus and T. suevicus) have been recently recorded in non-marine floodplain environments (Kim et al., 2002).

In addition, Thalassinoides frequently occur in well-oxygenated environments and soft but fairly cohesive substrates (Bromley and Frey, 1974; Kern and Warme, 1974; Ekdale et al., 1984; Bromley, 1990), although Thalassinoides occurs in a range of sediment consistencies. Well-defined Thalassinoides is common in softgrounds, but may also occur in firmgrounds. Pemberton et al. (2004) stated that Thalassinoides is a common element of the Glossifungites ichnofacies.

REFERENCES


