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ORDOVICIAN ROCKS IN THE OMAN MOUNTAINS: THE AMDEH FORMATION[1]

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ABSTRACT

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Recent work in the Saih Hatat region of the Oman Mountains has established an early Ordovician age for the Amdeh Formation. This dating is based on assemblages of brachiopods, trilobites, and lamellibranchs together with microflora and trace fossils from several localities.

The formation comprises a sequence of shallow marine clastic rocks at least 3400 m thick which has been measured in detail in Wadi Kahza, some 40 km southwest of Muscat. The sequence may be divided into five members and a preliminary account of the stratigraphy is given, accompanied by illustrations of some of the characteristic sedimentary structures, macrofauna, and trace fossils.

The Amdeh Formation is a marine equivalent of the continental to shallow marine sediments of interior Oman and the Saq and Tabuk Formations of Saudi Arabia and southwest Jordan. It has apparently been subjected to Late Paleozoic orogenic movements tentatively related to the Hercynian Orogeny.

INTRODUCTION

The Saih Hatat region is the largest of a number of tectonic windows in the Oman Mountains that bring pre-Permian autochtonous rocks to the surface (Fig. 1). It occupies an area of some 1600 km^2 to the south of Muscat.

On the northern, western, and southern sides, the mainly low lying pre-Permian rocks are overlain by thick Permian and Triassic carbonates (the Saiq and Mahil Formations) which form great cliffs; to the east, however, the older rocks reach the coast.

In the north and northeast, the Permo-Triassic and pre-Permian rocks have both been involved in severe thrusting and recumbent folding probably in late Cretaceous times during the closing of the Hawasina Ocean (GLENNIE ET AL., 1974). The compression seems to have come from the northeast. Elsewhere in the Saih Hatat, the younger rocks are relatively undeformed and it is apparent from differences in dip and erosional truncation of thrusts that the pre-Permian rocks have undergone a quite separate earlier period of deformation, involving compression from the southwest. The fossil evidence recently obtained in the Amdeh Formation shows that this occurred in post-early Ordovician to pre-early Permian times, which is in agreement with a total rock K/Ar age of 327 ±20 Ma. obtained from altered basic rocks in the Hatat Metamorphics (GLENNIE ET AL., 1974).

The diametrically opposed directions of stress applied during these two separate tectonic episodes explain to a large extent the extremely complex tectonics of the northeast quadrant of the Saih Hatat and the increase in metamorphic grade seen there remarked upon by earlier workers.

The accompanying geological map (Fig. 1, after KAPP & LLEWELLYN, 1965, and GLENNIE ET AL., 1974) shows that the the pre-Permian geology of the Saih Hatat is dominated by the presence of three distinct mappable units, none of which has yet been formally described:

a) an undated shaly formation, the Hatat Metamorphics, including some altered ?volcanic rocks.
b) a carbonate sequence, the Hijam Formation, thought to belong to the Huqf Group of interior Oman and of probable Late Precambrian age. It is regarded by GLENNIE ET AL., (1974) as younger than the Amdeh Formation.

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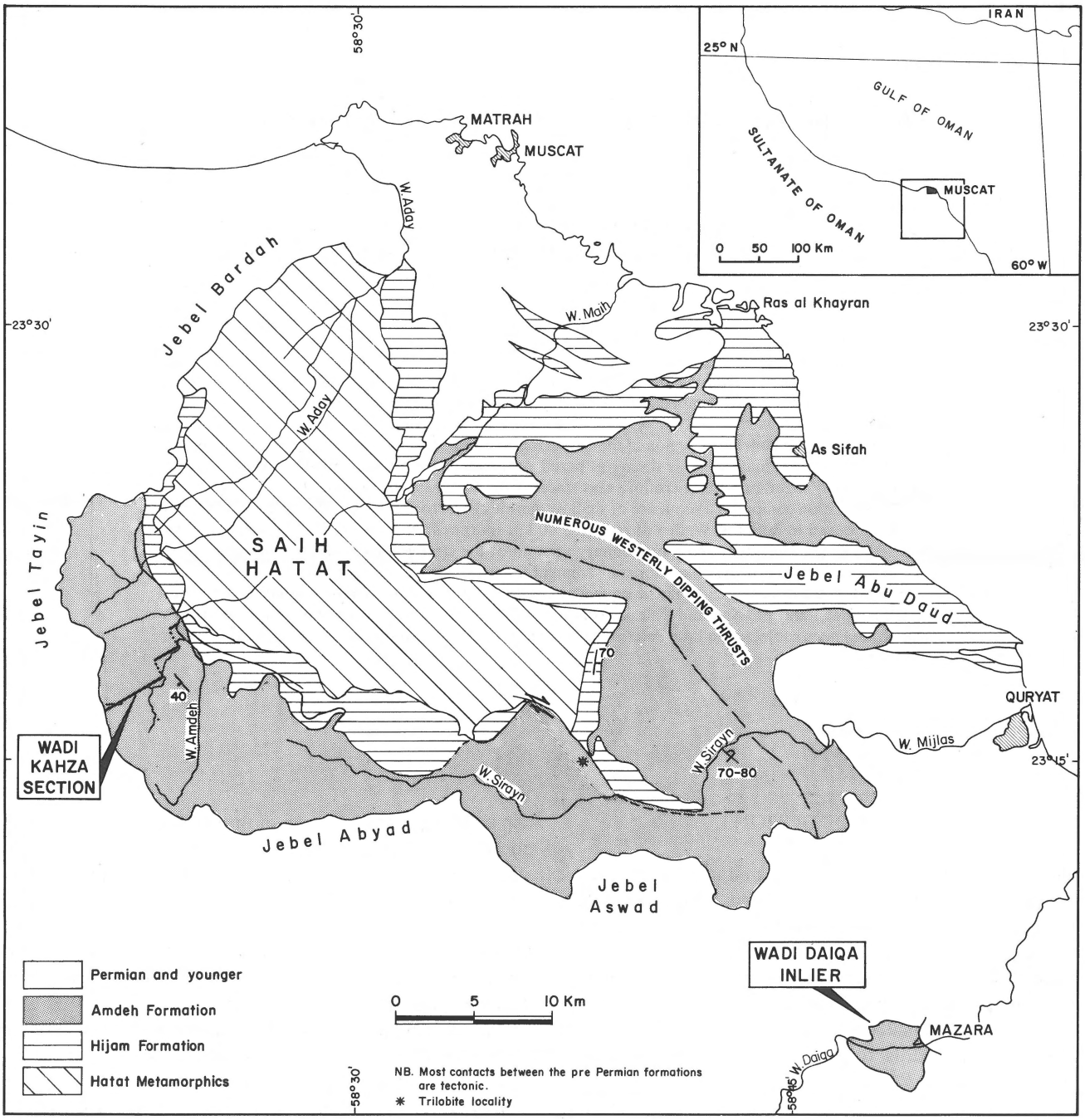


Fig. 1
Geological map of the Saih Hatat region, N. Oman (after Glennie et al., 1974).

c) a clastic sequence, the Amdeh Formation.

The name 'Amdeh' was originally restricted by LEES (1928) and by KAPP & LLEWELLYN (1965) to the thick sequence of relatively undeformed quartzites which crop out in the south-west and south of the Saih Hatat. However, GLENNIE ET AL. (1974) altered the definition to include the Hatat Metamorphics which they regard as a possible lateral equivalent of the Amdeh in a state of higher metamorphic grade. Although this may well be true, we recommend for the time being that the name 'Amdeh' is applied to the quartzite formation; in our view, the shaly formation should be referred to as 'Hatat Metamorphics' until such time as its relationship with the Amdeh has been clarified.

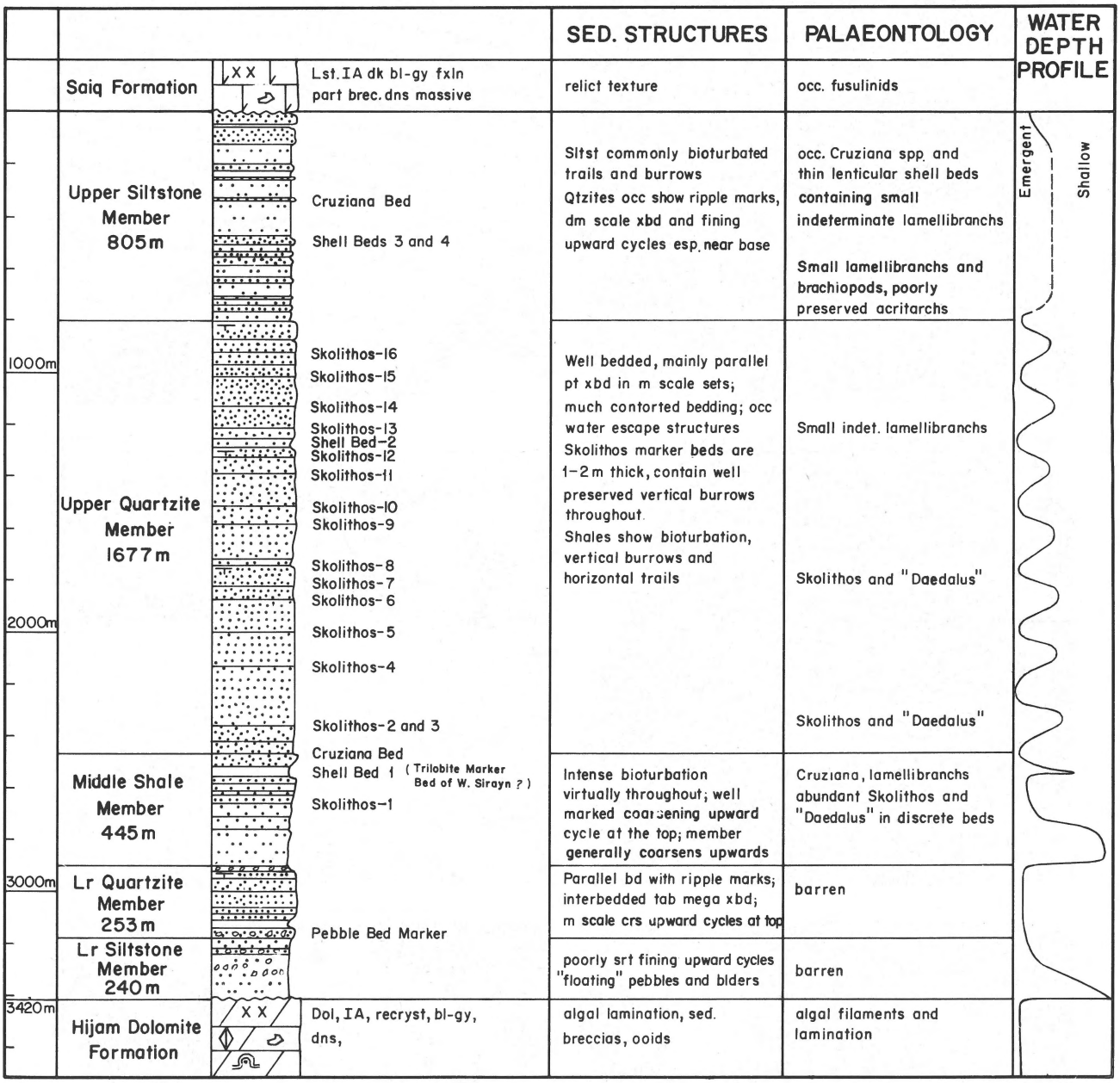
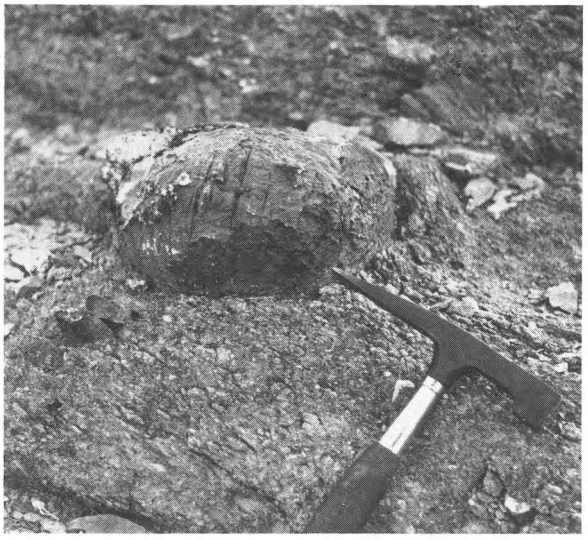


Fig. 2
Stratigraphic column of the Amdeh Formation – Wadi Kahza, Oman.

STRATIGRAPHY OF THE AMDEH FORMATION

The Amdeh Formation has been studied and measured in Wadi Kahza and the lower part of Wadi Amdeh about 40 km southwest of Muscat (Fig. 1). Additional sections have been studied in Wadi Sirayn and Wadi Daiqa. The rocks crop out in a deeply dissected arid mountain region which rises to a maximum summit level of 1560 m above sea level. Previous workers (LEES, 1928) regarded the section as probably the least disturbed and most complete in the region. The rocks dip monoclinally at an average of 40° to the west and exposure is virtually 100%.

The section was measured using a ranging pole placed normal to the bedding and thicknesses periodically checked by measurements of outcrop width and average dip with assistance of air photographs. The total thickness was found to be about 3400 m ± 10% (see Fig. 2) and the sequence may be divided into five conformable members described below starting at the base.



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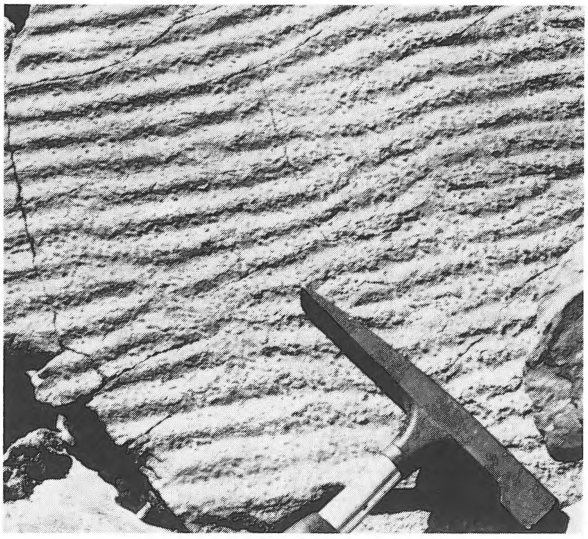

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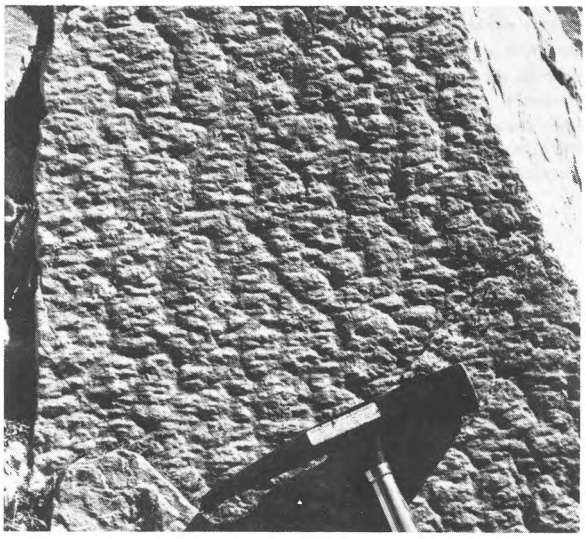

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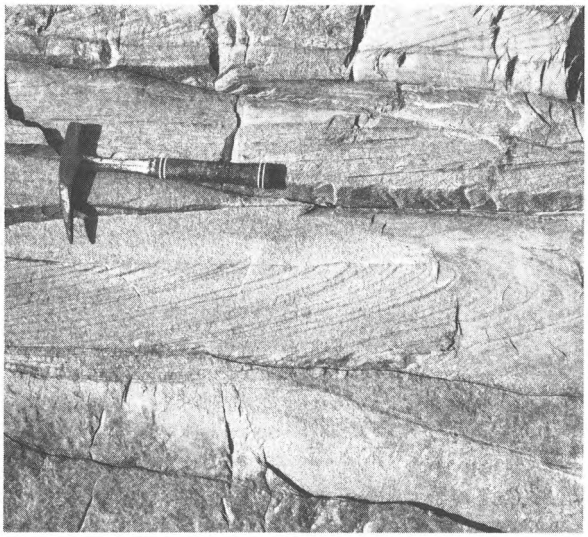

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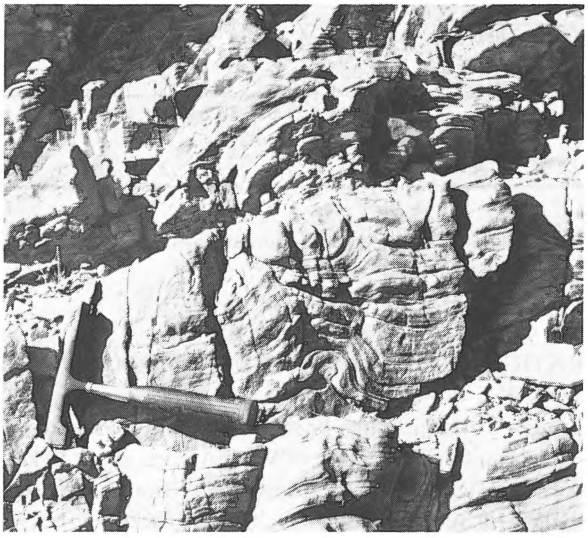

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Fig. 3
Sedimentary features of the Amdeh Formation: a Boulder of Hijam Dolomite 'floating' in a finer-grained poorly sorted matrix (Lower Silstone Member, Wadi Kahza), b Wave-ripple surface with questionable rain or hail prints (Lower Quartzite Member, Wadi Kahza), c Sandstone bedding surface with possible adhesion warts (Lower Quartzite Member, Wadi Kahza), d Sedimentary overfolds, (Upper Quartzite Member, Wadi Sirayn), e Medium-scale liquefaction structure (Upper Quartzite Member, Wadi Kahza), f Small-scale liquefaction structure (Upper Quartzite Member, Wadi kahza).

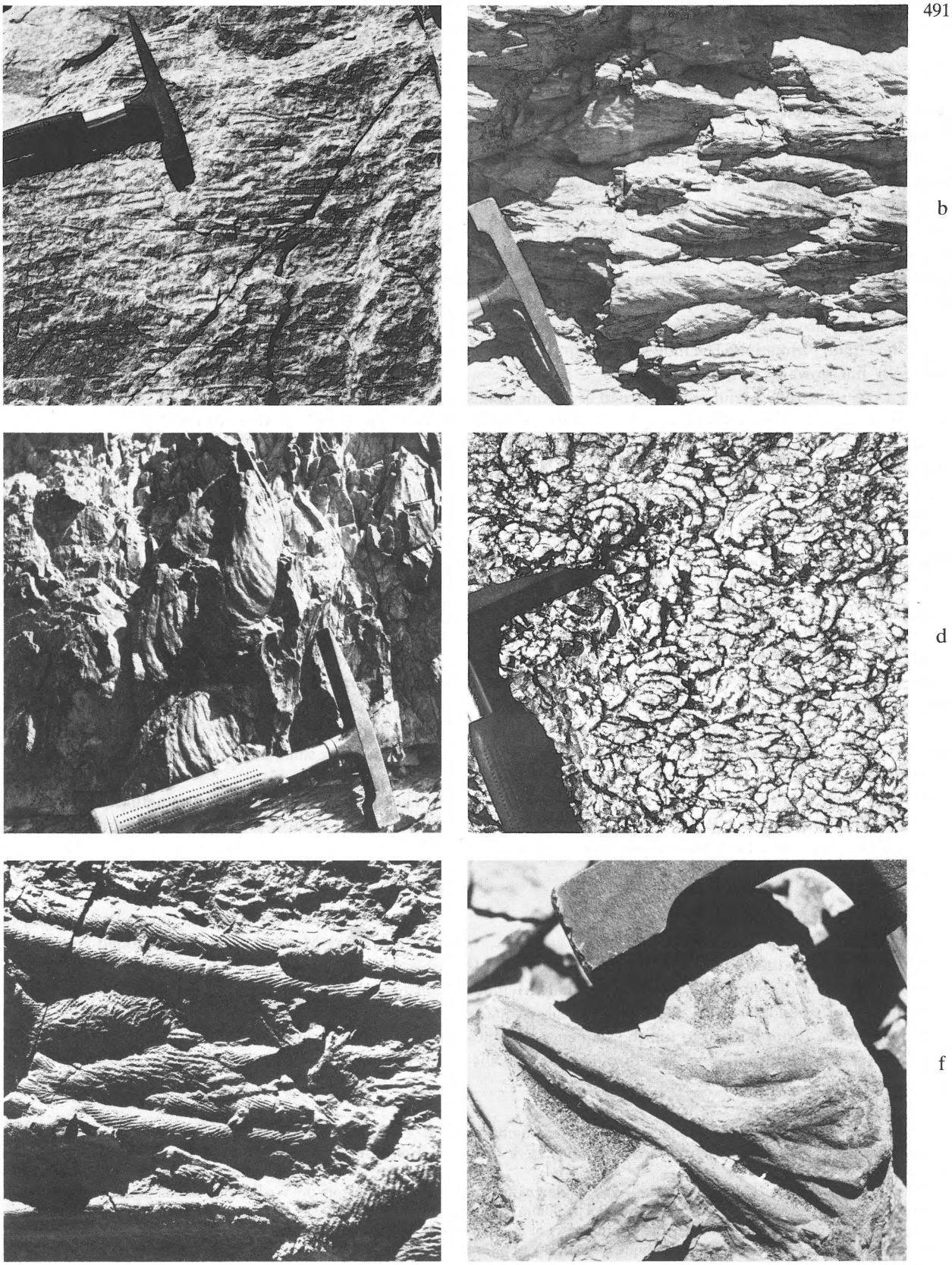

Fig. 4
Trace fossils from the Amdeh Formation: a *Skolithos,* Upper Quartzite Member, Wadi Sirayn, b *Daedalus?,* Vertical section, Middle Shale Member, Wadi Sirayn, c *Daedalus?,* Vertical section, Middle Shale Member, Wadi Kahza, d *Daedalus?,* cross section, Middle Shale Member, Wadi Kahza, e *Cruziana,* Middle Shale Member, Wadi Sirayn, f *Phycodes?,* Wadi Daiqa.

(1) *Lower Siltstone Member (240 m)*

This unit is thought to rest unconformably on the Hijam Formation but actual contacts are in most cases tectonised to varying degrees. The Lower Siltstone Member comprises greenish-grey poorly bedded pebbly siltstones and sandstones with rounded dolomite boulders up to 1 m in size. (Fig. 3a). The boulders occur both dispersed and in distinct horizons. They are texturally indistinguishable from the Hijam Formation and are most probably derived from it. The pebbles in this unit consist of dolomite, chert, siltstone, and quartzitic sandstone and they are also thought to have been mainly derived from the Hijam Formation. The individual sedimentary units generally fine upwards in metre-scale beds.

The Lower Siltstone Member is regarded as marine and is thought to represent the infill of a rapidly inundated Hijam paleo-relief by means of intermittent mass gravity transport and sedimentation from suspension. We take the dolomite boulders to be clear evidence that the Amdeh Formation is younger than the Hijam Formation.

(2) *Lower Quartzite Member (253 m)*

The base is taken at the bottom of a clean, sorted conglomerate bed, comprising mainly rounded chert pebbles. Apart from the basal part, which is shaly and poorly exposed, the Lower Quartzite Member consists of pale grey to pale brown well bedded quartzitic sandstones. Bedding type is mainly parallel with well-preserved wave ripples (Figs. 3b and 3c) on many bedding surfaces and indications of subaerial exposure. Occasionally metre-scale tabular mega-crossbedded (lateral accretion) units are intercalated. Towards the top, a few coarsening upwards sequences occur.

The Lower Quartzite Member is thought to form part of a coastal barrier system.

(3) *Middle Shale Member (445 m)*

The base is placed at the top of the last coarsening upwards sequence of the underlying unit. The Middle Shale Member comprises poorly bedded shales, siltstones and shaly to quartzitic sandstones. From bottom to top the sequence becomes sandier. Intense bioturbation occurs throughout, with discrete generally sandier beds showing well preserved *Skolithos, Daedalus* and *Cruziana* (Fig. 4a-e).

Daedalus (?) occurs mainly in the upper part in discrete beds 1-2 metres thick which are packed with easily recognizable impressions or moulds which have a left-handed spiral structure. Figs. 4b and 4c show the typical appearance of this trace fossil in sections normal to the bedding and Fig. 4d shows the characteristic pattern seen on a bedding plane surface. Although generally the height of a typical specimen is about 15-20 cm, much larger, metre-scale varieties have been observed. The affinities of this trace fossil are unknown.

The Middle Shale Member is thought to represent a change to lower energy deposition in a shallow marine shelf environment.

(4) *Upper Quartzite Member (1677 m)*

The base is marked by an abrupt increase in thick sandy beds and by a sharp reduction in shale, clearly visible in air photographs. It corresponds with the top of the last *Cruziana* bed of the underlying shaly unit. The Upper Quartzite Member comprises grey-brown well bedded quartzitic sandstones intercalated with argillaceous sandstones and occasional thin shale beds. Metre-scale tabular crossbedding, parallel lamination, oversteepened foresets (Fig. 3d), liquefaction structures (Figs. 3e and 3f) and bioturbated beds are common. The sequence may be conveniently subdivided by fifteen *Skolithos* marker beds (Fig. 4a) and appears to be cyclic in nature. *Daedalus?* occurs in the lower part, and thin lenticular shell beds containing small indeterminate lamellibranchs appear in the upper part.

The member is regarded as originating in a rapidly subsiding coastal to shallow-marine shelf environment.

(5) *Upper Siltstone Member (805 m)*

The base is taken at the last thick quartzitic sandstone unit of the underlying Member. The top is eroded and unconformably overlain by the Permian Saiq Formation. The Upper Siltstone Member comprises greenish-grey siltstones, intercalated with quartzitic sandstones, argillaceous sandstones and occasional shale beds. Bioturbation is common in the middle part of the unit while in the upper part metre-scale

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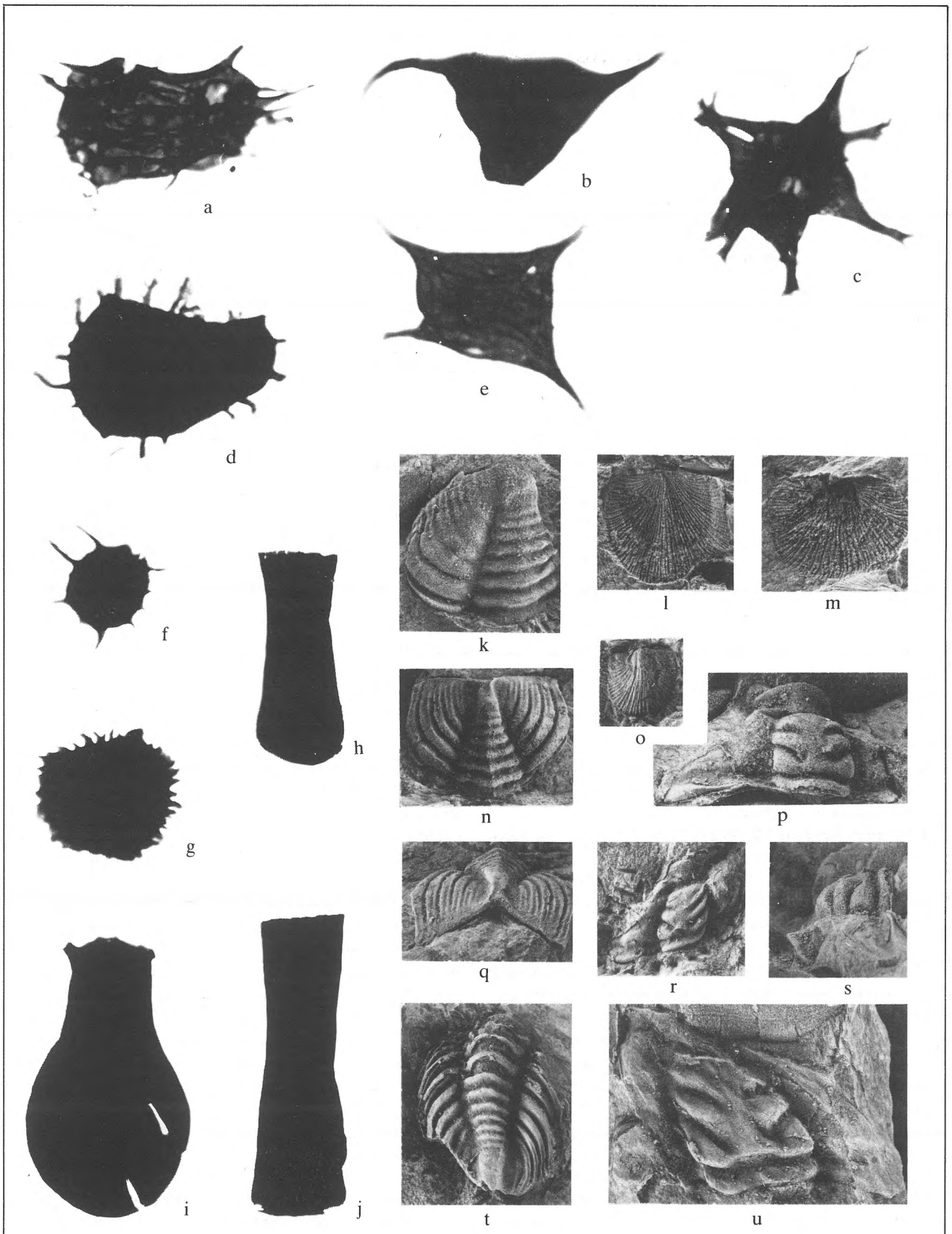
Fig. 5 (facing page)
Microflora and Fauna from the Amdeh Formation: a *Actinotodissus* sp., b *Arkonia* sp. (incomplete specimen), c *Multiplicisphaeridium* sp., d *Stelliferidium* sp., e *Striatotheca* sp., f *Micrhystridium* sp., g *Comasphaeridium* sp., h *Conochitina* sp., i *Lagenochitina* sp., j *Conochitina* sp.

Acritarchs (X 1000) and chitinozoa (X 250). All specimens are single grain mounts from the Wadi Daiqa assemblage: k, n, p-u. *Neseuretus?* sp. nov., k dorsal view of internal mould of broken pygidium, SM. A/109718., n, q dorsal and posterior views of internal mould of complete pygidium, SM. A/109721., p, s dorsal and lateral views of internal mould of cranidium SM. A/109723., r dorsal view of internal mould of distorted cranidium SM. A/109724., t oblique dorsal view of internal mould of pygidium with attached thoracic segments, SM. A/109725., u dorsal view of internal mould of large cranidium SM. A/109726.

l, m, o, ? Dalmanellid: l external mould of brachial valve, SM. A/109719., m external mould of pedicle valve, SM. A/109720., o internal mould of brachial valve, SM. A/109722.

All specimens of *Neseuretus* and ? dalmanellid brachiopod from the Amdeh Formation, Wadi Sirayn. All magnifications x 2. Photographs and description courtesy of C. P. Hughes. SM = Sedgwick Museum Collections, Department of Earth Sciences, Cambridge University, U.K.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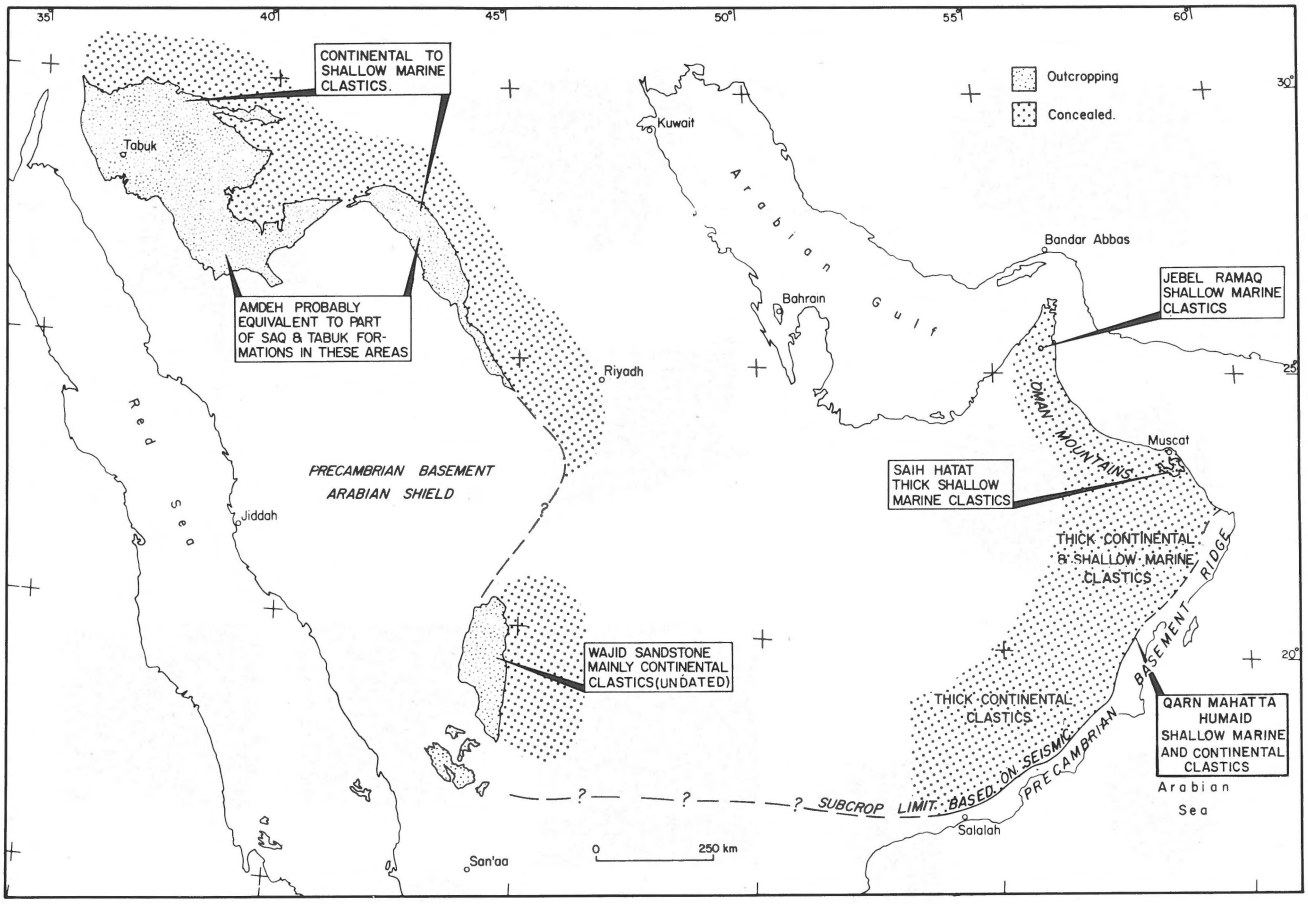

Fig. 6
Map showing distribution of Cambro – Ordovician clastic formations in the Arabian Peninsula.

tabular crossbedding together with an increase of coarse sand occurs. Locally, shell beds and beds containing *Cruziana* are present. In the lower part, some shale beds yielded a fragmentary microflora (see below).

The Upper Siltstone Member is thought to represent deposition in a shallow marine shelf environment.

PALEONTOLOGY

Paleontological evidence relating to the age of the Amdeh Formation has been derived from studies of the macrofauna, microfauna, microflora, and trace fossils. A macrofauna consisting mainly of brachiopods, lamellibranchs and trilobites, mostly preserved as internal and external moulds (Fig. 5), was recovered from the Middle Shale Member of the Amdeh Formation near Wadi Sirayn (23°15′ N, 58°38′ W). This material has been examined by Dr. C. P. Hughes and others (C. P. Hughes, written communication, material deposited at the Sedgwick Museum, University of Cambridge).

The trilobite *Neseuretus?* sp. nov. is considered by Hughes to indicate an Ordovician, probably pre-Caradocian age. Some ? dalmanellid brachiopods from the same assemblage are thought by Dr. M. Lockley and Dr. A. Williams to indicate an Ordovician age possibly as young as Caradocian. Hughes summarizes the macrofaunal evidence by suggesting that the most likely age is within the range Arenigian to Llandeilian. Two poorly preserved conodonts isolated by Dr. M. J. Orchard (C. P. Hughes, written communication) are considered by him to indicate an Ordovician to Silurian age, possibly towards the younger end of the age range suggested for the macrofauna, namely Llanvirnian-Llandeilian.

Samples from a location in Wadi Kahza (23°17′ N, 58°21′ W) near the base of the Upper Siltstone Member, and from a shaly horizon in the Amdeh Formation of the Wadi Daiqa inlier (23°05′ N, 58°50′ W) have yielded microfloral assemblages. The Wadi Kahza material consists of the fragmented and to a large extent carbonised remains of acritarchs attributable to the genera *Arkonia, Micrhystridium, Protoleiosphaeridium, Striatotheca* and *Veryhachium.* The Wadi Daiqa assemblage (Fig. 5) consists of specimens in a less fragmented state and includes in addition to the forms mentioned above specimens attributable to the genera *Actinotodissus, Comasphaeridium, Goniosphaeridium, Leiofusa, Multiplicisphaeridium, Peteinosphaeridium,* and *Stelliferidium.* Chitinozoa, for the most part representatives of the genera

Conochitina and *Lagenochitina*, are also present in the Wadi Daiqa assemblage. The Wadi Kahza samples yielded only fragmented specimens of Chitinozoa. The constitution of both these assemblages is consistent with an Ordovician age; the presence of *Arkonia* sp. lends most support to a Llanvirnian age designation.

Photographs of trace fossils from Amdeh Formation outcrops in Wadi Daiqa, Wadi Kahza and Wadi Sirayn have been examined by Dr. T. P. Crimes. In the absence of the original material, Crimes (written communication) tentatively identified *Cruziana furcifera, C. rugosa, Phycodes circinatum* (Fig. 4f), and *Daedalus*, (Figs. 4b, 4c, 4d) all of which he considers indicative of an Ordovician, most probably Arenigian age.

The evidence from fossils summarized here indicates that the Amdeh Formation has an age for the most part, if not entirely, within the range of Early and Middle Ordovician.

REGIONAL IMPLICATIONS

Figure 6 illustrates the distribution of formations of known or presumed Cambro-Ordovician age in the wider Arabian region. It is clear from this map that the Saih Hatat together with the inlier at Jebel Ramaq (HUDSON ET AL., 1954) and the outcrop at Qarn Mahatta Humaid (MORTON, 1959) provides an important eastern control point on the palaeogeography of part of this time interval. The Amdeh Formation appears to represent a thick and largely shallow-marine equivalent of the mainly continental clastic rocks seen in the interior of Arabia. On the basis of published accounts by POWERS (1968) and SELLEY (1972), we tentatively correlate the Amdeh Formation with the upper part of the Saq and lower part of the Tabuk Formations of northern Saudi Arabia and the equivalent formations outcropping in southern Jordan. Unfortunately the palaeontological control in the Amdeh Formation is inadequate to correlate more precisely.

Recognition of the Early-middle Ordovician age of the Amdeh Formation demonstrates that northern Oman was affected by severe orogenic movements during late Palaeozoic times (?Hercynian). These include recumbent folding, severe overthrusting and some regional low-grade metamorphism accompanied by minor igneous activity. From evidence in the Saih Hatat, the compression appears to have been from the south-west but details are obscured by subsequent tectonic events which took place in Cretaceous and Tertiary times.

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