Miocene stratigraphy, geology and flora (Algae) of eastern Saudi Arabia and the Ad Dabtiyah vertebrate locality

P. J. Whybrow

Department of Palaeontology, British Museum (Natural History), Cromwell Road, London SW7 5BD

H. A. McClure

Arabian American Oil Company, Dhahran, Saudi Arabia

G. F. Elliott

Department of Palaeontology, British Museum (Natural History), Cromwell Road, London SW7 5BD

Synopsis

Studies of the Miocene deposits in eastern Saudi Arabia are briefly reviewed. The stratigraphical succession is explained and the geological details of the vertebrate-bearing, non-marine deposits at Ad Dabtiyah presented. The stratigraphical position of the fossiliferous beds is believed to lie near the boundary of the continental sequence of the Hadrukh Formation and continental equivalents of the Dam Formation, the beds themselves locally close to, and the lateral equivalent of, the basal deposits of the Burdigalian marine carbonates of the Dam Formation. The fresh-water depositional environment at Ad Dabtiyah contains many bones of terrestrial vertebrates, found in close association with several large stromatolitic bioherms. These, and similar encrustations also of a fresh-water origin, are associated with *in situ* logs, probably of palm trees. Overall, both the stratigraphical position of the Ad Dabtiyah deposits and their contained fauna suggest an age of about 17–19 Ma; middle Orleanian (European land-mammal age equivalent); early Burdigalian (marine chronology).

Introduction

Until the 1930s, almost nothing was known of the geology of the central part of the Arabian Peninsula. Observations on its general geology had been carried out by Philby (1933) during his explorations of Saudi Arabia, and his fossil collections were presented to the British Museum (Natural History) by King Abdul Aziz ibn-Saud. Cox (1933) studied the Tertiary fossils Philby had found at a hill called Qarn Abu Wayil (Fig. 2) and identified the oyster *Ostrea latimarginata*, and natural casts of *Mytilus*, *Anomia*, *Cardium*, *Clementia*, *Anadara* and other molluscs previously known from the Lower Fars rocks of Iran. South of Qarn Abu Wayil at Jaub Anbak (Fig. 2), Philby had noted the marine beds were overlain by a considerable thickness of red sandstones which Cox suggested might also be of Miocene age, but equally might be equivalent to the Pliocene Bakhtiyari deposits of Iran (Cox, *in* Philby 1933: 386–387). Cox's work therefore provided the first evidence of the presence of Miocene rocks in Arabia.

Mapping and surface collecting by geologists of the Arabian American Oil Company, ARAMCO, started in the mid-1930s and revealed in detail the extent of Miocene deposits in eastern Saudi Arabia. Three formations were formally designated (Steineke *et al.* 1958), together with the lithological details at their type localities. Later, the first published evidence that vertebrate fossils occurred in the region was given by Powers *et al.* (1966: D97) who recorded 'vertebrate fragments' in their lists of the Miocene biota.

In 1974 a collection of Miocene crocodile, turtle, antelope, rhinoceros and proboscidean remains was presented to the British Museum (Natural History), representing the first known

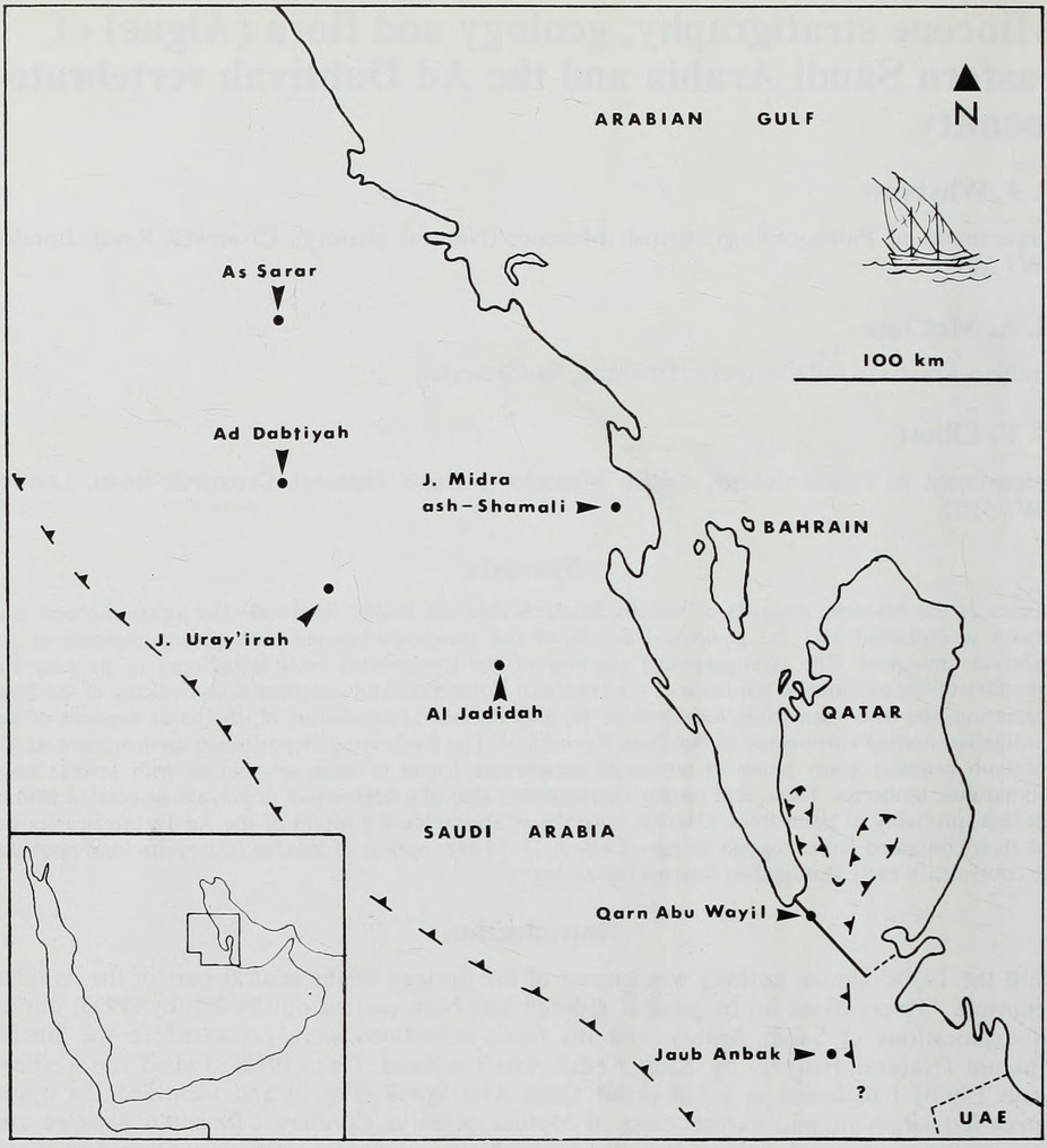

Fig. 2 Eastern Saudi Arabia, the State of Qatar and part of the United Arab Emirates showing localities referred to in the text. The most western extent of the Miocene deposits in Saudi Arabia and their location in south-western Qatar is indicated.

vertebrate palaeofauna from Arabia (BM(NH) 1975: 18). In the same year staff of the Palaeontology Department added more material by collecting from Miocene continental deposits at Ad Dabtiyah (Fig. 2). They also collected vertebrate-bearing rocks near a hill called Jabal Midra ash-Shamali, *c.* 6 km north-west of Dhahran (Fig. 2) where Tleel (1973) had discovered 'artiodactyl' remains. Chemical breakdown of these rocks yielded rodent, lagomorph and bovid teeth and preliminary reports on the faunas from both localities were published (Hamilton *et al.* 1978; Andrews *et al.* 1978). Further work on the Ash-Shamali material showed a new genus of fruits of aquatic plants, *Midravalva arabica* (Collinson 1982), to be present, together with new rodents, *Arabosminthus quadratus* and *Shamalina tuberculata* (Daams, *in* Whybrow *et al.* 1982: 111–116).

In 1978, H. Thomas of the Museum National d'Histoire Naturelle, Paris, and colleagues excavated vertebrate fossils, *Percrocuta*, *Gomphotherium angustidens*, *Dicerorhinus*, *Lopholistriodon*, *Pachytragus*, *Protragocerus*, *Caprotragoides* and a new rodent, *Metasayimys intermedius*, from red-coloured sandstones at Al Jadidah (Fig. 2); see Thomas *et al.* (1978), Sen & Thomas (1979), Thomas (1983). Later, they collected from the As Sarar region (Fig. 2) in collaboration with the Saudi Arabian Department of Antiquities. Abundant vertebrate remains were found including two gomphothere species, a deinothere, several carnivores and cricetid, ctenodactylid, dipodid, gerbellid, pedetid and phiomorph rodents (Thomas *et al.* 1982).

These discoveries of terrestrial vertebrates in eastern Arabia have now bridged the palaeogeographical gap between the better-known Miocene faunas of Africa and those of south-western Asia. In addition, interpretations of the eastern Arabian palaeoenvironments have been made (Whybrow & McClure 1981; Thomas *et al.* 1982; Whybrow *et al.* 1982) and, because of the proximity of the fossil localities to the contracting Tethys epicontinental seaway, there have been suggestions concerning the location of a Neogene land connection between Arabia and south-western Asia (Adams *et al.* 1983; Rogl & Steininger 1983; Whybrow 1984; Thomas 1985).

The collected papers in this issue of the *Bulletin*, with the exceptions of the descriptions of a delphinoid ear bone and a gomphothere tooth from other localities, are the results of studies on the Ad Dabtiyah fauna and flora collected and donated in 1974.

Stratigraphy and the age of the deposits

Towards the end of the middle Eocene, widespread emergence of the eastern Arabian shelf coincided with continued uplift and a slight north-easterly tilting of the Arabian plate, events that began in the late Cretaceous and continue today as a consequence of the movement of the Arabian plate against the more stable south-western Asian plate. Red Sea rifting was also a contemporaneous consequence of this plate activity (Schmidt *et al.* 1983; Sellwood & Netherwood 1984). Since that time mainly continental deposition, with the exception of a marine transgression from the Indian Ocean, has prevailed in eastern Arabia. Rocks of Oligocene age have not been recognized in the region; Miocene deposits unconformably overlie rocks of Ypresian or Lutetian age.

Where the rocks formed by the marine transgression (represented by the Dam Formation) occur, the continental Neogene has been divided into units. From the oldest, these are the Hadrukh Formation (*c.* 20–120 m thick), succeeded by the Dam Formation itself (*c.* 30–100 m thick), and the Hofuf Formation (*c.* 30–100 m thick).

Towards the western interior, where the marine marker beds of the Dam intercalate with the continental deposits, become thin and eventually disappear, the eastern divisions of Hadrukh, Dam and Hofuf no longer apply. The undifferentiated deposits are treated as a single un-named unit—Tertiary continental sandstone, marl and limestone, marked 'Tsm' in Figs 3 and 5 (Steineke *et al.* 1958). In such deposits a gomphothere $M^2 + M^3$ (M.42946) was found in the 1930s; see Gentry, p. 401 in this issue.

The age of the Hadrukh is important and is currently controversial (see Whybrow 1984) as it contains a new cricetid rodent, *Shamalina tuberculata*, whose descendant relatives appear to be present in the Miocene Lower Siwaliks of Pakistan (Daams, *in* Whybrow *et al.* 1982; E. H. Lindsay, personal communication 1985). The Hadrukh is undoubtedly coeval with the Ghar Formation of Kuwait and southern Iraq and, in the neighbouring part of Iran, 215 m (700 ft) of sandstone (subsurface section from a drill hole) is said to be the eastern wedge-end of the Ghar Formation and called the Ahwaz Sandstone (James & Wynd 1965: 2229). Adams *et al.* (1983: 278) indicated that at least part of the Ahwaz Sandstone is of Late Oligocene (Chattian) age, but Murris (1980: 614) suggested an Early Miocene, Aquitanian, age for these deposits, which he called the Ahwaz delta formed from eroded Saudi Arabian pre-Neogene rocks. Thin beds near to the top of the Hadrukh contain poorly-preserved marine molluscs and the oyster *O. latimarginata* which indicates a Burdigalian (marine chronostratigraphy) age. These beds crop out in a small area near the modern coastline; their lithology has not been described and

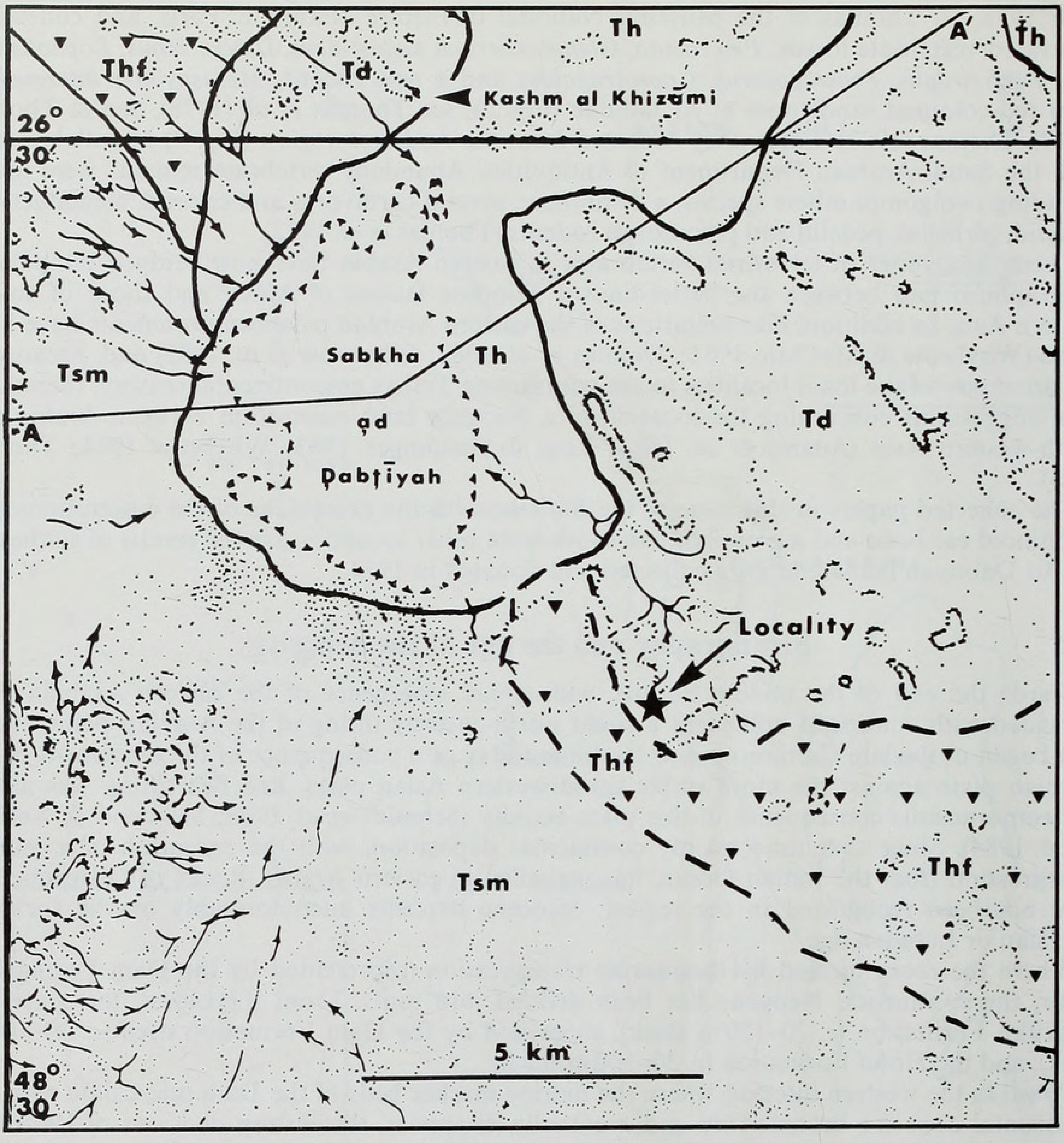

Fig. 3 Geology and topography around Sabkha Ad Dabtiyah and the position of the vertebrate-bearing locality. Tertiary units are: Th = Hadrukh Formation, Td = Dam Formation, Thf = Hofuf Formation, Tsm = undifferentiated continental equivalents of the Dam and Hofuf Formations. Broken line indicates that the contact is uncertain. A–A′ refers to the schematic cross-section in Fig. 5. Adapted from Steineke *et al.* (1958).

they are the only evidence of marine Hadrukh in Saudi Arabia (Powers *et al.* 1966: D93). They may be in part coeval with the basal Miocene of Qatar; see below.

The continental Hadrukh must be older than the overlying marine carbonates of the Dam Formation, and its thickness in Kuwait of 244 m, together with regional stratigraphy, suggests that a 21–18 Ma age for its deposits in eastern Arabia is a plausible estimate.

Adams *et al.* (1983: 278) pointed out that there should be a distinct 'discontinuity between the Hadrukh and the overlying Dam Formation'. The top of the Hadrukh as defined by Steineke *et al.* (1958: 1313) is 'at the base of the *Echinocyamus*-bearing limestone and marl of the basal Dam'. This echinoid *Echinocyamus* was described by Kier (1972) as *Fibularia damensis*. The limestone in which it occurs is known as the 'Button bed'; it is an echinoid coquina, which has been used as a Miocene marker horizon throughout eastern Saudi Arabia and Qatar. It also marks the change from mainly clastic continental deposition to a shallow-water marine carbonate environment. A local discontinuity has been observed in the basal Miocene sequence of Qatar. Here marine carbonates and the Button bed overlie thinly bedded ferruginous claystones showing desiccation and rainspot structures and an intraformational conglomerate in erosional contact with underlying medium-bedded sandstones (Whybrow & Bassiouni 1986).

The marine biota of the Dam Formation is of an Indo-West Pacific origin and dated as Burdigalian, about 16–19 Ma, a time when there was no marine connection with the Mediterranean (Kier 1972; Adams *et al.* 1983).

Basal continental extraformational conglomerates and sandstones of the Hofuf Formation unconformably overlie the Dam Formation marine carbonates. The contact is well represented in Qatar where the Dam terminates in a regressive evaporitic phase. The vertebrate-bearing Hofuf locality of Al Jadidah lies stratigraphically about 30 m above the contact of Hofuf conglomerates with the underlying Dam Formation. Some 70 m of red-coloured sandstones overlie the vertebrate horizon (Thomas 1978; Fig. 2). From his study of the bovids found at Al Jadidah, Thomas (1983) concluded that their age is close to that of the Fort Ternan, Kenya, vertebrate locality dated at 14 Ma (Shipman *et al.* 1981).

The Ad Dabtiyah locality

Sabkha ad-Dabtiyah, a large salt flat (*sabkha*), from which the vertebrate-bearing site takes its name, is the dominant topographic feature of the area. It occupies the central part of a local drainage depression, itself probably a reflection of an underlying minor post-Miocene structure, and is surrounded by low hills and long mesa-topped escarpments of Neogene rocks. The whole region, generally bare of both vegetation and Recent sediments, is heavily dissected by small wadis (Fig. 3).

The vertebrate-bearing sediments (26° 27′ 02″ N, 48° 35′ 24″ E) were first discovered during geological mapping surveys in the late 1930s (Fig. 4). The locality is about 4 km from the

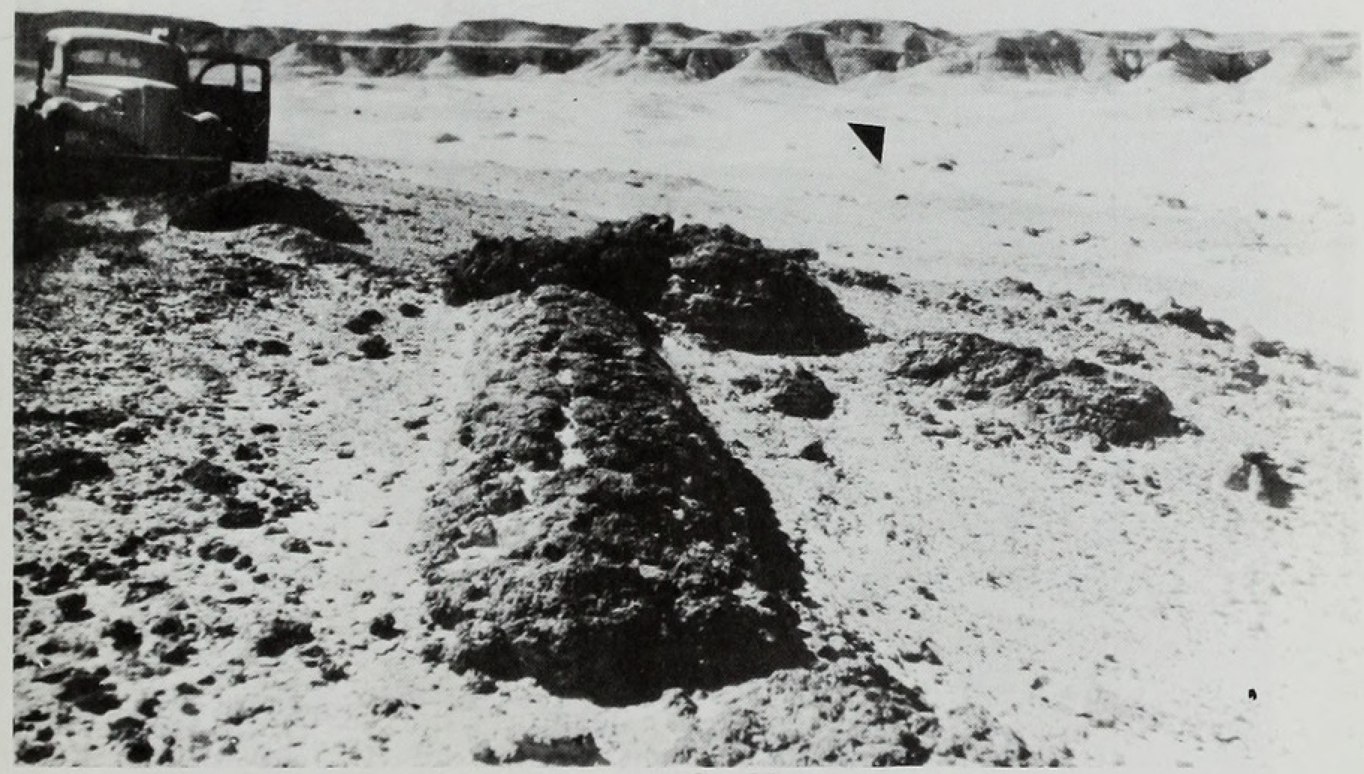

Fig. 4 Photograph of part of the Ad Dabtiyah locality taken by geologists of the Arabian American Oil Company in the early 1930s; note the Ford field vehicle. In the foreground are *in situ* 'logs' encrusted with stromatolite. View is south-west; compare drainage channel (arrow) with Fig. 6.

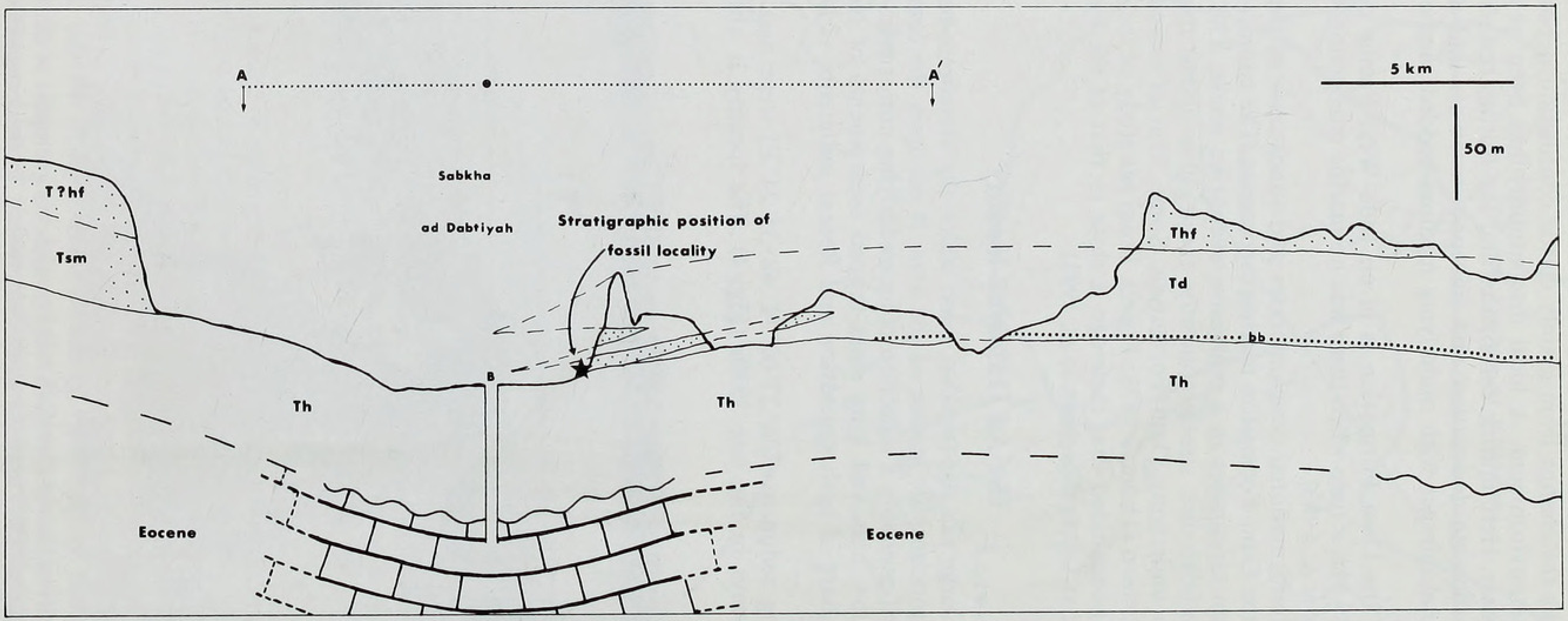

Fig. 5 Schematic cross section around the Ad Dabtiyah locality. The unconformity between Neogene and Eocene rocks is indicated; B = a bored water well that provided subsurface information, bb = 'Button bed'. See Fig. 3 for other abbreviations.

south-eastern edge of the sabkha, in hummocky terrain. The low-lying area with centripetal drainage into Sabkha ad-Dabtiyah is floored by continental sediments mapped as Hadrukh Formation. Along a north-westerly line and to the east, low hills mapped as Dam Formation flank the sabkha, while stratigraphically higher and to the north-west and south-east gravels and sandstones of the Hofuf Formation occur. To the south-west, beyond the limits of marine Dam outcrops, the Neogene formations cannot be divided, see p. 373.

Fig. 6 Similar view to Fig. 4 (photo taken 1979) showing the *in situ* 'logs'. The drainage channel, shown in Fig. 4, indicates little erosion in over 40 years. Tape = 1 metre.

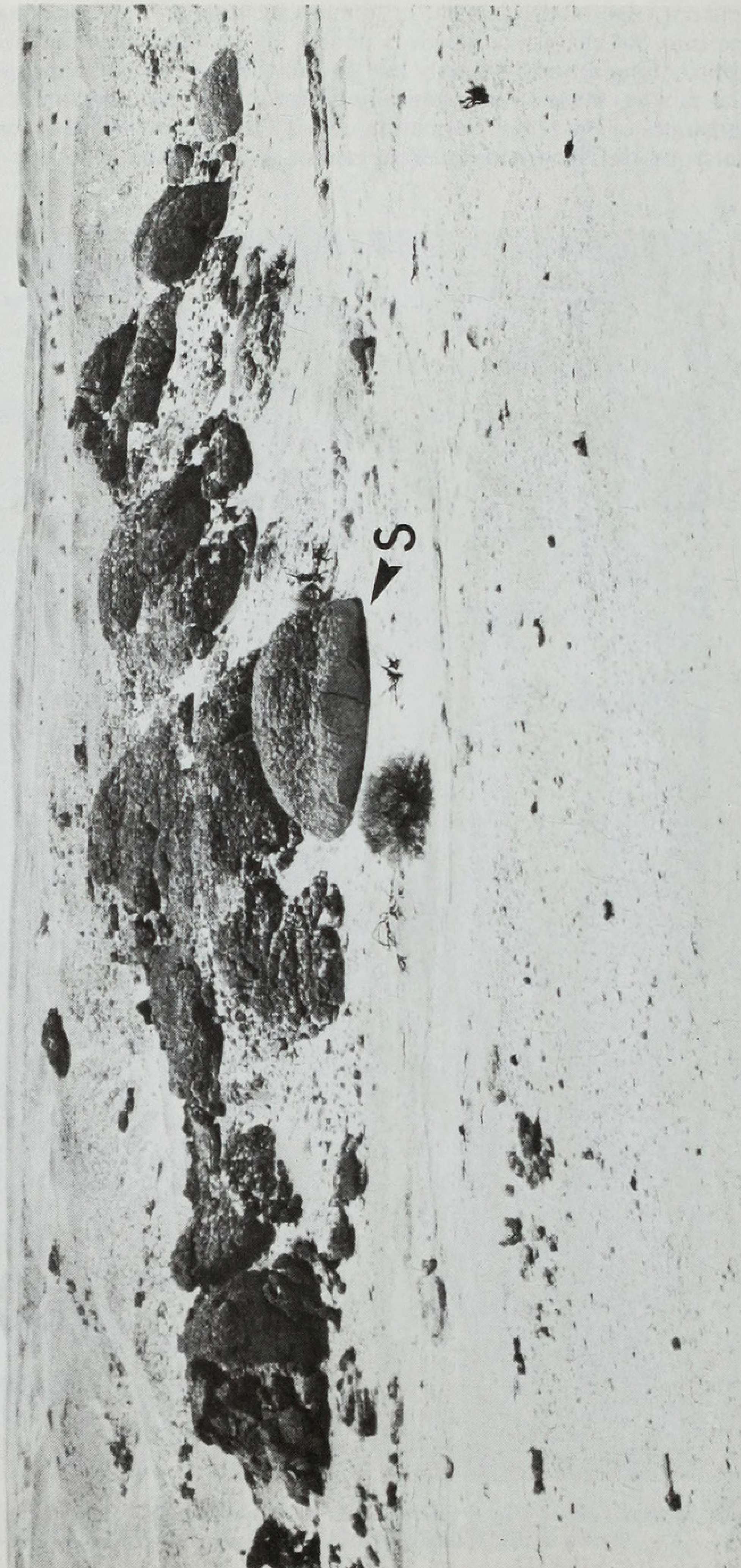

Fig. 7 Large stromatolitic bioherms found to the north-east of the vertebrate locality. S measured 223 cm in width.

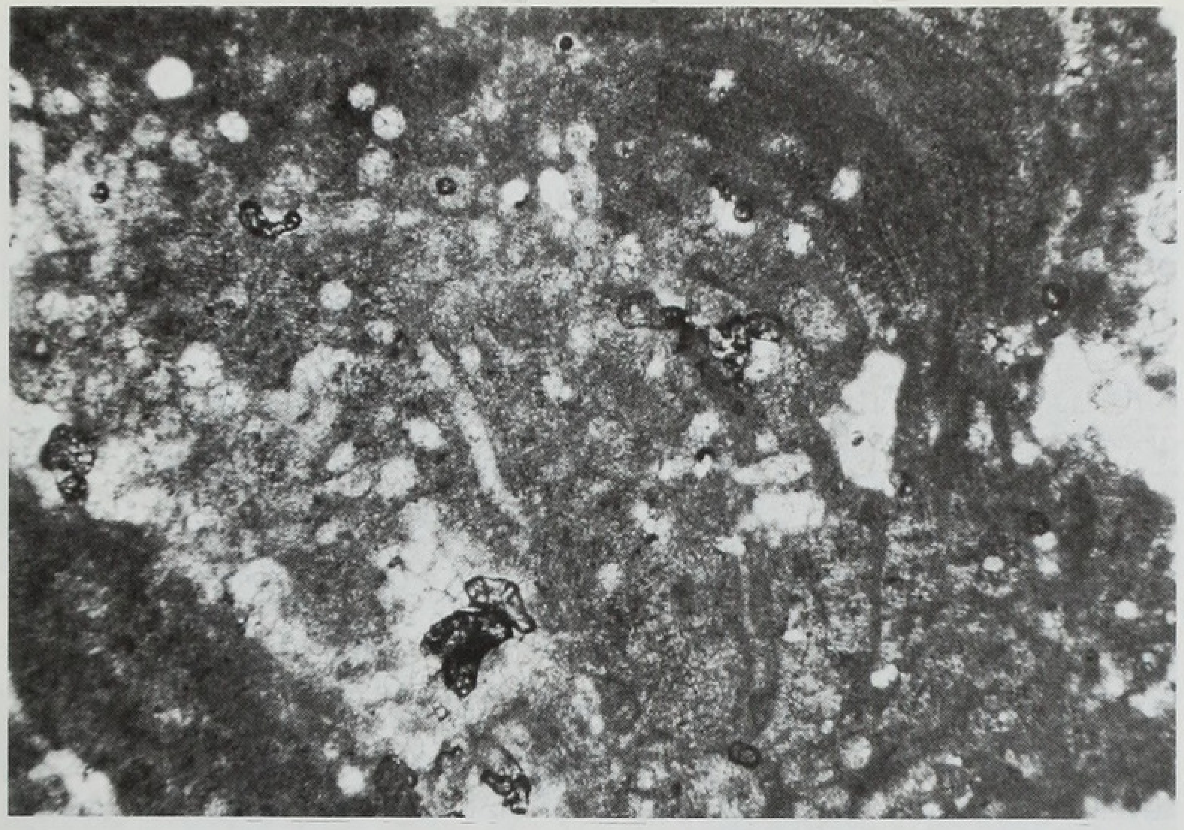

Fig. 8 Photomicrograph of a thin section of calcareous crust (V.60434c) found covering the skull of a rhinoceros. Banded algal growth of radial cyanophyte filaments are at top right. × 45.

The vertebrate site lies at or near the contact of the Hadrukh Formation with other continental sediments coeval with and laterally equivalent to the basal parts of the marine Dam sequence. The basal Dam marker horizon—the 'Button bed' with *Fibularia damensis*—is absent at the locality, but is found about 10 km to its east. The south-western limit of the Dam sea in

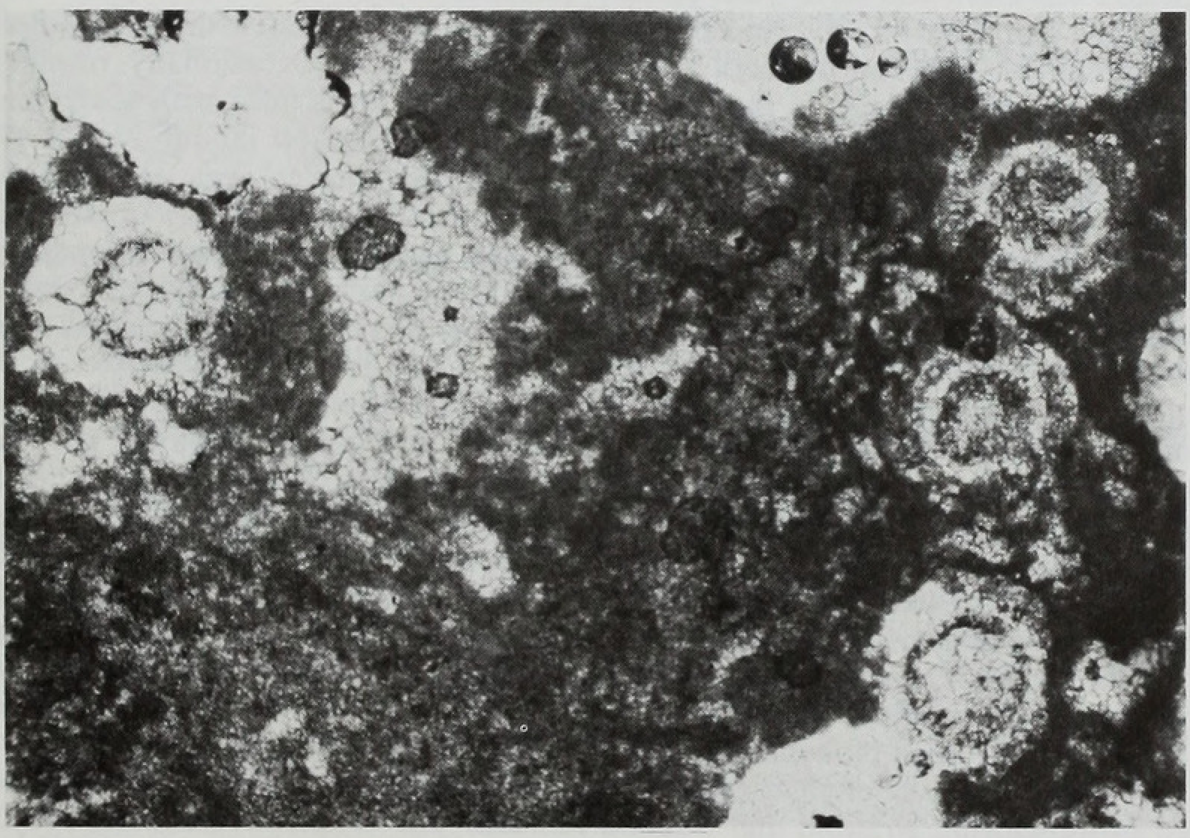

Fig. 9 Algal crust showing conspicuous charophyte oogonia, left and right. Same sample as Fig. 8. × 45.

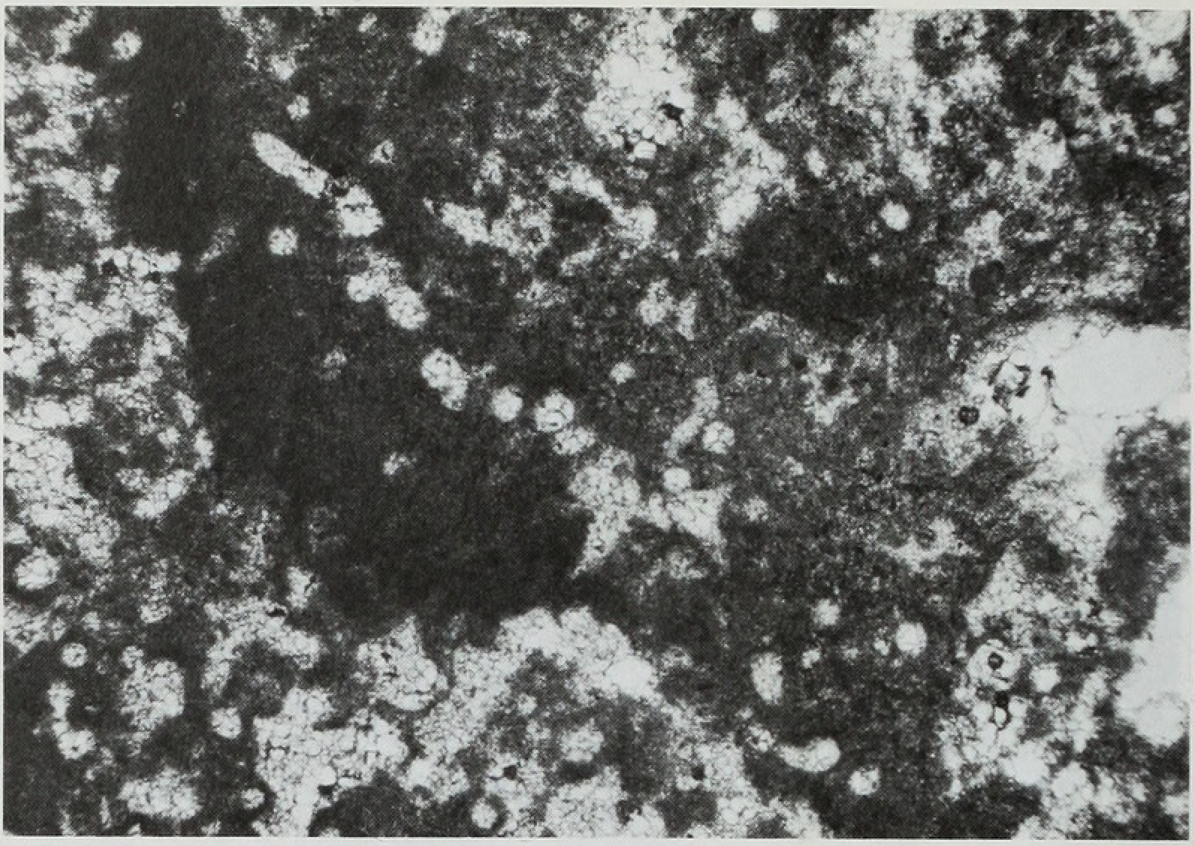

Fig. 10 Algal crust with probable traces of chironomid larval tubes, centre. Same sample as Fig. 8. × 45.

the area appears to have been near Kashm Khizami (Fig. 3), where marine fossils are associated with beach boulder conglomerates. A schematic cross section of the area indicating the relationship of the stratigraphy to the vertebrate site is shown in Fig. 5.

The main excavation was carried out in hard, unbedded White N9 (United States Geological Survey Rock-Color Chart 1980) sandstones. These were well sorted with fine-grained (about 280 μm), angular to subrounded, micrite supported quartz clasts. Occasionally, rounded micritic pebbles were present. Voids in the sandstones were sometimes filled with sparry calcite or, rarely, a form of manganese oxide known as wad. The excavation (about 22 m × 17 m, 50–80 cm in depth) produced scores of isolated bones, mainly lower jaws, teeth, limb bones, pectoral and pelvic elements, mostly of rhinoceros. None was preferentially orientated. Vertebrae and ribs were rare and, although none of the bones showed sign of depositional transport, rhinoceros mandibles had been broken and their anterior parts were missing. Except for the dryopithecine maxilla (see Andrews & Martin, this issue, p. 383), no other cranial bones were excavated.

About 5 m stratigraphically higher than the main excavation, and 110 m to its west, the sediments exposed on a ridge trending north-east showed a change in lithology. They consisted of an unsupported conglomerate formed of pebbles and cobbles of micritic limestone. In these sediments a proboscidean scapula and incomplete but uncrushed fish skulls were found (see Greenwood, this issue, p. 451). On top of this ridge were five *in situ* fallen logs encrusted with stromatolite (Fig. 6). Three measured 3·0 m, 5·3 m and 7·2 m in length and all, including the encrustation, were about 1·5 m in diameter. At one end of each of these logs stromatolitic crusts, 2 m in diameter, suggested the position of the bole of the fallen tree. The microstructure of a large amount of silicified wood found in this area resembled palm wood. At the same level and 11 m east of the logs, a bioherm had been fractured to reveal a fragmented rhinoceros skull encrusted with a 3-cm layer of algal material. Surface collecting in the area of the conglomerate produced proboscidean, giraffoid and tragulid remains. The conglomerate facies continued to the east and on the northern flank of a parallel ridge, many large stromatolitic bioherms were present (Fig. 7).

The bioherms and the crusts are largely of cyanophyte (myxophyte) algal origin. In thin section the rock shows marked banding with differential growth, and in places a ragged radial structure survives from the original microscopic thread-algae (Fig. 8). The rock shows intrinsic evidence of freshwater origin with embedded charophyte oogonia and debris, and what are probably chironomid larval tubes. All are poorly preserved and filled with sparry calcite (Figs 9, 10).

The depositional environment

Immediately prior to or at about the time of the deposition of basal transgressive marine sediments of the Dam Formation coming from the east, the environment at Ad Dabtiyah appears to have been a fluvial regime, transporting sandy carbonate muds, with laterally discontinuous conglomerates suggestive of channel sediments. Remains of terrestrial mammals, freshwater fish, turtle and crocodile (cf. *Crocodylus pigotti*, see Buffetaut, 1984) occur in these sediments. Subsequently, clastic deposition ceased and ponded fresh water was present; this was perhaps as a lake high in dissolved carbonates and deep enough to allow continuous growth of large stromatolitic bioherms and thick stromatolite crusts on hard substrates.

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