Journal of African Earth Sciences, Vol. 6, No. 4, pp. 427–455, 1987
Printed in Great Britain

0731–7247/87 $3.00 + 0.00
Pergamon Journals Ltd.

The sediments of Wadi Qena (Eastern Desert, Egypt)

KLAUS BANDEL

Geologisch–Paläontologisches Institut der Universität Hamburg, Bundesstrasse 55, 2000 Hamburg 13, West Germany

JOCHEN KUSS

Institut für Geologie und Paläontologie der TU, Ernst-Reuter-Platz 1, 1000 Berlin 10, West Germany

and

NIKOLAUS MALCHUS

SFB 69, Ackerstrasse 71–76, 1000 Berlin 62, West Germany

(*Received for publication* 5 *September* 1986)

Abstract—The first deposition of near-shore sandstones on basement rock in the northern Wadi Qena area occurred during Lower Carboniferous times. Paleozoic deposits are overlain by similar sandstones of Cretaceous age with a large but inconspicuous hiatus between them representing erosion and non-deposition. A Cenomanian transgression inundated sandstones in the north as well as basement rock in the south. The Cenomanian and Turonian sea deposited marine and near-shore material in the Wadi Qena area, and only to the south of it were fluviatile beds laid down. The extant Red Sea Hills, at that time, represented a high and formed a peninsula extending in northerly direction into the shelf sea of the Tethys ocean. The sea withdrew in or after Coniacian times and the following erosion removed almost all Coniacian marine deposits. During Campanian times, the sea returned and also flooded the Red Sea Hill peninsula. Phosphoritic marls, at times of unrest, were redeposited as phosphorite sands in the south. Carbonate deposition followed, ending in Maastrichtian times. An erosional phase during the Cretaceous–Tertiary transition removed most of these chalks and limestones from the Wadi Qena area, and Paleocene and Eocene seas deposited limestone and marly chalk before a final regression marked the closure of the Tethys ocean.

1. INTRODUCTION

THE WADI Qena represents a large, wide and long valley that begins at the southern slopes of the South Galala height and extends in a north–south direction to the town of Qena where it issues into the Nile. In its course it is situated between the Red Sea Hill range on the eastern side and an extensively high carbonate platform on the western side. Its dip is opposite to the Nile from north to south. At its northern end, modern Wadi Qena has been tapped by deeply incised side-valleys such as Wadi Tarfa flowing to the Nile and Wadi Hawashia flowing to the Gulf of Suez. Gravel that was produced during humid times at the end of the Tertiary and in the Quaternary covers much of the valley floor and low tabular outliers, and reaches far up the slopes of the western escarpment. From the Red Sea Hills, fans of fanglomeratic erosional products of the basement rocks of the Red Sea Hills have covered gravel and older rock alike and commonly extend deeply into the Wadi Qena. At this eastern side of Wadi Qena, the oldest sediments rest on Precambrian basement and well exposed sections are found all the way from the Safaga–Qena road in the south to the escarpment of the South Galala in the north. Tabular outliers connect these across the valley floor with the eastern escarpment of the carbonate platform, where basement is not exposed, but a complete sequence into Eocene rocks usually present. Deep-sided wadis expose the sequence rather well.

Wadi Qena has clearly been excavated along faults that run parallel to the Gulf of Suez and the range of the Red Sea Hills. These faults are seen well exposed at numerous places within the valley, especially on its eastern side. They are still active and have been so at various times; during the Miocene, basaltic magma utilized them to ascend and erupt at various places in Wadi Qena.

While in the Eastern Desert to the south of Wadi Qena, in the upper Nile valley, at the shores of the Gulf of Suez and the Red Sea, in the Galala heights and in the Western Desert, the sedimentary cover is fairly well to well studied, the area of Wadi Qena, as Said (1962) stated, "represents one of the least understood areas in Egyptian geology where further investigations would be most fruitful". Equipped with data on field observations carried out by E. Klitzsch, the present authors tried to invalidate this statement and fill the gap.

2. CARBONIFEROUS SEDIMENTARY CYCLE

2.1 *Um Bogma Formation*

The measured outcrops are sections S_I, S_{II} and S_{III}, in central Wadi Qena (Fig. 1).

The Um Bogma Formation consists of sandstones which crop out in the central and northern part of the Wadi Qena. Its southernmost outcrop lies just south of

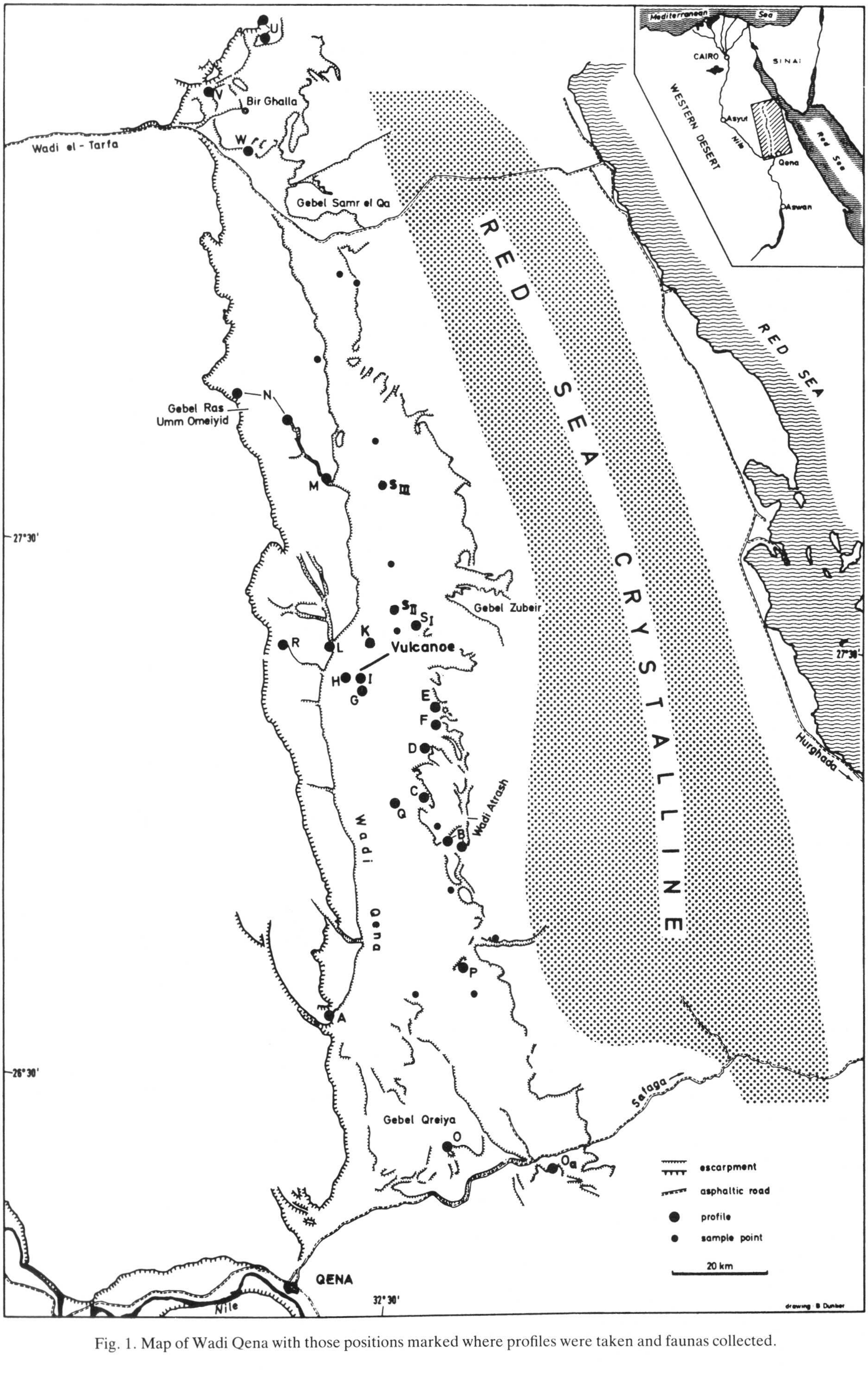

Fig. 1. Map of Wadi Qena with those positions marked where profiles were taken and faunas collected.

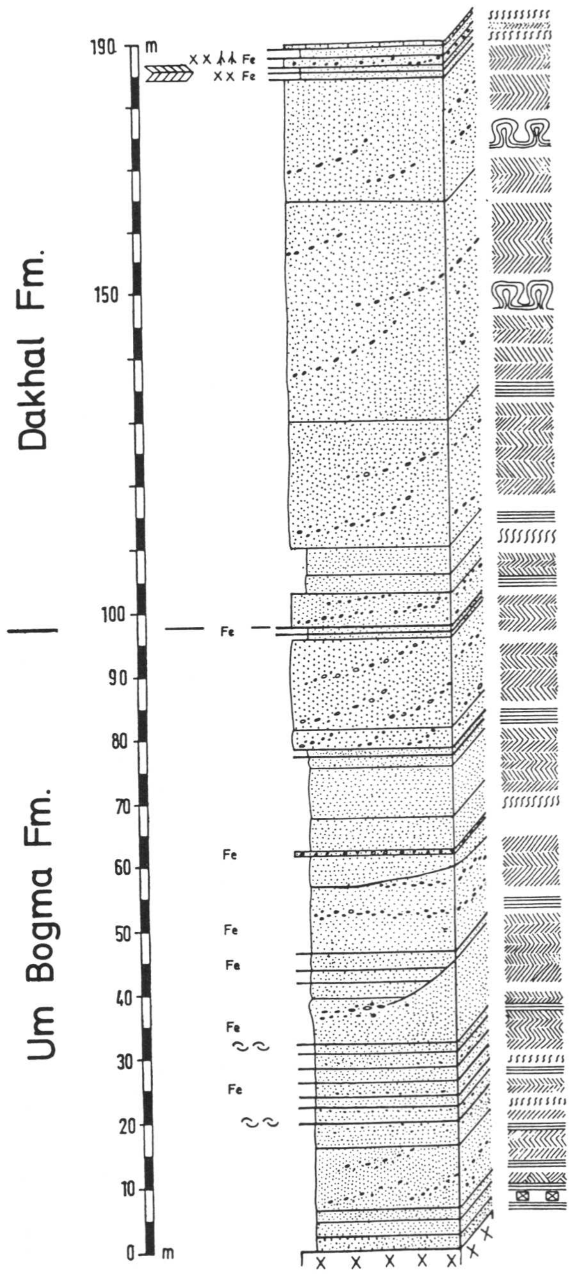

Fig. 2a. Columnar section assembled from localities S I and S II in central Wadi Qena and encompassing the Um Bogma Formation (lower 90 m) and the Dakhal Formation (upper 100 m).

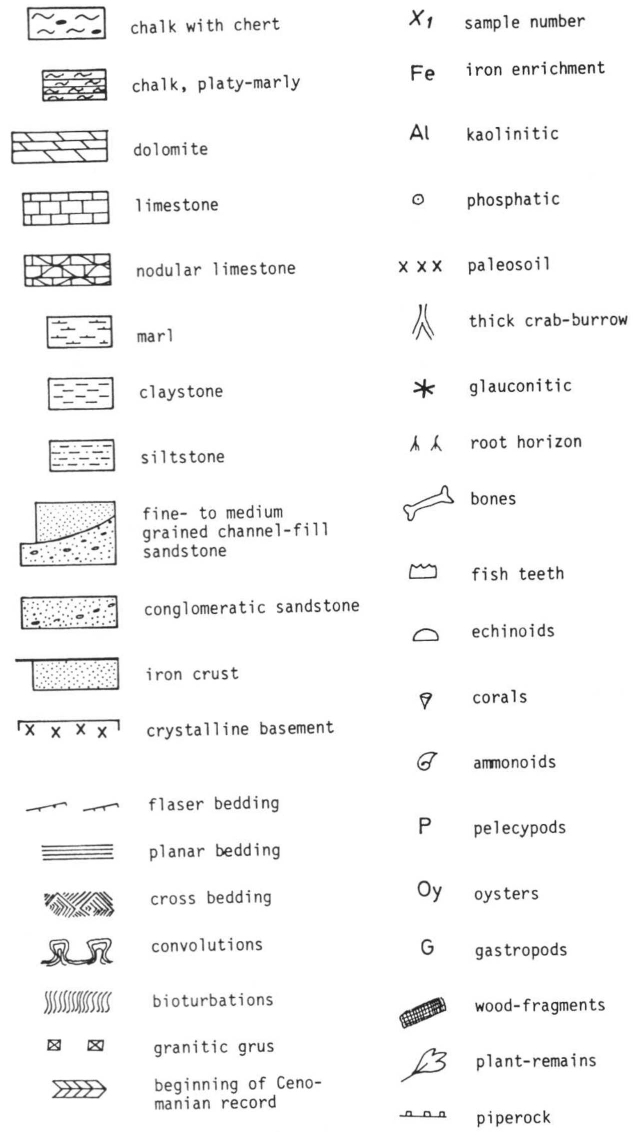

Fig. 2b. Explanation of the legend used in all sections.

the conspicuous black volcanic pipe in central Wadi Qena (Fig. 1). It dips below Cretaceous beds in the west and, together with Dakhal Formation, is here covered by them. In the northeast, it wedges out to reappear at Wadi Dakhal, and in the east and south it is eroded. The lower 18 m of the Um Bogma Formation were measured in section S_I (Figs. 1, 2). The basal beds consist of coarsely angular material that was reworked from the crystalline (here granitic) basement which is present below. The following beds of fine-grained laminated sandstone are reddish and include some layers rich in dark grains of heavy minerals. Above, sandstones are intercalated with thin conglomeratic beds containing angular to subangular quartz pebbles and white grains of decomposed feldspar. Conglomerates grade into arcosic, very immature layers of disintegrated granitic material. A conspicuous *Scolithos* (pipe-rock) is found in the upper part of the section. Just above, ferruginous bedding surfaces show *Cruziana*-like tracks and small crawling and resting trails of bivalves. Cross-beds in this sandstone have a generally northerly dip. In sections farther to the north, pipe-rock layers become more dominant. Burrows commonly are iron-stained and sometimes transformed into nailboard-like iron-oxide spikes of the same size as or larger than the original burrows due to diagenetic alteration and concentration of iron oxide.

The Um Bogma Formation underlies the Dakhal Formation in the outcrop 8 km north of the conspicuous volcanic vent (Fig. 1, S_{II}) and is sketched in Fig. 3. A bed of pipe-rock marks the base of this section and it ends with conglomeratic layers composed of well rounded larger pebbles after 95 m. The sandstones are usually fine- to medium-grained with brownish colours. The bedding surfaces of the lower laminated and platy sand-

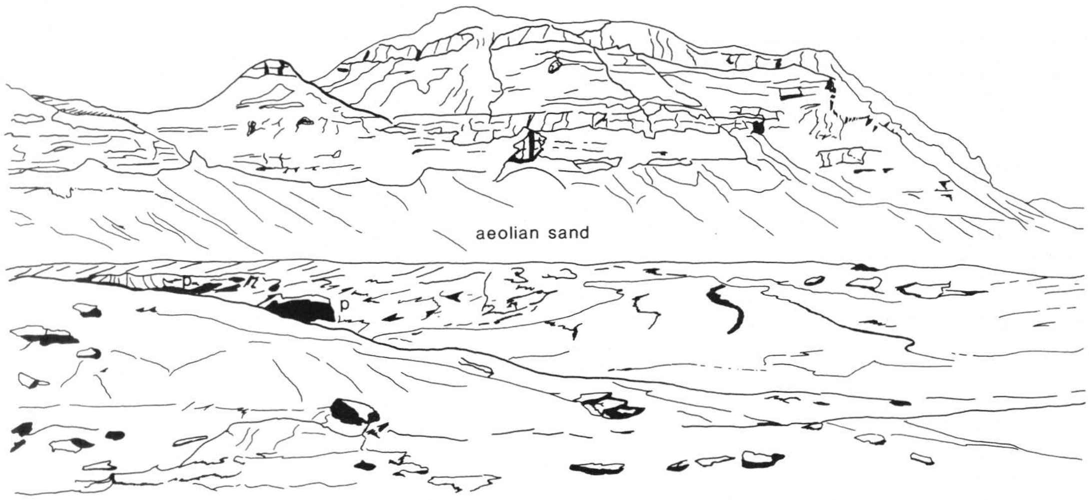

Fig. 3. Sketch of profile S_{II} with Um Bogma Formation exposed. Pipe-rock layers (p) can be correlated to such layers in section S_I just to the east. The sequence measures about 90 m in thickness. View from southeast.

stones are commonly encrusted by iron oxides. One layer contains up to 10 cm large baritic desert roses and some others show badly preserved trace fossils resembling *Cruziana*. The laminated series is topped by massive beds with large-scale cross-bedding. Some layers are totally convoluted. Channels of variable thickness may show overturned cross-beds of variable dip. They are overlain by cross-bedded sandstones, some of which have been indistinctly bioturbated. The section ends with layers containing well rounded platy and oval pebbles smaller than 1 cm. Similar beds occur at the base of section S_{III} at the Wadi escarpment. Here and in outcrops few km to the south, pipe rocks are frequent.

2.2 *Discussion*

At the type section at Um Bogma in the Western Sinai, the lower sandstones resting on the basement have been named the Um Bogma Group. We consider rocks of a similar position in Wadi Qena to represent the Um Bogma Formation. Sand and fine pebbles of the Um Bogma Formation often are angular to subangular, while larger pebbles are well rounded. This demonstrates the rather immature nature of this sandstone and a source area that lay close by. The formation wedges out, in the east, in its northernmost outcrop as well as in the south. Layers of hardly sorted granitic debris intercalated with sand in the southernmost occurrences indicate a source from the crystalline base of the east, at least during deposition of the lower beds. At Gebel Samr el Qa, the whole sequence of Um Bogma Formation is preserved. Marine influence is commonly documented by pipe-rock beds as well as (less commonly) by *Cruziana*-like trails which, together with other arthropod tracks and bivalve trails, indicate an estuarine to marine origin for at least large parts of this formation. There is no indication that these sandstones and those of the Dakhal Formation above have been deposited under glacial conditions as assumed by Jux and Issawi (1982).

Arthropod trails both of the *Cruziana*-type (Plate 1, nos. 10, 11) and of the larger xiphosoran type (Pl. 1, nos. 9, 12) connect the sandstones of the Um Bogma Formation in Wadi Qena (location Fig. 4) with the Um Bogma Formation in Wadi Dakhal and at the type section at Um Bogma in the western Sinai (Um Bogma Group, in Said 1971). Very similar *Cruziana*-like trails have been found

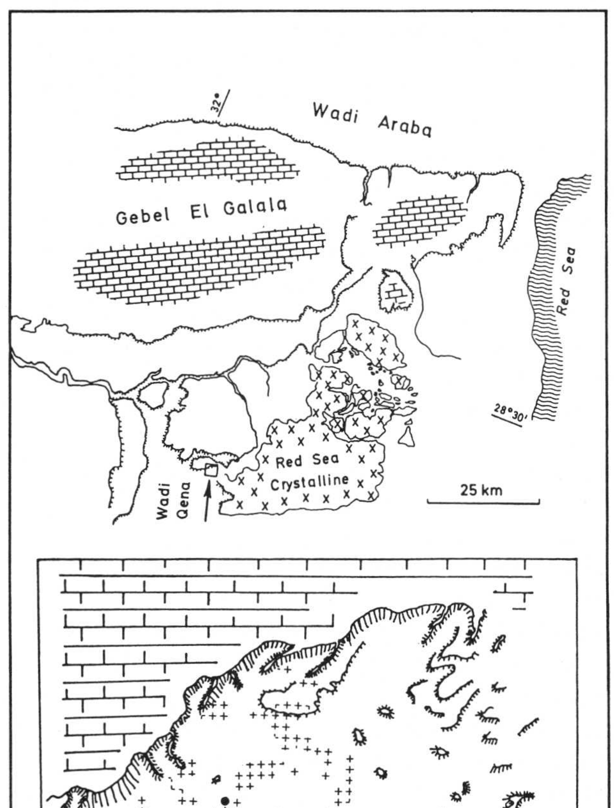

Fig. 4. Maps of the locality where *Cruziana*-like trace fossils (Pl. 1, nos. 10 and 11) occur about 500 m south of profile W.

in the type section (Seilacher, personal communication). Bandel and Kuss (in press) found both trails south of Wadi Dakhal in Carboniferous sandstones with *Lepidodendron* (Klitzsch, personal communication). Carboniferous plant fossils have been described from the Um Bogma locality as well (Kostandis 1959).

The occurrence of similar beds about 40 km to the east of section U at Wadi Qena in the area of and south of Wadi Dakhal provides the best stratigraphic correlation. At Wadi Dakhal, the base of a more than 400 m thick Carboniferous/Permian sequence is exposed, which has been dated as Carboniferous since the studies of Walther (1890) and Schellwien (1894).

3. THE LOWER CRETACEOUS SEDIMENTARY CYCLE

3.1 *Dakhal Formation*

The type locality of the Dakhal Formation (Fig. 2) lies at the south-westerly end of Wadi Dakhal (Bandel and Kuss, in press). As in northern and central Wadi Qena, it overlies the Um Bogma Formation and underlies the Cenomanian Atrash Formation. At the north-western escarpment of Wadi Qena, the Dakhal Formation rests on the conglomeratic top of the Um Bogma Formation.

The fine to medium, light sandstone shows no Fe stains, is not banked and is about 100 m thick. Its structure consists of cross-beds throughout, which are strongly convoluted in several layers. Some cross-beds with fish-bone pattern and twisted-up blade ends are developed. Large sand grains as well as small-sized gravel are commonly angular to subangular. Very well rounded pebbles of milky quartz with sizes above 1 cm occur throughout, scattered in a random pattern and never enriched in conglomeratic layers. Cross-bed units are lenticular, extending up to 10 m laterally and up to 1 m vertically.

3.2 *Discussion*

The sandstones of the Dakhal Formation at Wadi Qena have provided no fossils. At the type section, in Wadi Dakhal, about 40 km to the east on the other flank of the Red Sea Hill basement complex, crab burrows of the *Ophiomorpha* type are present throughout in these sands, indicating a marine influence during their deposition. At Wadi Qena, a fluviatile origin is probable. The Dakhal Formation was truncated and eroded when, or before, the Atrash Formation was deposited in southern and north-eastern Wadi Qena.

The age for this sandstone is Cretaceous, older than Cenomanian (Klitzsch, personal communication), perhaps older than the Malha Formation (Abdallah *et al.* 1963) in the North Galala area.

Bandel and Kuss (in press) provide evidence that indicates that the sandstones of Malha Formation are not truncated by the marine beds of the Cenomanian, but rather grade into them. Thus, the Malha Formation contrasts with the sandstones of the Dakhal Formation which are truncated by the marine beds of the Cenomanian transgression. While sands of the Dakhal Formation came from a southerly source, those of the Malha Formation came from northerly directions. Both units are separated from each other by an area of non-deposition which lay in the southern Wadi Araba, northern el Galala el Qibiliya areas (Bandel and Kuss, in press).

4. UPPER CENOMANIAN–LOWER TURONIAN SEDIMENTARY CYCLE

4.1 *Atrash Formation*

The Atrash Formation has been named after Wadi Atrash, a large Wadi coming from the Red Sea Hills and ending in the southern central portion of Wadi Qena just to the south of the type section of the upper member of the Atrash Formation.

4.1.1 *Lower Atrash Member*. The Lower Atrash Member is best exposed in the northern Wadi Qena where it rests on the crystalline basement or the wedging-out Um Bogma and Wadi Dakhal Formations (Fig. 5). Section W, which lies here, represents the type section for this member.

In the type section, the member measures about 60 m in thickness and rests on sandstone of the Um Bogma Formation. Several soil beds characterize the lower beds. Pipe-rock-like traces of roots penetrate the sandstones from above for about 40 cm and this bed resembles the *Scolithus* beds present only a few metres below in the Um Bogma Formation. Above, conspicuous green shales connected to glauconite-bearing beds indicate increasing marine influence, which culminates in bioturbated sand intercalated with glauconitic marl and silt, some of which contains exogyriid oysters (*Ceratostreon flabellatum* Goldfuss, Pl. 2, no. 9), *Rhynchostreon columbum* Lamarck, Pl. 2, no. 4a and small *Ilymatogyra* sp., rarely sea-urchins and fish-teeth. Only one bed of nodular limestone is found before the member ends with a clastic sequence, grading to the Upper Atrash Member with a limestone bed, that bears characteristic fossils of the Upper Atrash Member (Fig. 5).

Towards the south, the Lower Atrash Member decreases in thickness and becomes sandier until it is only a sandstone (section L) (Fig. 5).

In section M, five oyster beds with *Ostrea isidis* Fourtau, *Curvostrea rouvillei* Coqaund (Pl. 2, nos 8a,b) and rare *Exogyra olisiponensis* Sharpe (Pl. 2, no. 3) and *E. africana* Lamarck (Pl. 2, no. 7) are found in the column. The sandstone here is commonly bioturbated with crab burrows, but original cross-bedding is usually preserved. In section L and somewhat to the south, the Lower Atrash Member consists of 25 m pure sandstone with conglomeratic layers and ferruginous remains of tree

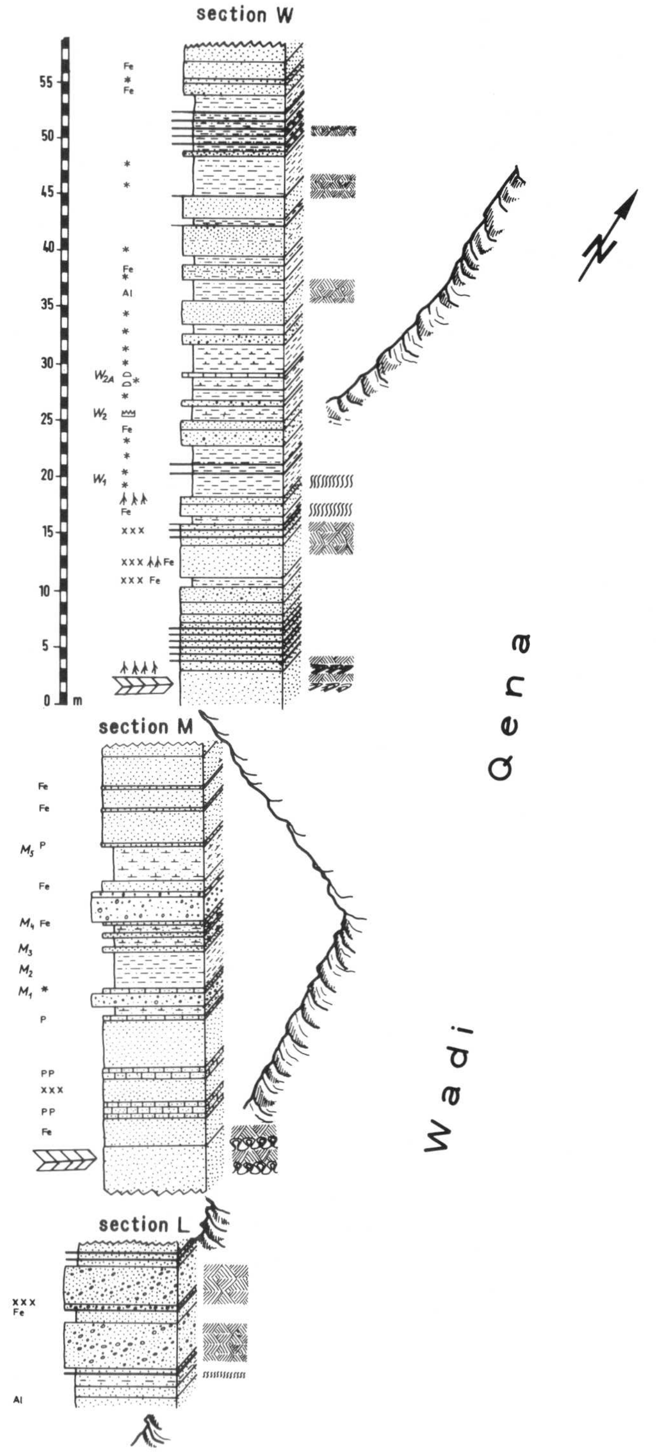

Fig. 5. Sections of the Lower Member of the Atrash Formation at the western escarpment of Wadi Qena.

trunks. Inclination of cross-beds is towards the NW; coarse sand beds are graded and angular to well rounded pebbles are up to 1 cm big. Farther to the south, this member is not present and the Upper Atrash Member rests directly on the crystalline basement.

4.1.2 *Upper Atrash Member*. The type section of the Upper Atrash Member lies in section B_{II} (Figs. 6–8). Here the about 30 m thick member rests on crystalline basement and ends below laminated ferruginous sandstones of the lower base of the Lower Tarfa Member. The basal beds consist of cross-bedded coarse sandstones that originated from barely reworked granitic and other crystalline debris. Gravel is angular and larger pebbles commonly show wind-polished faces. The following sandstone beds are bioturbated and contain root horizons and ferruginous concretions. In some beds, feldspar has changed into kaolinitic clay. Greenish silty shales grade into sandy marls with numerous gryphaeid oysters and these are overlain by more or less marly and glauconitic sandstones, with bivalves (mainly oysters: *Exogyra olisiponensis* Sharpe (Pl. 2, no. 3), *Rhynchostreon columbum* Lamarck (Pl. 2, nos. 4a,b), gastropods and echinids (e.g. *Rhabdocidaris* Pl. 1, nos. 1a,b)). Marly limestone with a rich fauna as below and, in addition, also ammonites, ends the member.

Near to the type section, lateral facies changes are common. A broad channel (Fig. 8) issued its deposits into the sea. It came from the crystalline basement rock lying in the east. Here, about 3 km to the north-east, it is exposed and filled with hardly reworked and little-sorted coarse granitic debris. Larger pebbles are angular and commonly show wind-polished faces. They originate from fragmented veins and sills that had become eroded from the basement rock nearby. Two kilometres in a seaward direction (southwest), about 4 m of sediment fill the channel with a conglomeratic layer at the base, coarse sand in the centre, and sandy to clay-rich, marly, soft sediment with ribbed oysters (*Exogyra olisiponensis*) and numerous shells of a cerithiid gastropod at the top. Marls contain additional oyster species and steinkerns of heterodont bivalves. Where the channel had issued into the sea, limestone beds present at the right and left are, in part, replaced by sandstones. Where the former debris flow from the terrestrial Red Sea Hills reached the shore, crab burrows were excavated into the sand. Here local lagoons periodically filled with water of different salinities occur with teeth plates of fresh-water lungfish (Pl. 1, nos. 7, 8) as well as marine sharks and bone fish. About 3 km to the southeast (section B_{III}), littoral sands have been vertically burrowed so that a conspicuous *Scolithos* bed has formed. Throughout deposition of the Atrash beds, the coast lay within the area of the B-section. The Red Sea Hills were a highland like today and the shore lay at almost the same position as the Wadi Qena alluvial deposits covering the western slopes of the Red Sea Hills.

Southwards, limestones of the Atrash Formation are still well developed about 16 km from B_{II}. In section P (Fig. 1, 6), marly sand and glauconitic shales have replaced the limestones. Only 2 km farther to the south, glauconitic sand and strong bioturbation indicate the marine environment in the now totally sandy Atrash section. In the southernmost section O, the crystalline basement is well exposed on both sides of the road to Safaga. Here basal conglomeratic beds consist mainly of reworked crystalline material but also contain some very well rounded quartz pebbles. Above, cross-bedded sandstone with only a few bioturbated layers completes the Atrash Formation (Fig. 6).

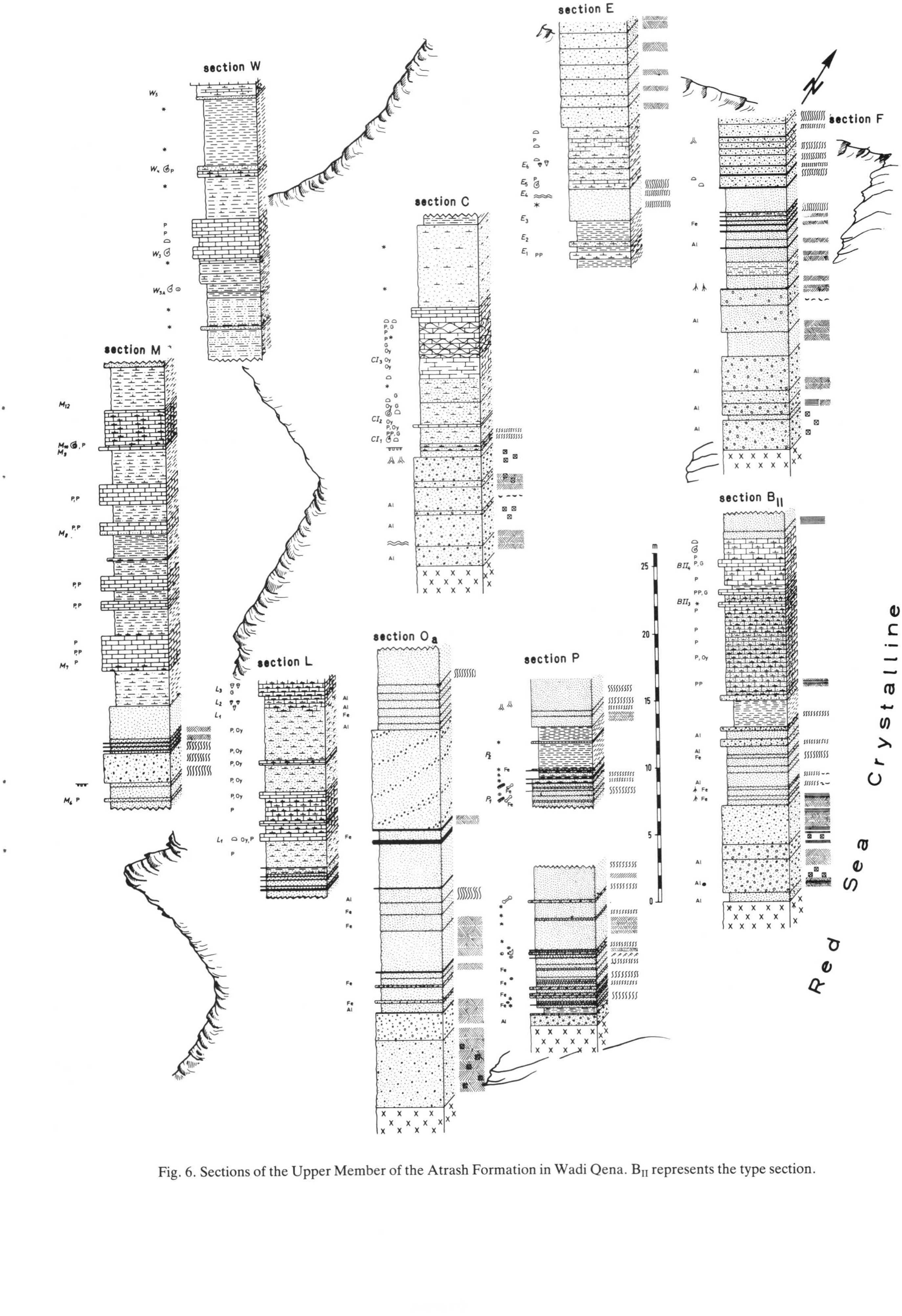

Fig. 6. Sections of the Upper Member of the Atrash Formation in Wadi Qena. B_{II} represents the type section.

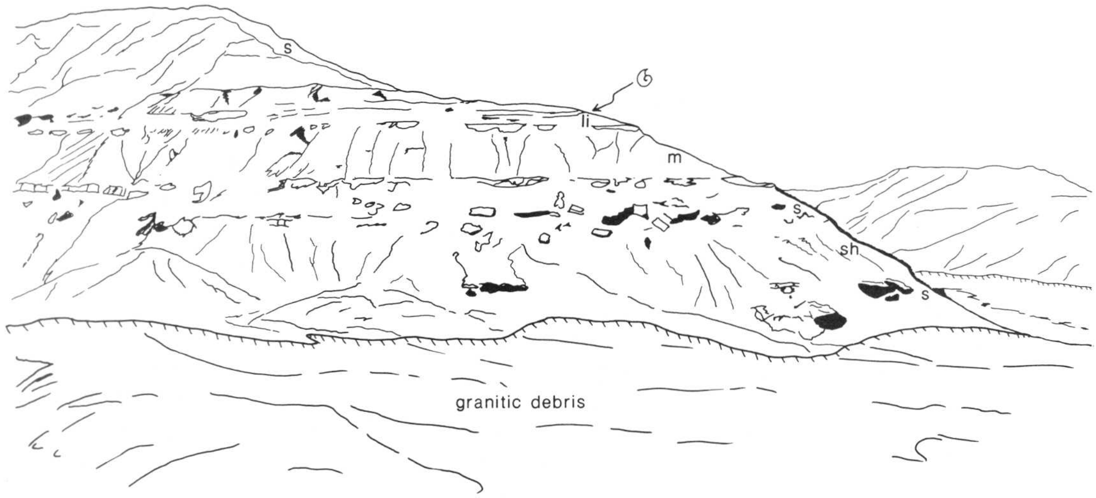

Fig. 7. Sketch of profile B_{II}. The limestone (li) contains ammonites of Turonian age (m—marl; s—sandstone). View from southwest.

To the north of the type section, in locations Q, L and D, the section is similar, with limestones well developed (Fig. 6). Just above first traces of bioturbation, a rich marine fauna is preserved with ammonites also present in the lower beds. Between sections E and F lay the Atrash coastline with limestone replaced by sand towards the shore within a distance of about 2 km to the east. Here also the ancient coastline follows roughly the course of the foothills of the Red Sea Hills.

In section E, one horizon contains abundant corals (*Actinastrea* sp. Pl. 3, nos. 8, 9) and calcareous algae, occurring within shallow water carbonates described by Kuss (1986). The same layer can be traced across Wadi Qena to section L. Here the Upper Atrash Member no longer rests on the crystalline base but overlies the most southerly fluviatile portion of the Lower Atrash Member. Across Wadi Qena, just north of section S, the Upper Atrash Member in nearshore facies almost rests on the crystalline basement with only a few metres of reworked sandstones of the Um Bogma Formation at its base.

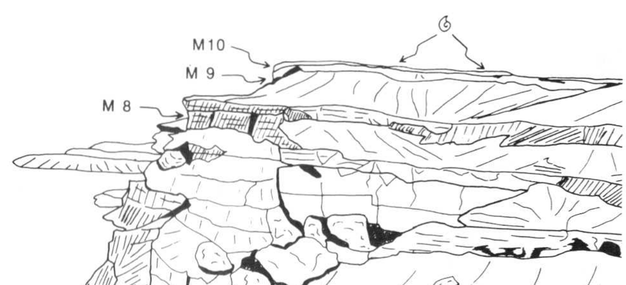

Fig. 9. Sketch of the locality where the central portion of profile M (Upper Member of the Atrash Formation) was measured. M7–M10 are marly limestones with a rich bivalve fauna. The top limestone contains ammonites of Turonian age. View from west.

In section M on the western escarpment (Fig. 9), the sequence is similar to that of section L, but limestones have increased in thickness and the uppermost marly limestone contains a rich and diverse fauna of ammonites. The northernmost section W lies in the lower escarpment of the South-Galala plateau. Here, ammonite-bearing marls form the base of the Upper Atrash Member and the marine transition to the Lower Atrash Member. Here several beds contain ammonites and a species-rich marine fossil assemblage is present throughout.

4.2 *Tarfa Formation*

The Tarfa Formation derives its name from Wadi Tarfa at the northern end of Wadi Qena (Fig. 1).

4.2.1 *Lower Tarfa Member* (Fig. 10). The type locality for the Lower Tarfa Member was chosen on the western escarpment of the central Wadi Qena (section M) (Fig. 1). Here the member is about 35 m thick and begins with marly sand beds that overlie the uppermost limestone and marl of the Atrash Formation. The member ends with a conspicuous limestone that crosses the floor of the wadi and bears numerous disk-like ammonites (Wiedmann det.) (Pl. 4, no. 8) which indicate a Turonian age. Since the uppermost beds of the Atrash Formation also hold Turonian ammonites, the whole Lower Tarfa Member is of Turonian age.

Sandstone beds above the base of the member have undisturbed cross-beds with laminae inclined towards the NW. In the upper part, a conspicuous crust with large Fe-oxide concretions covers slopes with its erosion relicts. Bioturbated marly shales, glauconitic marls, ferruginous crusts and marly limestones follow in a sequence that ends with limestones rich in sea-urchins, among them *Micropedina bipatellis* Gregory (Pl. 5, nos. 6a,b). It is overlain by a shale topped with limestones and marls that are strongly bioturbated, and also contain ammonites.

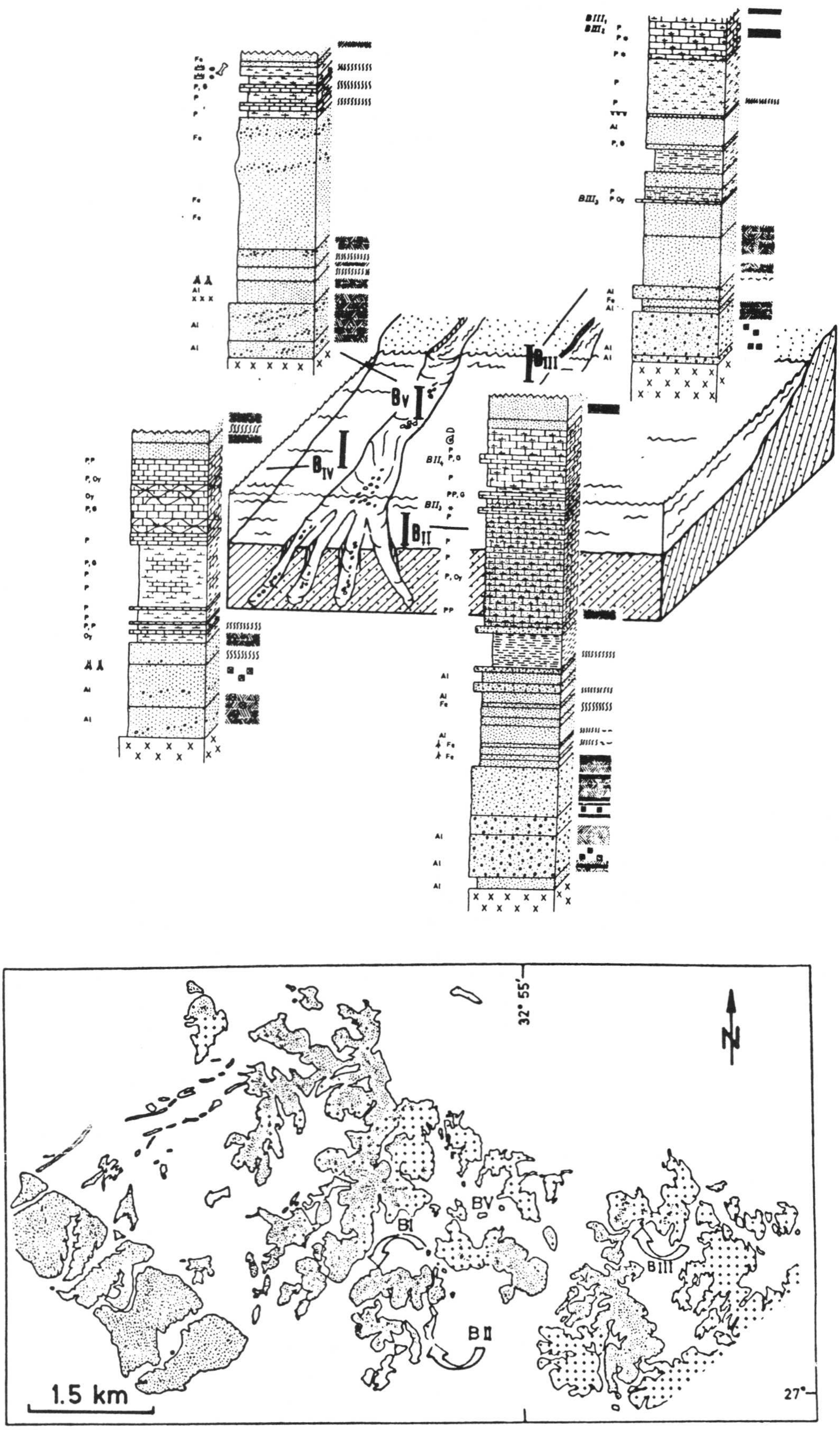

Fig. 8. Sketch of sections B_I–B_{IV} representing deposits of a distributory system of channels beginning on the Red Sea Hill peninsula and issuing into the Cenomanian–Turonian Sea.

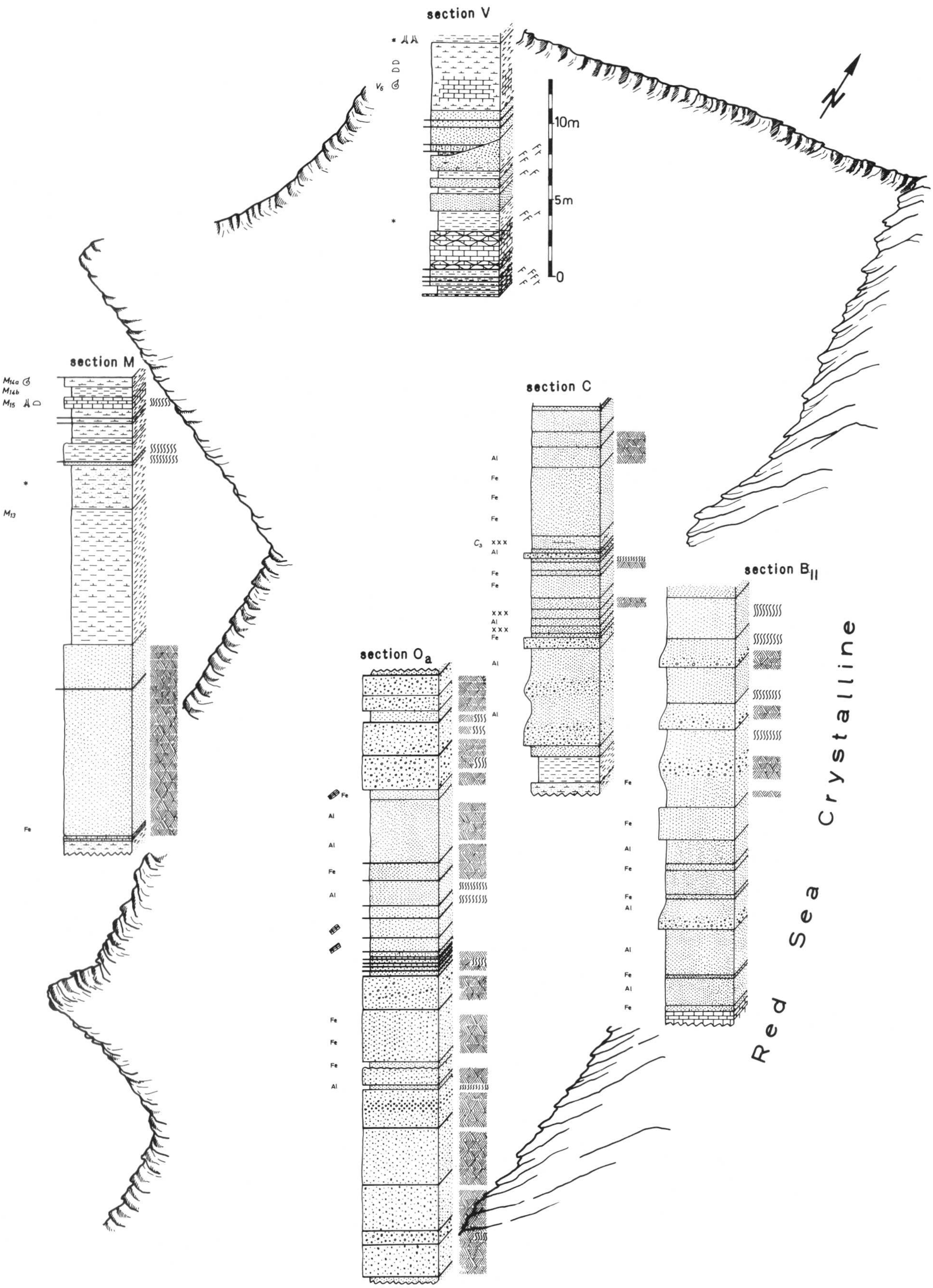

Fig. 10. Sections of the Lower Member of the Tarfa Formation in Wadi Qena. Profile M represents the type section.

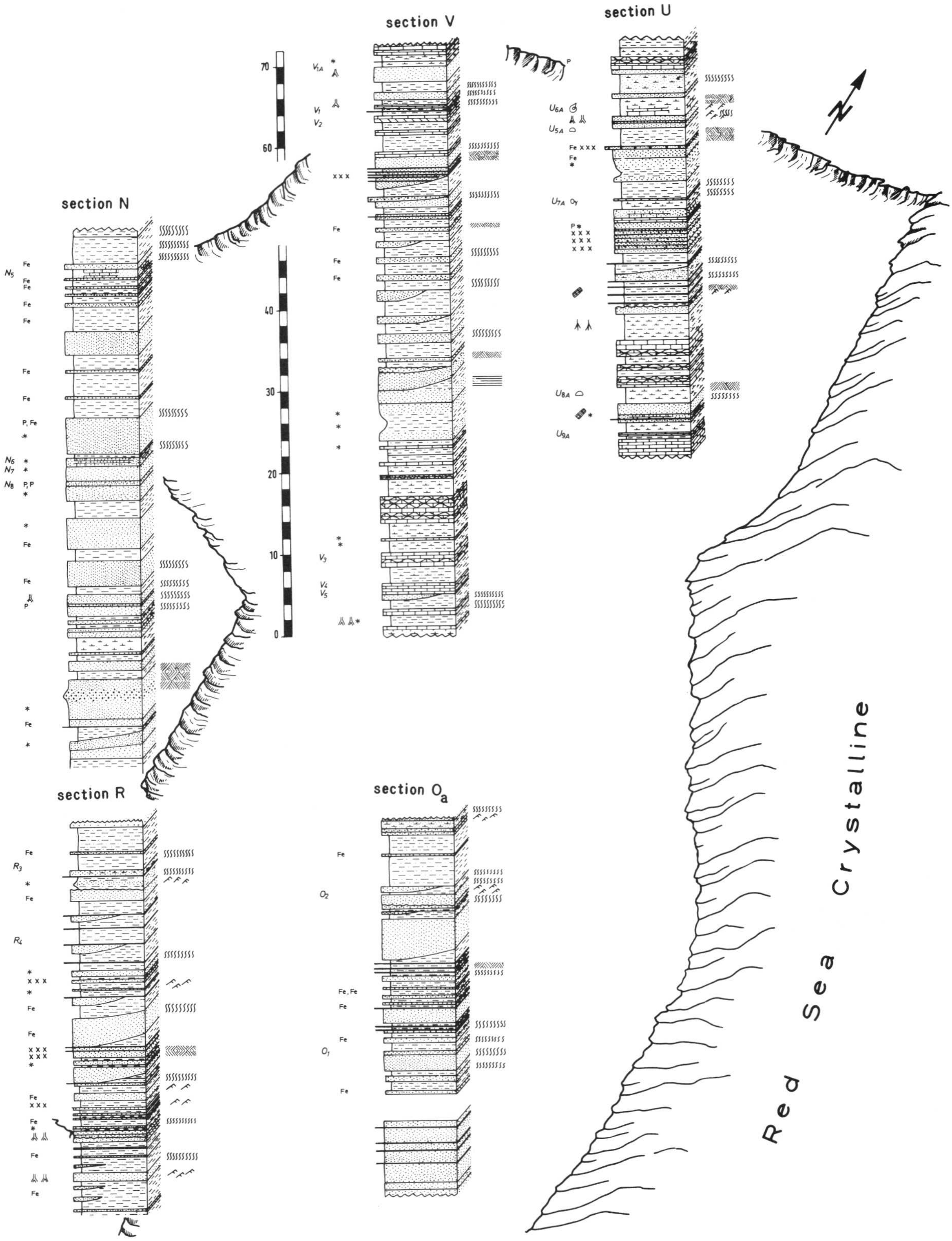

Fig. 11. Sections of the Upper Member of the Tarfa Formation in Wadi Qena. Profile N represents the type section.

In section B, the lower beds of the Lower Tarfa Member are ferruginous sandstones and crusts, both cross-bedded and bioturbated. Drift wood as well as clay pebbles and interclast beds are intercalated.

In the southernmost section O of Wadi Qena, the Tarfa Formation cannot be delimited clearly from the underlying Upper Atrash and the overlying Upper Tarfa Member. The uppermost beds of Atrash Formation could be represented by the uppermost bioturbated sandstones (Figs. 6, 10, 11). The Upper and Lower Members of Tarfa Formation together measure about 100 m. The lower 50 m consist of coarsely cross-bedded sandstones with layers of clay pebbles, kaolinitic sands, driftwood layers and rippled beds. Numerous iron-oxide crusts are present. The upper beds of this sequence grade into bioturbated beds, which could be correlated to the top limestone, indicating the end of equivalents of the Lower Tarfa Member farther to the north.

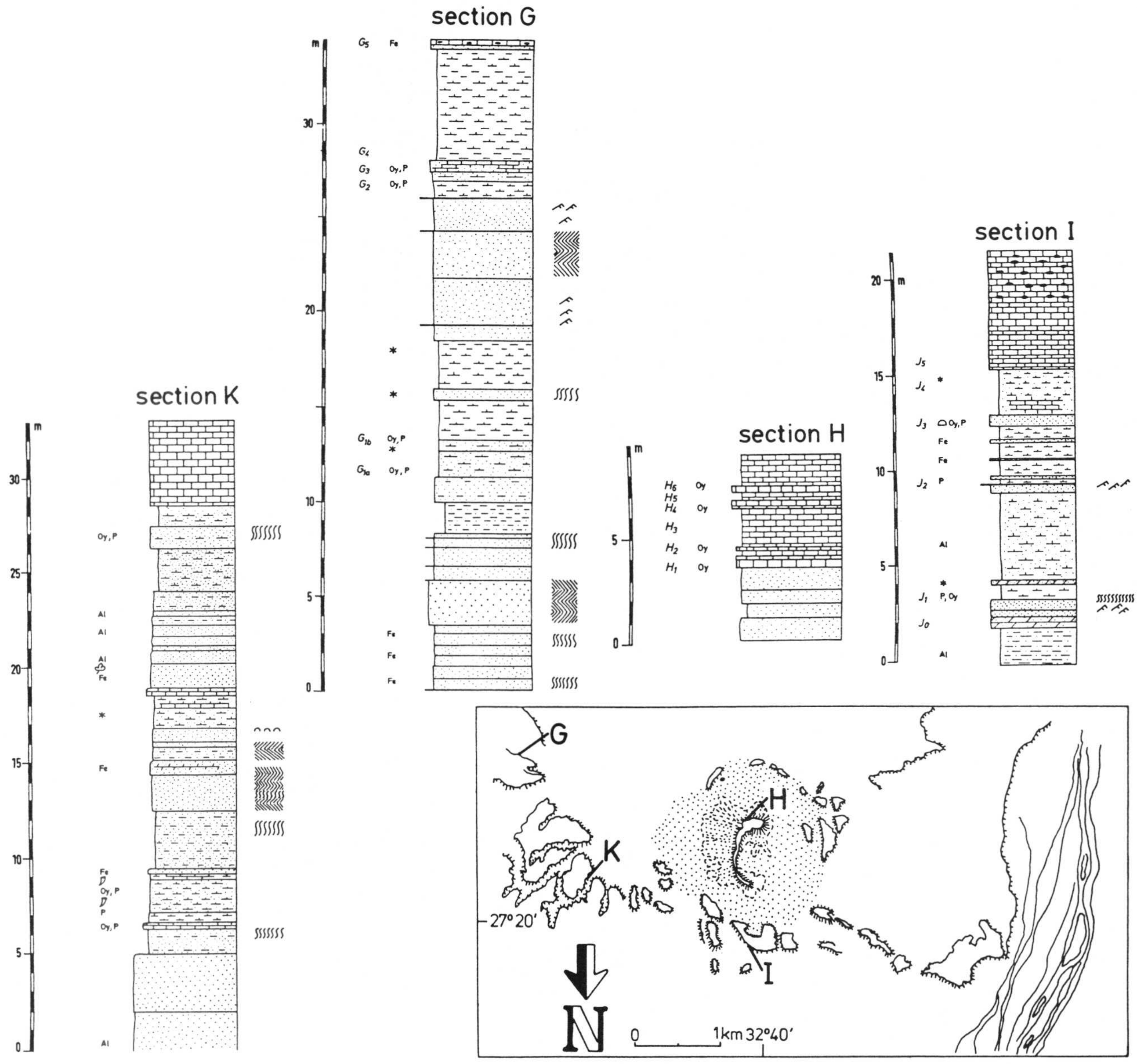

Fig. 12. Schematic map drawn from aerial photograph with the ring structure in central Wadi Qena. Sections H, G and I are indicated.

A peculiar development of rocks of this formation is noted near the 'ring structure' (sections H, I) Figs. 1, 12. In section G, possible equivalents of the Lower Tarfa Member consists of intercalations of bioturbated sandstones and Fe-oxidic crusts. Cross-beds of the lower central part of the sequence are inclined towards the north and south. Following shaly marls and marly sands with three oyster beds possibly belong to Coniacian/Santonian (see section 8).

4.2.2 *Upper Tarfa Member* (Fig. 11). The type section of the Upper Tarfa Member was measured in section U (Figs. 1, 11).

The conspicuous ammonite-bearing limestone at the top of the Lower Tarfa Member of Turonian age forms the base of the Upper Tarfa Member, which is about 50 m thick and ends with ammonite-bearing marls and limestones, which contain ammonites also indicating Turonian age. Beds of the sequence between both limestones vary in their lithology, not only from section to section, but even within the area of the type section.

The base of the Upper Tarfa Member consists of flaser-bedded, channel-cut sands with root horizons, overlain by a nodular limestone with reworked ammonites. Channels cut into the limestone are filled with quartz sand. Nodular limestones and marls, rich in oysters, contain some layers with sea-urchins and ammonites. Channels are filled with glauconitic sand with some trunks of driftwood.

Marly beds above contain glauconite layers as well as root horizons. Intercalated sandstones, clays and silts may be destratified by roots, but, more commonly, by endobenthic animals. Channels that were filled with sand, were cut into them. Clay and sand with cross-beds and driftwood above are riddled by large crab burrows as well as by large roots. All beds show rapid lateral changes in bioturbation and grain size. Soil beds above grade into terrestrial breccias. Silty clays here hold root traces. A nodular limestone and a narrow iron-oxide bed with small bivalves and gastropods end this terrestrial sequence. Glauconitic and sandy marls are overlain by iron-stained cross-bedded sandstones, containing drift logs, reworked and rounded Fe-oxidic crusts, pebbles of milky quartz and oysters. Bioturbated flaser silt and sand with crab burrows, exogyriid oyster beds form the transition into marls with abundant sea-urchins. The sandstone above continues into crab burrows that have been excavated into the marl. Small channels of about 10 cm width and up to 3 m length are filled with coquinas of exogyriid oysters. The Tarfa Formation here ends with nodular limestones and marls with oysters, sea-urchins and some ammonites.

Just south of the type section of the Upper Tarfa Member and about 10 km to the south, most of the Tarfa Formation consists of massive, brownish, cross-bedded channel sandstones, which are less easily eroded than the softer, surrounding rocks. In an air-photo analysis of the area, such channels could easily be misinterpreted to represent faults which are also common in the area.

In section V, only about 10 km southwest of section U, the rock column has changed considerably due to the rapid lateral facies change. Here the uppermost Lower Tarfa Member consists of an intercalation of flaser silts, clay beds, ferruginous crusts, sand-filled channels and a nodular limestone with numerous ammonites (Pl. 4, no. 8). Above, an intercalation of limestones, silts, clays and glauconitic marls follow, and channel-sands are marly and bioturbated. The middle portion of the upper member is occupied by ferruginous channel sandstones which are responsible for the great thickness of this member here. The upper part of the Upper Tarfa Member consists of bioturbated sandstones, marly shales and nodular limestones.

About 40 km south of the type section (section N), the Upper Tarfa Member is about 75 m thick. The basal limestone has been replaced by glauconitic marls and sandstones with bioturbations and oyster beds. Cross-bedded massive sandstones follow, overlain by an intercalation of marls, oyster beds, glauconitic sandstones and silts, iron-oxide-rich sandstones and clay beds. Bioturbation is present throughout, and crab burrows are often filled with coarser sediment from the bed above. Towards the top of the member, clays are commonly greenish with an increase of glauconite. A grey clay here ends the Tarfa Formation.

About 40 km to the south of section N, at section R, only the upper beds of Tarfa Formation are well exposed with a truncation marking the top of the formation which is underlain by grey and green clays above an intercalation of ferruginous silty sandstones, reworked iron-oxide crusts and root horizons.

The most southerly exposure of the Upper Tarfa Member was measured at the road from Qena to Safaga (section O). It consists of a 50 m thick series of predominantly bioturbated sandstones, intercalated with silty clay and iron-oxide crusts. Onset of bioturbation marks the base of the member. Conspicuous channels, filled with massive sandstone, have been eroded into silt and clay beds of the uppermost portion of the member and its top lies below a bone bed that forms the base of the Abu Had Formation.

4.3 *Discussion of the Upper Cenomanian–Turonian sedimentary cycle*

The Lower Atrash Member is of Upper Cretaceous age and has been deposited under marine influence in the north (section W) and under purely fluviatile influence in the south (section L), with intermediate character in section M. Fossil-bearing beds indicate fully marine conditions; increasing bioturbation, content of fossils, glauconite as well as carbonate, demonstrate increasing marine conditions from south to north. The Lower Atrash Member wedges out towards the south-east and south. It is not present in the southern outcrops of Wadi Qena, where the Upper Atrash Member overlies the crystalline basement. At St. Paul monastery, hard, Paleozoic sandstones are overlain by equivalents of the Upper Atrash Member (Bandel and Kuss, in press), indicating that the Cenomanian sea covered a somewhat rugged topography during its transgression over the Precambrian basement and the Paleozoic sandstones in the north and east of Wadi Qena and near St. Paul and Wadi Dakhal. When the sea flooded the area, the thin soil covering the basement was eroded down and almost fresh crystalline rock exposed. Erosion also destroyed the most southerly occurrences of Um Bogma Formation and Dakhal Formation as well as the cover of the northern Red Sea Hills. The Atrash sea reached the southernmost Qena area only during its highest levels and it was limited by the Red Sea Hills forming a shore along their eastern margin as far north as the central Wadi Qena. The northern portions of the Red Sea Hills, dipping below the Galala height, had been flooded, but the original sediment cover has since been largely eroded.

In the southern section O, Atrash Formation has graded into Nubian sandstone facies representing the El Kanaiess Formation as proposed by Abd el Razik (1972) for the Quseir and Safaga areas. Ward *et al.* (1979) studied equivalent sandstones resting on the crystalline basement in the central Eastern Desert south of Qena. They interpreted the lower portions as predominantly fluviatile deposits.

Bioturbation indicates that most beds of the Tarfa Formation have been deposited under marine influence. In the northern sections, this influence was dominant as is documented by limestone beds containing echinoids and ammonites. Farther to the south, limestones grade into marly and glauconitic sands and oyster beds are common. In the far south of Wadi Qena, body fossils disappear, but trace fossils are still present.

Plates 1–6 appear on the following pages.

Plate 1.

1a,b. *Rhabdocidaris* sp., Upper Atrash Member (sample no. B 2-3; reg. no. E 9).
2a,b. *Micropedina bipatellis*, Gregory, 1906, Upper Atrash Member (sample no. L 1; reg. no. E 10).
3a,b. *Glyphocyphus cf. radiatus* (Hoeninghaus, 1926), Upper Atrash Member (sample no. I 3; reg. no. E 11) magnification ×1.8.
4;5a,b;6. Pavement teeth of unknown affinities (reg. no. Vb 348).
7a,b;8a,b. Toothplates from Dipnoi (lungfishes). (reg. no. Vb 349, 350). Figs. 4 to 8 belong to the same horizon (sample no. B I_5) of the Upper Atrash Member.
9. Pusher prints of an arthropod, Um Bogma Formation (sample no. S; reg. no. Ic 147).
10. Series of resting tracks of trilobite-like arthropod, Um Bogma Formation (sample W; reg. no. Ic 148).
11. Lower surface of sandstone covered by *Rusophycos*- and *Cruziana*-like arthropod trails, Um Bogma Formation (sample W; reg. no. Ic 149).
12. Scratch marks of arthropods and imprints of legs produced during feeding on muddy-silty bottom and preserved on lower face of sandstonebed. Um Bogma Formation (sample S; reg. no. Ic 150).

Plate 2.

1. *Ostrea ouremensis* Choffat, 1901. This oyster is believed to be of at least Coniacian age as they can be correlated with ammonite bearing horizons of that age (Luger, pers. comm.). External view of a right valve (sample no. G1a; reg. no. Py 417).
2a,b. *Nicaisolopha nicaisei* (COQ., 1862) from the Abu Had Formation (sample no. R 2/2; reg. no. Py 418). 2a: left valve, external side, 2b: internal side.
3. *Exogyra olisiponensis* Sharpe, 1849. A common oyster of the Atrash Formation. External view of left valve (sample no. M II_1; reg. no. Py 419).
4a,b. *Rhynchostreon columbum* (LMK, 1801), another common guide fossil of the Atrash Formation and Lower Tarfa Member. External and internal view of left valve (sample no. C 2/2; reg. no. Py 420).
5a,v. *Lopha tissoti* (TH. and P., 1890) from the Abu Had Formation. 5a: external view of left valve, 5b: internal view of right valve (sample no. V 4A; reg. nos. 421a, 421b).
6. *Pycnodonte vesiculare* (LMK., 1806) is a very common oyster in the Campanian chalk; Abu Had Formation. External view of a right valve of a closed bivalve (sample no. V 7A; reg. no. Py 422).
7. *Exogyra africana* (LMK., 1801), a very variable and common oyster of the Atrash Formation (sample no. E_0, reg. no. Py 423). External view of a left valve.
8a,b. *Curvostrea rouvillei* (COQ., 1862), a little smooth oyster of the Atrash Formation. 8a and 8b show the external views of the left and right valves of the same bivalve (sample no. M II,1; reg. no. Py 424).
9. *Ceratostreon flabellatum* (GOLDF., 1834), typical of the Atrash Formation in the northern Wadi Qena. External view of a left valve (sample no. W 4A; reg. no. Py 425).
10a,b. *Gyrostrea delettrei* (COQ., 1862), common only in the Upper Tarfa Member. 10a: External view of left valve; 10b: external view of right valve (sample no. V 1A; 10a: reg. no. Py 426, 10b: reg. no. Py 432).

Plate 3.

1a,b. Large steinkerns of common gastropod from Lower Atrash Member, named *Pterodonta* sp. in literature, but of unknown affinities, perhaps large Strombacean or large Pseudomelaniid (sample no. W1A; reg. no. G 66).
2. Large Tonnacean gastropod that is characteristic for the Atrash Formation and the lower part of the Tarfa Formation (reduction ×0.55; sample no. CI_2; reg. no. G 67).
3a,b. Large potamidid gastropod that lived in lagoonal or estuarine environments along the shore of the Atrash sea (sample no. $BIII_2$; reg. nos. G 68 (3a) G 69 (3b)).
4,6. Strombacean gastropods, *Anchura* sp., from the Abu Had Formation, that lived within the soft sea bottom by suspension feeding (sample no. U3A; reg. nos. G 70 (4), G 71 (6)).
5. A characteristic assemblage of *Turritella* forming mass occurrences in Abu Had Formation in section U. This is also a filter feeder that was buried in the soft bottom during activity (sample no. U3A; reg. no. G 74).
7. Large cerithiid gastropod from the shallow littoral sea of the Upper Atrash Member, at Cenomanian/Turonian time (sample no. W4A; reg. no. G 73).
8,9. Disk and cupola like colonial coral *Actinastrea* sp., common in distinct layer in the north of Wadi Qena (reduction ×1/2; 8: sample no. L2, reg. no. Co 4; 9: sample no. L3; reg. no. Co 5).

Plate 4.

1a,b. *Metoicoceras* sp. from Upper Atrash Member (sample no. C I1; reg. no. C 25).
2. *Neolobites* sp., Upper Atrash Member (sample no. W 4A; reg. no. C 26).
3a,b. *Metoicoceras* sp., Upper Atrash Member (sample no. D; reg. no. C 27) reduction ×0.55.
4a,b. *Exiteloceras* sp., Duwi Member of Abu Had Formation (sample no. O 5,2; reg. no. C 28).
5. *Solenoceras* sp., Duwi Member (sample no. O 5,2; reg. no. C 29).
6a,b. *Coilopoceras* sp., from the Upper Atrash Member (sample no. M 14A; reg. no. C 30) reduction ×0.55.
7. *Nostoceras* sp., Duwi Member (sample no. O 5,2; reg. no. C 31).
8a,b. *Coilopoceras* sp., Upper Tarfa Member (sample no. U 10A; reg. no. C 32) reduction ×0.55.
9,10. *Baculites* sp., both from the Duwi Member (sample no. O 5; O 5,2; 9; reg. no. C 33; 10: reg. no. C 34).

Plate 5.

1a,b. *Paravascoceras* sp., Upper Atrash Member (sample no. M 12; reg. no. C 35) reduction ×0.55.
2a,b. *Vascoceras* sp., Upper Atrash Member (sample no. 11.10.6; reg. no. C 36).
3a,b. *Acanthoceras* sp., Upper Atrash Member (sample no. M 7; reg. no. C 37).
4a,b. *Heterodiadema libycum* (Agassiz and Desor, 1846), Upper Atrash Member (sample no. W 3; reg. no. E 6).
5a,b. *Goniopygus menardi* (Desmarets, 1825), Upper Atrash Member (sample no. E 4; reg. no. E 7) magnification ×1.8.
6a,b. *Micropedina bipatellis* Gregory, 1906, Upper Atrash Member (sample no. M 10; reg. no. E 8).

Plate 6.

1a,b. *Plicatula* sp. (sample no. CI_3; reg. no. Py 410) from Upper Atrash Member.
2a,b. *Plicatula* sp. from the Upper Atrash Member in the most northerly part of Wadi Qena (sample no. W4A; reg. no. Py 411).
3. A pinnacean bivalve also from the Upper Atrash Member (sample no. M7; reg. no. Py 413).
4a,b. *Plicatula* sp. from another section of the Upper Atrash Member (sample no. B1; reg. no. Py 412).
5. Shell-layer with fragments of *Lyropecten (Aequipecten) acuteplicatus* (Alth, 1850) above the Abu Had Formation in southern Wadi Qena (sample no. 012,2; reg. no. Py 414).
6a,b. *Neithea* sp. from the Upper Atrash Member (sample no. M10; reg. nos. 6a: Py 415, 6b: Py 416).

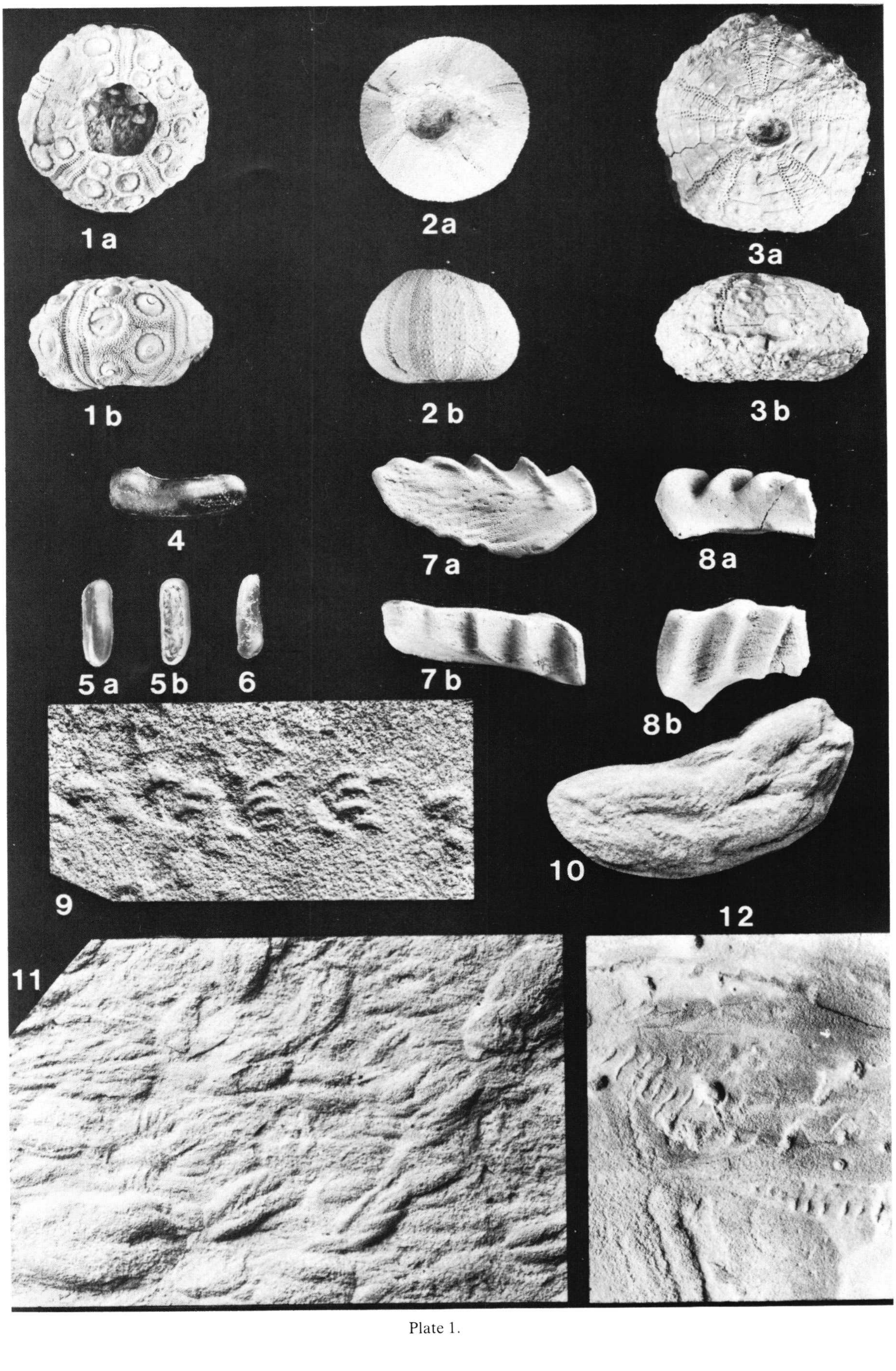

Plate 1.

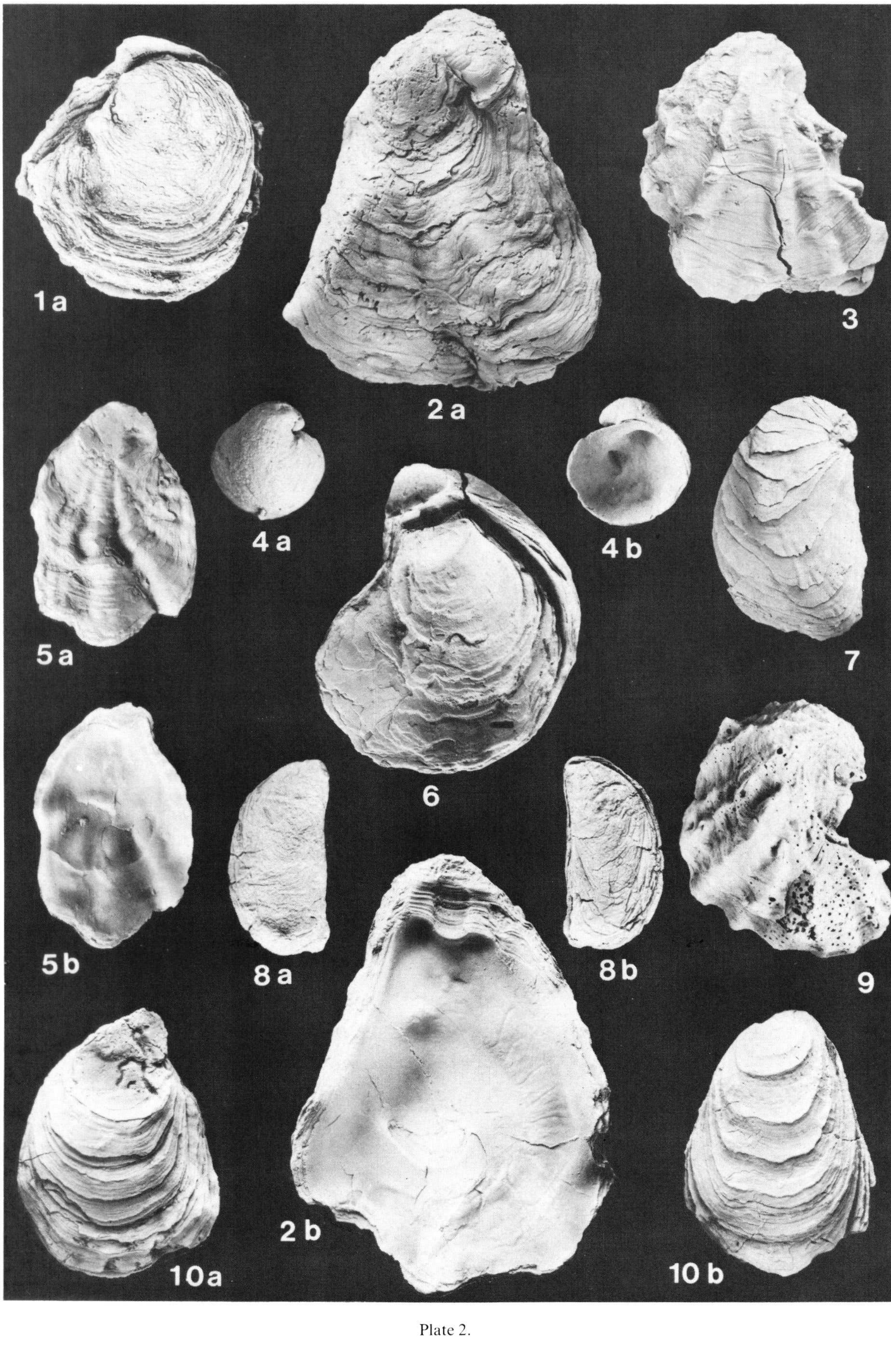

Plate 2.

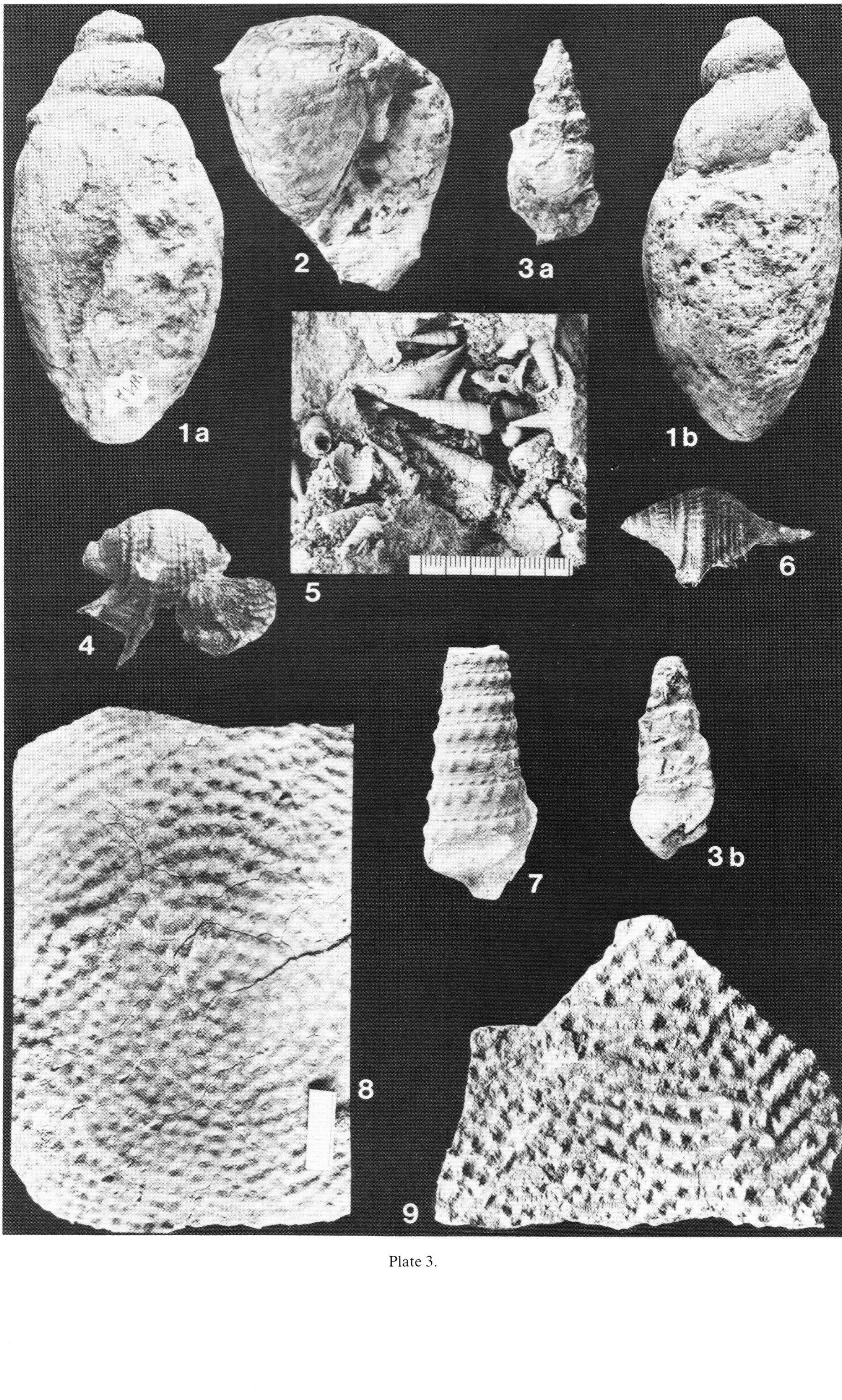

Plate 3.

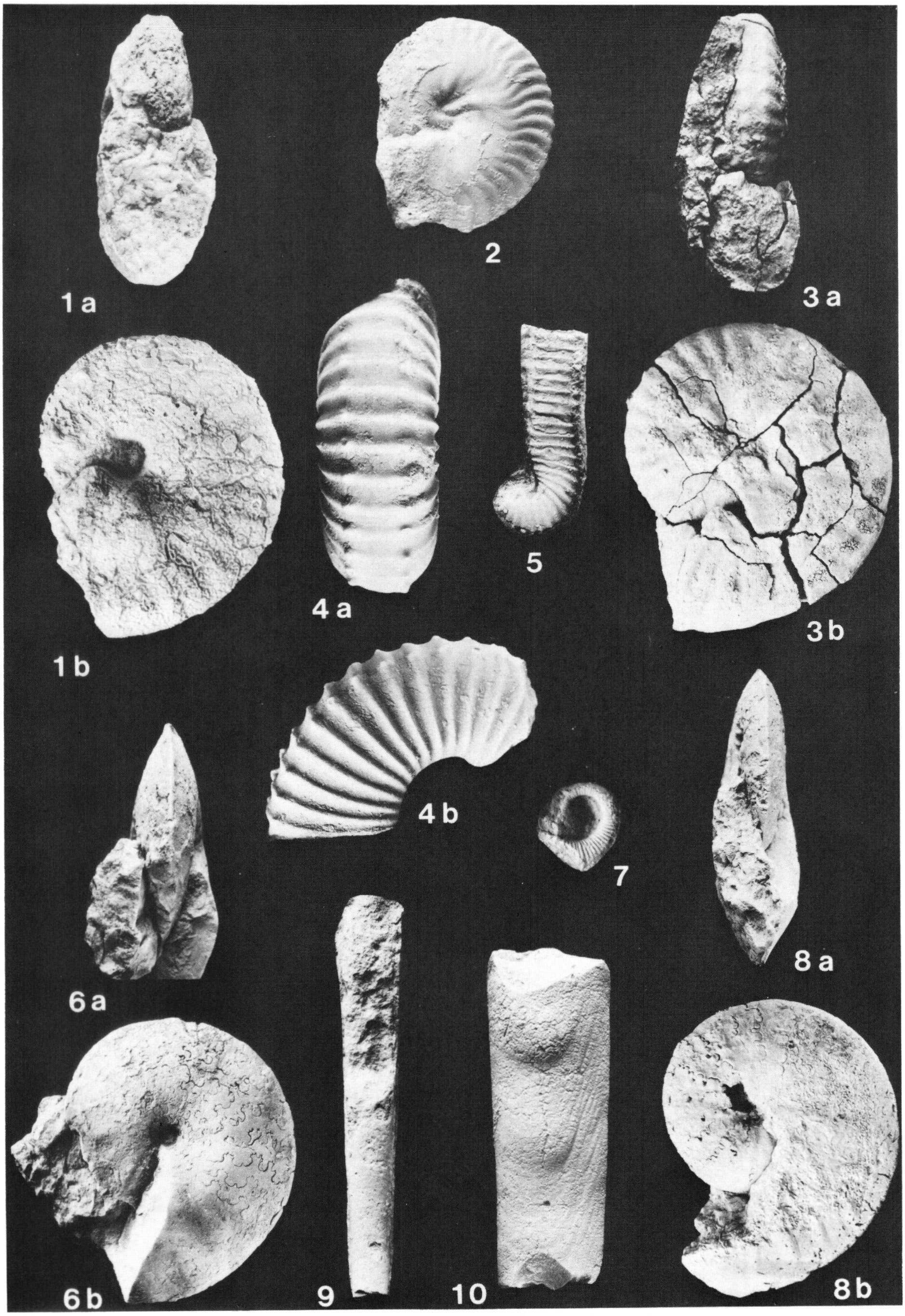

Plate 4.

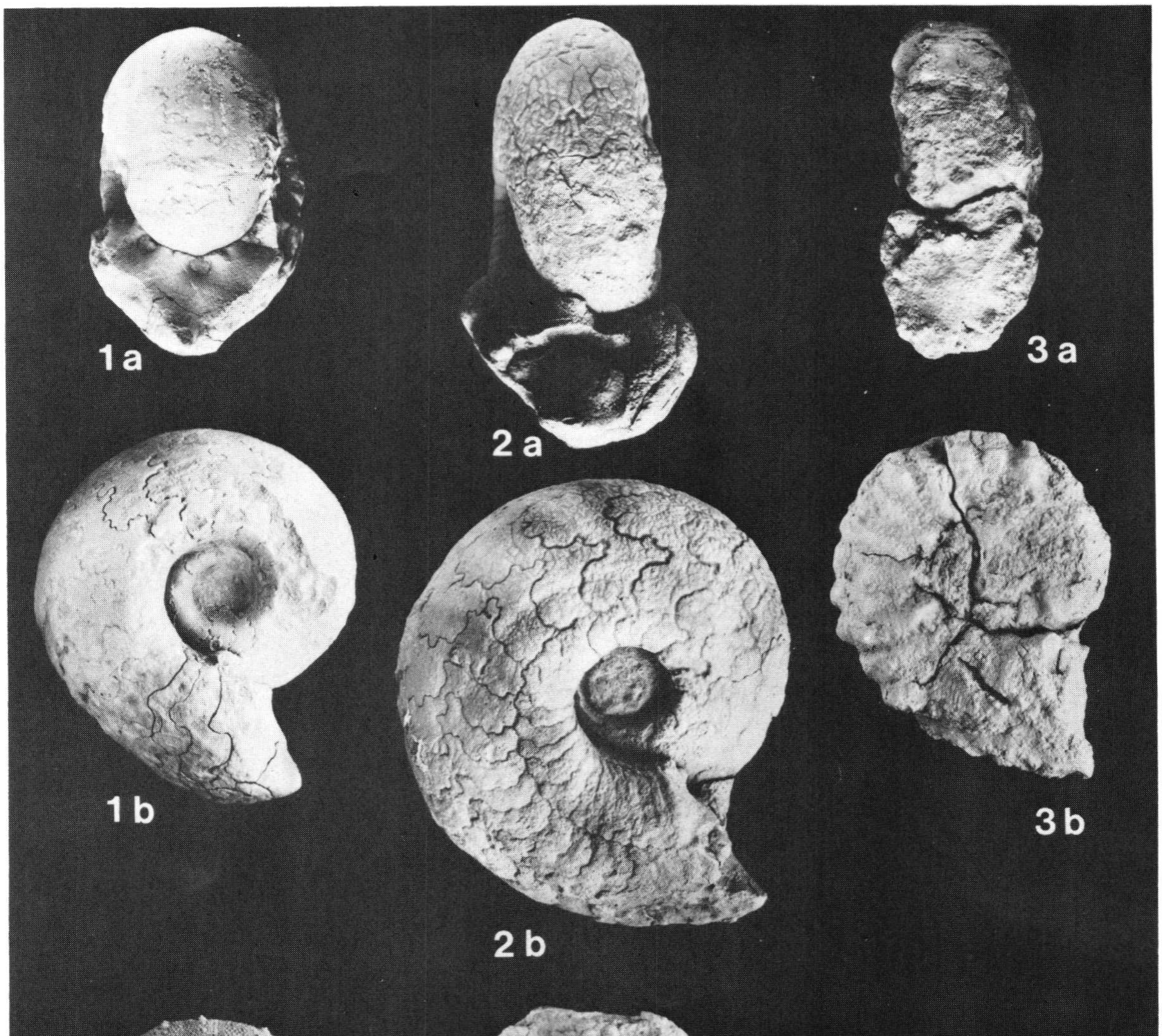

Plate 5.

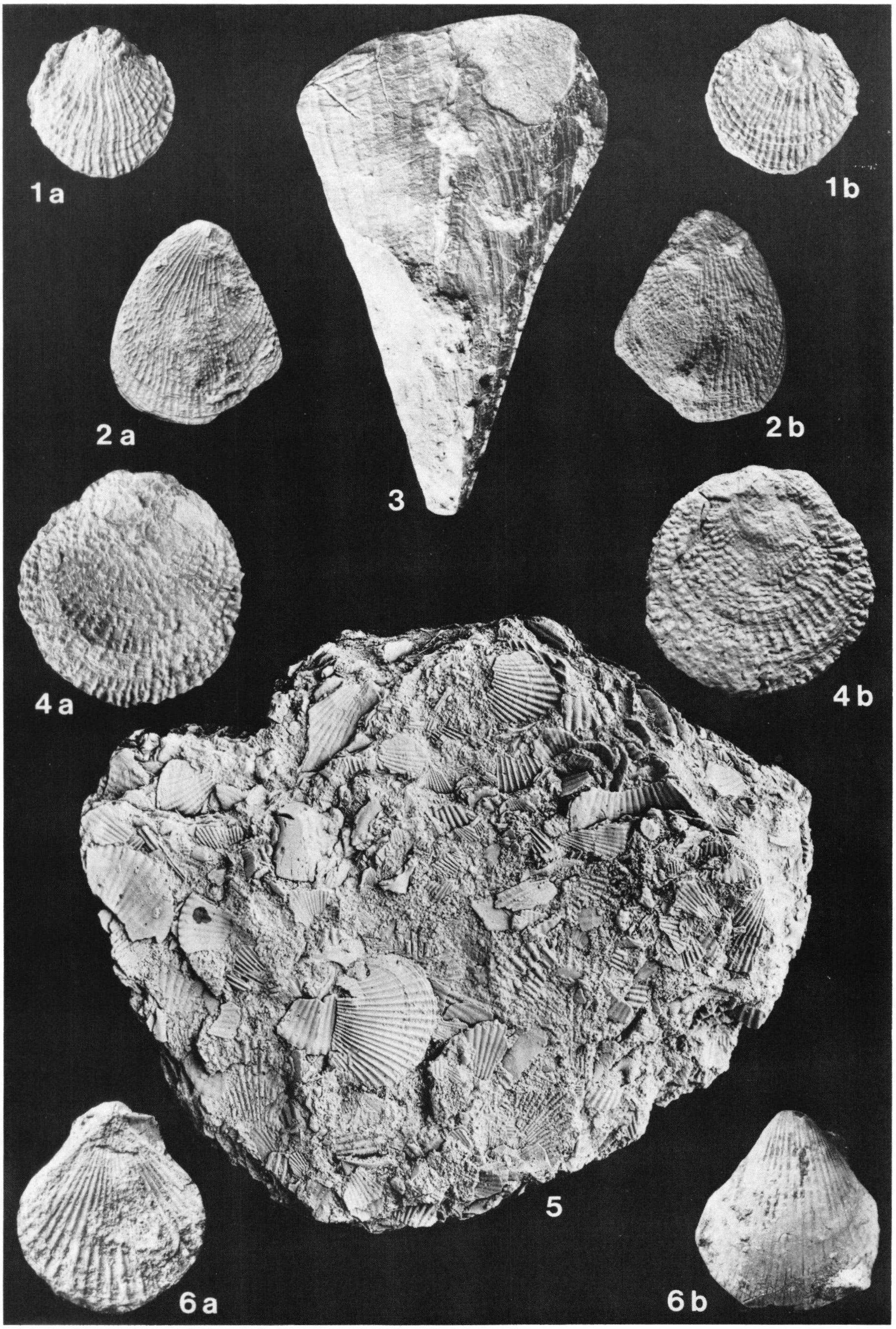

Plate 6.

Tidal currents and river channels have cut their beds into marine and terrestrial deposits and have become filled with sand derived from nearby. Equivalents to the Tarfa Formation in the south of Wadi Qena have been called the Batur Formation by Abd el Razik (1972). According to Ward *et al.* (1979), these beds are of terrestrial origin, deposited in fluviatile environment.

To the north of Wadi Qena, rocks of Cenomanian/Turonian age are exposed at the escarpments of the Galala heights with Wadi Araba and the Gulf of Suez. Abdallah *et al.* (1963) have named them Galala Formation at Khashm el Galala. Said (1962) described them as 170 m thick, but used the terms Raha and Wata Formations suggested by Ghorab (1961) for the western Sinai. Observation by the authors indicates that the equivalents of the Atrash and Tarfa Formations in the Wadi Qena area farther to the east and the north become richer in carbonates (Bandel and Kuss, in press).

In the area of Kharga and Dakhla oasis, probable age equivalents of the Tarfa Formation are represented by the fluviatile Taref sandstone. The lower portion of Taref Formation, in the sense of Issawi (1973) and Issawi *et al.* (1978), was given formation status by Barthel and Böttcher (1978), and called the Sabaya Formation. A few beds of this lower portion of the Taref Formation (*sensu latu*) show influence of bioturbation by crabs, indicating that the pulse of the Upper Cenomanian/Lower Turonian sea reached as far south as to the area of *Lingula* dome south of Maghrabi.

Taref sandstone (Issawi 1973) (Sabaya, Maghrabi and Taref Formations in the sense of Fay and Hermann-Degen 1984) overlies the Lower Cretaceous (Aptian) Abu Ballas Formation (Böttcher 1981, 1985). To the northwest rocks of similar age to the Taref overlie sandstones of unknown age (Dominik 1985). The upper three units (Gebel Ghorabi Member, Gebel Dist Member and el Heiz Member of Dominik) show marine influence and indicate that the shore, at times, lay within the Bahariya area.

An Upper Cenomanian– Turonian coastal fringe can be reconstructed crossing Egypt in a W–E direction from the Bahariya area to the southern Wadi Qena area. The Red Sea Hills formed a peninsula. Only very rare pulses of the sea reached farther south of that line.

5. CAMPANIAN PHOSPHATIC SHALE CYCLE

5.1 *Abu Had Formation* (Fig. 13)

The type locality for the Abu Had Formation lies at Gebel Abu Had (section O) just north of the Qena–Safaga road. The base of the Abu Had Formation is formed by the first bone bed overlying the upper Tarfa sandstones.

The top of the Abu Had Formation, formed by phosphatic beds of the Duwi Member, ends with the transition from phosphates to younger chalks.

5.1.1 *Quseir Member.* The Quseir Member, as the lower part of the Abu Had Formation, was first named by Youssef (1957), after suggestions from Ghorab (1956), and has since been used for different portions of phosphate-bearing beds found in many parts of Egypt. The Quseir Member consists of blue/greenish and black shales intercalated with fine, silty sand and ferruginous crusts, the latter decreasing in frequency towards the top of the member. Some beds contain numerous fish teeth and fragments of bones. The greenish shales grade into and interfinger with bituminous shales. From here onward, two parallel sections were measured, one about 2 km to the east of the other one. Rapid lateral changes in the composition of units were noted.

5.1.2 *Duwi Member.* The Duwi Member as the upper part of the Abu Had Formation was introduced by Youssef (1949) in the Quseir area, and here at Gebel Duwi. The upper portion of Abu Had Formation and thus the Duwi Member in the southern Wadi Qena is characterized by sand-filled channels which are cut into bituminous clay, marl and silt. These channels are connected to synsedimentary slip-fault movements (Figs. 14 and 15), and occur within an about 15 m thick sequence; they do not interfere with beds above this sequence. Channels have been filled with fine sand while slip movements were still active, so that channel sediment could fill fissures which project into the beds below. Slip movement ended before channels were totally filled and the relief of the sea bottom had become even again.

The upper beds of the Duwi Member consist of hard phosphate intercalated with sandstones and thin beds of shale and silt. Phosphatic sands hold bonebeds and limestone pebble layers with ammonites. Conspicuously large sand- or phosphate-filled crab burrows give evidence for the influence of strong bioturbation aside from physical erosion and redeposition.

The upper layers of the Duwi Member are of the same composition and thickness in both sections measured at Gebel Abu Had, while the channel-rich layers below are of quite different thickness and composition, due to the synsedimentary movements.

5.1.3 *The Abu Had Formation in central and northern Wadi Qena.* The next northerly exposure of the Abu Had Formation was measured in section R (Fig. 13). Here, a silty and clay-rich, red and green intercalation starts with a conspicuous discordance on top of the Tarfa Formation. The Abu Had Formation here cannot be differentiated into the two members which otherwise are widely recognized in the east (Red Sea area) and west (Abu Tartur area) of Gebel Abu Had.

Reworked iron-rich material above the basal erosional surface holds bones. Above, a dolomitic bioturbated sandstone follows, overlain by clays. These may be bituminous (almost a coal) and hold many fragmented plant fossils. Bituminous clay is commonly cut by sand-filled channels. A silty, greenish sequence of shales holds several conspicuous, up to 50 m thick beds with well preserved dinosaur bones and teeth. The layers

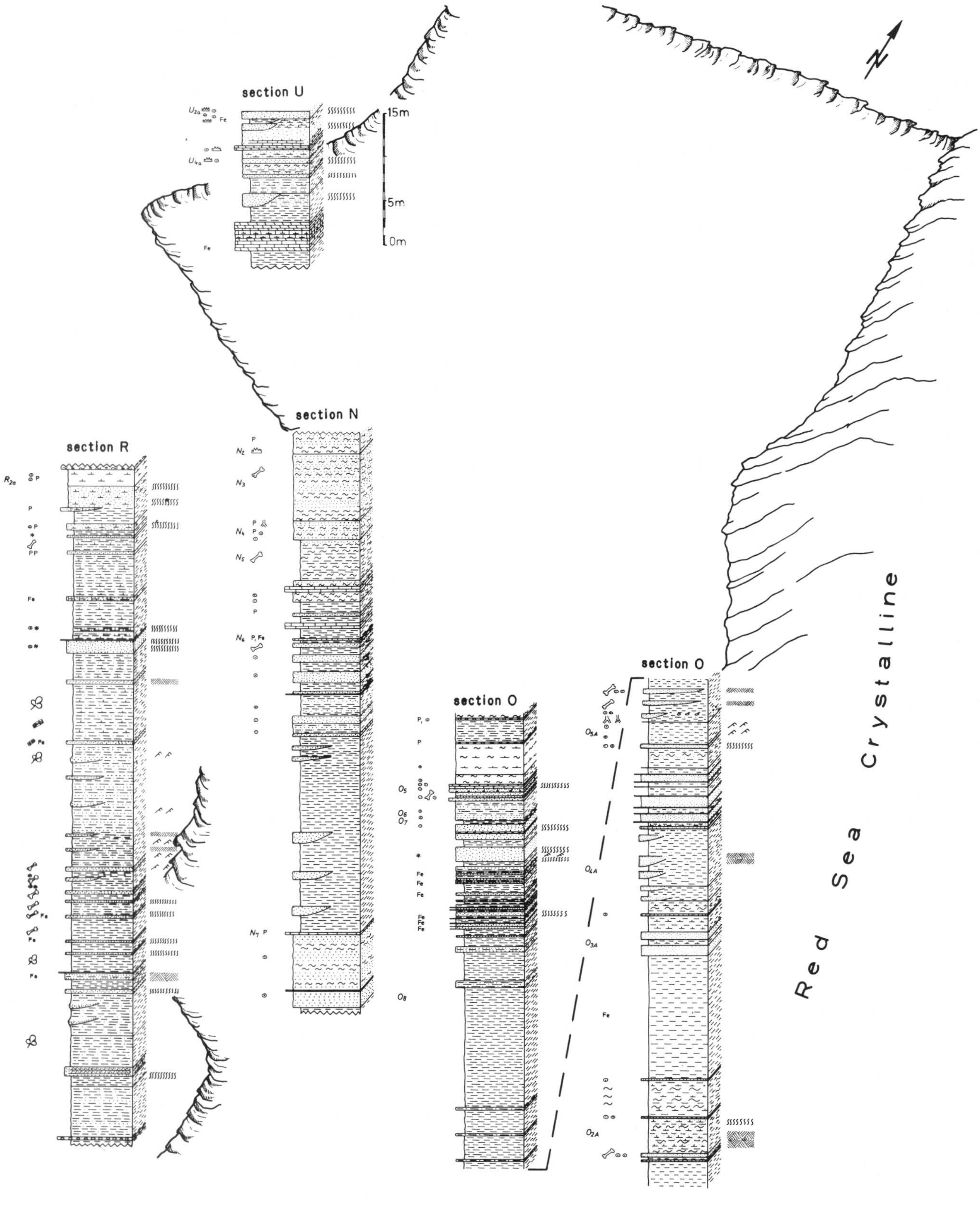

Fig. 13. Sections of the Abu Had Formation in Wadi Qena. Profile O represents the type section.

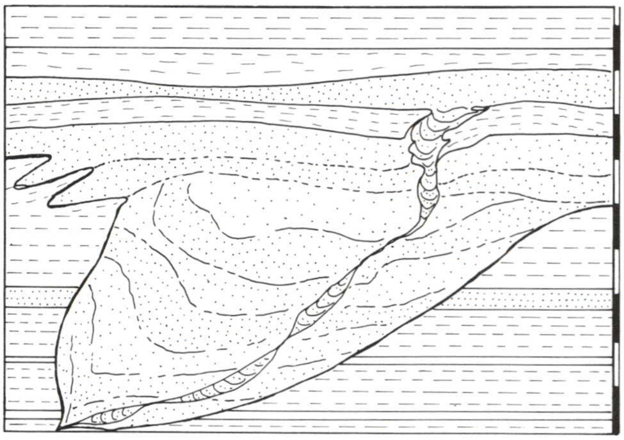

Fig. 14. Sketch of channel exposed at Gebel Abu Had. The sand-filled channel was eroded in a zone where sliding had occurred and continued during channel filling. Scale: 1 bar = 1 m.

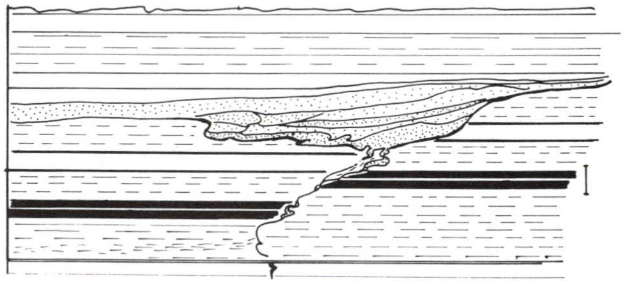

Fig. 15. Sketch of channel exposed at Gebel Abu Had. The left side had been sliding on the basal shales, so that central beds were displaced. When the channel filled, movements were still going on. Afterwards, structural unrest ended. Scale at right: 2 m.

above the bone beds consist of intercalated silts and shales without any bioturbation into which small sand-filled channels have been eroded. The following bituminous shales and marls are bioturbated. Marls are intercalated with silt, and phosphatic, glauconitic and ferruginous sand. The top of the Abu Had Formation here contains, among others, pycnodont oysters in a series of bituminous silt, shale, marl, and sandy marl, all rich in phosphatic particles.

About 30 km to the north, in section N (Fig. 16), bituminous marly and sandy shale overlies non-bituminous shale and sands of the upper Tarfa Formation. Into this sequence, small channels have been eroded which are filled with fine, cross-bedded sand. The beds become more chalky farther up and oysters (*Pycnodonta vesicularis*) are present in some layers. The Abu Had Formation here ends with chalks that contain numerous teeth of sharks, other vertebrates, and shells of pycnodont oysters.

At the very end of the Wadi Qena depression (section U, Fig. 13), the Abu Had Formation is quite thin. It begins with dolomitic beds intercalated with marls. These overlie the fossiliferous limestones of the uppermost Tarfa Formation. Bituminous shales follow into which sand-filled channels have been eroded. Chalky shales above are intercalated with sandy beds and overlain by a totally bioturbated sandstone with abundant fish teeth and phosphatic debris. The limestones and marls above contain numerous marine fossils. Bioturbated sandstone with large crab burrows is overlain by ferruginous *Turritella*-rich shales and limestones also containing sea-urchins, other gastropods and bivalves. The formation ends with totally bioturbated sandstone with glauconite and phosphatic sand as well as numerous fish teeth. The border to the white chalk of the St. Paul Formation is very conspicuous.

5.2 *Discussion*

Campanian phosphoritic deposits in Egypt have been studied by a number of authors in the Eastern Desert as well as in the Western Desert. Usually a differentiation between lower shales and upper sands has resulted in the

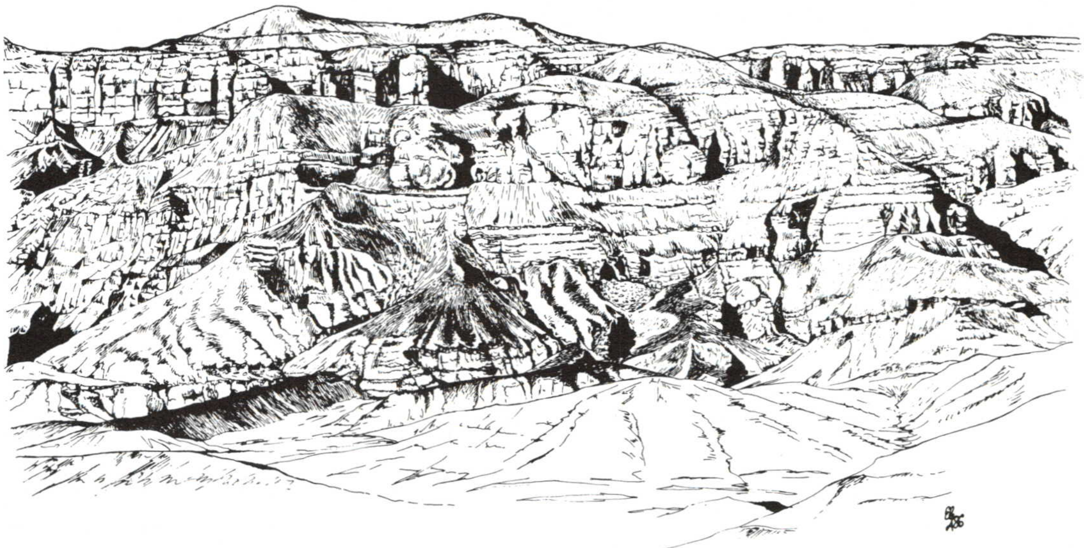

Fig. 16. Sketch of the area where profile N was measured. The rocks in the foreground are mainly shales and silts of the Abu Had Formation while the cliffs of the escarpment consist of chalks and limestones. View from the east.

separation of two units, in the Eastern Desert termed 'Quseir variegated shales' (Youssef 1957) or 'Quseir clastic member' (El Deftar *et al.* 1978) or 'Quseir Formation' (Issawi *et al.* 1978) for the lower part and 'Phosphate Formation' (Youssef 1949) or 'Duwi Formation' (Ghorab 1956, Issawi *et al.* 1978) for the upper part; in the Western Desert, the term 'Mut Formation' was introduced by Barthel and Hermann-Degen (1981) for the lower shales and 'El Hindaw Member of Dakhla Formation' for the phosphatic upper part.

For the Abu Tartur phosphates in the Western Desert, Garrison *et al.* (1979) demonstrated that phosphatic grains represent winnowed coarse material from soft sediments that were concentrated into off-shore tidal sand bars. Bandel and Mikbel (1986) have shown that such phosphoritic beds in Jordan formed in response to structural unrest. In the Gebel Abu Had sections of southern Wadi Qena, evidence of synsedimentary structural unrest is also convincing. Here winnowed shales of the Quseir Member type resulted in the deposition of sands of the Duwi Member type.

However, when phosphatic sands are only the product of synsedimentary reworking, lithological differences cannot be used to describe a formation.

Within Wadi Qena, a further complication becomes evident. As was shown by Bandel and Mikbel (1986), phosphatic grains formed during very early diagenesis within the soft marine deposits. However, when deposits were laid down under lagoonal or terrestrial conditions, as in parts of section R, no phosphatic pellets formed. When such sediments were current-winnowed, no phosphoritic sand formed. Here only bones could become concentrated in bone beds, giving evidence for rich life also in the shore area, thus Duwi Member-type sediment could not form.

Barthel and Hermann-Degen (1981) separated their 'El Hindaw Member' from the 'Mut Formation' by a change in colouration from greenish to reddish clays (Mut) to greyish clays (El-Hindaw). The authors' observations (1985) of these silts and shales at Abu Tartur revealed that they had originally all been marine deposits bearing a characteristic assemblage of trace fossils and holding thin layers of phosphatic sand and pebbles. However, while in the 'El-Hindaw' sediments there has been little change, in the 'Mut' below they have subsequently been altered due to terrestrial influences. During this process, phosphates as well as carbonates were leached out, root horizons developed and former dark colours changed into bright reds and greens due to the oxidation of disseminated pyrite. Even at Gebel Taref, about 60 km E of Abu Tartur, only very minor parts of the 'Mut Formation' have been transformed into colourful beds due to terrestrial influence and remained black due to the conservation of pyrite and organic matter. Thus marine shales of the Quseir Member of the Eastern Desert and the Mut Formation of the Western Desert are to be separated from each other only due to secondary transformation of the latter by terrestrial processes.

Thus the present authors prefer to use the new term Abu Had Formation to describe the shale-rich Campanian deposits that overlie the sediments of the Cenomanian–Turonian cycle with a large hiatus and underlie Campanian chalks. Sediments of the cycle of the Abu Had Formation formed in a shallow sea and close to its shore. The sea teemed with life and was enriched in dissolved phosphates that resulted after their deposition on the sea floor due to biological activity in the early diagenetic formation of phosphorite pellets. These may have become enriched in phosphorite sands when the sediment was reworked and fine particles winnowed. Terrestrial conditions were present as well in local depositional environments as in secondary transformation of former marine muds and phosphatic particles.

6. CAMPANIAN CHALK CYCLE

6.1 *St Paul Formation* (Fig. 17)

The Cenomanian beds at the monastery of St Paul are truncated and overlain by a characteristic sequence of well-banked chalky to marly beds. A greenish marly shale and a conspicuously massive limestone lies above. This about 90 m thick sequence is here given the name St Paul Formation. Forty to one hundred centimetre thick chalky limestone beds are separated from each other by marly interlayers. The St Paul Formation, with a reduced thickness, is also present in section U at Wadi Tarfa head waters, as a 15 m thick sequence overlying the Campanian Abu Had Formation. It begins with an intercalation of 20 to 50 cm thick chalky limestones and thin marly layers. These 15 m are totally bioturbated and hold some layers with formerly siliceous sponges that have been transformed into iron salts during diagenesis (now Fe-oxide). Rocks of the St Paul Formation are also well exposed in a larger area forming a very wide and white stretch about 25 km WSW from section U. The oyster *Pycnodonta vesicularis* is common at the base of the chalk sequences.

At the Gebel Abu Had in section O, a marly clay with many oysters and pectinid bivalves overlies the Abu Had Formation. This bed may represent remnants of the St Paul Formation. A more detailed section of the layers above the Abu Had Formation was measured by Luger (1985, personal communication).

6.2 *Discussion*

The St Paul Formation rests on an erosive surface at Tarfa head waters as well as at the type section near St Paul monastery. While chalks on both sides of the Red Sea Hills at section U, as well as 5 km to the south of St Paul monastery, overlie truncated beds of the lower Abu Had Formation, St Paul erosion had reached down to Atrash Formation before chalk deposition began. An equivalent to the St Paul Formation in Sinai may be the Sudr-chalks and in the Western Desert the Campanian chalks as they are exposed west of Mut. While in Wadi

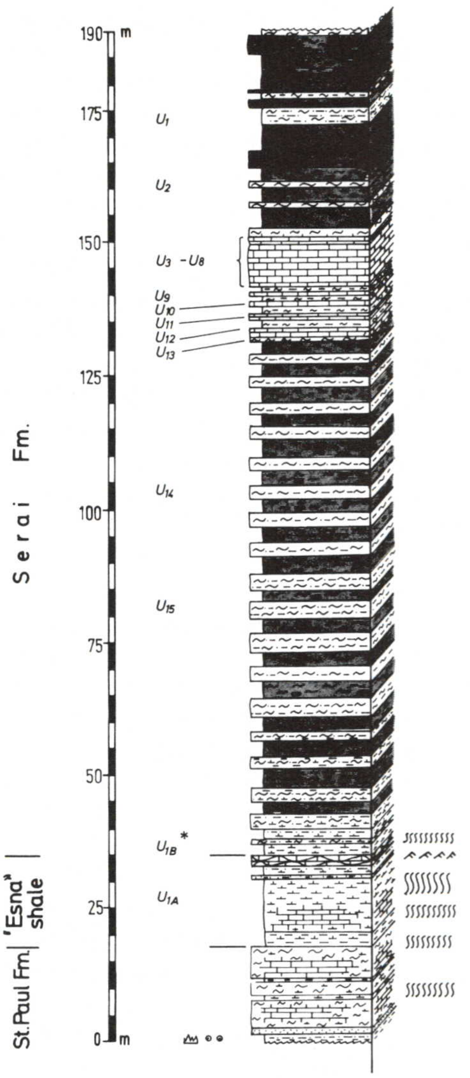

Fig. 17. Columnar section of the St Paul Formation. 'Esna shale' and Serai Formation in profile U. The base is formed by the last bed of the Abu Had Formation.

Qena the St Paul Formation is absent or present as relicts only, in southern Galala it forms a conspicuous unit well exposed on the southern escarpment as well as on the northern slopes near St Antony monastery (Kuss 1986, Bandel and Kuss, in press).

7. PALEOCENE–EOCENE CYCLE (Fig. 17)

7.1 *'Esna' shales*

A 6 m thick chalky shale overlies the Abu Had Formation at section N and is overlain by chalky limestone of the Serai Formation. This shale has delivered Maastrichtian foraminifera.

Thirteen metres of totally bioturbated marly clay overlie the chalky beds of the St Paul Formation at section U. Bioturbation here consists of a dense network of crab burrows of the Thalassinoides-type as well as single burrows of the Rhizocorallium-type. Some layers in the top are sandy and contain shale intraclasts as well as coquinas of bivalves. From the marly clay, Paleocene foraminifera have been determined. Similar marly clays with a fauna of foraminifera of the same age are present on top of the section of the St Paul Formation at St Paul monastery.

7.2 *Serai Formation*

Said (1960) described the flint-bearing chalk sequence from the Nile valley near Luxor and called it the Thebes Formation. But this sequence had before been named the Serai limestone by Barron and Hume (1902). Similar chalks and well bedded marly chalks with flint layers throughout occur in the upper escarpment along the whole western flank of Wadi Qena in sections A, N and U. We use the term Serai Formation for them, according to the priority of the old name.

In section N, the lower 70 m of the Serai Formation were measured and in section A, the upper 90 m of it were studied with the base not exposed. At section A, the lower 42 m of the Serai Formation consists of chalk with layers of flint nodules and beds of continuous flint intercalated at a distance of about 5–15 cm. Flint layers are thinner than the chalk beds between them. This lower unit is a bit softer than the following 30 m, which form conspicuous cliffs in the escarpment. This characteristic unit is visible in the escarpment from section A all the way to the north of Wadi Qena. A synsedimentary gliding surface was noted that resulted in only a few decimeters' disjunction of beds. The sediment on the surface of this slump fault was later transformed into chert. Eighteen metres of softer marly chalk with flint intercalations end section A. All beds of the Serai Formation lack macrofossils. A general bioturbation resulted in a total destruction of original, sedimentary structures, while individual trace fossils are invisible or inconspicuous.

In section N, the Serai Formation begins with 35 m of massive chalk flint intercalations. The 25 m above are slightly softer and consist of marly chalk and some chalk layers with flint intercalations. In the uppermost portion of the measured section, a chalky marl shows conspicuous tube-like burrow structures.

In the Wadi Tarfa head waters (section U), the sandy top of the 'Esna' shale is overlain by 110 m of bedded marly to platy chalks with flint intercalations. The lower 61 m form a steep slope, while the beds above are somewhat softer. A lithological change from chalky deposits to massive limestones occurs within the next 17 m of section. Here a nummulitic limestone sequence is overlain by about 80 m of flint-rich chalks and marly chalks.

Comparable limestones to those of the upper central section U are found in a structurally isolated occurrence to the west of location P (Fig. 1). Here operculinid foraminifera may predominate in some layers.

7.3 *Discussion*

Since Ball's (1900) time, the term 'Esna shale' has been used for Paleocene shales and chalks (Said 1960).

In northern Wadi Qena, marly shales overlie the Campanian chalks of the St Paul Formation with a great hiatus. Maastrichtian foraminifera at section N may either indicate reworking or a continuous sedimentation of 'Esna shale' equivalents across the Cretaceous–Tertiary boundary.

The 'Serai Chalk Member' of Abd el Razik (1970) overlies the Esna shale' in the Gebel Abu Had section. The flint-rich chalks and chalky limestones of the Wadi Qena grade into limestones with approach to the South Galala (Bandel and Kuss, in press), which is indicated in section U. The nummulitic limestones of the Serai Formation are of Upper Paleocene to Lower Eocene age as indicated by alveolinid foraminifera; they may thus be equivalents of the Minia Formation (Said 1962, Keheila 1983).

8. UNIQUE VOLCANIC AND STRUCTURAL FEATURES OF CENTRAL WADI QENA

In central Wadi Qena, two conspicuous mountains rise from the valley floor and differ from the flat topped outliers of the Atrash and Tarfa Formations in the south and the Um Bogma and Dakhal Formations in the north. One represents the black pointed cone of a basaltic pipe (just SSW of sections S_I and S_{II}; Fig. 1) and the other rises about 170 m above the surrounding outliers and shows a circular structure (Fig. 1, H). It lies almost 20 km to the SW of the volcanic cone.

The southmost exposure of rocks of the Dakhal Formation occurs in fragments of sandstone with characteristic, round quartz pebbles in the tuffaceous mantle of the basalt pipe. The volcanic rocks have carried up also oyster-bearing limestone of the Upper Atrash Formation.

About 10 km to the south of the volcanic cone, a series of sandstones of about 25 m thickness is exposed, raised above the valley floor. These coarse sands contain subangular pebbles and, most likely, represent the southernmost exposure of the fluviatile Lower Atrash Member.

The ring structure lies about 20 km to the SW of the volcanic cone and here, limestone of the Upper Atrash Member rests on basement rocks directly. The sandstone units of the Um Bogma, Dakhal and Lower Atrash Formations are no longer present.

In section H, at the top of the central mount of the ring structure as well as at its flanks, marls and limestone have become strongly altered due to heat-induced metamorphosis. Limestone has changed into coarsely crystalline marble, diopside laminae and blastoids have grown in the former marls, and sandy layers have been made molten and turned into glass-like structures.

This metamorphosis has also altered the granitic basement below and changed it into a sandy clay-rich material. The circular dome-like structure has a diameter of about 3 km. North and west slopes dip at about 10°, south and east slopes at 20° and more. The central dome rises above the surroundings for at least 150, perhaps 200 m and shows a flat top. Some sills found near the base of the structure contain andesitic basalt which, most probably, forms a solid cushion-like intrusive body within the dome and is responsible for metamorphosis above. A similar basalt sill-induced metamorphosis, but this time in the sandstones of the Um Bogma Formation, can be studied farther to the north in the Samr el Qa mountains.

Near to the ring structure, in sections G and I, sediments are encountered which cannot be correlated to others seen in exposures farther away from the ring structure. Oysters studied by us and ammonites found here later by Luger (1986, pers. comm.) indicate that Coniacian deposits have here become preserved which, in other places of the Wadi Qena, were eroded prior to the deposition of Campanian sediments. Klitzsch (1986) also mentioned Coniacian/Santonian ammonites from central Wadi Qena.

Ring structure, a volcanic pipe, erosion of Carboniferous and Cretaceous sandstones to the south and preservation of them to the north, and conservation of Coniacian deposits here only, indicate that faults cross over the Wadi Qena which have been active prior to the Cenomanian transgression, after Coniacian deposition, and at emplacement of basaltic magma during the Late Tertiary.

9. SEDIMENTATION MODEL—A RECONSTRUCTION OF THE GEOLOGICAL HISTORY OF THE AREA OF WADI QENA (Fig. 18)

The sedimentary history after Precambrian folding, faulting and metamorphosis connected with numerous intrusions and volcanic events began after a prolonged time and peneplanation. During Paleozoic times, a sequence of sandstones (Um Bogma Formation) was deposited, in which fluviatile sands show the imprints of marine advances in form of trace fossils, produced by marine organisms. Towards the north of Wadi Qena, marine influence is somewhat stronger, indicated by the presence of more trace fossils, such as arthropod tracks, and an increase of the number of pipe-rock (*Scolithus*) layers.

The exact age of these rocks remains to be shown. The Um Bogma Formation of the Wadi Qena area may be correlated with Lower Carboniferous sand and siltstones exposed at Wadi Dakhal, some 50 km to the NE. The belts of sedimentation probably followed the contour of the Arabian/Nubian continent. The sea lay in the north, that is to the north of the area of South Galala, at the western shore of the Gulf of Suez and north of the area of Um Bogma on the western Sinai, near the eastern shore of the Gulf of Suez.

Paleozoic sandstones were eroded and, only after a very long period of non-deposition, were covered by the sands of the Dakhal Formation during pre-Cenomanian, probably Lower Cretaceous times. The sands were derived from the continent in the south and were laid down mainly by rivers. At Wadi Dakhal, to the northeast

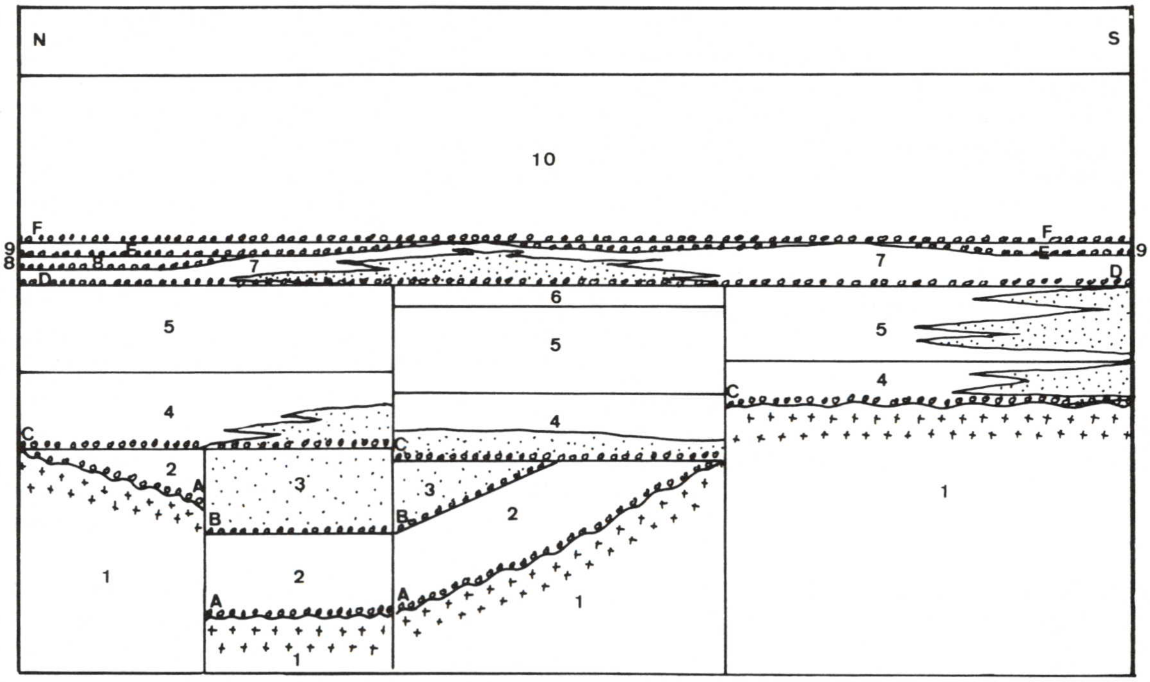

Fig. 18. Hypothetical reconstruction of facies relations of the sediments of Wadi Qena, utilizing a model of faults that have been active before Atrash time (all) and after Coniacian time (in central Wadi Qena). 1: Basement; 2: Um Bogma Formation; 3: Dakhal Formation; 4: Atrash Formation; 5: Tarfa Formation; 6: Coniacian; 7: Abu Had Formation; 8: St Paul Formation; 9: 'Esna shale'; 10: Serai Formation; A: Hiatus Precambrian–Carboniferous; E: Internal Campanian–pre St Paul Formation hiatus; E: Pre-Paleocene hiatus; F: Post Esna hiatus. The northmost fault zone was active prior to Atrash deposition; the central fault zones were also active at that time, but also prior to Abu Had times.

of Wadi Qena, sandstone of the Dakhal Formation has been bioturbated by marine crustaceans (*Ophiomorpha*-type) indicating the influence of the sea in the north. A connection to the sandy and silty Abu Ballas Formation (Böttcher 1982) in the Western Desert exposed south of the Mut–Kharga–Dakhla escarpment may have existed. If so, belts of deposition of the shore followed the contour of the northern margin of the Nubian continent.

During Cenomanian times, this sea flooded the northwestern portion of Wadi Qena, reworking terrestrial soil and sandstones of the Um Bogma and Dakhal Formations. The sea flooded crystalline basement in the east and sandstone in the west; during Lower Atrash times, it remained in the northern portion of the Wadi, with marine sediments grading into fluviatile sands in the middle Wadi Qena region.

During Upper Cenomanian time, a new transgressive pulse of the sea pushed the sedimentation farther to the south. It flooded terrestrial regions consisting of erosional surfaces of crystalline rock, predominantly granite, porphyritic volcanics and tuffitic pyroclastics and sediments. The shore lay in the south, coinciding more or less with the southern end of the Wadi Qena depression. Very little fluviatile sediment came from the south during that time, but, from the Red Sea Hills, fanglomeratic sediments entered the sea coming from the north.

A similar stream of erosional debris as that exposed in the B-profiles coming from the eastern slope of the Red Sea Hills during Upper Cenomanian times, was discovered by Ward *et al.* (1979) in the 'Lower Nubian Formation' of the Safaga–Qusseir area. The shore line followed more or less the western margin of the Red Sea Hills up to the central Wadi Qena area and then turned to the east. The northern part of the Red Sea Hills, as they are presently developed, was flooded at Cenomanian/Turonian time. Some shore conglomerates are angular or contain reworked pebbles with wind-polished surfaces. Many of the conglomerates which are well rounded resemble pebbles from the Dakhal Formation and have probably been eroded from it and redeposited. Fluvial influence became more prominent in the south and dominated south of Wadi Qena.

During Turonian times, the influence of rivers from the south increased, but fluctuating sea levels remained in a similar frame as during Atrash times. The climate may have become more humid, so that plant remains are more commonly preserved, especially root horizons. Terrestrial near-shore deposits within short distance may change into off-shore limestones, both laterally and horizontally. Channels were cut by river arms and frequently small-scale regressions resulted in the transformation of sediments into soils with clear imprints of terrestrial exposure even in the north of Wadi Qena. Angular debris from crystalline rocks of the Red Sea Hills during Tarfa time still reached the Wadi Qena area. In the south of the Wadi Qena depression, fluviatile sediments predominate over marine ones, and, farther to the south, Ward *et al.* (1979) noted fluviatile deposition with an indication of transport direction from S and SE to N and NW. The sea never reached farther south than Qena, and Van Houten and Bhattachariya's (1979) assumption that Cenomanian/Turonian marine transgressions reached the area of Assuan is unlikely.

Little evidence of Coniacian deposition survived in Wadi Qena, but marine Coniacian beds exposed near the ring structure in central Wadi Qena give evidence that marine sediments had been present but were eroded prior to the Campanian transgression. This Coniacian pulse of the sea may have reached farther to the south than can be documented for the Cenomanian and Turonian pulses. It is perhaps during Coniacian times that the sea reached as far south as Assuan. The period of sedimentation lasting from the Cenomanian through the Turonian into the Coniacian ended and a long time of non-deposition and erosion followed, as has been documented by Lewy (1975) for the Sinai area. This was not realized by Mazhar *et al.* (1979), who thought it was possible to trace a rock sequence that is continuous from the Turonian to the Campanian in the South Galala area.

When the sea returned into the Wadi Qena area during the Campanian, it reached farther south than in Cenomanian–Turonian times, flooding areas to the south of Wadi Qena depression documented south into the Kom Ombo region. At this time the Red Sea Hills were covered by the sea which was not deep, so that large areas were estuarine or consisted of coastal terrestrial swamps. Productivity both in the sea as well as on land was high, so that a rich fauna of vertebrates could exploit coastal plant growth as well as marine plankton. In marine sediments of the Abu Had Formation, in addition, fecal pellets and other organic material became phosphatized. Winnowing of muddy bottom sediments due to currents, therefore, resulted in phosphatic sand enriched with bone material. Winnowed terrestrial material, in contrast, only resulted in bone beds with few fecal elements and with no phosphatic sand. During deposition of the Duwi member during Upper Campanian times, structural unrest was widespread. This resulted in synsedimentary slip structures and erosion from uplifted areas and redeposition nearby. Rapid facies and thickness changes laterally as well as horizontally are characteristic. Similar rapid facies changes were noted from the Safaga/Qusseir area at the Red Sea during Abu Had times and also from the Abu Tartur area in the Western Desert (Glenn and Mansour 1979, Garrison *et al.* 1979). After unrest and local erosion, the marine deposition continued and the chalks of the Campanian St Paul Formation were laid down in a shallow, open sea. Deposition was continuous into the Maastrichtian as can be documented from the profile near the St Antony monastery of the northern escarpment of the South Galala (Bandel and Kuss, in press). But in the Wadi Qena most or all of limestones, chalks and sandstones were eroded; commonly erosion reached into the top of the Abu Had Formation. The sea returned during Paleocene times and covered the area until the Eocene, depositing chalks, marls and limestones (Serai Formation and beds above it). Equivalents of the Serai Formation have become preserved at Thebes and well to the south of it (Luger 1984) and also to the east of Wadi Qena near the shore of the Red Sea (Youssef 1957). During the Paleocene and Eocene the Red Sea Hills were covered by sea and presented no peninsula as indicated in the reconstruction of Basahel *et al.* (1982). After a last regression, at the end of the Eocene, the sea never returned to the Qena area.

Acknowledgements.—We wish to express our gratitude to the German Research Foundation (DFG) for financial support. GPC/Cairo facilitated the field work. H. Glowa and B. Kleeberg helped with the photographs, B. Dunker with some drawings. Prof. Dr J. Wiedmann (Tübingen) determined the ammonites, Dr F. Geys (Antwerpen) determined the regular sea-urchins. Prof. Dr E. Klitzsch, speaker of the Special Research Project (SFB) 69, Technical University Berlin, supported this work. All specimens pictured are kept in the collection of the Technical University of Berlin (SFB 69, Ackerstrasse 71–76) according to the numbers indicated with the reg. no.

REFERENCES

Abdallah, A. A. and Fahmy, N. 1963. Stratigraphy of the Lower Mesozoic rocks, western side of Gulf of Suez, Egypt. *Geol. Surv. Egypt, Cairo*, **27**.

Abd El Razik 1972. Comparative studies on the Upper Cretaceous–Early Paleogene sediments on the Red Sea Coast, Nile Valley and Western Desert, Egypt. 8th Arab Petrol Cong. Algiers, Paper **71** (B. 3).

Bandel, K. 1981. New stratigraphical and structural evidence for lateral dislocation in the Jordan Rift Valley connected with a description of the Jurassic rock column in Jordan. *N. Jb. Geol. Paläont. Abh.* **161**, 271–308.

Bandel, K. and Kuss, J. 1986. Depositional environment of the pre-rift sediments of the Galala heights (Gulf of Suez, Egypt). *Berliner geowiss. Abh. (in press)*.

Bandel, K. and Mikbel, S. 1986. Origin and deposition of phosphate ores from the Upper Cretaceous at Ruseifa (Amman, Jordan). *Mitt. Geol. Paläont. Inst. Univ. Hamburg* **59**, 167–188.

Barthel, K. W. and Böttcher, R. 1978). Abu Ballas Formation (Tithonian/Berrissian; Southwestern Desert, Egypt), a significant lithostratigraphic unit of the former "Nubian Series". *Mitt. Bayer. Staatssammlg. Paläont. hist. Geol.* **18**, 153–166.

Barthel, K. W. and Herrmann-Degen, W. 1981. Late Cretaceous and Early Tertiary Stratigraphy in the Great Sand Sea and its SE Margins (Farafra and Dahkla Oases) SW Desert, Egypt. *Mitt. Bayer. Staatssammlg. Paläont. hist. Geol.* **21**, 141–184.

Basahel, A. N., Bahafzallah, A., Jux, U. and Omara, S. 1982. Age and structural setting of a Proto-Red Sea embayment. *N. Jb. Geol. Paläont. Mh.* **8**, 456–468.

Böttcher, R. 1982. Die Abu Ballas Formation (Lingula Shale) (Apt?) der Nubischen Gruppe Südwest-Ägyptens. Eine Beschreibung der Formation unter besonderer Berücksichtigung der Paläontologie. *Berliner geowiss. Abh.* **A39**, 145 pp.

Böttcher, R. 1985. Environmental model of the shallow marine Abu Ballas Formation (Aptian, Nubian Group) in South-Western Egypt. *N. Jb. Geol. Paläont. Abh.* **169**, 261–283.

Dominik, W. 1985. Stratigraphie und Sedimentologie (Schwermineral-analyse, Geochemie) der Oberkreide von Bahariya und ihre Korrelation zum Dakhla–Becken (Western Desert, Ägypten). *Berliner geowiss. Abh.* **A62**, 173 pp.

El Deftar, T., Issawi, B. and Abdallah, A. M. 1978. Contributions to the geology of Abu Tartur and adjacent areas: Western Desert, Egypt. *Ann. Geol. Surv. Egypt* **8**, 51–90.

Fay, M. and Herrmann-Degen 1984. Mineralogy of Campanian/Maastrichtian sand deposits and a model of basin development for the Nubian Group of the Dakhla Basin (Southwest Egypt). *Berliner geowiss. Abh.* **A50**, 99–117.

Garrison, R. E., Glenn, C. R., Snavely, P. D. and Mansour, S. E. A. 1979. Sedimentology and origin of Upper Cretaceous phosphorite deposits at Abu Tartur, Western Desert, Egypt. *Ann. Geol. Surv. Egypt* **IX**, 261–281.

Ghorab, M. A. 1956. A summary of a proposed rock stratigraphy classification for the Upper Cretaceous rocks in Egypt. *Geol. Soc. of Egypt*.

Ghorab, M. A. 1961. Abnormal stratigraphic features in the Ras Gharib oil fields. 3rd Arab Petrol. Cong. Alexandria II.

Issawi, B. 1973. Nubia Sandstone: Type section. *Bull. Am. Ass. Petrol. Geol.* **57**, 741–744.

Issawi, B., Hassan, M. Y. and Attia Saad, A. N. 1978. Geology of Abu Tartur plateau, Western Desert, Egypt. *Ann. Geol. Surv. Egypt* **VIII**, 91–127.

Jux, U. and Issawi, B. 1982. Contribution to the stratigraphy of the Paleozoic rocks in Egypt. *Egypt Geol. Surv.* **64**, 1–28.

Keheila, E. A. 1979. Geological studies on the area southeast of Minia. M.Sc. Thesis, Dept. of Geol., Asiut Univ., Asiut.

Klitzsch, E. 1986. Plate tectonics and cratonal geology in Northeast Africa (Egypt, Sudan). *Geol. Rdsch.* **75**, 755–768.

Klitzsch, E., Harms, J. G., Lejal-Nicol, A. and List, F. K. 1979. Major subdivisions and depositional environments of Nubia strata, Southwestern Egypt. *Bull. Am. Ass. Petrol. Geol.* **63**, 967–974.

Kostandis, A. B. 1959. Facies maps for the study of Paleozoic and Mesozoic sedimentary basin of the Egyptian region. 1st Arab. Petrol. Congr., Cairo, **2**, 54–62.

Kuss, J. 1986a. Upper Cretaceous Calcareous Algae from the Wadi Qena/Eastern Desert (Egypt). *N. Jb. Geol. Pal. Mh.* **4**, 223–238.

Kuss, J. 1986b. Facies development of Upper Cretaceous–Lower Tertiary sediments from the monastery of St. Anthony/Eastern Desert, Egypt. *Facies* **15**, 177–194.

Lewy, Z. 1975. The geological history of Southern Israel and Sinai during the Coniacian. *Isr. J. Earth Sci.* **24**, 19–43.

Luger, P. 1985. Stratigraphie der marinen Oberkreide und des Alttertiärs im südwestlichen Obernil-Becken (S-Ägypten)—unter besonderer Berücksichtigung der Mikropaläontologie, Palökologie und Paläogeographie. *Berliner geowiss. Abh.* **A63**, 151 pp.

Mazhar, A., Enani, N. and Kader, Y. A. 1979. Contributions to the Cretaceous–Early Tertiary stratigraphy of the El Galala–El Qibliya Plateau. *Ann. Geol. Surv. Egypt* **9**, 377–387.

Said, R. 1960. Planktonic foraminifera from the Thebes Formation, Luxor/Egypt. *Micropaleontology* **6**, 277–286.

Said, R. 1962. *The Geology of Egypt*. Elsevier, Amsterdam.

Said, R. 1971. Explanatory notes to accompany the geological map of Egypt. *Geol. Surv. Egypt* **56**.

Schellwien, E. T. T. 1894. Über eine angebliche Kohlenkalk-Fauna aus der ägyptisch–arabischen Wüste. *Z. deutsch, geol. Ges.* **46**, 68–78.

Schweinfurth, G. 1886. Reise durch die Arabische Wüste von Heluan bis Qeneh, 24. März bis 18. Mai 1877. *Peterm. Mitth. (Gotha)* **23**, 387–389.

Van Houten, F. B. and Bhattachariya, D. P. 1979. Late Cretaceous Nubia Formation at Aswan, Southeastern Desert, Egypt. *Ann. Geol. Surv. Egypt* **9**, 408–419.

Walther, J. K. 1890. Über eine Kohlenkalk-Fauna aus der ägyptisch–arabischen Wüste. *Z. deutsch. geol. Ges.* **42**, 419–449.

Ward, W. C., McDonald, K. C. and Mansour, S. E. I. 1979. The Nubia Formation of the Quseir-Safaga area, Egypt. *Ann. Geol. Surv. Egypt* **9**, 420–431.

Youssef, M. I. 1949. Stratigraphical studies in Kosseir area. Ph.D. Thesis, Alexandria University, Alexandria.

Youssef, M. I. 1957. Upper Cretaceous rocks in Kosseir area. *Bull. Inst. Desert Egypt* **7**, 35–54.

Youssef, M. I. and Shinnawi, M. A. 1954. Upper Cretaceous rocks of Wadi Sudr, western Sinai. *Bull. Inst. desert, Egypt* **4**, 94–111.

Zittel, A. K. 1883. Beiträge zur Geologie und Paläontologie der Libyschen Wüste und der angrenzenden Gebiete von Ägypten. *Paläontographica* **30**, 1–112.