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**Abstract**

The fossiliferous strata at Ghabah, Oman (21°13'55''N : 57°34'10''E - Altitude 74-149 m), comprise interfingering marine and terrestrial deposits. The marine faunal remains from the sediments include a variety of gastropods and bivalves (abundant oysters) and various sawfish, shark and ray teeth. The terrestrial remains are diverse, including freshwater fishes, frogs, turtles and crocodiles, associated with terrestrial tortoises and a varanid lizard, accompanied by a range of mammals, dominated by proboscideans (gomphotheres, zygolophodonts and deinotheres) together with a tragulid, a small pecoran, a primitive giraffoid, an anthracothere, a rodent and a rhinocerotid. The Ghabah mammalian assemblage indicates a basal middle Miocene correlation, its affinities being closest to faunas from African localities such as Gebel Zelten, Libya, Moghra, Egypt, and Moruorot, Kenya (ca 16 +/- 1 Ma). The biogeographic affinities of the Ghabah mammals are strongly African, with three genera of proboscideans and ruminants that occur widely in that continent.

« Ghabah » which means « forest » in Arabic, is today a steppic environment, meriting the name Ghabah because the wadis in the region are rich in scattered *Acacia* and other trees. During the early Miocene, in contrast, the region was more densely vegetated, being either thick woodland or forest, which could support three taxa of proboscideans, three of ruminants and one each of rhinocerotids, suids and anthracotheres. The Ghabah deposits have good potential for yielding additional fossil material, and the position of the area at the « crossroads » of Africa, Europe and Asia, makes them of particular relevance to the study of intercontinental dispersals of terrestrial faunas at the end of the early Miocene.

The aim of this report is to provide an update of the marine, freshwater, amphibious and terrestrial palaeontological resources of Ghabah and to situate them in their biochronological, palaeoecological and palaeobiogeographic contexts.

**KeyWords** : Miocene, Tethys, Eustacy, Mammals, Biostratigraphy, Palaeoenvironment, Palaeobiogeography

## Introduction

Fossil vertebrates of Early Miocene to Basal Middle Miocene age were first recognised at Al Ghabah, Oman, in the late 1980's during regional mapping by the BRGM, France (J. Roger). A preliminary seven-day palaeontological survey under the leadership of H. Thomas (Collège de France, Paris) was carried out by M. Pickford and S. Al-Busaidi in January, 1992, but heavy rains hampered the field work. Nevertheless abundant faunal remains were collected which revealed the presence of a low diversity of mammals and fish, but abundant and diverse chelonians and crocodiles. Following this survey, an age of 17.5 Ma was estimated for the fauna (Roger *et al*. 1994; Thomas *et al*. 1999). The biogeographic relations of the vertebrate fauna are clearly African, with a number of mammalian taxa known from North African (Gebel Zelten, notably) and East African localities of similar age, but there are some faunal connections to Eurasia.

In January, 2014, seven days were spent at Ghabah by Drs E. Gheerbrant, S. Sen and M. Pickford of the MNHN, Paris, Dr J. Roger, of the BRGM and Dr Z. Al-Sulaimani, Muscat, with a visit by M. Al-Kindi, Geological Society of Oman and A. Hartmann, Muscat, this time without rain, so prospecting, excavation and screening proceeded unhindered. The result was that 122 fossils were entered in the field catalogue. Better samples of gomphotheres, deinotheres and anthracotheres were found which enabled the species to be determined with confidence. New records for the deposits included a frog, fish (*Pristis*, Batoids), mammals (*Zygolophodon*) and a rodent (indeterminate species based on a post-cranial bone). More tragulid post-cranial bones were collected, but no teeth of this family were found.

In September, 2014, a further survey of four days duration was carried out at Ghabah by M. Pickford and M. Al Waely, Geological Society of Oman, with a visit by M. Al-Kindi. 37 fossils were entered in the field catalogue.

In 2019 three days were spent at Ghabah by M. Pickford, D. Gommery, Yusuf Al-Sinani, Mohammed Al Badaai and Majid Al Muqbali. Impressive quantities of terrestrial and aquatic vertebrate fossils (proboscideans, ruminants, crocodiles, turtles) as well as marine invertebrates and vertebrates were collected. New records for the deposits include a varanid, a suid and a small pecoran.

## Geographic and geotectonic context

The Arabian Peninsula is important in Cainozoic palaeontology because of its geographic position between Africa, Asia and Europe (Fig. 1). It can be considered to comprise the crossroads between the three continents, and thus, its fossil record yields evidence concerning the biogeography of the region, which can be used to throw light on the tectogenic evolution of Eurasia and Africa, as well as its eustatic history. During the Cainozoic, the ancient Tethys Ocean was closing, the Mediterranean was forming, the Red Sea opened, sea-level was rising and falling, and fauna and flora were dispersing between the three continents. The deposits yielding the palaeofauna from Ghabah (Fig. 2) are thus strategically

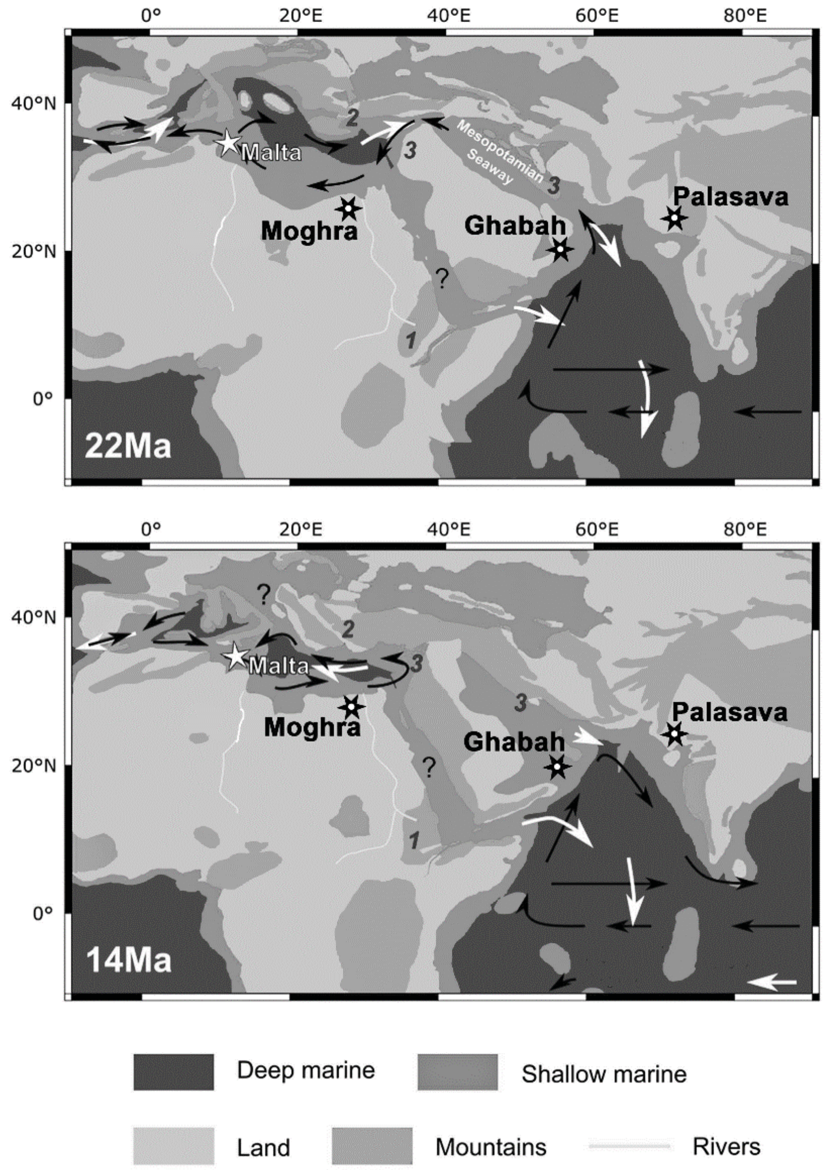


**Figure 1**. Reconstructions of the Tethys and Paratethys seaways during two phases of the Miocene showing the strategic positions of Ghabah, Palasava and Moghra for throwing light on intercontinental dispersals of terrestrial faunas (maps modified from Bialik *et al*. 2019).

situated to throw light on intercontinental dispersions during the early and middle Miocene. In this context, other localities of approximately similar age are Palasava, Kachchh, India (Kapur *et al*. 2019) and Moghra, Egypt (Miller & Simons, 1996).

**Figure 2**. Conical Hill, a local landmark at Ghabah, with the main area of fossiliferous erosion gullies in the background. Image taken from the summit of Ghabah Mesa looking eastwards.

**Table 1. Fossiliferous localities in the Ghabah Area 1992 Survey**

| Locality | Latitude | Longitude | Altitude (GPS) |
|---|---|---|---|
| Ghabah 1 | 21°13'48.7"N | 57°34'02.5"E | 85m |
| Ghabah 2 | 21°13'46.8"N | 57°34'01.2"E | 74m |
| Ghabah 3 | 21°13'44.3"N | 57°33'58.3"E | 82m |
| Ghabah 4 | 21°13'07.4"N | 57°34'06.2"E | |
| Ghabah 5 | 21°14'23.7"N | 57°34'12.4"E | 118m |
| Ghabah 6 | 21°14'24.23n | 57°34'11.5"E | 78m |
| Ghabah 7 | 21°14'25.3"N | 57°34'13.0"E | 83m |
| Ghabah 8 | 21°14'24.4"N | 57°34'16.3"E | 123m |
| Ghabah 9 | 21°14'25.3"N | 57°34'24.0"E | 85m |
| Ghabah 10 | 21°14'24.4"N | 57°34'27.2"E | 99m |
| Ghabah 11 | 21°14'27.0"N | 57°34'29.2"'E | 87m |
| Ghabah 12 | 21°14'33.4"N | 57°34'31.1"E | 101m |
| Ghabah 13 | 21°14'24.3"N | 57°34'38.1"E | 90m |
| Ghabah 14 | 21°14'21.8"N | 57°34'40.6"E | 91m |
| Ghabah 15 | 21°14'24.4"N | 57°34'30.5"E | 83m |
| Ghabah 16 | 21°14'21.5"N | 57°34'47.2"E | 61m |

**2014 Survey**

| Locality | Latitude | Longitude | Altitude (GPS) | Synonym |
|---|---|---|---|---|
| GH 15-2 | 21°20'40.4"N | 57°34'00.8"E | | Ghabah 3 |
| GH 15-2A | 21°12'34.6"N | 57°33'57.1"E | | |
| GH 15-2B | 21°12'34.6"N | 57°33'57.2"E | 117m | |
| GH 15-2C | 21°12'34.6"N | 57°33'57.1"E | | |
| GH 15-3 | 21°13'55.4"N | 57°34'10.6"E | | Ghabah 6 |
| GH 15-3A | 21°13'56.7"N | 57°34'10.6"E | 80m | |
| GH 15-3B | 21°13'57.7"N | 57°34'02.1"E | 89m | |
| GH 15-3C | 21°13'57.8"N | 57°34'02.5"E | 93m | |
| GH 15-3D | 21°13'56.9"N | 57°34'08.2"E | 93m | |
| GH 15-3E | 21°13'59.0"N | 57°34'03.1"E | 86m | |
| GH 15-3F | 21°14'03.9"N | 57°34'04.2"E | 114m | |
| GH 15-3G | 21°14'01.9"N | 57°34'04.7"E | 106m | |
| GH 15-3H | 21°13'55.0"N | 57°34'06;3"E | 89m | |
| GH 15-3I | 21°13'58.5"N | 57°34'04.4"E | 78m | |
| GH 15-3J | 21°14'07.5"N | 57°34'07.8"E | 95m | |
| GH 15-3K | 21°14'09.1"N | 57°34'07.7"E | 86m | |
| GH 15-3L | 21°14'10.0"N | 57°34'08.6"E | 108m | |
| GH 15-3M | 21°14'11.9"N | 57°34'08.6"E | 93m | |
| GH 15-3N | 21°14'08.6"N | 57°34'06.5"E | 83m | |
| GH 15-3O | 21°14'07.8"N | 57°34'10.4"E | 87m | |
| GH 15-3P | 21°14'10.2"N | 57°34'09.5"E | 90m | |
| GH 15-3Q | 21°14'15.0"N | 57°34'08.0"E | 71m | |
| GH 15-4 | 21°14'20.8"N | 57°33'54.1"E | 89m | |
| GH 15-4AA | 21°14'21.4"N | 57°34'03.5"E | 74m | |
| GH 15-4AB | 21°14'23.4"N | 57°34'07.3"E | 89m | |
| GH 15-5 | 21°14'29.0"N | 57°34'18.9"E | 88m | |
| GH 15-5A | 21°14'25.8"N | 57°34'20.8"E | 82m | |
| GH 15-5B | 21°14'25.2"N | 57°34'19.4"E | 89m | |
| GH 15-5C | 21°14'25.7"N | 57°34'18.6"E | 87m | |
| GH 15-5D | 21°14'25.4"N | 57°34'22.5"E | 82m | |
| GH 15-5E | 21°14'24.5"N | 57°34'24.3"E | | |
| GH 15-6A | 21°13'04.1"N | 57°33'39.3"E | 81m | |
| GH 15-7 | 21°13'03.2"N | 57°34'03.4"E | | |
| GH 17-1 | 21°13'41.5"N | 57°35'20.0"E | 149m | |
| GH 17-2 | 31°13'51.8"N | 57°34'34.1"E | 142m | |

**2019 Survey (new localities)**

| Locality | Latitude | Longitude | Altitude (GPS) | |
|---|---|---|---|---|
| GH 19-1 | 21°14'02.5"N | 57°33'55.4"E | 86 m | |
| GH 19-2 | 21°13'59.3"N | 57°34'10.0"E | 91 m | |
| GH 19-3 | 21°13'55.0"N | 57°34'09.6"E | 82 m | |

## Previous work

Roger *et al*. (1994) listed a diverse vertebrate fauna from Ghabah (Table 2).

More recent surveys at Ghabah have extended the diversity of vertebrates to include an additional freshwater fish (Bagridae), a frog, a varanid lizard and a suid. Additional remains of rhinocerotids, pecorans and tragulids were collected.

**Table 2.** Vertebrates from Ghabah listed by Roger *et al*. (1994).

| | | |
|---|---|---|
| Sélaciens | Pristidae? | indet. |
| | Rajiformes | gen. et sp. indet. |
| Téléostéens | Clariidae | *Clarias* sp. |
| | Siluroidea | indet. |
| | | *Lates* sp. |
| | Perciformes | indet. |
| Crocodiliens | | ?*Crocodylus* sp. (groupe *Tomistoma-Euthecodon*) |
| Chéloniens | Pleurodira | |
| | Bothremydidae | gen. et sp. indet. |
| | Podocnemididae | ?*Schweboemys* sp. |
| | Cryptodira | |
| | Trionychidae | aff. *Cycloderma* sp. |
| | Carettochelyidae | aff. *Carettochelys* sp. |
| | Testudinidae | cf. *Geochelone* sp. |
| Mammifères | Carnivora | indet. |
| | Proboscidiens | Elephantoidea gen. et sp. indet. |
| | | *Prodeinotherium* sp. |
| | Rhinocerotidae | indet. |
| | Anthracotheriidae | *Afromeryx zelteni* |
| | Giraffoidea | *Canthumeryx* sp. |
| | Bovidae | indet. |
| | Tragulidae | indet. |

## <u>The Marine Realm</u>

Lithophage borings

In order to underline the marine contribution to the Ghabah fossil record, locality GB 2 yielded a block of limestone containing several lithophage borings (Fig. 3).

**Figure 3**. GB 144’14, stereo images of lithophage borings in limestone from locality GB 2.

Marine Mollusca

Bivalves

*Ostrea* shells are common at certain intervals of the stratigraphic column at Ghabah, notably beneath and above the main mammal-bearing strata, but also occasionally associated with mammal fossils (Fig. 4). The younger part of the column at Ghabah yielded small bivalve shells preserved as re-crystallised gypsum (Fig. 5). The dimensions and form of the shells resemble extant *Donax*, but better preserved fossils are required to provide a definitive identification.

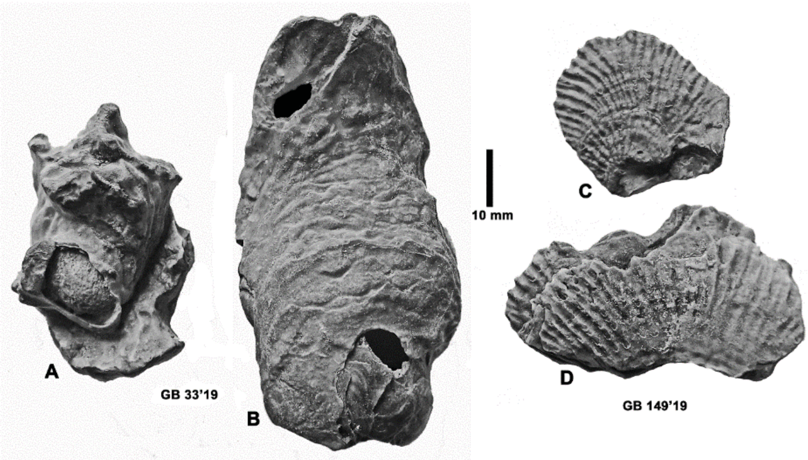


**Figure 4**. Oyster shells from Ghabah, Oman. A-B) GB 33’19, C-D) GB 149’19, (scale : 10 mm).

Gastropoda

Fossil gastropods from Ghabah are generally poorly preserved. The assemblage includes specimens of a large turriform shell, possibly related to *Turritella* (Fig. 5).

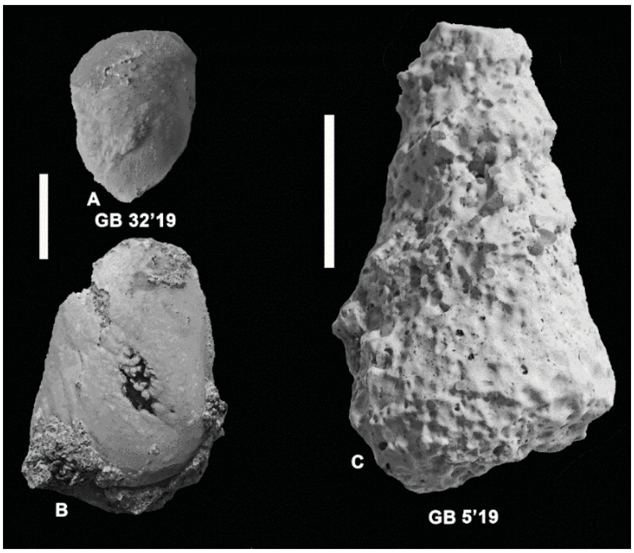


**Figure 5**. Marine molluscs from Ghabah, Oman. A-B) GB 32’19, unidentified small *Donax*-like bivalves preserved as crystals of gypsum, C) GB 5’19, poorly preserved *Turritella*-like snail (scales : 10 mm).

Marine Fish

Marine fish remains are relatively common at Ghabah. Vertebrae and spines dominate the assemblage, but there are also a few teeth. Among the identifiable fossils are saw-fish (*Pristis*), rays (Batoids, cf *Dasyatis*), and sharks (Fig. 6, 7).

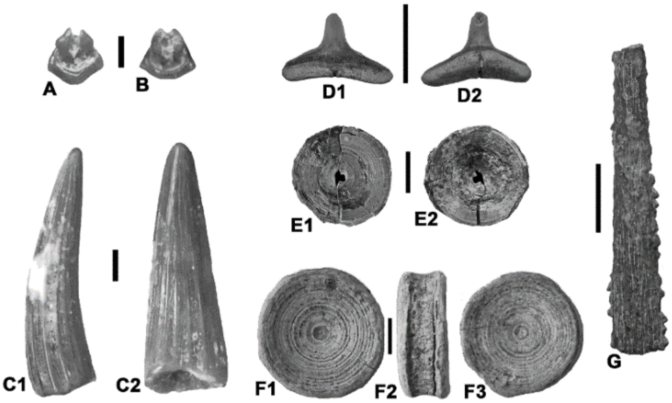


**Figure 6**. Ray, shark and fish teeth and shark vertebrae from Ghabah. A-B) GB 115’14, cf *Dasyatis*; C) GB 114’14, unidentified tooth, D) GB 4’19, shark tooth, E) GB 67’19, shark vertebra, F) GB 147’14, vertebra of a shark from locality GB 2, G) GB 154’19, fish spine with serrated margins (scale for A-C: 1 mm, scales for D-G : 10 mm).

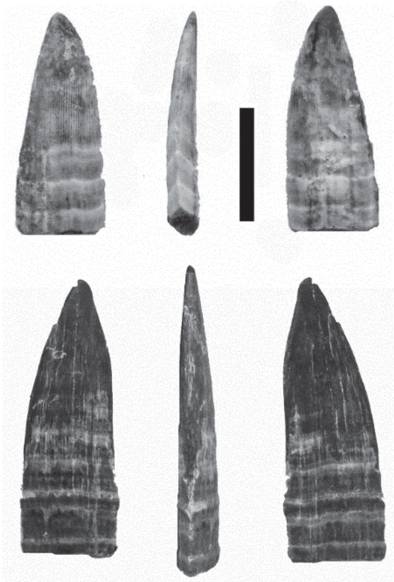

**Figure 7**. GB 100’14, teeth of *Pristis* sp. from Ghabah, Oman (scale : 10 mm).

## <u>The Freshwater Realm</u>

Freshwater Fish

The Ghabah deposits have yielded a few freshwater fish remains including specimens of the Nile Perch (*Lates*) and catfish (clariids and bagrids).

Clariidae

Head-plates of Clariidae have been found at several sites at Ghabah, but the genus and species identification remains elusive due to the fragmentary nature of the fossils.

Bagridae

A bagrid fish is identified at Ghabah on the basis of a thick head-plate with characteristic pustular ornamentation (Fig. 8a).

*Lates*

Fish related to the Nile Perch were recorded at Ghabah by Roger *et al*. (1994) and additional fossils were found during recent surveys. A cleithrum (Fig. 8b) is characteristic of the genus *Lates*, but the species cannot be identified precisely.

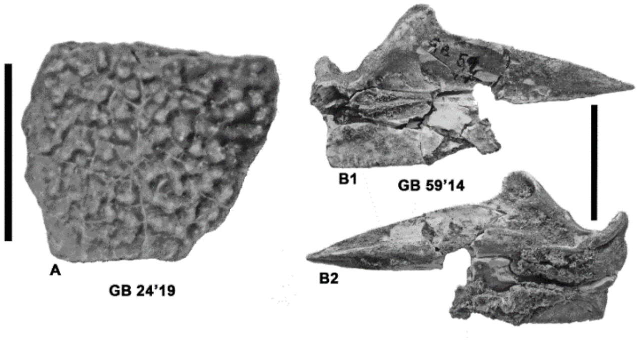


**Figure 8**. Freshwater fish remains from Ghabah, Oman. A) GB 24'19, bagrid head-plate, B) GB 59'14, cleithrum attributed to the Nile Perch, *Lates* sp. (scales : 10 mm).

Freshwater Reptiles

Crocodiles

*Crocodylus sensu lato*

There are two varieties of crocodile at Ghabah, one with *Crocodylus*-like teeth, the other with *Tomistoma-Euthecodon*-like teeth (Fig. 9).

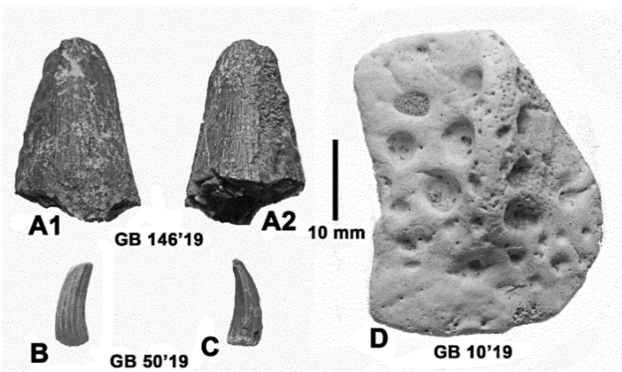


**Figure 9**. Crocodile remains from Ghabah, Oman. A) BG 146'19, *Crocodylus sensu lato* tooth, B-C) GB 50'19, *Tomistoma-Euthecodon* teeth, C) GB 10'19, crocodilian dermal scute (scale : 10 mm).

Chelonia

Three or four freshwater chelonian taxa occur at Ghabah, including cyclanorbids and trionychids, indicating an environment suitable for a high diversity of turtles (Fig. 10).

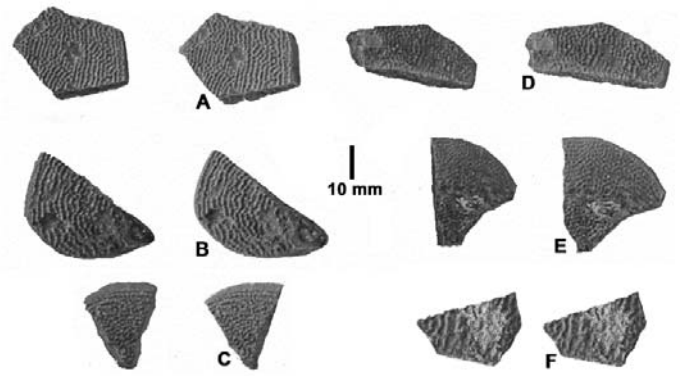


**Figure 10**. Freshwater chelonians from Ghabah, Oman, A-E) GB 119’14, *Trionyx* scutes from locality GB 12, F) GB 126’14, cyclanorbid scute from locality GB 14 (stereo pairs) (scale : 10 mm).

## The Amphibious Realm

Amphibia

The first known fossil of an amphibian from Ghabah is a proximal humerus of a large frog (Fig. 11). The head is almost spherical and is bordered by prominent lateral and medial processes.

**Figure 11**. GB 113’14, frog proximal humerus from Ghabah, GH 15-3F, Oman (scale : 10 mm).

Artiodactyla

Anthracotheriidae

Several anthracothere specimens have been collected at Ghabah, all representing a homogeneous size-group (Fig. 12, 13). The most informative specimens are a maxilla fragment containing the D4/ (16.7 x 17.0 mm) and an upper second molar, which are tetracuspidate and have a large loop-like parastyle and mesostyle, all features characteristic of the genus *Afromeryx*. The dimensions and morphology indicate close affinities with *Afromeryx zelteni*. This taxon is widespread but quite rare in the fossil record, having been found in Libya at Gebel Zelten (where it was defined), in Algeria (Nementcha) and Kenya (Ombo, Nachola, Loperot, Buluk, Rusinga). Its chronological range is from 18 Ma to 15.5 Ma (Pickford, 1991). It has not been recorded outside Afro-Arabia. It gave rise to Late Miocene *Libycosaurus* which, despite its name, is not a dinosaur as thought by the creator of the name (Bonarelli, 1947), but an anthracothere.

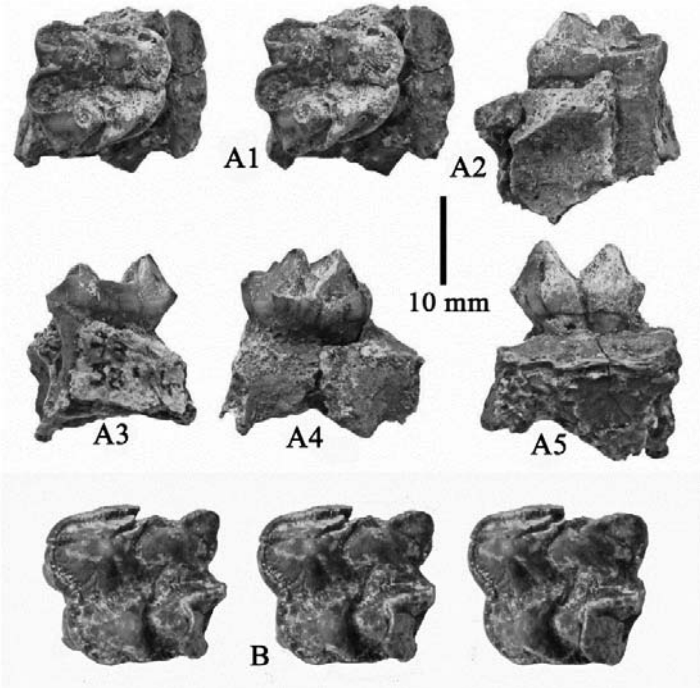


**Figure 12**. *Afromeryx zelteni* from Ghabah, Oman. A) GB 58'14, right D4/ in maxilla fragment from locality GH 15-3F (A1 - stereo occlusal view, A2 - mesial view, A3 - buccal view, A4 - distal view, A5 - lingual view); B) ONHM 92, left M2/, stereo occlusal views (scale : 10 mm).

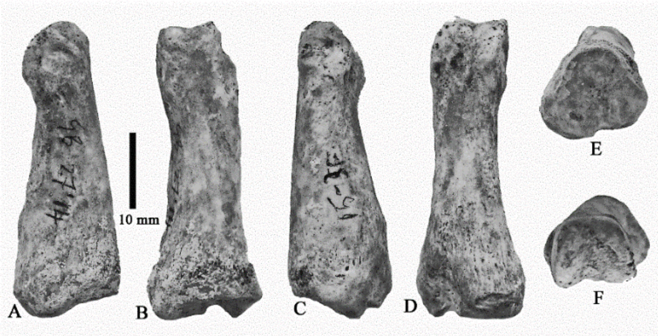


**Figure 13**. GB 27'14, first phalanx of *Afromeryx zelteni* from locality GB 15-3F, Ghabah, Oman. A) external view, B) dorsal view, C) internal view, D) volar view, E) proximal view, F) distal view (scale : 10 mm).

## The Terrestrial Realm

Chelonia

*Geochelone* was listed at Ghabah by Roger *et al*. (1994). No remains of this tortoise were found during the recent surveys.

Varanidae

A large varanid vertebra was collected at Ghabah during the 2019 survey (Fig. 14).


**Figure 14**. GB 23'19, varanid vertebra from Ghabah, Oman. A) proximal view, B) dorsal view, C) ventral view, D) lateral view (scale : 10 mm).

Mammalia

<u>Rodentia</u>

An isolated 1st phalanx of a rodent was excavated at Ghabah 15-3F (Fig. 15). The specimen has the dimensions of *Paraphiomys pigotti*.

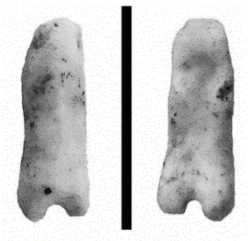

**Figure 15**. GB 99'14, first phalanx of a rodent from GH 15-3F, Ghabah, Oman (dorsal and volar views) (scale : 10 mm).

Carnivora

Roger *et a*l. (1994) listed an unidentified carnivore at Ghabah. No additional fossils of this group have been found in the area.

Proboscidea

Deinotheriidae

Teeth of *Deinotherium bavaricum* are common at Ghabah (Fig. 16-20) (Table 3). The range of metric variation of the specimens reveals that the Ghabah deinothere was not an insular dwarf as previously suggested, but that it falls within the range of metric variation of *Deinotherium hobleyi* and *Deinotherium bavaricum* (Fig. 21-25).

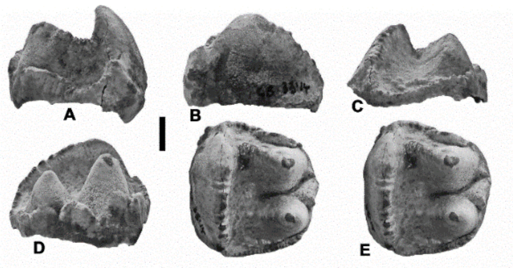


**Figure 16**. GB 33'14, right P3/ germ, *Deinotherium bavaricum* from Ghabah, Oman (A - mesial, B - buccal, C - distal, D - lingual, E - stereo occlusal views) (scale : 10 mm).

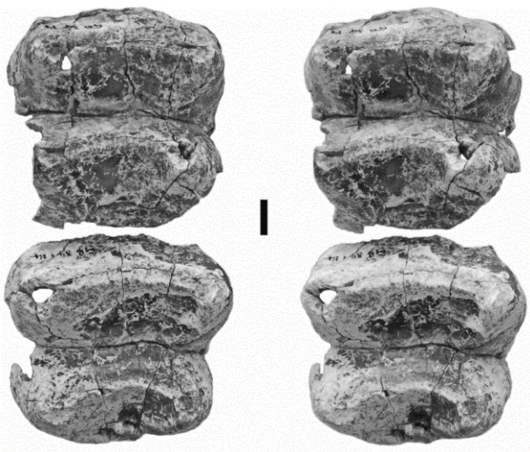

**Figure 17**. GB 34'14, left M2/-M3/, *Deinotherium bavaricum* from Ghabah, Oman, stereo occlusal view (scale: 10 mm)

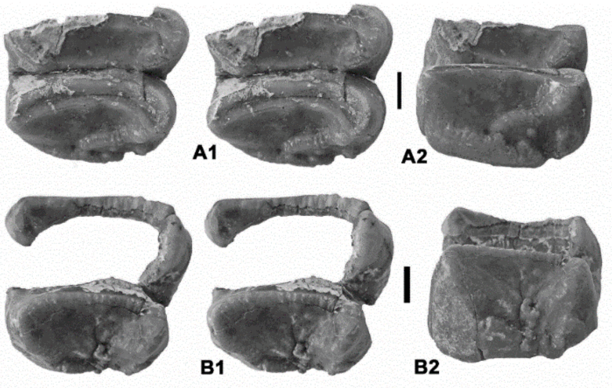


**Figure 18**. A) GB 37’14 and B) GB 104’14, upper second molars of *Deinotherium bavaricum*, Ghabah, Oman (1 - stereo occlusal views, 2 - oblique distal views) (scales : 10 mm).

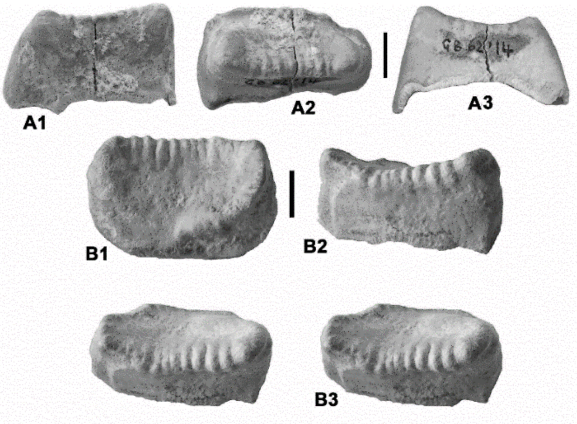


**Figure 19**. Fragments of lower first molars of *Deinotherium bavaricum*, from Ghabah, Oman, A) GB 62’14 (A1 - mesial, A2 - occlusal, A3 - distal views), B) GB 5’14 (B1 - mesial, B2 - distal, B3 - stereo occlusal views) (scales : 10 mm).

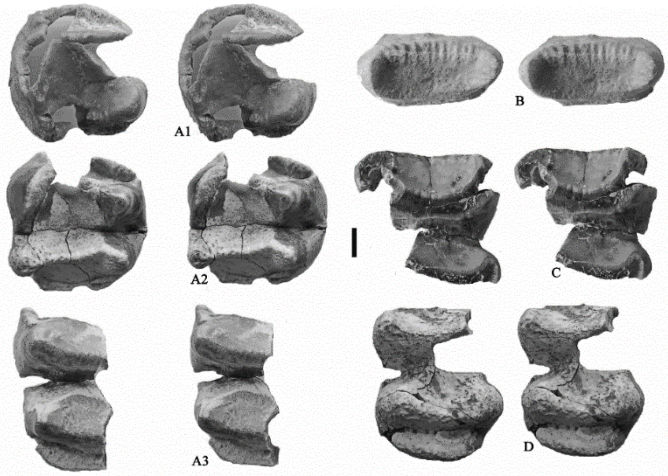


**Figure 20**. Teeth of *Deinotherium bavaricum* from Ghabah. A) GB 146’14, left P3/ and P4/ and part of left m/1 from locality GB 7; B) GB 117’14, half of an upper molar from locality GB 15; C) GB 118’14, incomplete molar from locality GB 9; D) GB 120’14, left m/2 from locality GB 4 (scale : 10 mm).

**Table 3**. Dimensions (in mm) of teeth of *Deinotherium bavaricum* from Ghabah, Oman (e - estimated).

| **Catalogue** | **Tooth** | **Mesio-distal length** | **Bucco-lingual breadth** |
|---|---|---|---|
| ONHM GB 33’14 | Left P3/ | 41.5 | 39.5 |
| ONHM GB 37’14 | Left M2/ | -- | 51.0 |
| ONHM GB 104’14 | Right M2/ | 52e | 54e |
| ONHM GB 34’14 | Left M2/<br>Left M3/ | 65.0<br>64.2 | 62.5<br>64.0 |
| ONHM GB 82’14 | Right M2/<br>Right M3/ | 60.0<br>71.0 | 61.5<br>68.0 |
| ONHM GB 31’14 | Right p/4 | -- | 41.2 |
| ONHM GB 62’14 | Molar loph | -- | 39.0 |
| ONHM GB 5’14 | Molar lophid | -- | 40.0 |
| ONHM GB 120'14 | Left m/2 | 53.5 | 43.0 |
| ONHM GB 146'14 | Left P3/ | 46.3 | 48.4 |
| ONHM GB 146'14 | Left P4/ | 48.0 | -- |
| ONHM 2490-06 (JR 1878A) | Right M2/ | -- | 50.8 |
| ONHM GB 1992-1 | Right m/3 | 61.0 | 50.0 |
| ONHM GB 1992-2 | Left m/3 | 59.9 | 48.8 |
| ONHM GB 1992-3 | Right M3/ | 57.1 | 58.5 |
| ONHM GB 1992-4 | Right m/2 | 50.0 | 46.0 |

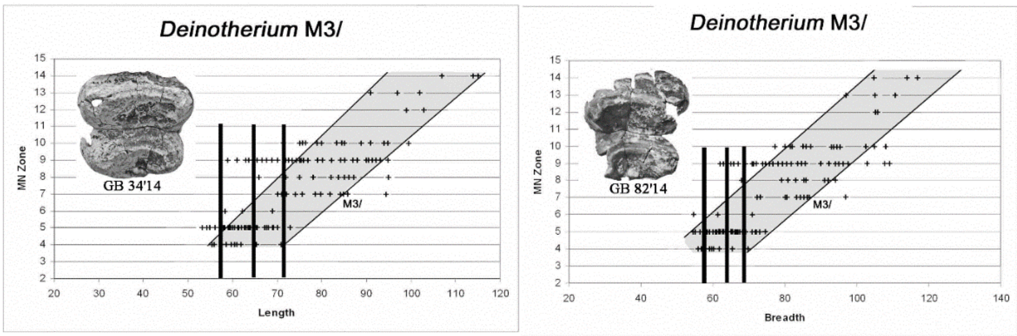


**Figure 21**. Length and breadth of Ghabah deinothere M3/s compared to European fossils arranged by MN Zone. The Ghabah specimens (vertical lines) correspond in dimensions to *Deinotherium cuvieri* and *Deinotherium bavaricum*.

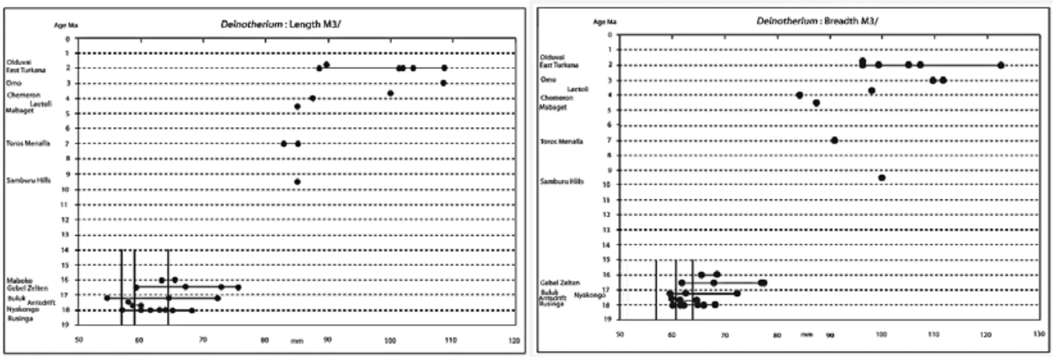


**Figure 22**. Comparison of length and breadth measurements of *Deinotherium* M3/s from Ghabah with African deinotheres arranged by chronological order. The Ghabah specimens (vertical lines) correspond in dimensions to *Deinotherium hobleyi* from Africa.

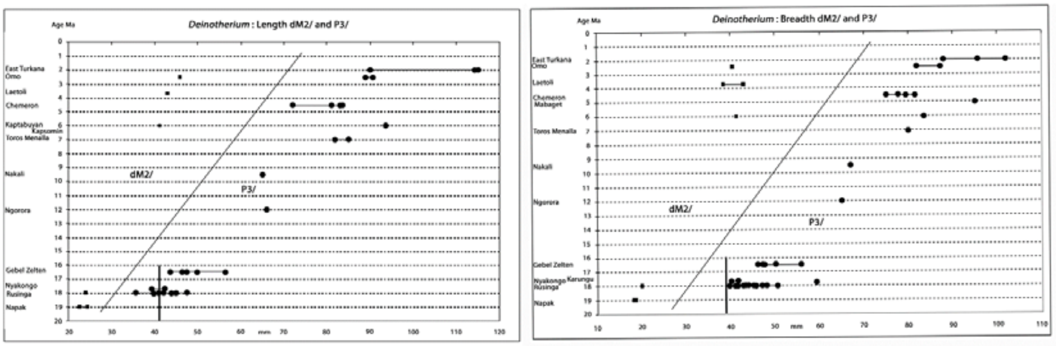


**Figure 23**. Comparison between deinothere P3/s from Africa arranged in chronological order, and the specimen from Ghabah, Oman (vertical line). The Ghabah tooth corresponds in dimensions to a very small *Deinotherium hobleyi*.

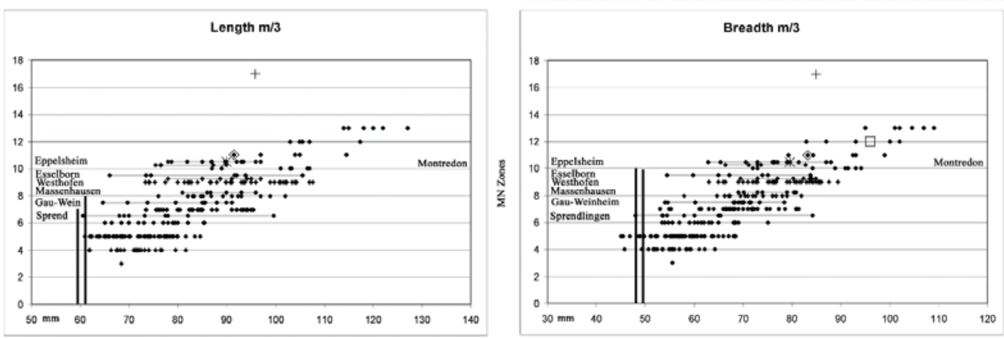


**Figure 24**. Comparisons between European deinothere m/3s arranged in chronological order (MN Zones) and the specimens from Ghabah, Oman (vertical lines). The Omani fossils plot at the lower end of the range of variation of *Deinotherium bavaricum* and *Deinotherium cuvieri* (MN 3, MN 4 and MN 5).

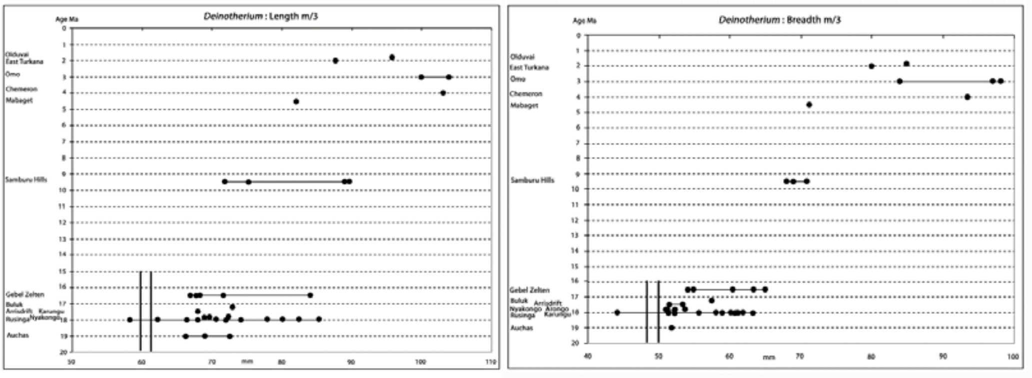


**Figure 25.** Comparisons between African deinothere m/3s and the specimens from Ghabah (vertical lines). The Omani fossils correspond in dimensions to the lower part of the range of metric variation of *Deinotherium hobleyi*.

## Gomphotheriidae

Two taxa of gomphotheres are present at Ghabah (Fig. 26-30). Previously all the remains were interpreted to belong to a single taxon close to the *Gomphotherium annectens* group, and because of their diminutive dimensions they were thought to indicate the possibility of insular dwarfing (Roger *et al*. 1994).

The new collections reveal the presence of two taxa of "gomphotheres" at Ghabah. One has very thick-enamelled cheek teeth and is likely to represent *Progomphotherium* Pickford, 2003, the other possesses thin enamel and has zygodont crests, indicating affinities with *Zygolophodon aegyptensis*, the type locality of which is Moghra, Egypt (Sanders & Miller, 2002).

One of the gomphothere specimens, GB 70'14, a right P4/, was excavated at GH 15-3F. The tooth is comprised of four bunodont cusps arranged in two lophs separated by a sagittal valley. The buccal cingulum is broken, but the anterior part is preserved, showing that it was a substantial structure. There is a prominent distal cingulum. The specimen measures 26 x 23 mm (md x bl) (Fig. 26).

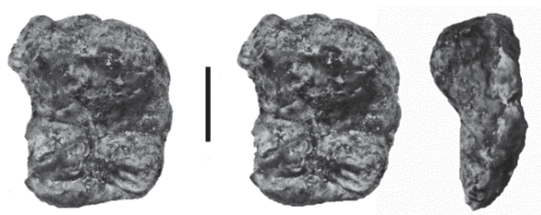

**Figure 26**. GB 70'14, right P4/ of a small bunodont gomphothere. Stereo occlusal and lingual view (scale : 10 mm).

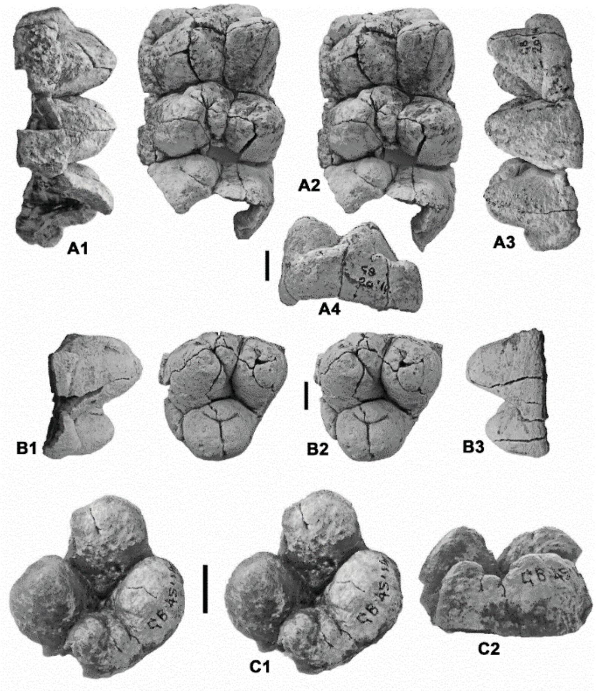


**Figure 27**. Molar fragments from Ghabah, Oman, attributed to *Progomphotherium* sp. A) GB 20’14 (A1 - buccal, A2 - stereo occlusal, A3 - lingual, A4 - mesial views), B) GB 61’14 (B1 - buccal, B2 - stereo lingual, B3 - lingual views), and C) GB 45’14 (C1 - stereo occlusal, C2 - distal views) (scales : 10 mm).

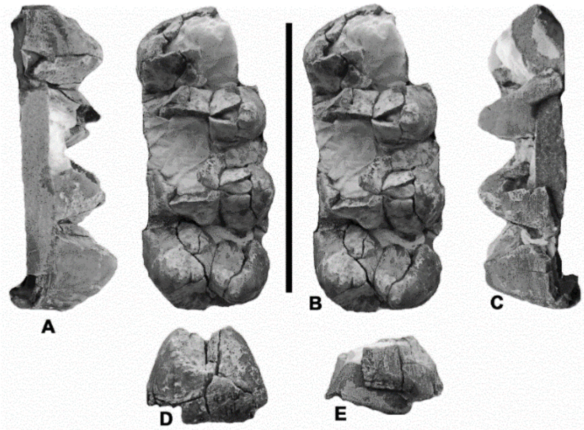


**Figure 28**. ONHM 2490-03, *Zygolophodon* left M3/ from Ghabah, Oman, collected in 1992 (A - buccal, B - stereo occlusal, C - lingual, D - mesial views) (scale : 10 mm).

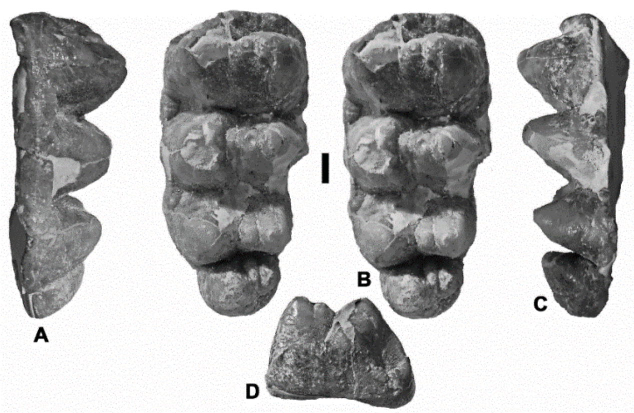


**Figure 29**. GB 116’14, gomphothere left m/3 from locality GB 6 (A - buccal, B - stereo occlusal, C - lingual, D - mesial, E - distal views) (scale : 10 cm).

Oman Natural History Museum, Muscat

Examination of fossils curated at the Oman Natural History Museum was authorised by the Directrice, Mrs Raiya Al Kindi. During the study it became evident that some of the collections of fossils curated under lot numbers, needed to be subdivided so that each fossil has a unique identifier within the original lot number. In collaboration with the person responsible for curating the fossils, Museum Specialist Azzah Ahmed Al-Jabri, the collection of proboscidean teeth from Ghabah were given unique numbers (Fig. 30).

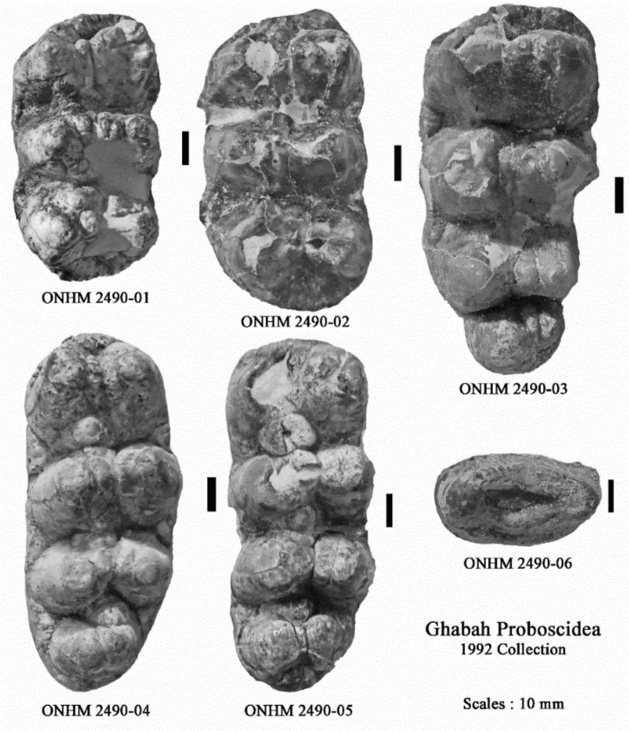


**Figure 30**. Curation of the 1992 collection of proboscidean teeth at the Oman Natural History Museum, Muscat, extended the previous curation system in order to give each fossil a unique identifier, but at the same time respecting the original lot number (ONHM 2490) (scales : 10 mm).

<u>Perissodactyla</u>

Rhinocerotidae was listed at Ghabah by Roger *et al*. (1994) but the remains were too poorly preserved for specific identification. Additional rhino fossils were collected during the recent surveys, but they too are too fragmentary for confident identification.

Artiodactyla

Suidae are recorded for the first time at Ghabah on the basis of a distal end of a lateral metapodial (Fig. 31). The specimen is of a size compatible with *Hyotherium medium* and *Kenyasus namaquensis*, but confident identification of the species will only be possible when teeth are found (Pickford & Tsujikawa, 2019).

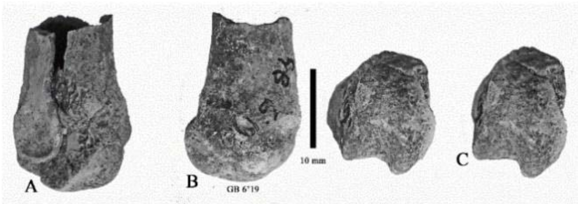


**Figure 31**. GB 6’19, distal end of an abaxial metapodial of a suid from Ghabah, Oman, of the dimensions of *Kenyasus namaquensis* and *Hyotherium medium*. A) internal view, B) external view, C) stereo distal view (scale : 10 mm).

## Tragulidae

Several tragulid post-cranial bones were collected at Ghabah (Fig. 32). All the specimens are compatible in dimensions and morphology to material from East Africa identified as *Dorcatherium pigotti*. Dental material has not yet been found, so the genus and species identification remains provisional.

GB 49'19 from site GH 15-7 is a distal radius of a tragulid compatible in dimensions with the other specimens from the locality.

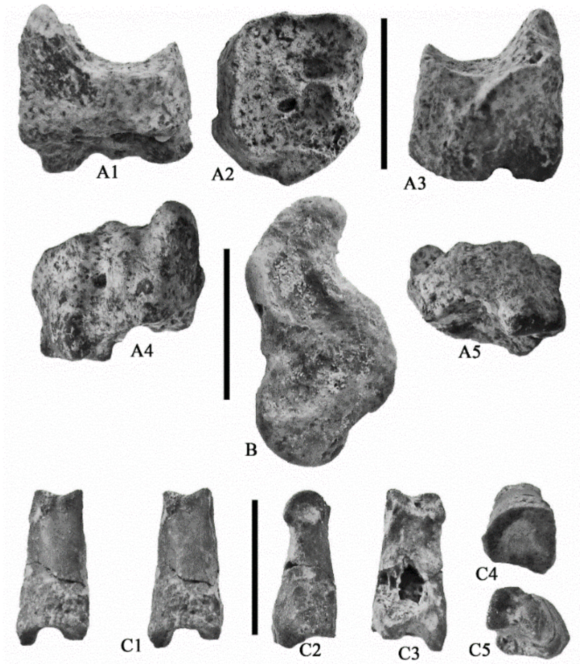


**Figure 32**. Tragulid post-cranial bones from Ghabah, Oman. A) GB 112’14, navicular-cuboid (A1 - medial, A2 - proximal, A3 - lateral, A4 - posterior, A5 - anterior views), B) GB 15’14, talus, lateral view, C) GB 19’14, first phalanx (C1 - stereo dorsal view, C2 - lateral view, C3 - volar view, C4 - proximal view, C5 - distal view) (scales : 10 mm).

## Giraffoidea

The genus *Canthumeryx* was previously listed for Ghabah by Roger *et al*. (1994) on the basis of an isolated lower molar (Fig. 33) and a talus.

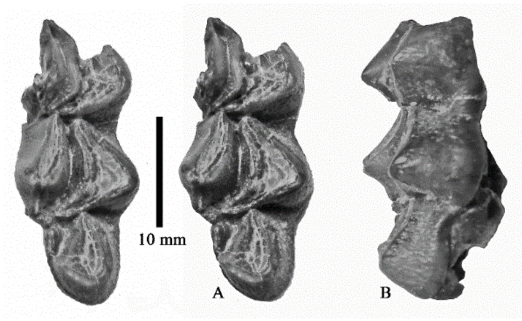


**Figure 33**. ONHM right m/3 from Ghabah attributed to *Canthumeryx sirtensis*. A) stereo occlusal view, B) buccal view (scale : 10 mm).

Several ruminant postcranial elements from Ghabah were collected during the recent surveys (talus, radius, metapodial pulleys, phalanges) (Fig. 34, 35) and all have the morphology and dimensions of corresponding elements in *Canthumeryx sirtensis* from Gebel Zelten, Libya (Hamilton, 1973), and this is probably the correct identification of the species.

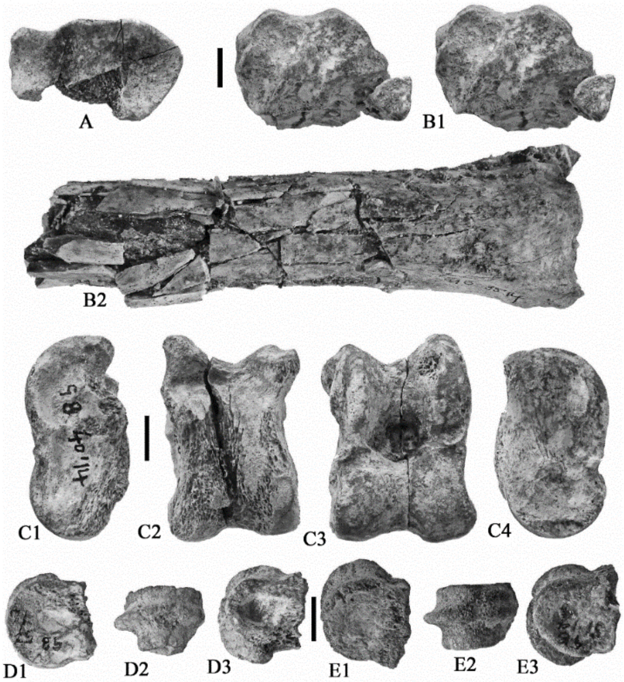


**Figure 34.** cf *Canthumeryx sirtensis* from Ghabah, Oman. A) GB 34’14, proximal end of radius (proximal view); B) GB 35’14, distal radio-ulna, (B1 - stereo distal view, B2 - anterior view); C) GB 40’14, left talus, (C1 - lateral view, C2 - calcanear view, C3 - anterior view, C4 - medial view); D) GB 51’14a, metapodial pulley (D1 - internal view, D2 - dorsal view, D3 - external view); E) GB 51’14b, metapodial pulley (E1 - internal view, E2 - dorsal view, E3 - external view) (scales : 10 mm).

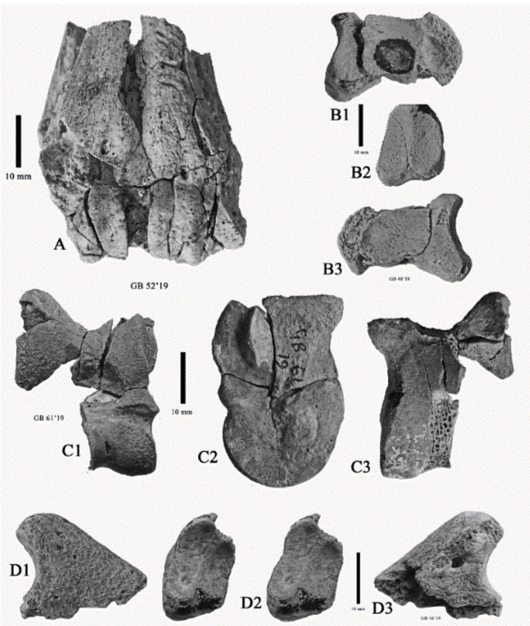


**Figure 35**. Artiodactyl post-cranial elements from Ghabah, Oman, attributed to *Canthumeryx* sp. cf *sirtensis*. A) GB 52’19, distal metapodial, dorsal view, B) GB 48’19, 2nd phalanx (B1 - external, B2 - proximal, B3 - internal views); C) GB 61’19, right talus (C1 - anterior view, C2 - medial view, C3 - calcanear view); D) GB 16’19, 3rd phalanx (D1 - external view, D2 - stereo proximal view, D3 - internal view (scales : 10 mm).

Pecora

Roger *et al.* (1994) listed an unidentified bovid at Ghabah. A phalanx found during recent surveys confirms the presence of a small pecoran at the site, but the material cannot be attributed with confidence to Bovidae as opposed to another family. The fossil (Fig. 36) is compatible in dimensions and morphology with the early Miocene genus *Walangania* from East Africa (Pickford, 2002) but precise identification will only be possible when teeth or horn cores have been collected.

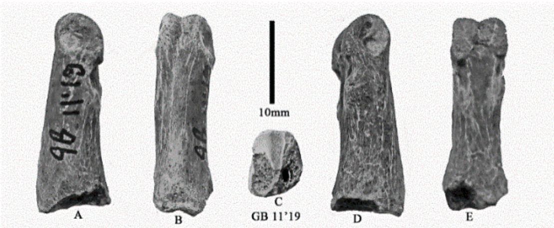


**Figure 36**. GB 11'19, 1st phalanx from Ghabah, Oman, of a small pecoran with dimensions comparable to *Walangania*. A) internal view, B) dorsal view, C) proximal view, D) exterior view, E) volar/plantar view (scale : 10 mm).

## Biostratigraphy and Palaeobiogeography

The hypothesis that the Ghabah gomphothere and deinothere represent examples of insular dwarfing (Roger *et al*. 1994) can be discarded, now that larger samples of teeth are available. The deinothere molars fall within the range of variation of *Deinotherium bavaricum*, the P3/ is small but is not the smallest known for the taxon.

Ghabah is located in a strategic position for throwing light on deinothere systematics and biogeography (Fig. 37). Traditionally, all African Early and Middle Miocene deinotheres have been classified as *Deinotherium hobleyi*, but detailed comparisons with Eurasian specimens reveal that the fossils from Ghabah and Gebel Zelten are closer morphometrically to *Deinotherium bavaricum* than to *Deinotherium hobleyi*. The Gebel Zelten material is also geographically closer to the European species than to the Kenyan one.


**Figure 37**. World distribution of *Deinotherium*. Note the strategic biogeographic position of Ghabah, between Africa, Asia and Europe.

Some of the Ghabah gomphothere specimens show a tendency towards lophodonty and zygodonty which, together with the presence of a lingual cingulum, thin molar enamel and zygodont crests, indicates affinities with the genus *Zygolophodon*. One of the specimens recalls the species *Zygolophodon aegyptensis*, defined at Moghra, Egypt.

There has been a long drawn-out debate in the literature concerning the Early Miocene "*Gomphotherium annectens*" group to which the Ghabah gomphotheres were previously linked (Roger *et al*., 1994). This "taxon" has been recorded from various localities in Japan (the type region), other parts of Asia, Europe and Africa, but it is always rare and usually rather poorly represented, most Eurasian sites yielding only one or two teeth (Fig. 38). The importance of this group is that it potentially provides an evolutionary link between the Early Oligocene *Palaeomastodon-Phiomia* group on the one hand and Middle Miocene gomphotheres and zygodonts on the other. There can be little doubt that fossils from Ghabah previously attributed to the "*annectens*" group comprise at least two taxa, one zygodont with relatively thin enamel in the cheek teeth, the other gomphodont with thick enamel, thereby mirroring the situation in the older *Palaeomastodon* and *Phiomia* group, and the younger *Gomphotherium* and *Zygolophodon* group. Ghabah, which is one of the few localities to yield teeth of both gomphothere dental "morphs", may thus be of significance for throwing light on the "*annectens*" problem.

Small gomphothere teeth are known from several Early Miocene localities in Africa, such as Auchas, Namibia (Pickford, 2003), Moroto, Uganda (Pickford & Mein, 2006) and Gebel Zelten, Libya, and in Portugal ("*Gomphotherium*" *olisiponensis*) (Zbyszewski, 1949) so the small dimensions of the Ghabah specimens are not surprising in a continental context. The upper molars from Ghabah agree in morphology and dimensions with the species *Progomphotherium maraisi* from similar-aged deposits in Namibia (Pickford, 2003).

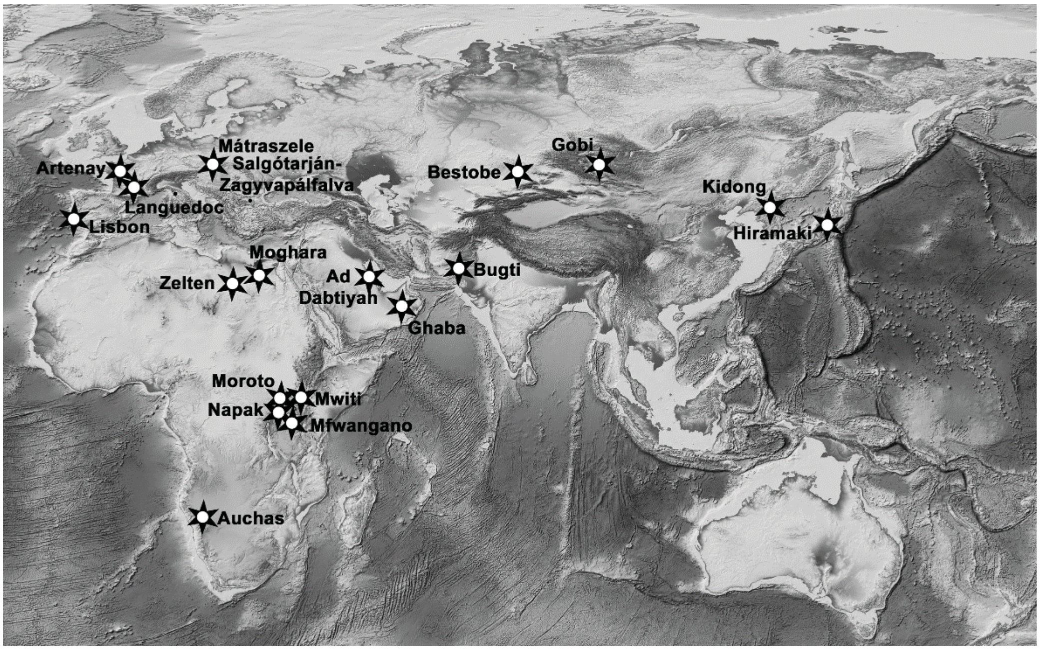


**Figure 38**. Distribution of fossils of the *Gomphotherium annectens* group, or of material which has, at one time or another, been attributed to this group. 1: Hiramaki Formation, Japan; 2: Kidong Formation, North Korea; 3: Bugti, Pakistan; 4: Ad Dabtiyah, Saudi Arabia; 5: Mwiti, Kenya; 6: Mfwangano, Kenya; 7: Quinta das Pedreiras, Portugal; 8: Artenay, France; 9: Mátraszele and Salgótarján–Zagyvapálfalva, Hungary; 10: Bestobe, Kazakhstan; ?: Auchas, Namibia. Map modified from Gasparik & Markov (2009). Note the strategic position of Ghabah at the crossroads between Africa, Asia and Europe.

In addition to the "*annectens*" problem, there is a debate concerning small bunodont proboscideans assembled as primitive amebelodonts. *Progomphotherium*, for example, was considered to be an amebelodont by Sanders *et al*., 2010, on account of its thick molar enamel and the simple morphology of the cheek teeth. The non-flattened lower incisors mitigate against this attribution, but the scanty fossil record of the genus leaves open the possibility that the only symphysis known from the type locality (Auchas, Namibia) could represent a different proboscidean.

## Palaeoenvironment

The presence of three taxa of proboscideans at Ghabah (comprising an obligate folivore, a thin-enamelled omnivore with folivorous tendencies and a thick-enamelled omnivore) suggests that there was a sufficient biomass of leaves and other plant products present on a year-round basis to support populations of these large mammals. The presence of a tragulid (cf *Dorcatherium pigotti*) amplifies the inferred presence of relatively dense stands of vegetation at Ghabah during the Early Miocene.

## Eustacy and Correlations

The sedimentary levels that yielded the mammal fossils at Ghabah also contain remains of vertebrates of freshwater (crocodiles, frogs, chelonians) and marine (rays and saw-fish (*Pristis*)) affinities. The association of marine, freshwater and continental faunal remains at Ghabah indicates that the Early Miocene depositional environment was close to the littoral zone. Immediately underlying the continental mammal-bearing deposits there are Burdigalian marine deposits containing abundant *Vermetus*, corals, oysters and microfossils (Roger *et al*. 1994). Overlying the continental deposits there are other marine beds yielding, in particular, oysters, probably of Langhian age (Fig. 39).

The marine and continental assemblages of fossils at Ghabah indicate correlation to the Burdigalian and Langhian, with the mammals so far restricted to the Langhian. This corresponds to the basal part of the middle Miocene, equivalent to the Tagus transgression cycle C5 and the following regression R5 while sea-levels were still above modern sea-level (i.e. to the left of the vertical lines in Fig. 40). On faunal grounds, the Ghabah deposits yielding fossil mammals could date from as old as 17 Ma or as young as 14.5 Ma.

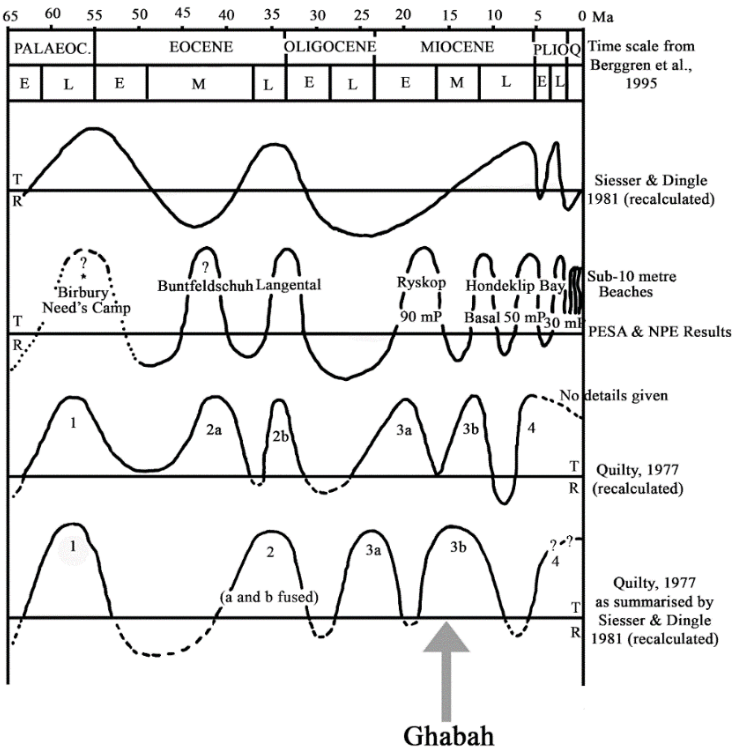


**Figure 39**. Tertiary Eustatic history according to Siesser & Dingle (1981), Quilty, 1977, and Pickford (1998). The Ghabah succession yielding mammalian fossils corresponds to the base of the Middle Miocene.

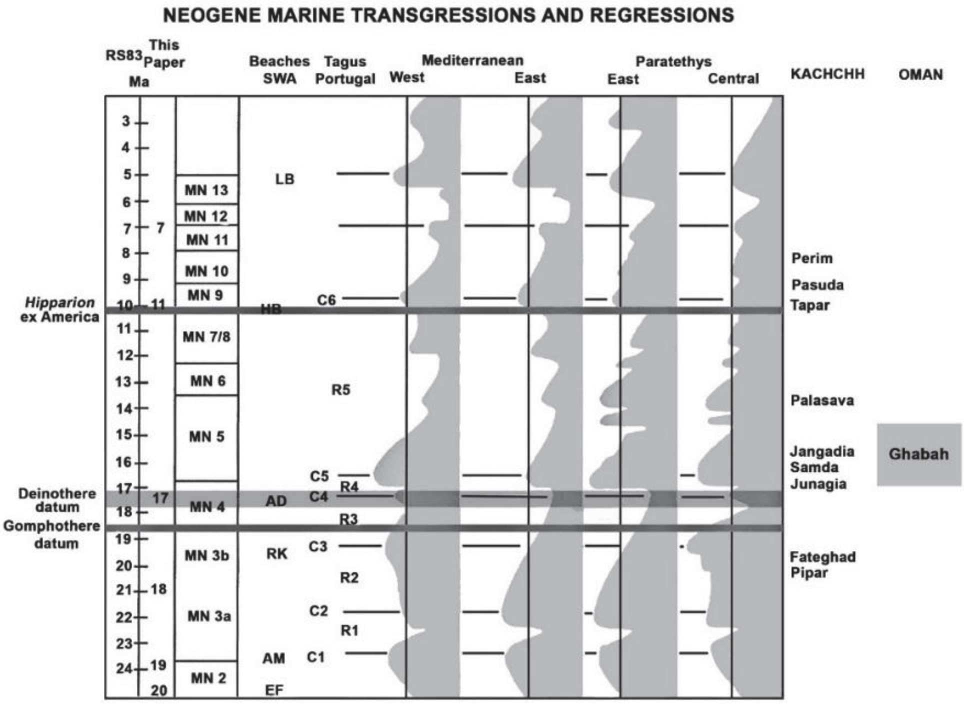


**Figure 40**. Eustatic history of the Mediterranean and Paratethys, the Tagus succession (Portugal) and Southwestern Africa, with major biostratigraphically significant faunal dispersal events (proboscideans and equids) and correlations of fossiliferous deposits in Oman and Kachchh (India). (Abbreviations - RS83 : Rögl & Steininger (1983), MN : Mammal Neogene zones of Europe, AD : Arrisdrift, AM : Auchas Main, EF : Elisabethfeld, HB : Hondeklip Bay, LB : Langebaanweg; RK : Ryskop, C : Transgression Cycle Tagus, R : Regression Cycle Tagus, Ma : Mega-annum) (modified from Bhandari *et al*. 2015)

## Conclusions

Basal and middle Miocene sedimentary deposits at Ghabah, Oman, have yielded interesting assemblages of fossils representing three major ecosystems – marine, freshwater and terrestrial. The deposits accumulated during the Burdigalian and Langhian stages in littoral settings, such that both onshore and offshore sediments are represented in the stratigraphic column. Fossil mammals from the deposits indicate correlation to the Langhian (equivalent to MN 5 in the European mammal zonation, and Faunal Set P III in the East African biostratigraphic scheme (Pickford, 1981)). The fossils could be as old as 17 Ma, as thought by Roger *et al*. (1994) or could be as young as 14.5 Ma on the basis of recent analyses of faunas in East Africa where radio-isotopic dating can be applied to the strata (Pickford, 1986).

The location of Ghabah within the Arabian Peninsula makes it relevant to the study of the geomorphological evolution of the Tethyan and Paratethyan seaways during the early and middle Miocene when activity related to plate tectonics was closing off the Mediterranean region from the Indian Ocean. This is partly due to the age control that the fossils impart to such avenues of enquiry, but it is of significance mainly because of the clearly African affinities of the mammalian fauna, and to some extent of the freshwater fish fauna. Comparisons with similar aged sequences at Moghra, Egypt (Miller & Simons, 1996) and Palasava, India (Kapur *et al*. 2019) reveal that quite a few African faunal lineages crossed the narrowing seaways during the early and middle Miocene and established themselves in the mid-latitude parts of Eurasia.

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