Fossil Mammals of Asia

NEOGENE BIOSTRATIGRAPHY AND CHRONOLOGY

EDITED BY Xiaoming Wang, Lawrence J. Flynn, and Mikael Fortelius

Fossil Mammals of Asia, edited by and with contributions from world-renowned scholars, is the first major work devoted to the late Cenozoic (Neogene) mammalian biostratigraphy and geochronology of Asia. This volume employs cutting-edge biostratigraphic and geochemical dating methods to map the emergence of mammals across the continent. Written by specialists working in a variety of Asian regions, it uses data from many basins with spectacular fossil records to establish a groundbreaking geochronological framework for the evolution of land mammals.

Asia's violent tectonic history has resulted in some of the world's most varied topography, and its high mountain ranges and intense monsoon climates have spawned widely diverse environments over time. These geologic conditions profoundly influenced the evolution of Asian mammals and their migration into Europe, Africa, and North America. Focusing on amazing new fossil finds that have redefined Asia's role in mammalian evolution, this volume synthesizes information from a range of field studies on Asian mammals and biostratigraphy, helping to trace the histories and movements of extinct and extant mammals from various major groups and all northern continents, and providing geologists with a richer understanding of a variety of Asian terrains.

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COVER IMAGE: About 15 Ma, in the early middle Miocene of central Asia, an agitated *Kubanochoerus*, with characteristically high facial horns, charges up a trail in a riparian habitat. *Kubanochoerus* was a large, long-legged member of the pig family (Suidae). It is charging past the fossorial rodent *Tachyoryctoides*, a fully subterranean extinct muroid unrelated to modern burrowing rodents. Both mammals are iconic for a large part of Asia, from Mongolia and China, westward to the Aral Sea. They overlap in time, although *Kubanochoerus* characterizes middle Miocene faunas, while *Tachyoryctoides* is commonly found in Oligocene and early Miocene assemblages. (Illustration by Mauricio Antón)

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COVER IMAGE: About 15 Ma, in the early Middle Miocene of Central Asia, an agitated *Kubanochoerus*, with characteristically high facial horns, charges up a trail in a riparian habitat. The *Kubanochoerus* was a large, long-legged member of the pig family (Suidae), with individuals of some species exceeding 500 kg. It is charging past the fossorial rodent *Tachyoryctoides*, a fully subterranean extinct muroid unrelated to modern burrowing rodents. *Tachyoryctoides* was larger than the living Asiatic zokor, a mole rat of body mass typically 200 g or more. Both mammals are iconic for a large part of Asia, from Mongolia and China, eastward to the Aral Sea. They overlap in time, although *Kubanochoerus* characterizes Middle Miocene Tunggurrian-age faunas, while *Tachyoryctoides* is commonly found in Oligocene and Early Miocene assemblages. (Illustration by Mauricio Antón)

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Chapter 27

Late Miocene Fossils from the Baynunah Formation, United Arab Emirates

Summary of a Decade of New Work

FAYSAL BIBI, ANDREW HILL, MARK BEECH, AND WALID YASIN

The region of Al Gharbia (previously known as the Western Region) comprises much of the area of Abu Dhabi Emirate west of the city of Abu Dhabi and bears the only known late Miocene terrestrial fossil biota from the entire Arabian Peninsula. Driving along the Abu Dhabi-As Sila' highway, which runs parallel to the Gulf coast and connects the United Arab Emirates to Saudi Arabia, one encounters a landscape of low dunes to the south, and sabkha (supratidal salt flats) and the sea to the north. Interspersed on both sides of the highway are low-lying jebels (hills), at most rising about 60 m above the surrounding terrain. These jebels are capped by a resistant gypsum-anhydrite-chert bed that produces characteristic table-top forms, or mesas. The sediments of these flat-topped jebels have been formally described as the Baynunah Formation (Whybrow 1989) and are composed mainly of reddish fine- to medium-grained sands of dominantly fluvial origin, along with brown and green silts, alternating sand-carbonate sequences, gypsum, and fine intraformational conglomerates. Several horizons within the Baynunah Formation bear fossils, either body parts or traces, of vertebrate, invertebrate, and plant taxa (figures 27.1 and 27.2).

From the sites of Rumaitha in the east to Jebel Barakah in the west, and from the sites of Shuwaihat in the north to Jaw Al Dibsa in the south, the area across which the Baynunah Formation is exposed forms a long east–west trending quadrangle measuring 180 × 45 km, covering 8100 km^2 (figure 27.3). Interspersed within this area are over two dozen documented sites from which fossil remains have been collected over three decades. These fossils include remains of hippopotamus, giraffes, crocodiles, rodents, turtles, catfish, ratites, machairodont felid, and hyaenids, as well as bivalves, gastropods, and fossil wood. The Baynunah Formation records a time when a perennial river supported a rich ecosystem in what is now a hyperarid part of the world.

By way of biochronology, the Baynunah fossil fauna is estimated to be between 8 Ma and 6 Ma (Whybrow and Hill 1999). No other terrestrial fossil sites of late Miocene age are known from the remainder of the Arabian Peninsula. The Baynunah fauna, then, represents the sole sample available to chart the biotic continuity between late Miocene Arabia and neighboring contemporaneous fossil sites in Asia (e.g., Siwaliks, Marageh), the Mediterranean (Pikermi, Samos), and Africa (Sahabi, Toros-Menalla, Lothagam, Tugen Hills).

Since the publication of a monographic treatment of the Baynunah fossils (Whybrow and Hill 1999), renewed fieldwork activities have brought new light to elements of the Baynunah fossil fauna. This chapter summarizes the latest knowledge on the fossil biota of the late Miocene Baynunah Formation.

HISTORY OF EXPLORATION

The first indications of the presence of vertebrate fossils from Al Gharbia came with the explorations of oil geologists working in the 1940s (Hill, Whybrow, and Yasin

Figure 27.1 Excavating lower jaws of a proboscidean at the site of Hamra 3-1. To the south, in the background, are the upper beds of the Baynunah Formation. Taken on December 17, 2007.

1999). The first publication of fossil remains from Al Gharbia came with Glennie and Evamy's (1968) description of fossil root casts and mention of proboscidean tooth remains from Jebel Barakah. Peter Whybrow (Natural History Museum, London [N.H.M.]) made fossil discoveries in Al Gharbia in 1979 and 1981, and described additional fossil root casts that he interpreted as mangroves (Whybrow and McClure 1981). In 1983, an archaeological survey of Al Gharbia by the Abu Dhabi Department of Antiquities and Tourism including Yasin and a team of German archaeologists (Vogt et al. 1989) resulted in the first significant collection of fossils from a number of sites in Al Gharbia. Upon invitation of the Department of Antiquities, Hill in 1984 visited Abu Dhabi to evaluate the recently collected fossils. In 1986, collaborative work began between Whybrow and Hill, and in 1989 a joint Yale--N.H.M. expedition was initiated to study the Al Gharbia fossil deposits. Extensive work on the Baynunah Formation, up to 1995, was given monographic treatment in Fossil Vertebrates of Arabia (Whybrow and Hill 1999). Beginning in 2002, the Abu Dhabi Islands Archaeological Survey, including Beech, undertook work on the Baynunah deposits. This included the discovery and salvage of important new sites (Beech and Higgs 2005), including sites preserving footprint trackways (Higgs et al. 2003). In 2003, Bibi was invited by the Abu Dhabi Public Works Department to further explore the Baynunah deposits. Two visits to Al Gharbia in that year with small teams resulted in the discovery of new sites and some 200 new fossil specimens, including the ratite *Diamantornis laini* (Bibi et al. 2006). In December 2006, Bibi and Hill joined Beech and Yasin under the invitation of the newly established Abu Dhabi Authority for Culture and Heritage (A.D.A.C.H.) for a brief survey of the Al Gharbia sites. Since the completion of this chapter, A.D.A.C.H. has become the Abu Dhabi Tourism and Culture Authority (A.D.T.C.A.). December 2007 saw the inception of the current Yale–A.D.A.C.H. project, with annual fieldwork expeditions to the Baynunah Formation.

FOSSIL FAUNA OF THE BAYNUNAH FORMATION

An up-to-date listing of the entire Baynunah fossil fauna is given in table 27.1. Fieldwork since 1995 (Whybrow and

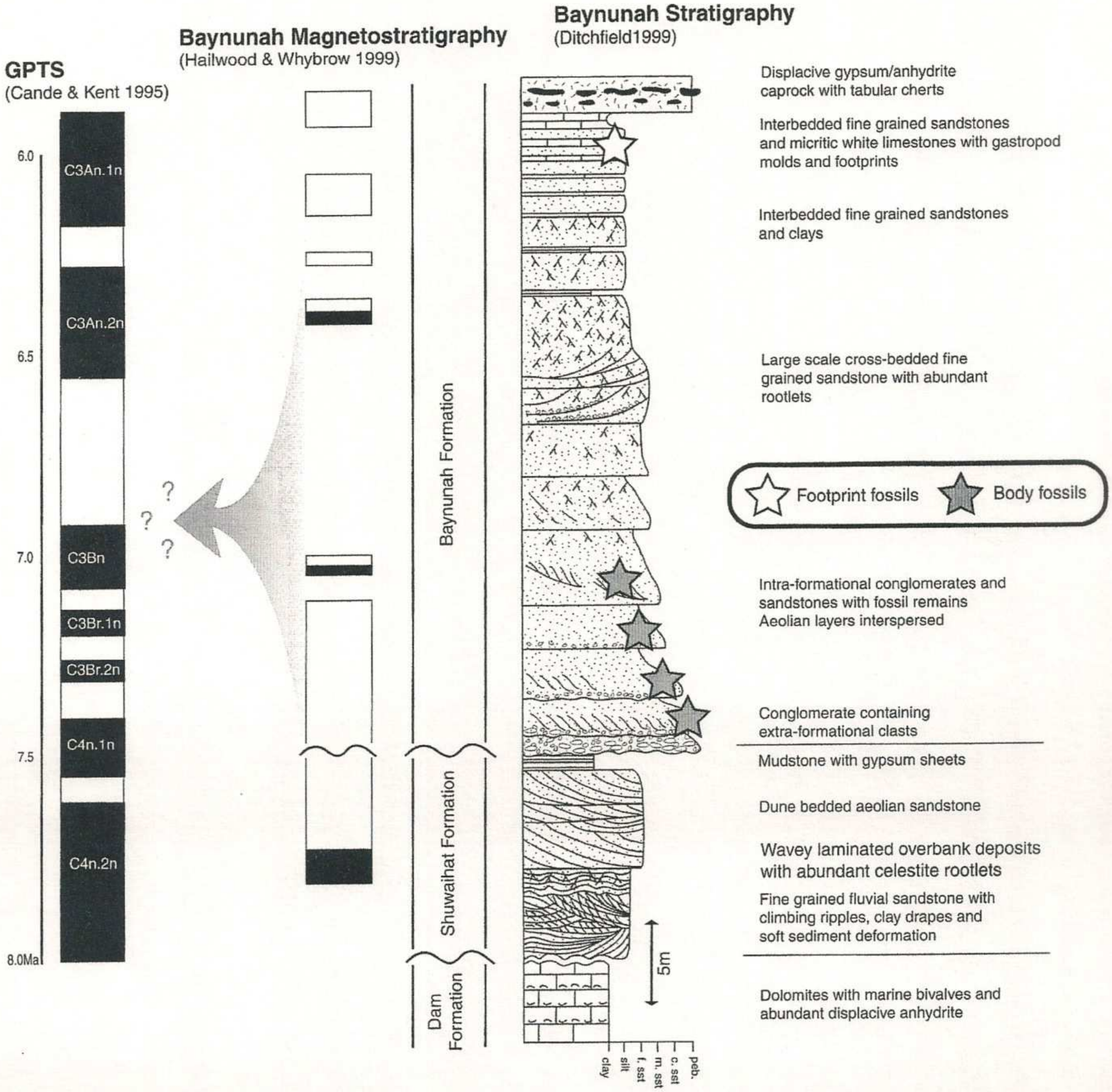

Figure 27.2 Stratigraphy and magnetostratigraphy of the Baynunah Formation. Body fossils (of vertebrates, invertebrates, and plants) are recovered from multiple horizons in the lower part of the Baynunah, while footprint fossils are recorded from carbonates correlating to the upper portion. Stratigraphic column reproduced from Ditchfield (1999:fig. 7.2), and paleomagnetic data from Hailwood and Whybrow (1999:fig. 8.5). The high frequency of polarity reversals in the period between 8 Ma and 6 Ma (Cande and Kent 1995) means any correlation of the Baynunah with the GPTS is equivocal, but the presence of at least four reversals in the Baynunah suggests a duration of 300,000 yr or more for this formation.

Hill 1999) has added the following taxa to the Baynunah fossil faunal list: two species of snake, one of which may be a colubrid; a sawfish (Pristidae); eggshells of two different ratites, *Diamantornis laini* and an aepyornithid-like form (Bibi et al. 2006); an anhinga (Stewart and Beech 2006); the giraffid *Palaeotragus cf. germaini*; and a sciurid rodent (Kraatz, Bibi, and Hill 2009). These come in addition to significant new material found of already-recorded taxa that will increase knowledge of the recorded forms and result in further taxonomic resolution. Among these

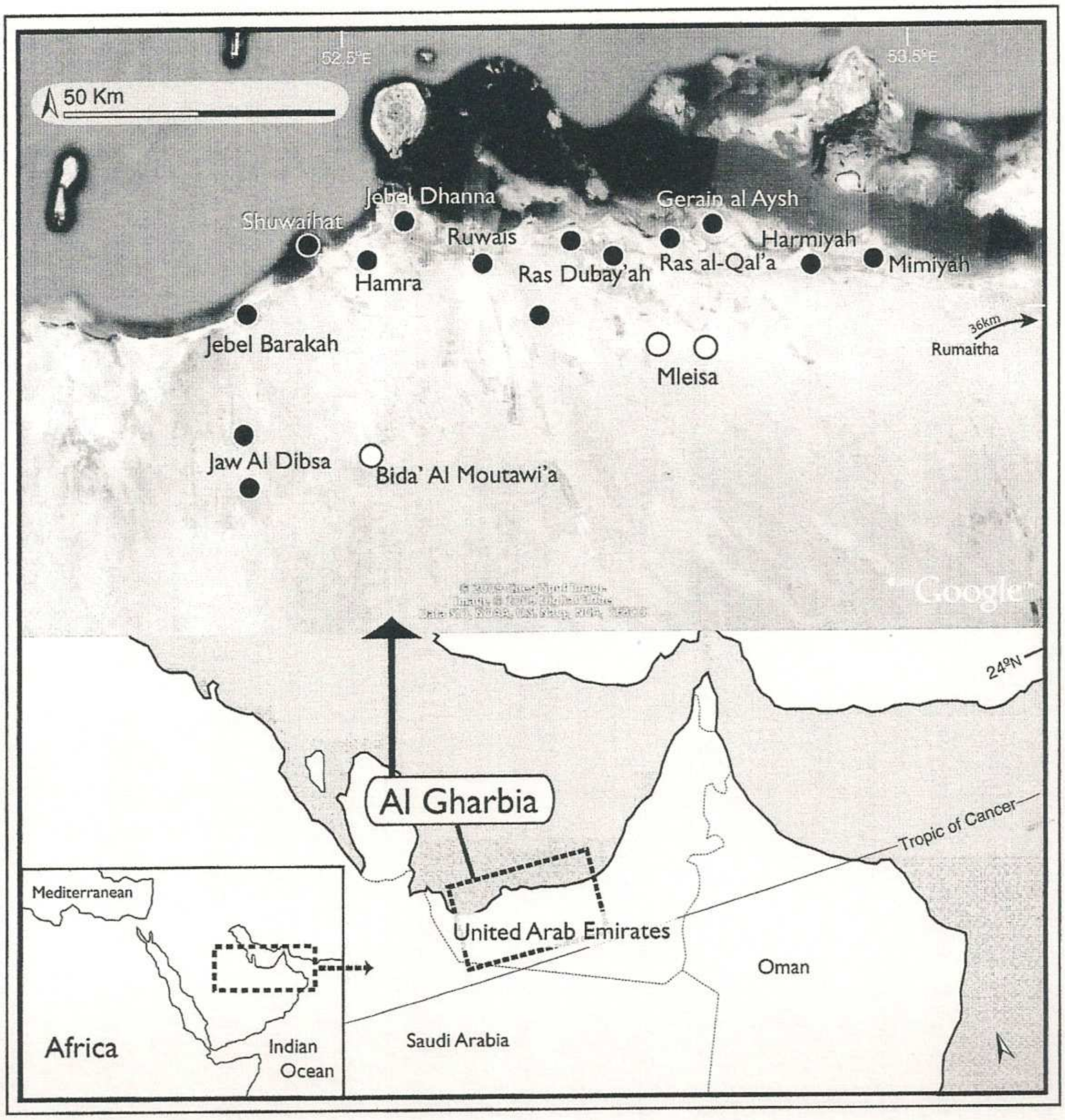

Figure 27.3 Map and satellite image of Al Gharbia showing main fossil localities. Black circles denote localities with body fossils; white circles denote fossil trackway sites.

are ostracods and foraminifera from the carbonates of the upper Baynunah; additional remains of the thryonomyid (cane rat) that suggest assignment to *Paraulacodus* and additional remains of the endemic gerbil *Abudhabia baynunensis;* a ratite synsacrum larger than that of modern *Struthio* that might be associated with either fossil eggshell type; new mandibular remains of *Hipparion* that will help further characterize *H. abudhabiense* (originally diagnosed on a partial mandible); relatively abundant remains of fossil proboscideans, including several mandibles, tusks and tusk fragments, a cranium, and postcrania attributable to *Stegotetrabelodon syrticus,* and mandibles of the shovel-tusked proboscidean (*Amebelodon*/"*Mastodon*" *grandincisivus*); and a deciduous monkey premolar, only the second primate specimen to have come from the Baynunah Formation (Hill and Gundling 1999).

In addition, fossil trackway sites have been discovered (figure 27.4), adding a new dimension of study to the Baynunah fossil fauna (Higgs et al. 2003; Higgs, Gardener, and Beech 2005). Currently, at least three sites are known at which footprint remains of proboscideans and ungulates are preserved in carbonates (figure 27.3). These

Table 27.1
Baynunah Faunal List

Taxon				Lower Nawata	Toros Menalla 266	Sahabi Mb. U	Africa	Greco-Afghan	Siwaliks Dhok Pathan	Remarks
Plantae	"Algae"		Gen. et sp. indet.							
	Leguminosae		?*Acacia* sp.							
Protista	Foraminifera		(in progress)							
Mollusca	Gastropoda	Buliminidae	?*Subzebrinus* or ?*Pesudonapaeus*							"Palaearctic and Oriental" (Mordan 1999)
	Bivalvia	Mutelidae	*Mutela* sp.				G			
		Unionidae	*Leguminaia* sp.					G		Iraq
Crustacea	Ostracoda	Cytherideidae	*Cyprideis* sp.							
Pisces	Siluriformes	Clariidae	*Clarias* sp.	(G)		(G)	G		G	
		Bagridae	*Bagrus shuwaiensis*	(G)	G		G			
	Cypriniformes	Cyprinidae	*Barbus* sp.				G			
	Pristiformes	Pristidae	(in progress)							
Reptilia	Crocodilia	Crocodylidae	*Crocodylus* cf. *niloticus*	G/(S)	G/(S)	G/(S)	G/(S)			
			Crocodylus sp.							
		Gavialidae	?*Ikanogavialis*							S. America, Australasia
			Gavialidae gen. et sp. indet.							
	Testudines	Trionychidae	*Trionyx* sp.			G	G	G		
		Testudinidae	cf. *Mauremys* sp.				(G)	(G)		
			Geochelone (*Centrochelys*) aff. sulcata			G	G			Subgenus *Centrochelys* Libya, Tunisia, possibly Saudi Arabia (de Lapparent de Broin and van Dijk 1999)
	Squamata	cf. Colubridae	Colubridae spp. (in progress)							
Aves	Ratitae	Incertae sedis	*Diamantornis laini*	S			S			
			'Aepyornithid-type' eggshell	'G'			'G'		'G'	
	Pelicaniformes	Anhingidae	*Anhinga* sp.	G		G	G			Today worldwide
	Ciconiiformes	Ardeidae	Gen. et sp. indet.							
Mammalia	Artiodactyla	Hippopotamidae	*Archaeopotamus* aff. *lothagamensis*	G/(S)		(G)	G/(S)			
		Bovidae	*Pachyportax latidens*						S	
			Prostrepsiceros aff. *libycus*			G/(S)	G/(S)			
			Prostrepsiceros aff. *vinayaki*					(S)	(S)	
			Gazella aff. *lydekkeri*	G		G			(S)	
			Tragoportax cyrenaicus	(S)		S	S			

(continued)

Table 27.1 (continued)

Taxon			Lower Nawata	Toros Menalla 266	Sahabi Mb. U	Africa	Greco-Afghan	Siwaliks Dhok Pathan	Remarks
		cf. Neotragini (in progress)							
	Giraffidae	*Palaeotragus germaini* (in progress)	S			S			
		? *Bramatherium*					(G)	(G)	
		gen. et sp. indet.							
	Suidae	*Nyanzachoerus syrticus*	S	S	S	S			
		Propotamochoerus hysudricus						S	
Carnivora	Mustelidae	*Plesiogulo praecocidens*				G	G	G	Species from China (Barry 1999)
	Felidae	*Machairodontinae gen.* et sp. indet.							
	Hyaenidae	gen. et sp. indet. "very large"							
		gen. et sp. indet. "medium-size"							
Perrisodactyla	Equidae	*Hipparion abudhabiense*		(S)		(S)			
		Hipparion sp.							
	Rhinoceratidae	gen. et sp. indet.							
Rodentia	Muridae	*Abudhabia baynunensis*			G	G	G	G	Genus in China also
		Myocricetodon (sp. nov.?)			G	G	G	G	Genus in China also
		Parapelomys cf. *charkhensis*					G	G	
		Dendromus aff. *melanotus*				G			Genus in Spain also
		Dendromus sp.							
	Dipodidae	Zapodinae gen. et sp. indet.							"Asiatic" (de Bruijn 1999)
	Thryonomyidae	cf. *Paraulacodus* (in progress)	(G/S)			(G/S)			Genus recorded from mid-Miocene Siwaliks (Flynn and Winkler 1994)
	Sciuridae	gen. et sp. indet.							
Insectivora	Soricidae	gen. et sp. indet.							
Primates	Cercopithecidae	gen. et sp. indet.							
Proboscidea	Deinotheridae	gen. et sp. indet.							
	Elephantidae	*Stegotetrabelodon syrticus*	G		S	S	(S)		Species occurrence in Italy (Ferretti, Rook, and Torre 2003)
	Gomphotheriidae (Amebelodontidae)	cf. *Amebelodon* / ?"*Mastodon*" *grandincisivus*			(G)	(G)	(G)		

NOTE: Genera or species in common with other sites are denoted by G or S, parentheses denoting uncertainty (usually result of a cf. designation).

SOURCES: Agustí (2008); Badgley et al. (2008); Barry (1999); Bishop and Hill (1999); Boisserie (2005); de Bruijn (1999); de Lapparent de Broin and van Dijk (1999); Eisenmann and Whybrow (1999); Ferretti, Rook, and Torre (2003); Flynn and Winkler (1994); Forey and Young (1999); Gentry (1999); Geraads and Güleç (1999); Higgs et al. (2003); Hill and Gundling (1999); Jeffrey (1999); Mordan (1999); Rauhe et al. (1999); Sanders (2008); Sen (1998); Tassy (1999); Whybrow and Clements (1999); Whybrow et al. (1990).

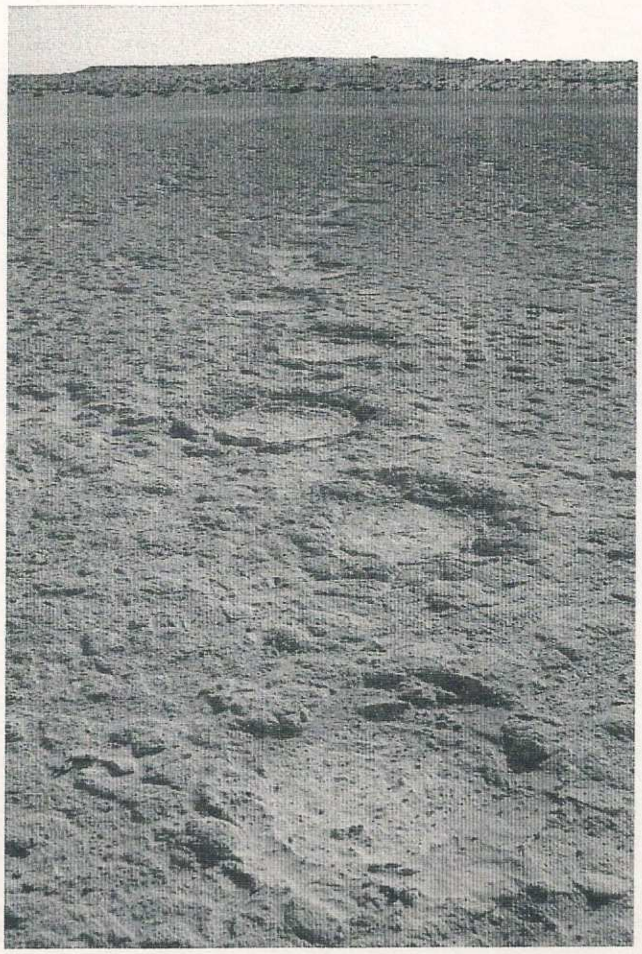

Figure 27.4 One of at least 10 proboscidean trackways at the site of Mleisa 1.

same carbonates also preserve molds of gastropods proposed to be "?cerithid" (Ditchfield 1999).

PALEOENVIRONMENTS OF THE BAYNUNAH

Despite the presence of a perennial river system in Al Gharbia, the environment in this region was clearly arid during the late Miocene. Though arid environments are clearly recorded in the sediments of the Shuwaihat Formation underlying the Baynunah (Bristow 1999), there is no unambiguous sedimentological evidence for arid environments in the Baynunah Formation. Fine- to medium-grained quartz sands with frosted grains (D. Peppe, pers. comm.) and large-scale cross-beds are commonly observable. Gypsum-cemented root casts are present in many such layers, which Glennie and Evamy (1968) interpreted as the remains of dune-stabilizing vegetation (contra Whybrow and McClure 1981).

Paleocurrent readings indicate Baynunah rivers derived from the northwest or west as outlined by Friend (1999). Topographically, the most likely western watershed and source that could provide a river system to the Al Gharbia area is the Wadi Sahba in Saudi Arabia (e.g., Whybrow and Hill 2002). A modern analogue for the Baynunah River can be sought in the Nile, which today flows its course through hyperarid parts of Sudan and Egypt. A late Miocene river system that is broadly analogous to the Baynunah one is the As Sahabi River, which took its source largely from the Tibesti Mountains in Chad and flowed north through a proto-Sahara to empty in the Mediterranean (Drake, El-Hawat, and Salem 2008).

Though no clear aeolian beds are present in the Baynunah, the underlying Shuwaihat Formation includes within it large aeolian dune beds (Bristow 1999). Much as Schuster et al. (2006) interpreted aeolian beds from the northern Chad Basin to indicate the onset of desertic conditions in the Sahara by around 7 Ma, the presence of aeolian deposits in the Shuwaihat Formation provides early evidence for the presence of desert conditions in the Arabian Peninsula going back to at least the late Miocene. The Shuwaihat Formation dune beds may push the evidence for desertification in Arabia even further back, if the age of this formation is accepted as being middle Miocene (15 ± 3Ma in Hailwood and Whybrow 1999).

The upper parts of the Baynunah Formation bear about a 15 m sequence of fine sands and clays alternating with carbonates. The carbonates are resistant to erosion and are extensively exposed several kilometers inland as deflated surfaces that are highly reflective and easily visible from satellite imagery (see figure 27.1). Within these large exposures are located three footprint sites, two of these recording proboscidean trackways (Higgs et al. 2003) and one site with an ungulate trackway. These same carbonates include ostracods and molds of gastropods resembling cerithids, suggesting a marine or brackish water origin. Shells of *Melanoides* reported from above the Mleisa 1 trackway carbonate by Higgs et al. (2003) are suspiciously well preserved. Despite years of fieldwork, no other occurrences of *Melanoides* have ever been found, neither at Mleisa 1 nor at any other site from the Baynunah Formation. Accordingly, we suspect the Mleisa 1 *Melanoides* to be surface finds not deriving from the Baynunah Formation itself.

The Baynunah deposits are exposed over a long area that is parallel to the coastline and that at its widest reaches at least 45 km (see figure 27.3). It is apparent that the original river system ranged over an even wider area in the course of its temporal span. A single fossil vertebra recovered in December 2007 is identifiable as a sawfish (Chondrichthyes: Pristidae). Living sawfish are known to inhabit shallow marine or estuarine environments, often swimming far up river. The discovery of sawfish remains among the Baynunah fauna begs further consideration of the proximity of the marine shoreline to the Baynunah fluvial system. It is conceivable that a proto-Gulf seaway may have been in existence, even though intermittently, in the area to the north or west of late Miocene Al Gharbia.

PALEOBIOGEOGRAPHY OF THE BAYNUNAH

The geographic location of the Baynunah Formation, at a locus between the Asian, European, and African continents, is reflected in its fossil fauna (see table 27.1), which comprises a unique mix of taxa not found together elsewhere. Taxa known from the Siwaliks, such as the bovid *Pachyportax latidens* and the suid *Propotamochoerus hysudricus*, are found with otherwise African taxa, including the ratite *Diamantornis laini*, the hippopotamid *Archaeopotamus*, and the giraffid *Palaeotragus* cf. *germaini*. Perhaps with the exception of the bivalve *Leguminaia*, all Baynunah fossil taxa are shared between either African or southern Asian (Siwaliks) faunas, with no taxa uniquely indicative of the Greco-Irano-Afghan zone (de Bonis et al. 1992). This is intriguing given the relative proximity of sites such as Injana (Brunet and Heintz 1983) and Marageh (Bernor 1986). It appears that faunal exchange was very much a function of latitude, with environmental factors permitting biotic dispersal in east–west directions and restricting it in north–south directions. The Himalayan-Zagros-Tauride mountain range has been proposed as a dispersal barrier throughout the late Miocene between sites in the Siwaliks/Iraq and the Greco-Afghan biogeographic zone (Brunet and Heintz 1983; Brunet et al. 1984; Beden and Brunet 1986).

The Baynunah fauna includes a much larger number of taxa in common with African rather than Siwaliks assemblages (see table 27.1). Three African sites dating to between 8 Ma and 5 Ma and with extensive faunal lists are chosen for comparison with the Baynunah: Toros-Menalla (Chad; Vignaud et al. 2002), the Lower Member of the Nawata Formation at Lothagam (Kenya; Leakey and Harris 2003), and Sahabi (Libya; Boaz et al. 2008), but collections from the Mpesida Beds and Lukeino Formation of the Tugen Hills, Kenya, are also relevant to this discussion (Hill et al. 1985; Hill 1999a, 1999b, 2002). Each of these three sites is situated within a different African region, and each shares taxa in common with the Baynunah fauna. Baynunah taxa with affinities to Sahabi include *Geochelone* (*Centrochelys*) aff. *sulcata*, *Myocricetodon*, and *Amebelodon*/"Mastodon" *grandincisivus*. Taxa in common between the Baynunah and the Lower Nawata include *Archaeopotamus* aff. *lothagamensis*, *Diamantornis laini*, and perhaps *Paraulacodus*.

CHRONOLOGY AND DURATION

No tuffs or other volcanics are present in the Shuwaihat or Baynunah formations. As a result, age estimates for the Baynunah so far derive exclusively from biochronological correlations. Previous age estimates based on biochronology had placed the Baynunah fauna at somewhere between 8 Ma and 6 Ma in age. More recently, *Archaeopotamus* (Boisserie 2005) and *Diamantornis laini* (Harris and Leakey 2003; Harrison and Msuya 2005; Bibi et al. 2006) have been determined to be present in the Baynunah fauna. These two taxa are also present in the Nawata Formation, specifically in the Lower Member but not the Upper Member. While the maximum age of the fossil fauna from the Lower Member is not precisely determined, the upper limit of this member is firmly established as at 6.5 Ma by the Marker Tuff (McDougall and Feibel 2003). Similarly, the suid *Propotamochoerus hysudricus* (Bishop and Hill 1999) ranges from 10.2 Ma to 6.8 Ma (Badgley et al. 2008). Assuming similar taxonomic age ranges applied in Arabia, these three taxa tentatively propose a minimum age limit of 6.5 Ma for the Baynunah.

Kingston (1999) sampled fossil enamel from the Baynunah for stable carbon isotopes and discovered a dominant C_4-feeding signal in teeth of *Stegotetrabelodon* sp., *Hipparion abudhabiense*, *Hipparion* sp., ?*Bramatherium* sp., *Tragoportax cyrenaicus*, and *Archaeopotamus* aff. *lothagamensis*. Analysis of paleosol carbonates indicated the presence of mixed C_3–C_4 habitats (but no C_4-dominated habitats [Kingston 1999]). In the Siwaliks and the Tugen Hills, the first enamel isotope values indicating a pure C_4 diet ($\delta^{18}C$ values > −2‰) do not appear until around 7 Ma (Cerling, Wang, and Quade 1993; Morgan, Kingston, and Marino 1994). The first C_4-dominated habitats (paleosols) do not appear in the Siwaliks until 7.37 Ma (Quade et al. 1989; Quade and Cerling 1995; Barry et al. 2002), though this is not apparent in the paleosols of the Tugen Hills sequence (Kingston, Marino, and Hill 1994). If the presence of a significant C_4 component in habitats and diets can be assumed to have had a similar chronology in the Arabian Peninsula, then the presence of a strong C_4 dietary signal in the Baynunah fauna might establish the maximum age of this assemblage as being around 7.4 Ma.

On the basis of the above evidence, then, we tentatively suggest a constrained age of between 7.5 Ma and 6.5 Ma for the Baynunah Formation. Continued fossil discoveries and analysis will help more precisely constrain the age of this fossil assemblage. Most promising among these is perhaps the taxonomic determination of the ostracods from the carbonates of the upper Baynunah.

How long the Baynunah river system was in existence is currently not known. The collective fossil fauna appears consistent with a single temporal window, but in reality a late Miocene fauna could sample a million years or more before biochronological inconsistencies are detected. The presence of up to four polarity reversals in the magnetostratigraphy of the Baynunah Formation (see figure 27.2; Hailwood and Whybrow 1999:fig. 8.5) indicates at least some geologically significant duration of time is represented. According to the geomagnetic polarity timescale (Cande and Kent 1995), 12 polarity reversals are present in the period between 8 Ma and 6 Ma, with magnetochron durations varying between 34 ka and 368 ka. This gives some indication that a span of over 300 ka might easily be accommodated by the Baynunah sediments, though without a direct chronological tiepoint, it is not possible to say more at the moment. Ongoing paleomagnetic work promises to build a more complete and precise local Baynunah magnetostratigraphy that will help better determine the age and duration of this set of deposits.

SITE DOCUMENTATION, MAINTENANCE, AND SALVAGE

Exploratory work since 1999 has significantly increased the recognized areal extent of the Baynunah fossil deposits. In particular, this has come with the discovery of fossils from a number of areas further inland than had previously been known. Primary among these are the sites of Jaw Al Dibsa (or Umm al-Ishtan), Bida' Al Mutawa'ah, and Mleisa. Jaw Al Dibsa comprises a collection of sites bearing remains of proboscideans, bovids, giraffids, fish, ratites eggshells, and fossil wood. The Bida' Al Mutawa'ah and Mleisa sites are fossil trackway sites where proboscidean and ungulate footprints have been discovered (Higgs et al. 2003). The discovery of these sites has increased the potential for further fossil discoveries in the Al Gharbia region. Current annual fieldwork efforts continue to focus on the survey and documentation of fossiliferous exposures inland of the coastal sites.

Paleontological work in Al Gharbia is a race against the rapid rate of development characteristic of the United Arab Emirates. All the Baynunah fossil sites are in real danger of development activities that either destroy them or make them inaccessible to scientists. For example, sites on Shuwaihat and Jebel Dhanna from which important fossil specimens were discovered and described (Whybrow and Hill 1999) have been appropriated by military and oil refinery installations. The Baynunah Formation type section at Jebel Barakah has itself in recent years been greatly disturbed by earth-moving activities and is now in a military area. Access to coastal and inland Baynunah exposures is being continually restricted by military, municipality, and oil industry appropriation. At this rate, it will be barely a matter of a decade before almost all the fossil sites are compromised.

The Abu Dhabi Authority for Culture and Heritage is taking important measures toward site maintenance and awareness that in some cases have proved successful at protecting fossil sites. These include fencing-off certain sites such as the Mleisa trackways and the placement of signs informing of the proximity of sites. These are, however, effectively temporary measures, and without the enactment of legislation and enforcement the fossil sites of Al Gharbia continue to remain in real threat of damage. Paleontological work in the Al Gharbia region takes on the aspect of a salvage mission, whereby fossiliferous deposits are studied and documented in anticipation of their being lost in the near future.

CONCLUSION

Since 1999, fossil discoveries have continued to be made in the late Miocene Baynunah Formation in Al Gharbia, Abu Dhabi Emirates. Since 1996, annual fieldwork efforts were restarted as a collaboration between Yale University and the Abu Dhabi Authority for Culture and Heritage, headed by the four authors. All in all, renewed efforts have resulted in the collection of hundreds of new fossil specimens, containing among them new taxa not before known from the Baynunah, and better representation of known taxa that promises further refinement of the faunal list. This comes in addition to the discovery of new fossil sites much further inland than had previously been known, including sites preserving trackways of proboscideans and an ungulate. Analyses seeking pollen, phytoliths, and an improved local paleomagnetic stratigraphy are underway, as are sedimentological studies of the sands and carbonates of the Baynunah Formation. These, in conjunction with the information provided by the fossil remains, should help better determine the age, duration, and paleoenvironments of the Baynunah Formation.

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