JOURNAL OF PALEONTOLOGY, V. 57, NO. 3, P. 447–460, 5 FIGS., MAY 1983

PALEOZOIC TRACE FOSSILS FROM THE KUFRA BASIN, LIBYA

BRIAN R. TURNER AND MICHAEL J. BENTON
Department of Geology, The University, Newcastle upon Tyne, NE1 7RU, England

ABSTRACT—The Paleozoic succession in the southeastern part of the Kufra Basin, Libya, comprises a sequence of sedimentary facies up to 250 m thick, representing fluvial, tidal, subtidal, shoreface and marine shelf depositional environments. Body fossils are rare, and precise age and stratigraphic relations uncertain. However, many of the formations contain trace fossils. The oldest association of *Cruziana*, *Arthrophycus* and *Monocraterion* comes from the Cambro-Ordovician at Jebel Archenu which unconformably overlies Precambrian basement. This is the first recorded presence of *Cruziana* and *Arthrophycus* from the Cambro-Ordovician in the Kufra Basin. Elsewhere, the Cambro-Ordovician contains fine, deep, shoreface sands characterized by the occasional presence of *Cylindrichnus* followed by coarser, shallower, shoreface sands with abundant *Phycodes*. *Arthrophycus* and *Cruziana* are common in the Lower Devonian Tadrart Formation (youngest record of true *Arthrophycus*) and the upper part of the Silurian Acacus Formation. The presence of abundant *Cruziana* at this level throughout the area provides a useful local stratigraphic marker. *Skolithos* is abundant at the base of the Upper Devonian Binem Formation and *Zoophycos* at the top where it forms a thin, but extensive marker bed known as the *Zoophycos* sandstone. The Carboniferous Dalma Formation has a more diverse ichnofauna including *Bifungites* (youngest record?), *Neonereites* and *Scoyenia* preserved mainly in the upper part of a major transgressive sequence representing a transitional environment between the shoreface zone and nearshore shelf.

INTRODUCTION

THE KUFRA BASIN in southeast Libya (Figure 1) occupies an area of about 400,000 km^2 and is filled by a sequence of Paleozoic and Mesozoic sediments up to 2,600 m thick, separated by an unconformity. Although outcrops of Paleozoic sediments are confined to the southwest, north and southeast corners of the basin the stratigraphy is remarkably consistent throughout despite variations in thickness of up to 600 m (Turner, 1980). The present study focusses attention on the Paleozoic succession in the southeast centered on Jebel Asba and Jebel Archenu (Figure 1) where the succession is discontinuously exposed along the southern limb of a large syncline dipping at between 5 and 10° north. Owing to the lack of exposure, subsurface data and biostratigraphic control, correlation between the two areas is uncertain. Body fossils are generally lacking but trace fossils are present, particularly at Jebel Asba where they occur throughout the succession. Little previous study of the trace fossils has been undertaken.

The main purpose of this paper is to describe the trace fossils and assess their stratigraphic and environmental significance with particular reference to the relationship between trace fossil distribution and lithofacies.

STRATIGRAPHY

The trace fossils come from two main sections measured at Jebel Asba and Jebel Archenu (Figures 2, 3). No previous description of the stratigraphy of the area has been published; the only reference to it is contained in confidential oil company reports. The succession at Jebel Asba extends from the Cambro-Ordovician through the Silurian and Devonian to the Carboniferous. The base of the succession is not exposed and lithostratigraphic subdivisions and age relations are based mainly on comparisons with other Paleozoic basins which generally retain the same terminology throughout Libya. The only exception in Kufra is the Carboniferous Dalma Formation which is named for exposures in the northern part of the basin at Jebel Dalma Kebir. Two major problems are 1) that the Carboniferous is confined to an area north of Jebel Asba where the base is not exposed; hence its relationship to the rest of the succession is uncertain and 2) that faulting has disrupted stratigraphic relations at the northern end of Jebel Asba where hitherto unrecognized Cambro-Ordovician sediments occur along a major fault plane trending northwest-southeast (Figure 1). Additional photogeological reconnaissance suggests that these Cambro-Ordovician sed-

0022-3360/83/0057-0447$03.00

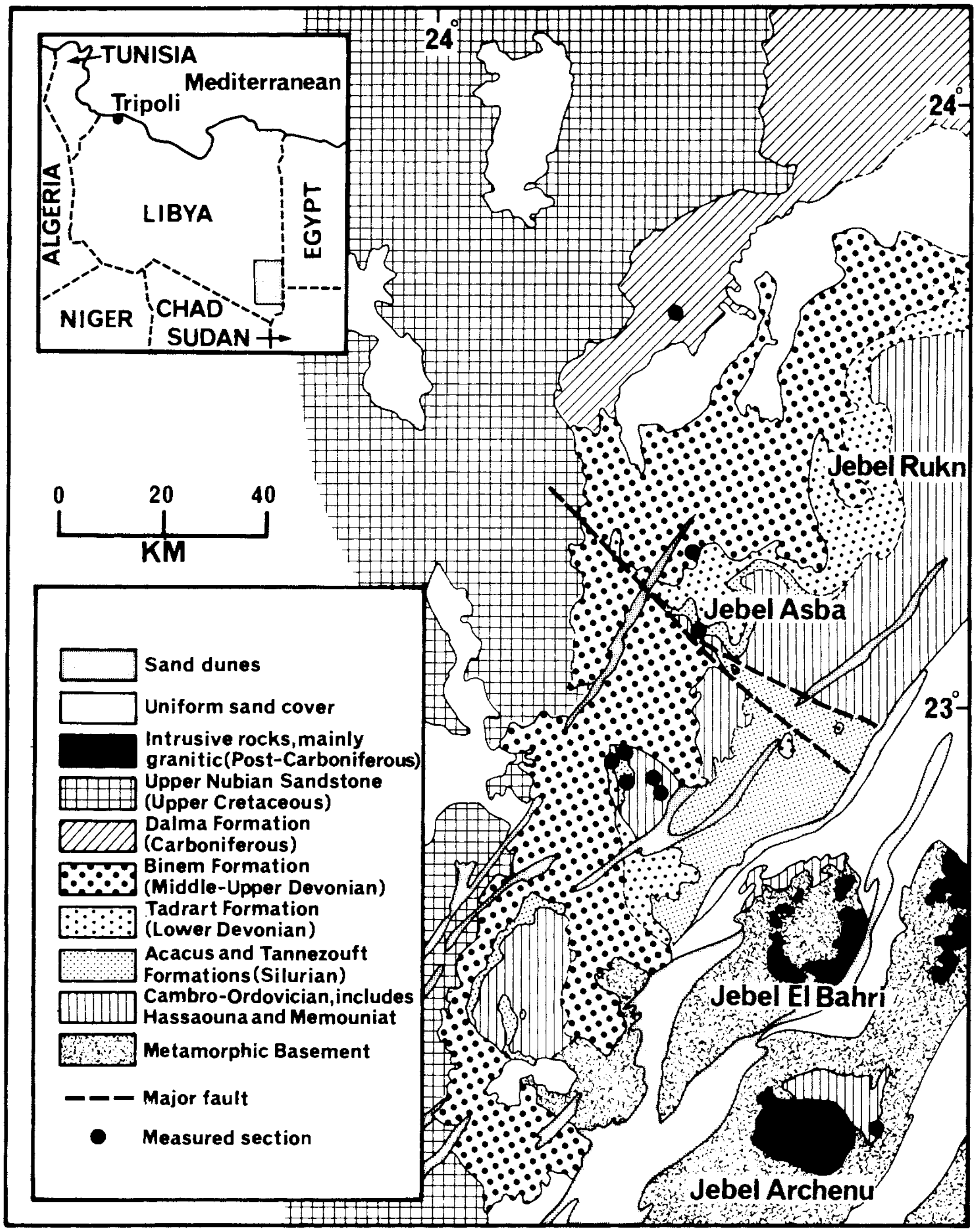


FIGURE 1—Generalized geological map of the southeastern part of the Kufra Basin and location of study area.

iments may extend farther to the northeast towards Jebel Rukn as depicted on the geological map (Figure 1). Body fossils are rare and have only been recorded from a shallow borehole penetrating Silurian shales in central Jebel Asba. These graptolites, chitinozoa and pelecypods have been identified (Turner, 1980). An extensive search of the shales on

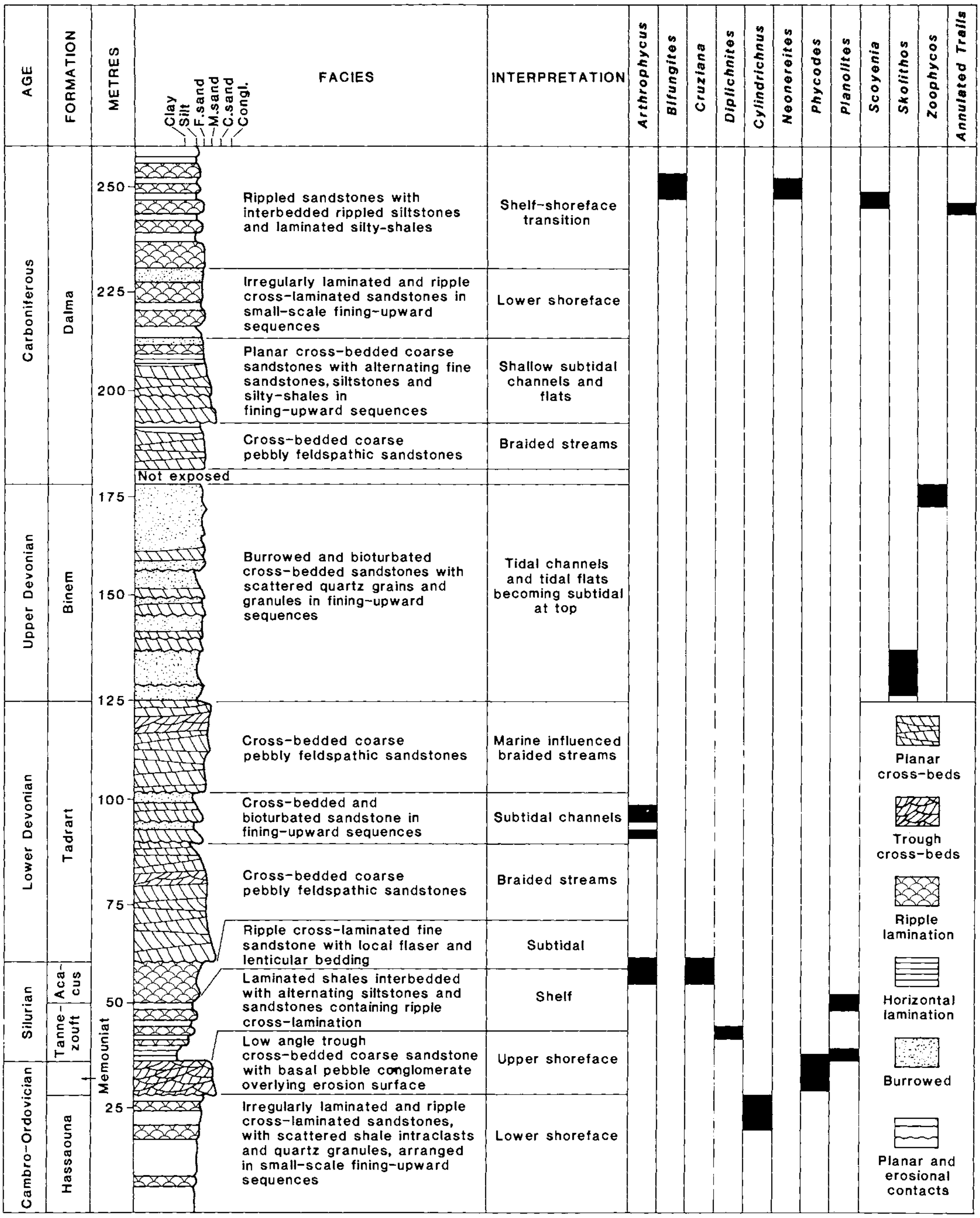


FIGURE 2—Generalized stratigraphy, facies analysis and trace fossil distribution in the Paleozoic succession at Jebel Asba.

the outcrop failed to reveal any further body fossils. Trace fossils in comparison are common and occur repeatedly at intervals throughout the succession (Figure 2).

The strata at Jebel Archenu are well exposed, but only accessible at one locality because of the precipitous cliff face. The strata rest unconformably on the Precambrian basement. The contact is defined by a thin, discontinuous pebble conglomerate. The

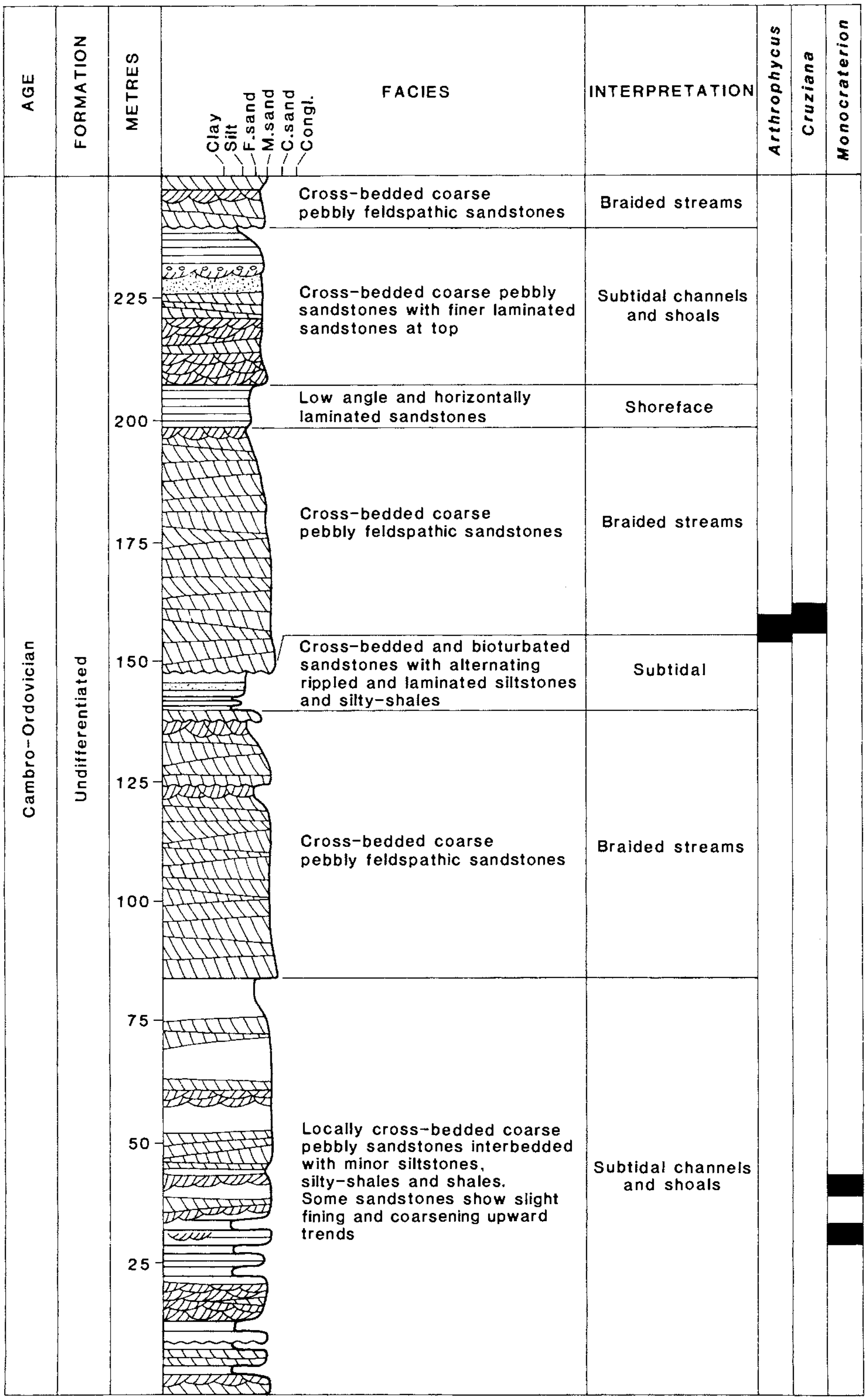


FIGURE 3—Generalized stratigraphy, facies analysis and trace fossil distribution in the Paleozoic succession at Jebel Archenu.

pebbles are composed mainly of subrounded to subangular vein quartz up to 7 cm in diameter and display a crude imbrication. The succession of strata is assigned to the Cambro-Ordovician solely on the basis of its position above Precambrian basement. There is no confirmatory biostratigraphic evidence and the generalized succession and lithofacies patterns do not correlate with the Jebel Asba section, 80 km to the north. However, it has been suggested that an erosion surface about 160 m above the base of the succession is the contact between the Hassouna and Memouniat formations recognized at Jebel Asba (Turner, 1977). Body fossils are absent and trace fossils uncommon; most of them being confined to the middle of the succession except for *Monocraterion*. According to unpublished oil company reports (Turner, 1977) *Monocraterion* occurs just above the base (Figure 3) and appears to be characteristic of the Cambro-Ordovician in other parts of the basin. The similar thickness of strata at Jebel Asba and Jebel Archenu is attributed to the fact that the Cambro-Ordovician in this area is very thick (400 m) compared to the rest of the strata.

SEDIMENTOLOGY

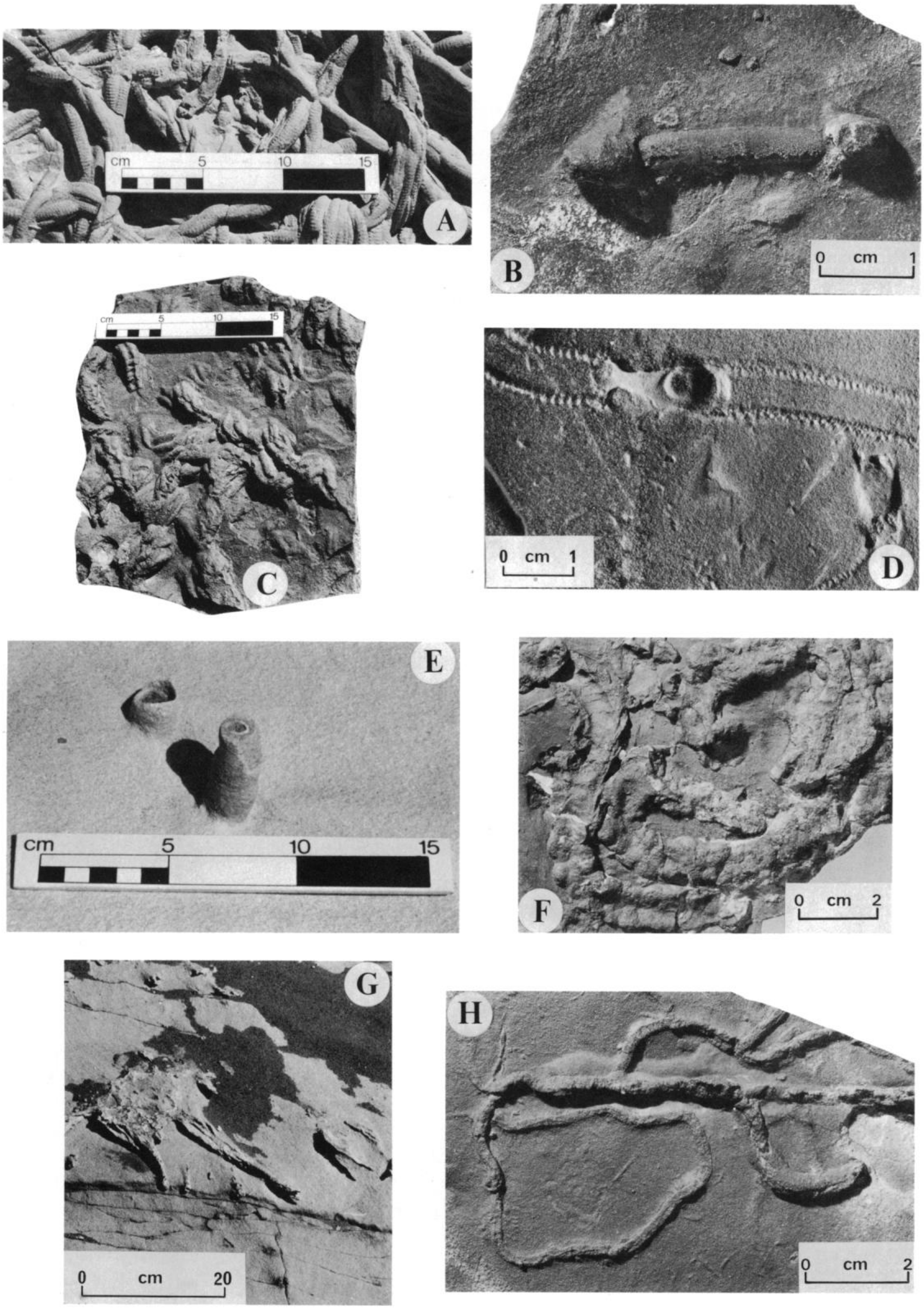
Detailed facies analysis and environmental interpretations of the succession at Jebel Asba and Jebel Archenu have been given elsewhere (Turner, 1980). Only a brief description of the sedimentology is presented here. The stratigraphy, facies descriptions and environmental interpretations, and trace fossil distribution are summarized in Figures 2 and 3. The sedimentary facies represent fluvial, tidal, subtidal, shoreface and marine shelf depositional environments. The repetition of similar facies implies a recurrence of similar depositional processes and environments which is attributed to interaction of a marine coastline and a braided alluvial plain. When the fluvial system was active due to source area tectonism or shifts in the depositional system the environments prograded seaward; when it was inactive transgression and drowning of the coastline occurred. This sequence of regressive and transgressive events caused a repeated northwest (regression) and southeast (transgression) shift of the facies tracts. The more common nearshore shallow water marine environments are indicative of a non-barred, macrotidal, tide-dominated, sandy coastline comparable with contemporary macrotidal coastlines, such as the North Sea coast of Germany. The only exception to this general trend occurs at Jebel Asba where burrowed shoreface sediments characteristic of a high energy, wave-dominated coastline such as the present day Oregon coastline occur beneath a high energy, tide-dominated sequence probably in response to changes in offshore slope and shoreline configuration. The dominance of strong tidal currents implies that the Kufra Basin was connected with an open ocean (Tethys), probably through the Quattara embayment in the northeast. The general lack of fine silts and muds is attributed to the low concentration of suspended sediment in the fluvial input to the basin, the effectiveness of wave and tidal processes in the nearshore area and the tidal flushing mechanism generated in response to basin hydrography (Turner, 1980).

TRACE FOSSIL DESCRIPTIONS

Ichnogenus ARTHROPHYCUS Hall, 1852
ARTHROPHYCUS ALLEGHANIENSIS (Harlan, 1831)
Figure 4A

Description.—Some slabs from the Tadrart Formation are packed with curving, crossing, branching horizontal to subhorizontal burrows which are 1–2 cm wide, and circular to elliptical in cross section. The burrows widen and become partly bilobate before branching and then run on in bunches. The burrows are crossed regularly by transverse ridges (3 to 4 per cm).

Remarks.—*Arthrophycus* has been described from the Lower Silurian of New York State (e.g., Hall, 1852, p. 4–6, Pls. 1, 2; Häntzschel, 1975, fig. 25.4), Lower Ordovician of Jordan (Selley, 1970, p. 485 ("*Harlania*")), and the Cambro-Ordovician of Spain (Baldwin, 1977, p. 26, Pl. 2a), in association with *Cruziana*. Libyan Cambro-Ordovician and Silurian material is also associated with *Cruziana*, and appears similar in form and relations to these described occurrences. Our Lower Devonian material resembles these in size and form, but shows more frequent and regular branching and does not occur with *Cruziana*. Later forms compared with *Arthrophycus* from the Cretaceous and Ter-


A
cm 5 10 15
B
0 cm 1
C
cm 5 10 15
D
0 cm 1
E
cm 5 10 15
F
0 cm 2
G
0 cm 20
H
0 cm 2

tiary of the United States (Frey and Howard, 1970, p. 147, 152) and Europe (Ksiazkiewicz, 1970, p. 284) are not typical of the genus (Häntzschel, 1975, p. W38–W39), and the Lower Devonian Tadrart material described here is, then the youngest representative of the genus yet described.

Arthrophycus is a feeding burrow formed by arthropods or worms and seems to be typical of Seilacher's *Cruziana* Facies.

Occurrence.—Tadrart Formation (Lower Devonian), Jebel Asba; Acacus Formation (Silurian), Jebel Asba; Cambro-Ordovician, Jebel Archenu.

Ichnogenus BIFUNGITES Desio, 1940
BIFUNGITES FEZZANENSIS Desio, 1940
Figure 4B

Description.—One specimen, preserved as a convex hyporelief, shows the typical dumbbell shape characteristic of *Bifungites.* The bulbous ends are 6 × 9 mm in area, and 5 mm thick, and the central tie is 2.1 cm long and 4 × 2 mm in diameter.

Remarks.—*Bifungites* has already been reported from the Devonian of Libya and other Sahara localities (Desio, 1940; Dubois and Lessertisseur, 1964). Other records include: Lower Cambrian of Pakistan (Seilacher, 1955, p. 382–385, fig. 5 (15)), Ordovician of Ohio (Osgood, 1970, p. 323–325, Pl. 65, fig. 6; Pl. 66, fig. 5; Pl. 70, fig. 5; Pl. 71, fig. 4), Lower Silurian of New York State (Hall, 1852, p. 20, 25, Pl. 6, fig. 2; Pl. 10, fig. 6), Lower Devonian of New York State (Miller, 1979, p. 125, Pl. 21), and Upper Devonian and Lower Mississipian of Montana (Rodriguez and Gutschick, 1970, p. 418–419, Pl. 5; Gutschick and Lamborne, 1975). Thus the Carboniferous Libyan material matches in age the youngest *Bifungites* from Montana. The Libyan *Bifungites* differs from the Montana material in that the bar is relatively broader and shorter and the Upper Devonian and Mississipian Montana material commonly displays arrow-shaped ends.

Bifungites has been interpreted as a cast of the top part of a U-shaped burrow by Seilacher (1955) and Dubois and Lessertisseur (1964), and as the base of a U-shaped burrow by Osgood (1970), Rodriguez and Gutschick (1970) and Gutschick and Lamborne (1975). The latter interpretation seems best supported by good material. Osgood (1970, p. 323–325) synonymized *Bifungites* with *Corophioides biclavata* (Miller, 1875) on the basis of a range of Cincinnatian (Upper Ordovician) specimens that show all gradations from typical dumbbells to complete flat-bottomed U-shaped burrows with *spreite.* However, since dumbbell forms are relatively common in the fossil record but not always associated with good comparative U-shaped burrow material, it is best not to synonymize *Bifungites* with *Corophioides.* Furthermore, most of these have now been synonymized with *Rhizocorallium.* Also, some *Bifungites* may belong to *Diplocraterion*-like forms, or even to U-shaped burrows without *spreite* (e.g., *Arenicolites*).

Bifungites occurs commonly in "shallow nearshore marine and brackish water environments" in the Upper Devonian and Lower Mississippian of Montana (Rodriguez and Gutschick, 1970; Gutschick and Lamborne, 1975), in the *Cruziana* Facies in the Lower Cambrian of Pakistan (Seilacher, 1955) and in the tidal and offshore zones in the Devonian of New York State (Miller, 1979). *Bifungites* is interpreted as part of a dwelling burrow produced by an annelid or arthropod.

Occurrence.—Dalma Formation (Carboniferous), Jebel Asba.

Ichnogenus CRUZIANA d'Orbigny, 1842
cf. CRUZIANA sp.
Figure 4C

←

FIGURE 4—*A, Arthrophycus alleghaniensis* (Harlan) on sole of sandstone bed, Lower Devonian Tadrart Formation. *B, Bufungites fezzanensis* Desio, on sole of sandstone bed, Carboniferous Dalma Formation. *C, Cruziana* sp., on sole of sandstone bed, Silurian Acacus Formation. *D,* cf. *Diplichnites* on sole of mudstone bed, Silurian Tannezouft Formation. *E, Cylindrichnus* sp., on top of partly eroded sandstone bed, Cambro-Ordovician Hassaouna Formation. *F, Neonereites biseralis* Seilacher, upper surface of siltstone bed, Carboniferous Dalma Formation. *G, Phycodes* aff. *palmatum* (Hall) on top of partly eroded sandstone bed, Cambro-Ordovician Memouniat Formation. *H, Planolites* sp., on sole of siltstone bed, Silurian Tannezouft Formation.

Description.—The figured slab is packed with crossing bilobed trails preserved as convex hyporeliefs, 1.5–2.0 cm wide and up to 2 cm deep. The central ridge is well marked, and transverse scratches are visible. The traces are up to 10 cm long, but generally shorter (4–6 cm), and they show some alignment, possibly in response to bottom currents. The resting traces, *Cruziana,* grade into *Rusophycus*-like forms.

Remarks.—No attempt is made to ascribe the present material to a species of *Cruziana* because of the worn nature of the surface.

Cruziana is typical of the distal shelf *Cruziana* Facies of Seilacher (1967), and it occurs here with *Arthrophycus* as in some other Lower Paleozoic examples (see above). The present specimens were probably produced by trilobites.

Occurrence.—Acacus Formation (Silurian), Jebel Asba; Cambro-Ordovician, Jebel Archenu.

Ichnogenus DIPLICHNITES Dawson, 1873
DIPLICHNITES sp.
Figure 4D

Description.—The figured specimen shows a 12 cm stretch of trail consisting of two parallel series of small grooves 5–6 mm apart. The grooves are chevron-shaped, 1–1.5 mm wide, and about 1 mm apart. The trail is interrupted by an ovoid impression, and another shorter trail on the same slab terminates in a similar mark.

Remarks.—This trail is interpreted as produced by the distal elements of the legs of an arthropod. The ovoid impression may be resting marks and may show the outline of the producer. Our material resembles some trails ascribed to *Diplichnites* (e.g., Cambro-Ordovician of Spain, Baldwin, 1979, p. 22, Pl. 2d) and the "?trail in the form of two parallel rows" from the Upper Precambrian of the USSR (Fedonkin, 1977, p. 190, Pl. 2a). Some forms of *Beaconichnus* from the Devonian of Antarctica appear similar (e.g., Häntzschel, 1975, figs. 27.1b, c) but they are much larger than our specimen (rows 2–30 cm apart).

Occurrence.—Tannezouft Formation (Silurian), Jebel Asba.

Ichnogenus CYLINDRICHNUS Toots in Howard, 1966

CYLINDRICHNUS sp.
Figure 4E

Description.—In several of the lithofacies investigated there occur vertical to subvertical tubes, circular or slightly flattened in cross section, and about 1 cm in diameter. There is a hard outer wall and a central funnel filled with soft sediment, which is clearly distinguished by weathering. The tubes extend to a depth of between 5 and 10 cm and are not crowded. In some cases, they bifurcate and appear to grade into *Phycodes* (q.v.).

Remarks.—*Cylindrichnus* is distinguished from *Skolithos* by the central core, the conical, weakly curved form, and the variation in orientation from nearly horizontal to vertical (Häntzschel, 1975, p. W57). Our material conforms with these features, although the conical, curved shape is not seen clearly. Some of the material could be integrated *Monocraterion,* but it shows no sign of the characteristic funnel at the top.

Frey and Howard (1970) consider *Cylindrichnus* from the Cretaceous of Utah as a permanent burrow of a filter-feeding organism living in slightly turbulent nearshore waters. It generally occurs in fine-grained sand with surface trails and burrows. The Libyan material is found within fine- to medium-grained shoreface sands and coarse, pebbly subtidal sand bodies, both environments suggesting a high energy, nearshore turbulent regime.

Cylindrichnus has previously been reported from the Pennsylvanian and Cretaceous of the United States (Häntzschel, 1975, p. W57). The Libyan material is the earliest occurrence of *Cylindrichnus* recorded to date.

Occurrence.—Hassaouna Formation (Cambro-Ordovician), Jebel Asba.

Ichnogenus NEONEREITES Seilacher, 1960
NEONEREITES BISERIALIS Seilacher, 1960
Figure 4F

Description.—The figured slab shows several irregularly meandering horizontal burrows consisting of two rows of alternate flattened subspherical beads, or lobes, preserved as convex hyporeliefs. The trace is 1.0–1.5 cm wide, and each bead is 0.4–0.8 cm in diameter. The beads occur clearly in places, but blend into a smoother burrow morphology elsewhere.

Remarks.—Although larger than Seilacher's type Jurassic material (beads 0.3–0.4 cm in diameter), our specimens correspond to the characters of *Neonereites biserialis. Nereites* may also be represented by flattened lobed burrows but they generally meander more regularly, and the lobes are well defined and regular. The figure of the "*Neonereites* view" of *Scalarituba* from the Pennsylvanian of the Ouachita geosyncline, as interpreted by Chamberlain (1978a, p. 32, fig. 4 (28); 1978b, p. 135, fig. 51), is very like our material.

Neonereites occurs in a range of ichnofacies from mid-shelf *Skolithos* to deep-sea *Nereites* Zones (Chamberlain, 1978a; Seilacher, 1978).

Occurrence.—Dalma Formation (Carboniferous), Jebel Asba.

Ichnogenus PHYCODES Richter, 1850
PHYCODES aff. P. PALMATUM (Hall, 1852)
Figure 4G

Description.—Subhorizontal burrows, 1 cm in diameter branching upwards in tight bundles to a total width of about 4 cm.

Remarks.—As suggested by Seilacher (1955, p. 383–386), Hall's *Buthotrephis palmata* is probably a species of *Phycodes.* Our specimens resemble those figured by Hall (1852, Pl. 6, fig. 1), Seilacher (1955, e.g., Pl. 25, fig. 1) and Crimes et al. (1979, p. 104, fig. 5i) as *P. palmatum.* The Libyan specimens differ from *P. circinnatum* Richter, 1850 (Häntzschel, 1975, figs. 59, 2b, d) which has far more and narrower branches, *P. flabellum* Miller and Dyer, 1878 (Osgood, 1970, e.g., Pl. 70, fig. 6) which consists of broad fans of tightly packed small arms, and *P. pedum* Seilacher, 1955 (p. 386–388, fig. 4) which is a curved burrow system with regular laterally and upwards directed branches.

Phycodes occurs in the *Cruziana* Facies of the Lower Cambrian of Pakistan (Seilacher, 1955), Cambro-Ordovician of Spain (Baldwin, 1977), Upper Ordovician of Ohio (Osgood, 1970), Lower Silurian of New York State (Hall, 1852), and in intertidal beds of the Lower Cambrian of Spain (Crimes et al., 1977).

Occurrence.—*Phycodes* crowds beds in the Memouniat Formation (Cambro-Ordovician), Jebel Asba.

Ichnogenus PLANOLITES Nicholson, 1873
PLANOLITES MONTANUS Richter, 1937
Figures 4H, 5A

Description.—Irregular horizontal burrows, 2–5 mm in diameter circular to subcircular in section. The burrows appear to branch in one specimen (Figure 4H), but this is a misleading appearance caused by crossing. In another specimen (Figure 5A), two circular 3–5 mm burrows run close together, and meet at one end. This is not a bilobed trace because the two burrows are separate for their whole length and their spacing varies. There are no signs of backfill structures and the burrow fill is rather different from the matrix.

Remarks.—The lack of backfill structures and the differentiation of the burrow fill from the matrix, suggest that these specimens are *Planolites* rather than *Palaeophycus* (as defined by Alpert, 1975, p. 512). *Planolites* is a well-known facies-crossing form and is of little use for environmental interpretation.

Occurrence.—Tannezouft Formation (Silurian), Jebel Asba; Memouniat Formation (Cambro-Ordovician), Jebel Asba.

Ichnogenus SCOYENIA White, 1929
SCOYENIA GRACILIS White, 1929
Figure 5B

Description.—Circular horizontal to subhorizontal burrows 4–8 mm in diameter, running straight for up to 20 cm, or curving. No branching but frequent crossing, and may pack entire bedding plane surfaces. The surface of the burrow is longitudinally striated (striae: 0.2 mm wide).

Remarks.—These burrows might be confused with *Fucusopsis* (see Häntzschel, 1975, p. W64), but the striations are too regular and well marked. *Scoyenia* is typical of Seilacher's *Scoyenia* Facies which is characteristic of nonmarine clastics (e.g., Permian red beds of North America and Europe). Bromley and Asgaard (1979) report *S. gracilis* from sandstone units of continental red bed sequences in the Triassic of East Greenland. They suggest that it was formed under very shallow water, or in subaerially exposed sediment, often in association with mud-cracks.

Occurrence.—Dalma Formation (Carboniferous), Jebel Asba.

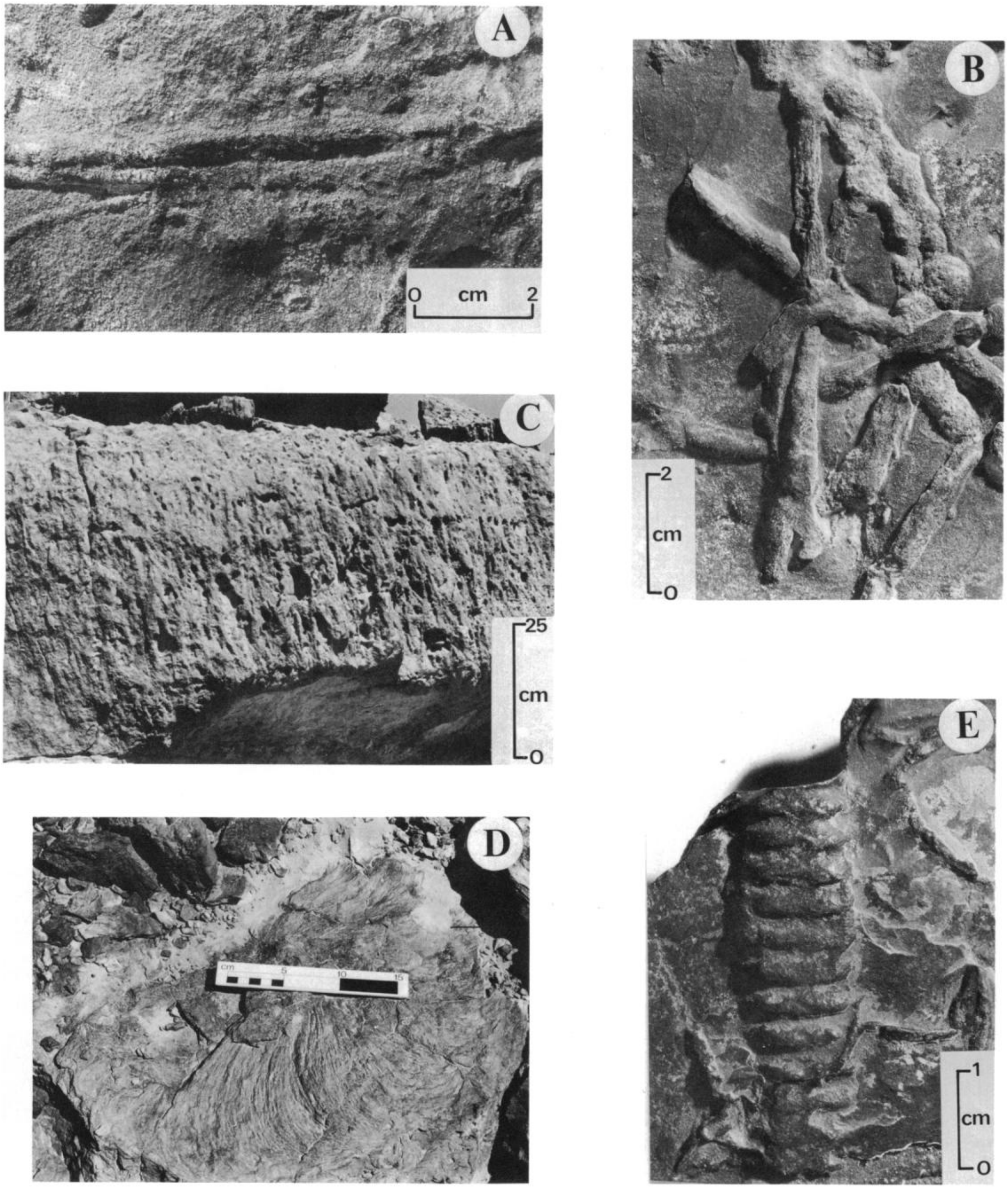


FIGURE 5—*A, Planolites* sp., on top of sandstone bed. Cambro-Ordovician Memouniat Formation. *B, Scoyenia gracilis* White, on sole of sandstone bed, Carboniferous Dalma Formation. *C, Skolithos linearis* Haldeman, field photograph of sandstone bed, Upper Devonian Binem Formation. *D, Zoophycos* sp., on top of sandstone bed, Upper Devonian Binem Formation. *E,* Annulated Trail, on sole of sandstone bed, Carboniferous Dalma Formation.

Ichnogenus SKOLITHOS Haldeman, 1840
SKOLITHOS LINEARIS Haldeman, 1840
Figure 5C

Description.—Packed vertical burrows, up to 30 cm deep, 1.0–1.5 cm wide, and circular to subcircular in cross section. The burrows taper downwards and do not branch.

Remarks.—Our material corresponds to *S. linearis* as defined by Haldeman (1840), Howell (1943), Osgood (1970, p. 325–327), and Häntzschel (1975, p. W106–W108), and reach the maximum recorded depth of 30 cm.

Skolithos occurs in tidal and shoreface zones (Chamberlain, 1978b, p. 142–143), and it is interpreted as a rapidly formed living burrow probably produced by many different animals (Crimes et al., 1977, p. 120).

Occurrence.—Binem Formation (Devonian), Jebel Asba.

Ichnogenus ZOOPHYCOS
Massalonga, 1855
ZOOPHYCOS sp.
Figure 5D

Description.—Apparently a planar circular form of *Zoophycos* showing irregular spreite ridges (minor lamellae) curving out from the central tunnel, which is not clear in this specimen. The ridges are about 3 mm wide and the diameter of the whole structure is about 40 cm. There are no clearly developed major lamellae (terminology as defined by Simpson, 1970; Häntzschel, 1975, p. W120–W122).

Remarks.—The nomenclature of the *Zoophycos* group is in a confused state and no attempt is made to ascribe our specimen to a species.

Zoophycos is typical of Seilacher's supposedly intermediate shelf *Zoophycos* Facies. More complex forms may occur in the deep water *Nereites* facies, and a detailed environmental study by Osgood and Szmuc (1972) showed that *Zoophycos* is also found in shallow water sediments deposited above wave base. Thus, no clear environmental evidence is given by the Libyan *Zoophycos*.

Occurrence.—*Zoophycos* occurs in the Binem Formation (Upper Devonian), Jebel Asba.

ANNULATED TRAIL
Figure 5E

Description.—A 5 cm length of 1.5 cm wide trail on a mudcracked surface, preserved as a convex hyporelief. Crossed by regular banded transverse annulations, 2.5 per cm. Cross sections show it is a trail or the cast of a washed out burrow.

Remarks.—This specimen resembles the genus *Plagiogmus* Roedel, 1929 in some respects. *Plagiogmus* is a Cambrian burrow form, 1–2 cm wide, with irregular transverse marks that reflect its strong internal backfill structures (Glaessner, 1969). However, our specimen differs in the regularity of the annulations, and in fact it is not preserved as a typical burrow. Since we have only one specimen, we do not name it.

Occurrence.—Dalma Formation (Carboniferous), northern Jebel Asba.

DISCUSSION

The trace fossils described are mainly shallow water forms that fall within Seilacher's (1967) *Skolithos, Cruziana* and *Zoophycos* facies. They occur at intervals throughout the succession but tend to be less common in the Cambro-Ordovician at Jebel Archenu which unconformably overlies Precambrian basement. However, the reported presence of *Monocraterion* in the lower part of the succession (A.G.I.P. report, in Turner, 1980) and *Cruziana* and *Arthrophycus* in the middle of the succession is comparable to the trace fossil distribution in the lower Cambrian of Spain (Crimes et al., 1977). The paucity of trace fossils in this section is largely attributed to the predominance of coarse-grained, thick bedded subtidal sands. The most abundant trace fossils occur in the more thinly bedded sands, silts and shales in the middle of the succession where *Cruziana* and *Arthrophycus* are recorded for the first time from the Cambro-Ordovician in the Kufra Basin. Thus, a strong facies control on trace fossil abundance and distribution is implied and this same pattern is repeated throughout the Paleozoic succession of Jebel Asba. In view of this it is difficult to assign an early Cambrian age to the succession with any certainty.

The upper part of the Cambro-Ordovician as seen at Jebel Asba shows a vertical increase in trace fossil abundance but low diversity within a sequence of shoreface sands. The finer grained deeper shoreface sands are characterized by the occasional presence of *Cylindrichnus* followed abruptly by coarser grained shallower shoreface sands with abundant *Phycodes* which show a distinct vertical variation in relative abundance and orientation. In the lower part they are very abundant and mainly oblique and horizontal in orientation, in the middle they are less abundant and almost exclusively horizontal to subhorizontal, and at the top, where they are again very abundant, they are vertically orientated. Bedding surfaces at the top of the facies show large symmetrical megaripples covered with *Scoyenia* traces. However, there is a rapid decrease in trace fossil abundance on successive rippled bedding surfaces within less than 1 m of sediment. In view of the uniform lithological character of the shoreface sands and their thinness (3 m), changes in orientation are largely a response to changes in energy level within the shoreface environment. The oblique and horizontal *Phycodes* in the lower part of the facies probably record higher energy conditions, as indicated by the scoured base and overlying pebble conglomerate up to 50 cm thick (Turner, 1980). The horizontal to subhorizontal *Phycodes* suggests a lower energy environment concomitant with the overall vertical decrease in scale of the crossbeds; the animal responsible for the burrows ultimately trying to escape (vertical burrows) as water depths increased in response to basinwide transgression and deposition of the overlying Silurian shelf shales.

There is no marked vertical stratigraphic variation in abundance and diversity of trace fossils in the Paleozoic succession at Jebel Asba; most of them are associated with the more thinly bedded shallow water tidal and subtidal sands and silts. One of the most prolific trace fossil horizons occurs at the top of the Silurian where thinly bedded, rippled, subtidal sands yield *Arthrophycus* and *Cruziana*. The presence of abundant *Cruziana* at this level throughout the area proved useful as a local stratigraphic marker for correlating and identifying sections and and isolated exposures. *Arthrophycus* is more widely distributed, but is particularly abundant in the finer grained sands filling tidal channels in the lower Devonian Tadrart Formation. Its presence here is the youngest representative of the genus yet described.

Zoophycos, which is confined to the uppermost 5–10 m of the Devonian forms a useful local stratigraphic marker referred to as the *Zoophycos* sandstone (Turner, 1980). The presence of *Zoophycos* at the same stratigraphic level in other parts of the basin suggests that it may be of more regional significance (cf. Crimes, 1981).

It occurs at the top of the most intensely burrowed and bioturbated facies in the succession. Most of the primary sedimentary structures have been obliterated and the only other identifiable traces are vertical *Skolithos* burrows at the base which may indicate an intertidal as opposed to a shallow subtidal environment (Rhoads, 1967) depending on energy levels. Although the fining-upward sequences in this facies resemble modern tidal flat deposits there is no preserved sedimentological evidence diagnostic of such an environment. If intertidal flats did exist they must have been predominantly sandy in character and protected from the full force of the sea to allow for the extensive development of *Skolithos*. This may have been a barrier or a sheltered embayment comparable to the present day Wash (Turner, 1980). The change from *Skolithos* to *Zoophycos* and the lateral persistence of *Zoophycos* may be a function of increasing water depth and lower oxygen levels (cf. Frey and Seilacher, 1980) related to transgression and progressive deepening of the basin thought to have occurred at this time (Turner, 1980). Unfortunately the contact with the Carboniferous is not exposed and locally the Devonian is unconformably overlain by Cretaceous Nubian sandstone.

A slight increase in trace fossil abundance at the top of the Carboniferous reflects the repeated presence of tidally influenced sequences of sandstone, siltstone and silty-shale, forming part of a major transgression phase of sedimentation.

The shelf deposits contain comparatively few trace fossils despite the fact that they consist of thinly bedded sands, silts and shales. The succession becomes more sandy towards the top in passing from an offshore shelf to a nearshore shelf environment, accompanied by an overall increase in trace fossil abundance. Most traces occur as walking and surface crawling traces on sandstone bedding surfaces, and there is little evidence of burrowing and bioturbation. This, together with the paucity of body fossils suggests that the depositional environment may have been rather euxinic and not conducive to the extensive development of benthic life.

ACKNOWLEDGMENTS

The work on which this paper is based was carried out whilst one of us (B.R.T.) was coordinator of the Kufra Basin Project, financed by the National Oil Corporation of Libya. Thanks are due to Farag Said and Ahmed Asbali of the National Oil Corporation and William Kanes of the University of South Carolina, without whose help the work could not have been completed. We are grateful to Chris Kendall and Richard Vos for their encouragement during the course of the work. The manuscript benefited considerably from the helpful reviews by R. W. Frey and R. G. Osgood, Jr. We are particularly indebted to T. P. Crimes for his comments on the final version of the manuscript. Finally our thanks to Christine Cochrane for drafting and Elizabeth Walton for typing.

REFERENCES

ALPERT, S. P. 1975. *Planolites* and *Skolithos* from the Upper Precambrian–Lower Cambrian White Inyo Mountains, California. Journal of Paleontology, 49:508–521.

——. 1977. Trace fossils and the basal Cambrian boundary, p. 1–8. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils 2. Geological Journal Spec. Issue 9.

BALDWIN, C. T. 1977. The stratigraphy and facies associations of trace fossils in some Cambrian and Ordovician rocks of north western Spain, p. 9–40. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils 2. Geological Journal Spec. Issue 9.

BROMLEY, R. and U. ASGAARD. 1979. Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. Palaeogeography, Palaeoclimatology and Palaeoecology, 28:39–80.

CHAMBERLAIN, C. K. 1978a. Trace fossil biofacies of an American flysch. Society of Economic Mineralogists and Paleontologists Fieldguide to the Ouachita Mountains, p. 23–27.

——. 1978b. Recognition of trace fossils in cores, p. 119–166. *In,* P. B. Basan (ed.), Trace Fossil Concepts. S.E.P.M. Short Course.

CRIMES, T. P. 1981. Lower Palaeozoic trace fossils of Africa. *In,* C. H. Holland (ed.), Lower Palaeozoic of the Middle East, Eastern and Southern Africa and Antarctica. John Wiley and Sons Ltd.

——, I. LEGG, A. MARCOS and M. ARBOLEYA. 1977. ?Late Precambrian–low Lower Cambrian trace fossils from Spain, p. 91–138. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils 2. Geological Journal Spec. Issue 9.

DESIO, A. 1940. Vestigia problematica paleozoiche delle Libia. Annali del Museo Libico di Storia Naturale, 2:47–92.

DUBOIS, P. and J. LESSERTISSEUR. 1964. Note sur *Bifungites,* trace problematique du Devonien du Sahara. Bulletin de la Société Géologique de France (7), 6:626–631.

FEDONKIN, M. A. 1977. Precambrian-Cambrian ichnocoenoses of the east European platform, p. 183–194. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils 2. Geological Journal Spec. Issue 9.

FREY, R. W. and J. D. HOWARD. 1970. Comparison of Upper Cretaceous ichnofacies from siliceous sandstones and chalk, western Interior Region, U.S.A., p. 141–166. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils. Geological Journal Spec. Issue 3.

GLAESSNER, M. F. 1969. Trace fossils from the Precambrian and basal Cambrian. Lethaia, 2: 369–393.

GUTSCHICK, R. C. and R. LAMBRONE. 1975. *Bifungites,* trace fossils from Devonian-Mississipian rocks of Pennsylvania and Montana, U.S.A. Palaeogeography, Palaeoclimatology and Palaeoecology, 18:193–212.

HALDEMAN, S. T. 1840. Supplement to Number One of "A Monograph of the Limniades, or freshwater univalve shells of North America" . . . , p. 3.

HALL, J. 1852. Palaeontology of New York. Vol. 2. C. Van Benthusyen, Albany. 358 p., 85 pl.

HALLAM, A. and K. SWETT. 1966. Trace fossils from the Lower Cambrian pipe rocks of the north-west Highlands. Scottish Journal of Geology, 2:101–106.

HÄNTZSCHEL, W. 1975. Trace fossils and problematica. *In,* C. Teichert (ed.), Treatise on Invertebrate Paleontology, Part W, Suppl. 1. Univ. Kansas Press and Geol. Soc. Amer.

HOWELL, B. F. 1943. Burrows of *Skolithos* and *Planolites* in the Cambrian Hardyston Sandstone at Reading, Pennsylvania. Wagner Free Inst. Sci. Publ., 3:1–33.

KSIAZKIEWICZ, M. 1970. Observations on the ichnofauna of the Polish Carpathians, p. 283–322. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils. Geological Journal Spec. Issue 3.

MILLER, M. F. 1979. Paleoenvironmental distribution of trace fossils in the Catskill deltaic complex, New York State. Palaeogeography, Palaeoclimatology and Palaeoecology, 28:117–141.

OSGOOD, R. G. 1970. Trace fossils of the Cincinnati area. Palaeontographica Americana, 6: 281–444.

—— and E. J. SZMUC. 1972. The trace fossil

Zoophycos as an indicator of water depth. Bulletin of American Paleontology, 62(271):1–22.

RHOADS, D. C. 1967. Biogenic reworking of intertidal and subtidal sediments in Barnstable Harbor and Buzzards Bay, Massachusetts. Journal of Geology, 75:461–476.

RODRIGUEZ, J. and R. C. GUTSCHICK. 1970. Late Devonian–Early Mississipian ichnofossils from western Montana and northern Utah, p. 407–438. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils. Geological Journal Spec. Issue 3.

SEILACHER, A. 1955. Spuren und Fazies im Unterkambrian. *In,* O. H. Schindewolf and A. Seilacher, Beiträge zur Kenntnis des Cambriums in der Salt Range (Pakistan). Akad. Wiss. Lit. Mainz. Math.-Nat. Kl., Abhandl., 10:11–143.

——. 1967. Bathymetry of trace fossils. Marine Geology, 5:413–428.

——. 1978. Use of trace fossil assemblages for recognizing depositional environments. *In,* P. B. Basan (ed.), Trace Fossil Concepts. S.E.P.M. Short Course 5:167–181.

SELLEY, R. C. 1970. Ichnology of Paleozoic sandstones in the southern desert of Jordan: a study of trace fossils in their sedimentological context, p. 477–488. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils. Geological Journal Spec. Issue 3.

SIMPSON, S. 1970. Notes on *Zoophycos* and *Spirophyton,* p. 505–514. *In,* T. P. Crimes and J. C. Harper (eds.), Trace Fossils. Geological Journal Spec. Issue 3.

TURNER, B. R. 1977. Kufra Basin Study. National Oil Corp. Tech. Report, Tripoli, 25 p.

——. 1980. Palaeozoic sedimentology of the southeastern part of the Kufra Basin, Libya: a model for oil exploration, p. 351–374. *In,* Salem and Busrewil (eds.), Geology of Libya. Vol. 2, Academic Press, London.

MANUSCRIPT RECEIVED JANUARY 24, 1981
REVISED MANUSCRIPT RECEIVED MARCH 7, 1982

LINKED CITATIONS

You have printed the following article:

Paleozoic Trace Fossils from the Kufra Basin, Libya
Brian R. Turner; Michael J. Benton
Journal of Paleontology, Vol. 57, No. 3. (May, 1983), pp. 447-460.
Stable URL:
http://links.jstor.org/sici?sici=0022-3360%28198305%2957%3A3%3C447%3APTFFTK%3E2.0.CO%3B2-T

References

Planolites and Skolithos from the Upper Precambrian-Lower Cambrian, White-Inyo Mountains, California
Stephen P. Alpert
Journal of Paleontology, Vol. 49, No. 3. (May, 1975), pp. 508-521.
Stable URL:
http://links.jstor.org/sici?sici=0022-3360%28197505%2949%3A3%3C508%3APASFTU%3E2.0.CO%3B2-C