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Received 22 January 1992
Revision received 26 May 1992
and accepted 15 August 1992

Keywords: Oligocene, Gebel Qatrani Formation, Fayum primates, Egypt, origin of Anthropoidea.

Oligocene age of the Gebel Qatrani Formation, Fayum, Egypt

Sea level sequence stratigraphy is especially valuable for correlating marine stages on passively subsiding continental margins. The continental Gebel Qatrani Formation in Egypt is separated from the underlying marine Qasr el-Sagha Formation by a major unconformity with a minimum of 76 m of section missing due to erosion and/or non-deposition. This unconformity is constrained by Priabonian planktonic foraminifera in the Gehannam Formation to be younger than early late Eocene and it is constrained by radiometric ages and a great thickness of Gebel Qatrani Formation to be older than late Oligocene. The only "type-1" sequence boundary within these age constraints that involved a low enough sea stand to explain the unconformity was at the Priabonian–Rupelian (Eocene–Oligocene) boundary, which means that the Gebel Qatrani Formation is entirely Oligocene in age. This corroborates earlier age assignments based on invertebrate and vertebrate faunal succession and it is consistent with new paleomagnetic evidence. The Gebel Qatrani Formation has yielded the earliest primates of anthropoid grade and the evolutionary emergence of higher primates may be related to profound environmental change during the Eocene–Oligocene transition.

Journal of Human Evolution (1993) **24,** 207–218

Introduction

Fossil primates from the continental Gebel Qatrani Formation of Egypt are usually considered to be Oligocene in age. This interpretation goes back to Blanckenhorn (1903), Stromer (1906, 1907), Depéret (1907) and Osborn (1908). The Gebel Qatrani Formation has yielded the primates *Catopithecus*, *Proteopithecus*, *Oligopithecus*, *Apidium*, *Simonsius*, *Propliopithecus* and *Aegyptopithecus*, which are all important for understanding the evolutionary origin of Anthropoidea. The age of the formation is important for understanding the timing and also the environmental context of anthropoid emergence.

Van Couvering & Harris (1991) recently reinterpreted the age of the Gebel Qatrani Formation in the context of global cycles of sea level change (sequence stratigraphy) and concluded that the formation and its primate faunas are late Eocene rather than Oligocene in age. Sea level and sea level change are important for interpreting the stratigraphy of passively subsiding continental margins like that in northern Egypt but, as explained below, evidence from sequence stratigraphy favors an Oligocene age for the Gebel Qatrani Formation.

The early Cenozoic stratigraphy of Egypt is complicated, due in part to excellent exposure over a broad area and in part to a large and scattered literature written in several languages over a period of more than 100 years. I recently completed a synthesis of the Eocene stratigraphy of northern Egypt (Gingerich, 1992), studied in the context of sea level change. This was based on five seasons of field work and an extensive review of the literature. The purpose of the study was better understanding of the age and depositional environments of Cetacea and Sirenia in the marine Gehannam, Birket Qarun and Qasr el-Sagha formations, but these have a bearing too on the age of the Gebel Qatrani Formation.

Van Couvering & Harris' (1991) conjecture that the Gebel Qatrani Formation is Eocene in age is implausible because their claim that the Qasr el-Sagha and Gebel Qatrani formations show no clear break in deposition is contradicted by field observations, including evidence of a major regional unconformity separating these formations in the Fayum (and

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separating similar formations of equivalent age elsewhere). A major unconformity indicates a time of markedly low sea level. The age of this low sea stand is constrained by planktonic foraminifera in underlying formations to be late Eocene or younger and constrained by radiometric ages on an overlying basalt to be early Oligocene or older. The Priabonian/Rupelian low sea stand at the Eocene/Oligocene boundary is the only "type-1" sequence boundary satisfying these constraints. An Oligocene age for the Gebel Qatrani Formation based on sea level stratigraphy is consistent with evidence from invertebrate faunal correlation, fossil mammal correlations and paleomagnetic stratigraphy.

Sequence stratigraphy

Sequence stratigraphy recognizes that sedimentary packages (depositional sequences or sequence tracts) are bounded by unconformities and that unconformities on passive continental margins may be caused by rapid lowering of sea level worldwide, giving them special value for broad chronostratigraphic correlation (Pitman, 1978; Vail *et al.*, 1977; Vail & Hardenbol, 1979; Haq *et al.*, 1987). Most marine stages are sequence tracts or groups of tracts and sequence stratigraphy provides a natural context for their study.

An unconformity is a surface of erosion or nondeposition (usually the former) representing a gap in time separating younger strata from older rocks. The most obvious of these is a conspicuous angular unconformity with lower strata folded or tilted some observable amount (say 1–2° or more) and then truncated by erosion before deposition of overlying beds. A *disconformity is a more subtle unconformity involving parallel strata with the lower bed(s)* truncated by small-scale erosion. A paraconformity is an unconformity where the erosion surface is parallel to bedding (there is no truncation), contact is a simple bedding plane and evidence of a temporal gap comes from unconformity between the same beds elsewhere or from missing fossil zones (sometimes signaled by an abrupt change in lithology). Conformity means adjacent sedimentary strata exhibit no evidence of unconformity or discontinuity in sedimentation.

Etymologically, discomformity and paraconformity sound like they might be particular kinds of conformities, but they are really kinds of unconformities. Another source of confusion is use of unqualified adjectives like "conformable" to describe parallel bedding even when two tracts are known to be separated by an unconformity. Disconformity and paraconformity are kinds of unconformity between "conformable" beds, and in such cases it would be preferable to use qualified adjectives like discomformable and paraconformable.

Conformity is a null hypotheses falsified immediately when an angular unconformity is found, but sequence tracts are not always folded or tilted before they are buried. This is a special problem when outcrops parallel the hinge axis of subsiding continental margins, as they generally do in Egypt. Consequently, discovery of more subtle erosion-nondeposition surfaces marking the disconformities and paraconformities associated with sequence boundaries requires regional investigation.

Eocene–Oligocene stratigraphy in Fayum

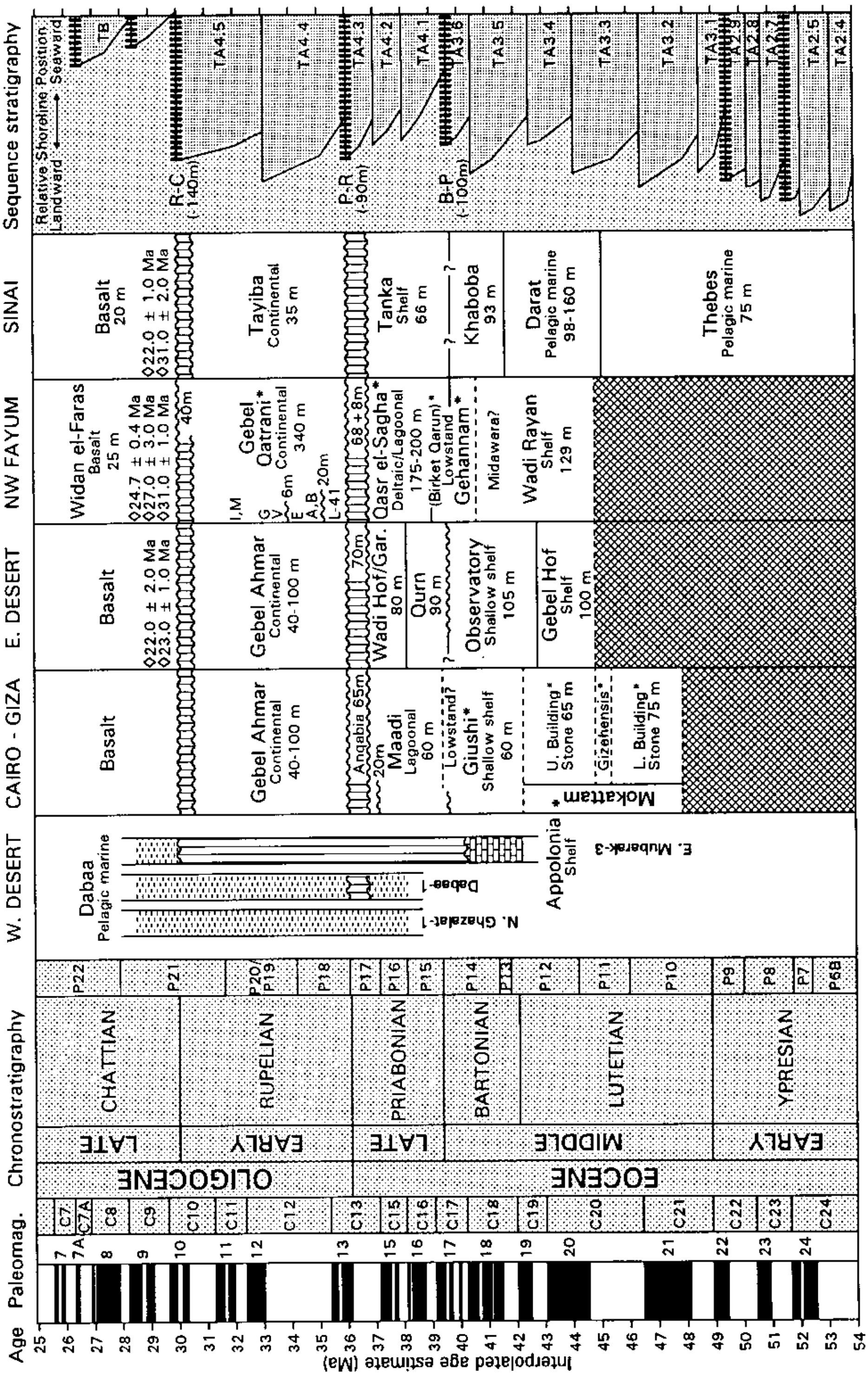
In the early Cenozoic Egypt was positioned on the northern edge of the African continent as it is today. The Tethys Sea lay to the north and occupied approximately the position of the present Mediterranean Sea. The northern part of Egypt was an unstable continental margin, passively subsiding beneath Tethys during this interval and accumulating a relatively complete stratigraphic record. The ancient shoreline ran across northern Egypt in a roughly WSW–ENE direction, with Tethys to the northwest and land to the southeast. Through Eocene and Oligocene time, continental deposits prograded northward and westward effecting long-term regression of sea level. This means, in general, that today shallower marine or continental sedimentary formations overlie deeper marine formations across much of northern Egypt.

The Eocene and Oligocene stratigraphy of northern Egypt is summarized in Figure 1, which includes radiometric calibration, paleomagnetic stratigraphy, chronostratigraphy and sequence stratigraphy (sedimentary sequence tracts and tract boundaries) taken from the most comprehensive current review (Haq *et al.*, 1987). Four stages are recognized in the Eocene (Ypresian, Lutetian, Bartonian and Priabonian) and two stages are recognized in the Oligocene (Rupelian and Chattian). "Type-1" sequence boundaries associated with major unconformities due to rapid sea level fall are shown as heavy dashed lines in the right-hand column of Figure 1. Stage boundaries usually coincide with type-1 sequence boundaries. The three type-1 sequence boundaries of interest here are those marking the transition from the Bartonian to the Priabonian, from the Priabonian to the Rupelian and from the Rupelian to the Chattian, labelled B–P, P–R and R–C, respectively, for ease of reference.

Generalized stratigraphic sections for five areas of northern Egypt are shown in Figure 1. These are, from west to east: Western Desert, Cairo–Giza, Eastern Desert, northwestern Fayum and western Sinai. WSW–ENE orientation of the shoreline means that the five generalized sections in Figure 1 describe environments positioned from west to east along shore, and also, to some extent, from west offshore to east onshore. Each section is reviewed in detail elsewhere (Gingerich, 1992) and the following discussion focuses on Fayum.

The Wadi Rayan Formation of Beadnell (1901, 1905; here including the Midawara Formation of Iskander, 1943) includes about 129 m of marine shelf sediments known to be Lutetian in age (and possibly, in part, Bartonian), based on nummulites and other evidence (Beadnell, 1905; Shamah & Blondeau, 1979; Shamah *et al.*, 1982). The overlying Gehannam Formation of Said (1962; Ravine beds of Beadnell, 1901, 1905) includes about 46 m of marine shallow shelf sediments known to be Bartonian and, in places, early Priabonian in age based partly on mollusks, but principally on planktonic foraminifera (Abdou & Abdel-Kireem, 1975; Strougo & Haggag, 1984; Abdel-Kireem *et al.*, 1985; Haggag, 1990). A conspicuous low sea stand with mangrove, *Moeritherium*, and abundant celestite separates the Gehannam Formation from the overlying Birket Qarun Formation in Wadi Hitan (Zeuglodon Valley; Gingerich, 1992). The Birket Qarun Formation of Beadnell (1901, 1905) is a long linear multistorey sandstone as much as 72 m thick lying parallel to the ancient shoreline and interpreted as an offshore barrier bar complex (Gingerich, 1992). Barrier sands are transgressive sequence tracts that are normally only preserved in the stratigraphic record during marine transgression, and their thickness provides a minimum estimate of sea level rise.

The Qasr el-Sagha Formation of Beadnell (1901, 1905) is 175–200 m thick, subdivided into Umm Rigl, Harab, Temple and Dir Abu Lifa members, representing outer lagoon, middle lagoon, inner lagoon and deltaic or interdeltaic facies (Vondra, 1974; Bown & Kraus, 1988; Gingerich, 1992). Bown & Kraus (1988:47) interpreted "conglomeratic coquina" beds in the Temple Member as strandline lag deposits. However, Blanckenhorn (1903) and Gingerich (1992) described a repeated *Ophiomorpha–Callianassa/Carolia/Ostrea*, *Kerunia* and *Turritella* vertical succession characteristic of each "coquina" that would not be expected


Age
Interpolated age estimate (Ma)
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
Paleomag.
7
7A
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
C7
C7A
C8
C9
C10
C11
C12
C13
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
Chronostratigraphy
OLIGOCENE
EOCENE
LATE
EARLY
LATE
MIDDLE
EARLY
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
P22
P21
P20/P19
P18
P17
P16
P15
P14
P13
P12
P11
P10
P9
P8
P7
P6B
W. DESERT
Dabaa
Pelagic marine
N. Ghazalat-1
Dabaa-1
E. Mubarek-3
Appolonia
Shelf
CAIRO - GIZA
Basalt
Gebel Ahmar
Continental
40-100 m
Angabia 65m
20m
Maadi
Lagoonal
60 m
Lowstand?
Giushi*
Shallow shelf
60 m
U. Building*
Stone 65 m
Gizehensis*
L. Building*
Stone 75 m
Mokattam*
E. DESERT
Basalt
◊22.0 ± 2.0 Ma
◊23.0 ± 1.0 Ma
Gebel Ahmar
Continental
40-100 m
70m
Wadi Hof/Gar.
80 m
Qurn
90 m
?
Observatory
Shallow shelf
105 m
Gebel Hof
Shelf
100 m
NW FAYUM
Widan el-Faras
Basalt
25 m
◊24.7 ± 0.4 Ma
◊27.0 ± 3.0 Ma
◊31.0 ± 1.0 Ma
40m
Gebel
Qatrani*
Continental
340 m
I,M
G
V
E
A,B
L-41
6m
20m
68 + 8m
Qasr el-Sagha*
Deltaic/Lagoonal
175-200 m
(Birket Qarun)*
Lowstand
Gehannam*
Midawera?
Wadi Rayan
Shelf
129 m
SINAI
Basalt
20 m
◊22.0 ± 1.0 Ma
◊31.0 ± 2.0 Ma
Tayiba
Continental
35 m
Tanka
Shelf
66 m
?
?
Khaboba
93 m
Darat
Pelagic marine
98-160 m
Thebes
Pelagic marine
75 m
Sequence stratigraphy
Relative Shoreline Position
Landward ← → Seaward
TB
R-C
(-140m)
P-R
(-90m)
B-P
(-100m)
TA4.5
TA4.4
TA4.3
TA4.2
TA4.1
TA3.6
TA3.5
TA3.4
TA3.3
TA3.2
TA3.1
TA2.9
TA2.8
TA2.7
TA2.5
TA2.4

in strand deposits. Bown & Kraus (1988:46–47) regarded the Dir Abu Lifa Member as "fluvial" based on sedimentary structures, but interbedded hermatypic scleractinian corals and other marine invertebrates reported from the giant crossbedded sandstone sequence of the Dir Abu Lifa Member (Blanckenhorn, 1903:384; Beadnell, 1905:50) make it unlikely that these sediments are really river deposits. The "fluvial" sedimentary structures were probably made by submarine currents carrying terrigenous clastic sediments (with some bones of estuarine or land vertebrates) delivered to the sea by rivers. The entire Qasr el-Sagha Formation appears to be marine as Blanckenhorn (1903), Beadnell (1905) and Vondra (1974) thought.

An idealized sequence stratigraphic model constructed to explain deposition of shallow marine and continental formations in northern Egypt is illustrated in Figure 2. It shows the spatial and temporal relationships of Fayum formations and facies (boxed) in relation to episodic low sea stands superimposed on secular progradation of a passively subsiding continental margin. The model is idealized in the sense that consideration of sea level change has been limited to episodes of major change, progradation has been assumed to proceed at a more or less constant rate and local structural influences have been ignored.

Virtually all geologists who have studied the Qasr el-Sagha/Gebel Qatrani formation boundary in the field in Fayum have recognized a profound change from marine to continental sedimentation in going from one formation to the other. This is most obvious in the change from predominantly drab planar strata of uniform thickness characteristic of the Qasr el-Sagha Formation to brightly-colored channeled beds of varying thickness characteristic of the Gebel Qatrani Formation. The change from marine to continental vertebrates and invertebrates at this boundary is also conspicuous.

Beadnell (1901) interpreted the transition from the Qasr el-Sagha Formation to the Gebel Qatrani Formation as "conformable," although these formations are now known to be separated by a major unconformity. The null hypothesis of conformity was rejected by Blanckenhorn (1903:399), who described their relationship as follows:

> "*Obwohl eine Diskordanz nicht direkt zu beobachten ist, könnte man doch speziell im NO. an eine Lücke oder Unterbrechnung der Sedimentation zu Beginn des Obereocäns (Bartonien) denken und geneigt sein, den ganzen*

Figure 1. Eocene and Oligocene stratigraphy of northern Egypt. Succession of geological formations is shown for five areas: the Western Desert, Gebel Mokattam and vicinity near Cairo and Giza, the Eastern Desert east of Cairo, northwestern Fayum and western Sinai. Formations are shown with environment of deposition and thickness when space permits. Asterisks identify important marine and continental mammal-bearing formations. Wavy lines represent unconformities (vertical lines separating pairs of wavy lines depict major unconformities); all are shown with an estimate of minimum thickness of missing section when available. Note that major unconformities are regional and extend across all but deep marine sections offshore in the Western Desert. Interpolated age estimates based on radiometric calibration are shown at left ("age") with paleomagnetic reversal stratigraphy. Eocene–Oligocene epochs and stages, with magnetochrons and Paleogene planktonic foraminiferal zones (P6B–P22), are shaded at left, and sea level sequence stratigraphy is shaded at right (all taken from Haq *et al.*, 1987). Diamonds depict radiometric ages of Widan el-Faras and correlative basalts. Letters I, M, G, etc., show positions of land-mammal localities in Gebel Qatrani Formation. Cross-hatching represents strata covered or missing in the area studied. Sequence tracts (TA2.4, TA2.5, etc.) separated by heavy broken lines are imporant "type-1" sequence boundaries corresponding to major sedimentary unconformities caused by rapid sea level fall moving shoreline seaward. Type-1 boundaries near the Bartonian–Priabonian transition [B–P], Priabonian–Rupelian transition [P–R] and Rupelian–Chattian [R–C] are shown with approximate magnitude of sea level change in parentheses (estimated as difference between long-term maximum and short-term minimum for transition). All measures of thickness, missing section and sea level change are in meters. Figure from Gingerich (1992).

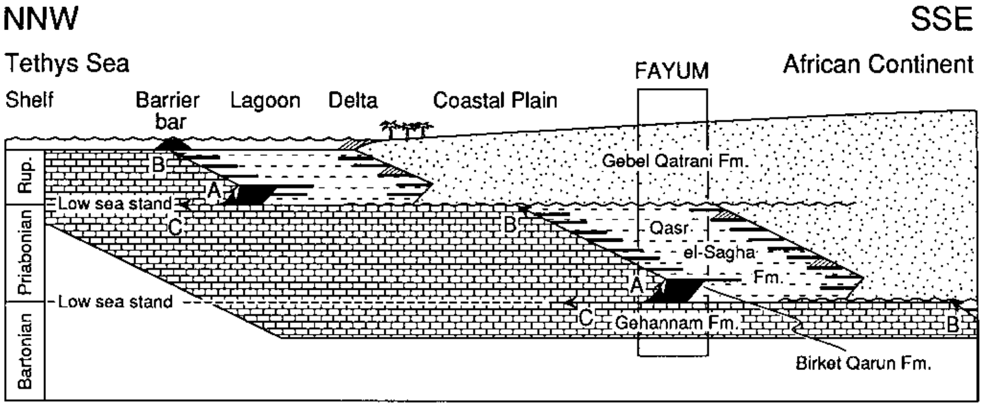


Figure 2. Idealized sea level sequence stratigraphic model constructed to explain deposition of shallow marine and continental formations observed in Eocene and Oligocene of northern Egypt. Succession of formations observed in Fayum is shown in the box. Model is NNW–SSE transect perpendicular to the southern Tethys–northern Africa coastline with open shallow shelf, barrier bar, lagoon, delta front and coastal plain facies. Barrier bar and lagoonal sediments and non-lagoonal delta front sediments represent alternate environments and would not have been deposited simultaneously in the same area. Cycles of sea level change depositing successive sequence tracts are shown with uppercase letters: A, marine transgression due to rapid isostatic sea level rise that exceeds regression due to progradation; B, normal regression due to progradation on slowly subsiding passive continental margin; C, major regression due to isostatic sea level fall. Gehannam Formation includes highstand and lowstand systems tracts that accumulated during Bartonian and Priabonian time (middle-to-late Eocene) in open shallow shelf environments. Birket Qarun Formation shown in black is a barrier bar transgressive systems tract that accumulated at beginning of Priabonian time (late Eocene) and was buried during isostatic sea level rise. Qasr el-Sagha Formation includes highstand systems tracts that accumulated during Priabonian time (late Eocene) in lagoonal environments (black lines represent hard "coquina" beds deposited on margins of inner and outer lagoon). Sloping delta front deposits (shown with sloping lines and representing, e.g., the Dir Abu Lifa Member) build out from shore and may obliterate or completely fill lagoons (not shown here). Gebel Qatrani Formation includes continental systems tracts that accumulated during Rupelian time (early Oligocene) in riverine environments on prograding delta plains. Vertical exaggeration is on the order of 100 × . Figure from Gingerich (1992).

> *fluviomarinen Komplex ins Oligocän zu stellen.*" [Although an unconformity cannot be observed directly, one can still recall, especially in the northeast, a gap or interruption of sedimentation at the beginning of the upper Eocene due to erosion, thus placing the whole overlying Gebel Qatrani fluviomarine complex in the Oligocene.]

Beadnell (1905:55) clarified this further:

> "From an examination of the [Gebel Qatrani] series in the field, there is no doubt that, in at least the centre of the area, the deposition of the lowest beds was continuous with those of the Qasr el Sagha . . . series below. Followed away from the centre . . . the series gradually thins out, and eastwards, at Elwat Hialla, some 23 kilometres north of Tamia, has a thickness of only 40 metres, the basal beds being apparently laid on to a bed of limestone of the Qasr el Sagha series about the horizon of Bed 12 in Section XXIII."

This means a 68 m thickness of upper Qasr el-Sagha strata present across the rest of Fayum is missing at Elwat Hialla.

Barron (1907) focused attention on the Ain Musa echinoid bed at the top of what is now Maadi Formation at Gebel Mokattam near Cairo [named for *Aïn Musa* or "Moses' spring" east of Cairo]. He described an erosional unconformity between the "upper Mokattam" (now Wadi Hof Formation) and the Oligocene (Gebel Ahmar Formation) at Gebel Awebed

80 km east of Cairo (Barron, 1907:64 and section V), and he recorded 70 m of "upper Mokattam" above the Ain Musa bed at Gebel Ataqa west of Suez and 100 km east of Cairo (Barron, 1907:85). Removal of the upper part of the "upper Mokattam" by erosion before deposition of the Gebel Ahmar indicates that a major unconformity separates the two formations in the Eastern Desert. Barron (1907:87–92) argued that the full 70 m of "upper Mokattam" was removed by erosion from the top of the Mokattam sequence (top of the Maadi Formation) in Cairo, and he argued, citing Beadnell, that 68 m was removed by erosion from the top of the Qasr el-Sagha Formation in Fayum.

Strougo (1976), following Blanckenhorn (1900, 1903), correlated the Ain Musa bed at Gebel Mokattam with one of the uppermost beds of the Qasr el-Sagha Formation in Fayum, and he described the Qasr el-Sagha/Gebel Qatrani formational contact and discontinuity of sedimentation marking the Eocene–Oligocene boundary in Fayum as follows (Strougo, 1976:1139):

> "*Au Fayoum, une discontinuité de sédimentation marque la limite de l'Éocène et de l'Oligocène comme le prouve le développement suivant.*
>
> *Blanckenhorn (1990) a assimilé à son niveau II-8 du Gébel Mokattam (équivalent du Membre Ain Musa) la couche terminale de la Formation Qasr el Sagha, puissante de 1 m seulement en renfermant de nombreux* Echinolampas crameri *et* Anisaster gibberulus. *Ce synchronism amena Barron (1907) à constater que plus de 70 m de roches reconnues par lui dans le district Le Caire-Suez, au-dessus du Membre d'Ain Musa, et appartenant encore à l'Éocène supérieur, n'avaient pas d'équivalents au Fayoum où le banc à* E. crameri *et* A. gibberulus *est directement subordonné à la Formation Qatrani, d'âge oligocène; il conclut qu'une profonde discontinuité de sédimentation sépara l'Éocène supérieur de l'Oligocène au Fayoum. . . .*
>
> *Nous venons de voir que les couches du Mokattam et de Qasr el Sagha pouvaient être considérées comme homologues sans difficulté. Seuls les 10 m du sommet de ce dernier gisement semblent appartenir à une tranche de temps un peu plus récente que celle ayant présidé au dépôt de la Formation Maadi, à l'est du Caire. Il n'en demeure pas moins qu'une grande partie des couches affleurant dans le district Le Caire-Suez, au dessus du Membre Ain Musa, fait encore défaut au Fayoum, ce qui implique l'existence d'une discontinuité de sédimentation à la limite Éocène–Oligocène dans cette dernière région.*"
>
> [In Fayum, a discontinuity of sedimentation marks the limit of the Eocene and Oligocene, as the following proves.
>
> Blanckenhorn (1900) included the uppermost bed of the Qasr el-Sagha Formation, only 1 m thick and containing numerous *Echinolampas crameri* and *Anisaster gibberulus*, as his Gebel Mokattam level II-8 (equivalent to the Ain Musa member). This synchrony led Barron (1907) to conclude that more than 70 m of rocks he recognized in the Cairo-Suez district, above the Ain Musa member and belonging to the upper Eocene, had no equivalents in Fayum where the *E. crameri* and *A. gibberulus* bed is directly beneath the Qatrani Formation of Oligocene age. He concluded that a profound discontinuity of sedimentation separated the upper Eocene from the Oligocene in Fayum . . .
>
> We come to see that the Mokattam and Qasr el-Sagha beds may be considered as homologs without difficulty. Only the uppermost 10 m of the latter deposit appear to represent a slice of time a little more recent than that at the top of the Maadi Formation east of Cairo. Little remains there of a great part of the beds deposited in the Cairo-Suez district above the Ain Musa member, missing also in Fayum, implying the existence of a discontinuity of sedimentation at the Eocene–Oligocene boundary in the latter region.]

Strougo regarded Bowen & Vondra's (1974) report of conglomeratic sandstone at the base of the Gebel Qatrani Formation as consistent with this discontinuity.

Bown & Kraus (1988:23), like Strougo, favored Blanckenhorn's interpretation of an unconformity at the Qasr el-Sagha/Gebel Qatrani formational boundary, writing:

> "Beadnell attributed this relationship to an earlier onset of Jebel Qatrani environments at Elwaht Hialla; however it appears instead to have resulted from the absence of deposition of . . . the upper

> Qasr el Sagha Formation. In the Eastern Desert, the Jebel Ahmar beds (= Jebel Qatrani Formation equivalents) lie unconformably on all older rocks."

Bown & Kraus (1988:20) described a new sedimentary unit of the Qasr el-Sagha Formation, the upper crossbedded sandstone and mudstone sequence, confined to the Wadi Efreet area. This new unit lies above the "bare limestone," which marks the top of the Qasr el-Sagha elsewhere in the Fayum. The "bare limestone" is generally correlated with the Ain Musa bed that marks the top of the Maadi Formation at Gebel Mokattam and east of Cairo (see Blanckenhorn, 1903; Barron, 1907; Strougo, 1976). The upper crossbedded sandstone and mudstone sequence of Bown & Kraus is up to 8 m thick and truncated by an erosion surface that descends more than 9 m in places, penetrating the "bare limestone." The thickness of the "bare limestone" (2 m) plus the thickness of the upper crossbedded sandstone and mudstone sequence (8 m) indicates a minimum of 10 m of erosional relief between the Qasr el-Sagha and Gebel Qatrani formations at Wadi Efreet.

Bown & Kraus (1988:20) noted that outside the Wadi Efreet area the upper crossbedded sandstone and mudstone sequence has been removed by erosion (or lies buried under the Gebel Qatrani Formation). They concluded: "This unit is important only in that it demonstrates that the Qasr el Sagha Formation–Jebel Qatrani Formation contact (and possibly also the Eocene–Oligocene boundary) is at least locally marked by a minor erosional unconformity." However, the total nondeposition (or deposition-plus-erosion) at the Qasr el-Sagha/Gebel Qatrani formational boundary involves a minimum of 76 m, which includes 68 m below the Ain Musa bed present at Dir Abu Lifa but missing at Elwat Hialla (Beadnell, 1905:55 and section XXIII; Barron, 1907:68), plus the lesser of 10 m above the Ain Musa bed present at Qasr el-Sagha (Strougo, 1976:1139) or 8 m of the upper crossbedded sandstone and mudstone above the "bare limestone" at Wadi Efreet (Bown & Kraus, 1988:20).

This must represent a considerable interval of time, and Rasmussen *et al.* (1992:560) are correct in describing the Qasr el-Sagha/Gebel Qatrani formational boundary as a major unconformity.

Non-deposition or deposition-and-erosion of 76 m of sediment at Elwat Hialla that is present 20 or so kilometers away near Qasr el-Sagha indicates a major unconformity, but this requires an angular relationship between beds averaging only about 0·2° (arcsin of 76/20,000), which could not possibly be detected in the field. This angle is small because outcrops being compared lie approximately parallel to the Eocene shoreline and parallel to the hinge axis of subsidence of the continental margin (the unconformity would be more obvious if beds being compared were exposed in a transect perpendicular to the axis of subsidence).

Age of the Gebel Qatrani Formation

The Gebel Qatrani Formation and the underlying Qasr el-Sagha Formation are separated by an unconformity in Fayum that involved erosion of a minimum of 76 m of Qasr el-Sagha strata in places before deposition of the Gebel Qatrani Formation. This minimum is close to the minimum of 65 m of Anqabia Formation eroded above the Maadi Formation before deposition of the Gebel Ahmar Formation in the Cairo-Giza area, and it is close to the minimum of 70 m eroded from the top of the upper Maadi or Wadi Hof Formation before deposition of the Gebel Ahmar Formation in the Eastern Desert. The great thickness of sediment removed by erosion at the Qasr el-Sagha/Gebel Qatrani formational boundary and the consistency of minimum estimates of erosion separating correlative formations across northern Egypt, taken together, provide clear evidence of a major regional unconformity. A rapid fall in sea level of 76 m or more is required to remove 76 m of shallow marine sediment on a passive continental margin. This happened three times in the middle to late Eocene and Oligocene (Haq *et al.*, 1987): at the Bartonian–Priabonian [B–P], the Priabonian–Rupelian [P–R] and the Rupelian–Chattian [R–C] sequence boundaries shown in Figure 1. These involved rapid sea level falls of about −100, −90 and −140 m, respectively.

Sea level falls at any one ofthe B–P, P–R, or R–C sequence boundaries would be sufficient to explain removal of 76 m of sediment between the Gebel Qatrani and Qasr el-Sagha formations. However, superposition and planktonic foraminiferal biostratigraphy demonstrate that the Qasr el-Sagha Formation is younger than the B–P sequence boundary (Abdou & Abdel-Kireem, 1975; Haggag, 1990). Radiometric ages on overlying basalts indicate that the Gebel Qatrani Formation is older than the R–C sequence boundary (Fleagle *et al.*, 1986). Consequently, the P–R boundary is the only "type-1" sequence boundary matching erosion at the Qasr el-Sagha/Gebel Qatrani formational boundary that is consistent with other constraints on the ages of the two formations.

Other evidence

Blanckenhorn (1903) was the first to place the Gebel Qatrani fluviomarine complex in the Oligocene, and he did so because of the unconformity separating this from underlying marine beds. Stromer (1906) regarded the Gebel Qatrani Formation as either late Eocene or early Oligocene, but then settled on early Oligocene (Stromer, 1907) when the molluscan fauna of the Qasr el-Sagha Formation proved to be late Eocene (Oppenheim, 1903–1906). Depéret (1907) contradicted Andrews (1906) in regarding Gebel Qatrani mammals as Oligocene because of the stage of evolution of anthracotheres, the creodont *Pterodon* and the proboscidean *Palaeomastodon* in comparison to related forms in Europe. Osborn (1908), citing Stromer, introduced this idea in the English language literature. An Oligocene age is consistent with introduction of a Gebel Qatrani-like species of the creodont *Apterodon* (rather than a Qasr el-Sagha-like species) into Europe in the Rupelian. The Gebel Qatrani-like *Apterodon* is known from Quercy and from the Mainz Basin (Simons & Gingerich, 1976).

Rasmussen *et al.* (1992) interpreted the lower 157 m of the Gebel Qatrani Formation as late Eocene (including all of the "lower fossil wood zone" with Duke Quarry L-41, American Museum quarries A and B, and Yale Quarry E). This was justified (Rasmussen *et al.*, 1992: 560) by correlation of mammals from Fayum Quarry E with mammals from Oman localities (Thomas *et al.*, 1989) that Rasmussen *et al.* characterized as having "paleomagnetic dates" older than the 34 Ma Eocene–Oligocene boundary. However, the Eocene–Oligocene boundary is not defined radiometrically, paleomagnetic correlations are not "dates," and Thomas *et al.* (1989) themselves regarded the Oman localities as Oligocene. Fossil mammals found at the Oman Thaytiniti locality lie within a double-normal magnetic anomaly in association with the Oligocene nummulite *Nummulites fichteli*. The double-normal anomaly was interpreted as paleomagnetic chron C13N (Thomas *et al.*, 1989), which is Oligocene whatever its radiometric age (Berggren *et al.*, 1985; Haq *et al.*, 1987; Odin & Montanari, 1989; Swisher & Prothero, 1990). If Fayum Quarry E is closely correlative with Thaytiniti in Oman based on its mammalian fauna, then the lower part of the Gebel Qatrani Formation is Oligocene rather than Eocene.

An Oligocene age for the Gebel Qatrani Formation is also consistent with initial paleomagnetic results of Kappelman (1991) indicating that primate localities in the Gebel Qatrani Formation lie within magnetochrons C13, C12 and C11. Kappelman has since revised this assessment, but I interpret the normal (black) interval at the base of Kappelman's paleomagnetic section as chron C15N, the double normal (double black) interval above that as chron C13N and the longest reversed (white) interval in the middle of the section as chron C12R.

Radiometric ages

The only radiometric ages published to date from Fayum come from the Widan el-Faras Basalt near the top of the Fayum stratigraphic section. These range from 31·0 through 24·7 Ma. Matching these to age estimates interpolated and integrated for the geological time scale globally indicates that the Widan el-Faras Basalt may be as old as mid-Oligocene or as young as early Miocene (radiometric ages calibrate the time scale, but the geological time scale itself is chronostratigraphic and derived from faunal succession of superposed strata).

The Haq *et al.* (1987) time scale used here has the Eocene–Oligocene boundary estimated at about 36 Ma. Odin & Montanari (1989) and Swisher & Prothero (1990) recently proposed a new estimate for this boundary at about 34 Ma. Such revision of the age estimate of the Eocene–Oligocene boundary does not change the meaning of Eocene or Oligocene, nor does it change the order of correlation of formations and formational boundaries shown in Figure 1. If the Eocene–Oligocene boundary is recalibrated at 34 Ma this might mean that the Gebel Qatrani Formation represents less time than previously thought, but its duration also depends on the true age of the overlying basalt (for which there is a considerable range of radiometric ages in Fayum and elsewhere). Recalibration of the Eocene–Oligocene time scale will require integration and interpolation based on all relevant radiometric ages. It is sufficient to note here that the age of the Eocene–Oligocene boundary may be about 34 Ma instead of 36 Ma, but little else in Figure 1 would be affected by this change. The body of the chart would have to shift slightly relative to million-year tick marks down the sides, and these would obviously have to be renumbered. The Swisher & Prothero study is problematic in that their radiometric calibration inexplicably changed not only the numbering of paleomagnetic polarity events but also correlation of polarity events with land mammal ages in the interval being studied (Swisher & Prothero, 1990: Figure 1). Mammals and magnetochrons are normally studied in the same strata and hence cannot move relative to each other.

Significance for primate evolution

The age of the Gebel Qatrani Formation is important because this formation has yielded most of what we know about land mammal evolution in Africa during the early Cenozoic, and it has yielded the earliest unequivocal (i.e., cranial) evidence for the existence of primates of anthropoid grade (Simons, 1989, 1990). The difference between the late Eocene and early Oligocene may seem slight in terms of the span of geological time involved, but the Eocene and Oligocene were profoundly different epochs in terms of ocean temperature, composition and circulation (Buchardt, 1978; Kennett & Stott, 1990; Zachos *et al.*, 1992), global climate (Barron, 1987) and continental and marine faunas (Stehlin, 1909; Crowley & North, 1988).

It is possible that anthropoid primates evolved in Africa during the Eocene and were unaffected by environmental change during the Eocene–Oligocene transition. Alternatively, it is possible that the emergence of anthropoids happened rapidly and coincided with environmental and faunal changes taking place as part of a "turnover-pulse" (Vrba, 1985) during the Eocene–Oligocene transition. Environmental change through the Eocene–Oligocene transition may have caused the emergence of anthropoids in some direct or indirect way. Coincidences in evolution (and subsequent questions of causation) can only be investigated by reference to a common scale of geological time. Evidence from sequence stratigraphy indicates that the Gebel Qatrani Formation is Oligocene, which means that the role Eocene–Oligocene environmental change played in the origin of Anthropoidea is an open and interesting question.

Acknowledgements

I thank Drs Thomas M. Bown, Gregg F. Gunnell, John Kappelman, D. Tab Rassmussen and John A. Van Couvering, and Messrs W. Clyde, W. Sanders and M. Uhen for comments on the manuscript. Dr Kappelman provided a preprint of his forthcoming paper on paleomagnetic stratigraphy. Five seasons of field work from 1983 through 1991 were carried out in cooperation with Dr Elwyn L. Simons and Mr Prithijit Chatrath of Duke University, and with Dr B. Holly Smith of the University of Michigan. Financial support for field work in 1987, 1989 and 1991 was provided by the Committee for Research and Exploration of the National Geographic Society, Washington (grants numbered 3424-86, 4154-89 and 4624-91).

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