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Temporal, Lithostratigraphic, and Biochronologic Setting of the Sahabi Formation, North-Central Libya

N. T. Boaz,[1]; A. El-Arnauti[2], J. Agusti[3], R.L. Bernor[4], P. Pavlakis[5], and L. Rook[6]

ABSTRACT

Detailed geological and palaeontological fieldwork at Aṣ Ṣaḥābī, north-central Libya in the late 1970s to 80s resulted in the naming of the Sahabi Formation as a formal lithostratigraphic unit by de Heinzelin and El-Arnauti in 1987. Massive gypsum deposits underlying the Sahabi Formation named "Formation P" were assigned a Messinian age, thus indicating a post-Messinian age for the fossiliferous Sahabi Formation. The recent realization elsewhere in the Mediterranean Basin that a number of desiccatory events occurred during the Messinian Stage casts doubt on this lithostratigraphically-based conclusion. Formation P may represent a protracted regressive "First Cycle" evaporite deposition, dated elsewhere to geomagnetic Chron C3Ar (earlier than 6.88 ma), or alternatively more rapidly deposited transgressive "Second Cycle" deposition, dated elsewhere to late in Chron C3An (later than 6.0 ma). Regional studies are needed to relate the Sahabi Formation to other Neogene sedimentary basins.

Past biochronologic studies of Aṣ Ṣaḥābī generally supported a post-Messinian age, i.e. a Pliocene or post 5.3 ma age, but new studies based on comparisons with both Eurasian and other African Neogene vertebrate faunas suggest a Miocene, perhaps "intra-Messinian age" for Member U of the Sahabi Formation, possibly as old as 6.8 ma and correlative to European land mammal unit MN 13. Supportive of this new age attribution are the biochronology of the carnivores, the hipparionine "*Cremohipparion*" aff. *matthewi*, the nyanzachoere suids, two proboscideans (an amebelont gomphothere and *Stegotetrabelon syrticus*), the hippopotamid *Hexaprotodon sahabiensis*, and the rodent *Abudhabia yardangi.* The large anthracothere *Libycosaurus petrocchii* is common in Sahabi Formation Member U and is a late Neogene northern African endemic shared with the hominid-bearing Toros-Menalla site (Chad). The identification of taxa indicative of a putative younger age in areas of western outcrop of the Sahabi Formation (Member V) underlines the importance of renewed collection as well as recovery and re-study of the early "Petrocchi material", collected between 1934-39, to refine the temporal placement of this important site.

INTRODUCTION

The late Neogene site of Qaṣr Aṣ Ṣaḥābī has become an important reference section for the circum-Mediterranean region, especially for studies on the Messinian period (dating to between ca. 6.8 ma to ca. 5.3 ma (Warny *et al.,* 2003)) and its geological, palaeogeographic, and biotic effects (Carmignani *et al.*, 1990; Boaz, 1996; Griffin, 2002). The site constitutes a primary datum for biostratigraphic comparisons with other Old World faunas at or near the Mio-Pliocene boundary (Geraads, 1998; Whybrow and Hill, 1999; Vignaud *et al.*, 2002; Boisserie *et al.*, 2003; Bernor and Scott, 2003). Boaz (1996) included Aṣ Ṣaḥābī in his definition of a distinct late Miocene-early Pliocene palaeobiogeographic zone ("A2") in North Africa, one separated from penecontemporaneous provinces in sub-Saharan Africa and circum-Mediterranean Eurasia.

The temporal setting of Aṣ Ṣaḥābī has been of primary research concern since the inception of our research in 1975 and the subsequent organization and continuing studies of the International Sahabi Research

[1]Department of Anatomy, Ross University School of Medicine, P.O. Box 266, Portsmouth, Commonwealth of Dominica; ntboaz@rossmed.edu.dm
[2]Department of Earth Sciences, Faculty of Science, Garyounis University, Binghāzī, Libya, GSPLAJ; alielarnauti@yahoo.com
[3]Institut de Paleontologia M. Crusafont, Escola Industrial 23, 08201 Sabadell, Spain; agustibj@diba.es
[4]Department of Anatomy, College of Medicine, Howard University, Washington, DC 20059, U.S.A.; rbernor@howard.edu
[5]Department of Historical Geology & Palaeontology, Faculty of Geology, University of Athens, Athens, Greece; pavlakis@isll.uoa.gr
[6]Dipartimento di Scienze della Terra and Museo di Storia Naturale (Sezione Geologia e Paleontologia) , Università di Firenze, via G. La Pira, 4, 50121 Firenze, Italy lrook@geo.unifit.it

Project. Dating Aṣ Ṣaḥābī has proved difficult for several reasons. Firstly, potassium-rich rocks, useful for absolute geochronological studies using radioactive isotopes of potassium and argon, are usually of volcanic origin. Volcanic sediments, or crystals of volcanic origin within sediments, have not been discovered at Aṣ Ṣaḥābī. Secondly, fossil coral from Formation M was tested by geologist F.H. Brown in 1977 with a view to undertaking thorium-uranium dating. Unfortunately, the original aragonite in the coral had been diagenetically altered and was undatable by this technique. Brown also collected samples for palaeomagnetic dating but discovered that the Aṣ Ṣaḥābī sediments he collected were too weakly magnetized and composed of too few magnetized grains to yield reliable results (Boaz *et al.*, 1982). A fourth approach for assessing the age of Aṣ Ṣaḥābī was the effort to relate marine microfaunal taxa discovered in the Sahabi Formation to the Deep Sea Core record for the Mediterranean, which is controlled by absolute chronology. Willems and Meyrick (1982) and Willems (1987) demonstrated that Formation M was of middle Miocene age by the identification of preserved foraminifera, but all micropalaeontological findings from the Sahabi Formation were of nearshore, shallow-water taxa or taxa characteristic of fresh water. Burckle (1982) was able to make the identification of only one diatom taxon (the freshwater *Melosira granulata*) from five coprolites from Unit U-1 of the Sahabi Formation, although he also noted fragments of centric, marine forms that were too fragmentary to be identifiable. *Melosira granulata* is characteristic of sub-Saharan freshwater lakes and slow-flowing rivers. Burckle inferred brackish conditions to explain the presence of the fragmentary centric diatoms, but they were not useful for inferring marine biostratigraphic and temporal relationships.

The most successful approaches in assessing the geological age of Aṣ Ṣaḥābī have been regional lithostratigraphy, which places the site within a context of Mediterranean Basin pre- and post-Messinian sedimentation (de Heinzelin and El-Arnauti, 1987), and vertebrate (primarily mammalian) biostratigraphy (Boaz *et al.*, 1979; Bernor and Pavlakis, 1987; Boaz, 1996), which related the fauna to dated sequences in sub-Saharan Africa and Eurasia. Nevertheless, neither approach has proved fully satisfactory in resolving questions about the precise age of the fossiliferous Sahabi Formation. In this paper, we review new studies of regional geology in this time period which allow a reassessment of the regional lithostratigraphic setting for Aṣ Ṣaḥābī, and we discuss new palaeontological data and analyses that bear upon the biostratigraphy of this important site.

RESULTS AND DISCUSSION

Lithostratigraphic setting of Formation P, the Aṣ Ṣaḥābī channels, and the Sahabi Formation

The geological setting of Aṣ Ṣaḥābī has been of primary importance in the researches of the East Libya Neogene Research Project (ELNRP). Detailed fieldwork by de Heinzelin and El-Arnauti (1982, 1987) recorded the microstratigraphy at all fossil localities, geographic locations of which were precisely mapped on aerial photographs of the entire area. There is no revision here of the previously reported microstratigraphy of localities or of the intra-Sahabi Formation stratigraphic correlations. All fossil specimens collected by the ISRP are numbered sequentially within localities and can be precisely localized microstratigraphically and geographically.

Initial conceptions of the Messinian Event in the Mediterranean were of a singular desiccatory event with widespread evaporite deposition, followed by rapid re-filling of the Mediterranean Basin at the beginning of the Pliocene (Hsü *et al.*, 1973; Cita and McKenzie, 1986). The regional lithostratigraphic setting of Aṣ Ṣaḥābī was initially interpreted in this framework.

De Heinzelein and El-Arnauti (1982) first identified a gypsiferous deposit of dark sands and clays up to 25 m thick underlying the Sahabi Formation. They named it "Formation P" and interpreted it "as having been deposited during the Messinian Salinity Crisis at the terminus of the Upper Miocene" (p. 8). Formation P unconformably overlies late Miocene marine beds, equated to the upper Al-Rajmah Formation, exposed in the bottom of the Ṣabkhat al-Qunnayyin. The top of Formation P contacts the base of the Sahabi Formation in transitional beds containing evaporites in the northern sectors of exposure, and at well-defined erosional unconformities in the southern sectors. The lowest member of the Sahabi Formation, Member T, is a sand ranging in thickness between 5 and 50 m, with alternating gypsiferous layers and shell beds. It is primarily estuarine in character but one section, Member T.X, records subaerial conditions and incipient soil development. The "sirenian field" at P66 with abundant sirenian fossils and associated shark teeth is located in this member. Member T was taken by de Heinzelin and El-Arnauti (1987) to be coeval with terminal-Messinian transgression, dated elsewhere in the circum-Mediterranean region to beginning at approximately 5.3

ma. The base of the Sahabi Formation on these grounds then could not pre-date 5.3 ma. Overlying sediments, Members U, V, and Z of the Sahabi Formation, and the fossils deriving from them, were assessed to be of lowest Pliocene age on these lithostratigraphic grounds.

More recent studies (Butler *et al*., 1999; Garcés *et al*., 1998; Griffin, 2002; Duggen *et al*., 2003) have now revised the unitary desiccation model of the Messinian Salinity Crisis in the Mediterranean Basin. More complex depositional sequences involving several cycles of (primarily climatically driven) evaporite deposition (e.g. Krijgsman *et al.*, 1999) now present at least two reasonable alternative explanations for the facies variations, stratigraphic transitions, and thus inferred age of Formation P. Formation P may represent a protracted regressive "First Cycle" evaporite deposition marginal to the Mediterranean deep basin, dated elsewhere to geomagnetic Chron C3Ar (earlier than 6.88 ma). Alternatively, this formation may have resulted from more rapidly deposited transgressive "Second Cycle" deposition, dated elsewhere to late in Chron C3An (later than 6.0 ma). Several observations suggest to us that the first alternative may now be the more likely.

Gypsiferous deposits, indicative of evaporation of marine waters in closed basins, occur not only in Formation P but sporadically throughout the members of the Sahabi Formation (de Heinzelin and El-Arnauti, 1987). Member T, for example, evinces significant gypsum content (along with anhydrite and halite (De Geyter and Stoops, 1987)) at its base and filling cracks over 5 m in depth. Co-occurring dolomite, either in nodular form or as widespread and homogeneous layers, is found in Formation P and throughout the Sahabi Formation. These deposits present a complex sedimentary and diagenetic history but they are associated with evaporitic facies. De Geyter and Stoops (1987) interpreted them as resulting "from salinity fluctuations in shallow shelf lagoons and subtidal ponds or eventually in shallow migrating ephemeral lakes in a relatively humid climate on regressive coastal plains." Such persistent indicators of cyclic deposition and desiccation might be expected to be more common in marginal basin sediments deposited under conditions of protracted drawdown of Mediterranean waters leading up to the Messinian Salinity Crisis (*cf*. Griffin, 2002). They would be less characteristic of post-Messinian sediments deposited by rapidly transgressive sedimentation accompanying re-filling of the Mediterranean Basin.

Another important regional geological clue to the stratigraphic placement of the Sahabi Formation is the presence of deeply incised (396 m deep), subsurface riverine or estuarine channels discovered by gravimetric research south of Qaṣr aṣ Ṣaḥābī (Barr and Walker, 1973). These authors interpreted the Sahabi Channels as having resulted from incision into underlying sediments by a major river emptying into the desiccating eastern Mediterannean Sea during the Messinian Salinity Crisis, paralleling similar deep erosional incisions observed in the Nile and Rhone valleys. Griffin (2002) has termed the Messinian-aged river course discovered by Barr and Walker (1973) the "Eosahabi", and the remnant Mediterranean water body into which it flowed, some 2000 m below current sea level, "Lake Cyrenaica". The dates of maximum Mediterranean drawdown, and by extension the dates of maximum incision of the Eosahabi Channel, are estimated to be between *ca*. 5.8 ma (Butler *et al*., 1999) and *ca*. 5.6 ma (Krijgsman *et al*., 1999).

De Heinzelin and El-Arnauti (1987) examined the location of the subsurface Eosahabi channels, more than 10 km south of the southernmost measured sections of the Sahabi Formation at Bir Guetin ("Brown Hills", localities P3 and P4). The land surface here is covered by Formation V of the Sahabi Formation, which de Heinzelin and El-Arnauti (1987:17) followed to this point, but they discovered no geomorphological features or satellite image findings to indicate the presence of the Eosahabi channels. Although it is reasonable to suggest that sediments of Sahabi Formation Member V fill the Eosahabi Channel, it was impossible in the field to establish any definitive stratigraphic correlation between the Sahabi Formation and the channel infilling. However, de Heinzelin and El-Arnauti (1987:17) did make the "strong suggestion that the Sahabi Formation… is the northern extension of the Calanscio Formation as defined by Benfield and Wright (1980)". This formation is known only from oil exploration wells and extends from the Aṣ Ṣaḥābī area south to Jālū (Fig. 1). If the subterranean Calanscio Formation is correlative with Member V (and/or Member Z) of the Sahabi Formation, thus identifying the post-Messinian sediment infilling the Eoshabi Channel, then a capping age range for the underlying Sahabi Formation would be 5.6 – 5.8 ma.

In an important synthesis that throws light on the further identification of the location and probable stratigraphic relationships of the Eosahabi Channel, Griffin (2002) identified physiographic features in detailed satellite imaging of central Libya. Figure 1 superimposes boundaries of the Eosahabi Channel seen to the east of the Tībistī massif, as identified by Griffin (2002), onto the International Geological Map of Africa

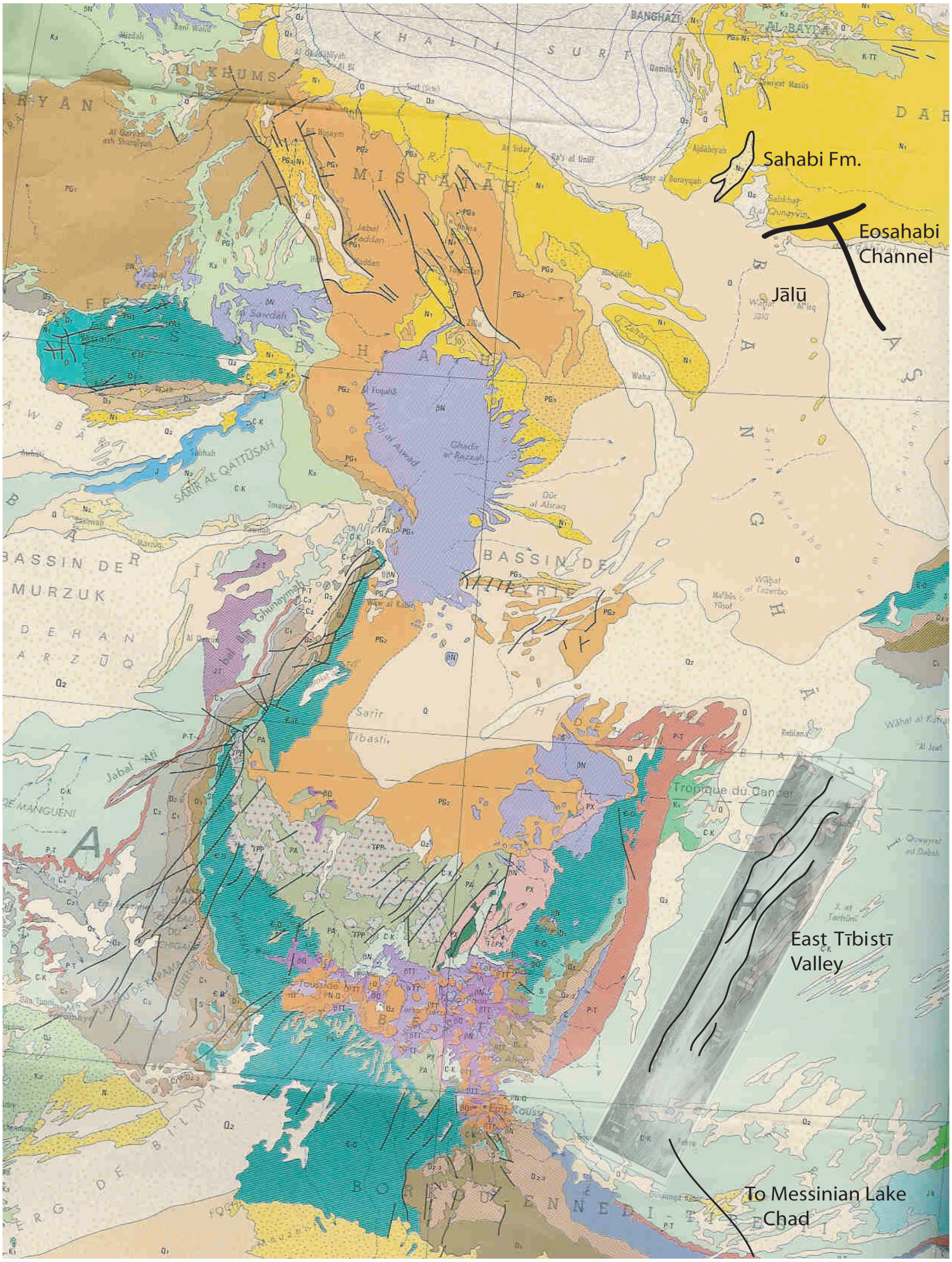

Fig. 1. Regional geology of northern and central Libya (Choubert *et al.*, 1987) showing the area of outcrop of the Sahabi Formation and the Eosahabi Channel of Barr and Walker (1973). Locations of the Eoshabi Channel, the East Tībistī Valley, and the proposed outflow of the Eosahabi River from Messinian Lake Chad were plotted from Griffin (2002). The Calanscio Formation, thought to be correlative with the Sahabi Formation at least in part, is known in cores as far south as Jālū.

(Choubert *et al*., 1987). Channel margins can be clearly traced to a point south of latitude 21°N. Griffin (2002) postulated a further SE-trending portion of the Eosahabi River connecting this point to a probable origin of the Eosahabi River from the NE extremity of Messinian Lake Chad, SE of Tībistī and at approximately latitude 17°N (Fig. 1). These remote sensing results establish a context for the Eosahabi Channel, extending from an origin in Messinian Lake Chad to a debouchement in Lake Cyrenaica, and can frame future research, even if exact stratigraphic relationships have yet to be established. It is likely that the sediments associated with the Eosahabi Channel will be directly correlative with fossiliferous sediments exposed in the Chad Basin and presumed to be of late Miocene to Pliocene age on biostratigraphic grounds (Vignaud *et al*., 2002).

Lithostratigraphy is consistent with the view that Formation P and most, if not all, of the fossiliferous Sahabi Formation may be Messinian in age, that is, deposited prior to the Pliocene re-filling of the Mediterranean Basin. Members V and Z may well be the only portions of the Sahabi Formation that are Pliocene in age, a view that receives some support from biostratigraphic considerations, particularly of collections made by Italian investigators in the 1930s in the western exposures of the Sahabi Formation that have yet to be precisely localized on the ground and in the stratigraphic column. Further research both in the field and in the laboratory is required to resolve many outstanding questions surrounding this new view of timing of the deposition of the sediments exposed at Aṣ Ṣaḥābī. At the present state of our knowledge it is impossible to state precisely where in the known stratigraphic column transgressive sediments recording the basal Pliocene occur, although with further investigation these may prove to be Member V or Member Z of the Sahabi Formation.

Biostratigraphic setting of the Sahabi Formation

Mammalian biostratigraphy has consistently indicated an age for the Aṣ Ṣaḥābī fauna near the Mio-Pliocene boundary. The first palaeontological research at Aṣ Ṣaḥābī, relying initially on the middle Miocene age accorded the marine limestones regionally underlying the sediments yielding fossils of terrestrial vertebrates, was firmly on the earlier, Miocene side of this divide (D'Erasmo, 1931; Petrocchi, 1941, 1943). Yet some fossil specimens discovered during the 1930s, such as a cranium of *Leptobos*, suggested a younger, Pliocene age (Petrocchi, 1956). There is now a clear possibility on lithostratigraphic grounds that a depositional hiatus, and thus a temporal discontinuity, may have intervened between the lower and upper members of the Sahabi Formation. If so, some of the difficulties in resolving the biostratigraphic age of the site may be attributable to the fact that the collections were of mixed ages, the fossils recovered from the 1930s deriving primarily from levels in upper Member U and Member V, and fossils collected by the ISRP deriving for the most part from lower Member U and Member T (de Heinzelin and El-Arnauti, 1987).

Another confounding factor in assessing the comparative biostratigraphic position of Aṣ Ṣaḥābī relative to fossil sites in other regions is some degree of provinciality of its fauna. The Aṣ Ṣaḥābī vertebrate fauna records a distinct North African Neogene palaeozoogeographic province, characterized by the abundance of anthracotheriids and informally termed by Boaz (1996) an "A2" African palaeozoogeographic province. The "A2" province is markedly set apart from most penecontemporaneous faunas in eastern and sub-Saharan Africa (except late Neogene Tunisia and Chad) and Eurasia by the presence and indeed abundance of anthracotheres. A suspicion of provinciality and a relictual character to the Aṣ Ṣaḥābī mammalian fauna in general were factors in our accommodating the observed Miocene affinities in a number of taxa with a lithostratigraphically supported post-Messinian age for the deposit. Provinciality has thus been another confounding variable in a straightforward assessment of faunal age of Aṣ Ṣaḥābī.

We review below the major faunal groups from Aṣ Ṣaḥābī from a standpoint of their contributions toward determining the biostratigraphic age of the site.

Rodentia

Munthe (1987) reported on the micromammalian fauna from the Sahabi Formation, virtually all of which derived from one locality, P61A, located in Unit U-1 of the Sahabi Formation. Although he compared a single crocidurine shrew molar to a species from the Miocene site of Beni Mellal, Morocco, Munthe was hesitant to ascribe a biostratigraphic age to this single specimen unidentified at the generic level. The rodent fauna includes 5 species: a sciurid *cf. Atlantoxerus getulus*, a ctenodactylid, *Sayimys* sp., a cricetid ascribed to *Myocricetodon cherifiensis,* a murid, *Progonomys* sp., and a new species of gerbil, *Protatera yardangi.* Munthe (1987) noted the close similarities of the Aṣ Ṣaḥābī ctenodactylid, cricetid, and murid taxa to Miocene forms, suggesting that an age estimate based on these taxa would be "approximately Vallesian" [middle to late Miocene] (p. 142). However, he conservatively did not ascribe an age to the most common small mammal at Aṣ Ṣaḥābī, the gerbil, because of the lack of knowledge of forms intermediate between it and the living gerbil, *Tatera*. He also pointed out that *Atlantoxerus* ranges from the middle Miocene to Recent and was of little help in constraining the biostratigraphic age. He concluded that "the presence of gerbils and a squirrel very closely related to *Atlantoxerus getulus* makes [a Vallesian age] exceedingly unlikely." Denys *et al*. (2003) report the discovery of a new species of xerine squirrel, *Xerus daamsi*, at the early Pliocene site of Kossum Bougoudi, Chad, but they differentiate it from extant *Atlantoxerus*, thus precluding a comparison with Sahabi Formation.

Renewed collecting of mammalian microfauna by teams led by one of us (J.A.) has led to the recovery of more specimens (Agusti *et al*., 2000). We confirm that the most common rodent species at Aṣ Ṣaḥābī is the gerbil, which we ascribe to *Abudhabia yardangi* (originally incorrectly listed as *Abudhabia yardangiensis*). The morphology of this species closely matches that of *A. baynunensis* from the late Miocene (late Turolian?) Baynunah Formation (Emirate of Abu Dahbi, United Arab Emirates) as described by Bruijn and Whybrow (1994). Although the Sahabi species is somewhat more advanced than the Arabian species (the anteroconid is connected to the protoconid in several specimens of *P. yardangi),* the affinities between the two species strongly suggest a late Miocene age for the Sahabi Formation.

Carnivora

Carnivores are relatively abundant in the deposits of Member U of the Sahabi Formation. Howell (1987) stressed the importance of the Sahabi carnivores as both biochronological indicators and for their palaeobiogeographic implications. Howell (1980, 1987) identified the carnivores from Sahabi with Messinian (MN 13) assemblages in the circum-Mediterranean region. By and large, carnivores at Sahabi "either have a wide distribution or their affinities were not sufficiently determined so as to be informative" (Howell, 1987). In any case their biochronological ranges tend to be toward a latest Miocene age rather than a more recent one.

Hyaenidae are relatively abundant and show a high diversity. An interesting hypothesis that needs further attention is the suggestion that the area could have acted as a centre of differentiation for the family and the subsequent occurrence in Eurasia of hyaenid taxa (Hendey, 1978a, b; Howell, 1987).

Interesting is the occurrence of two ursid genera, *Agriotherium* and *Indarctos*. The latter is the only occurrence of the genus in Africa.

Among small sized carnivores, the *Viverra* sp. nov. A (Howell, 1987) seems of particular interest. Although its general size is close to *Viverra pepratxi* (early Pliocene of Europe), the general proportions and morphology of its lower carnassial suggest a closer affinity with larger-sized late Miocene and Pleistocene species from Africa (*Viverra leakey*; from Langeebanweg and Omo) than with taxa from Europe (*Viverra pepratxi* and *Megaviverra*). This viverrine species could represent a taxon that had a latest Miocene circum-Mediterranean distribution, occurring at Sahabi, Baccinello V3 , Italy (Rook *et al*., 1991) and Lothagam, Kenya (Werdelin, 2003).

Felidae are represented by a large saber-toothed form attributable to the genus *Machairodus*, as well as poorly defined medium- to small-sized felines.

Howell (1987) drew particular attention to the absence of Canidae in the Sahabi assemblage. Canidae are a very rare element in the latest Miocene faunas of Europe. It has been recently demonstrated that representatives of the North American genus *Eucyon* (to include taxa formerly referred to *"Canis" davisi*) dispersed in the Old World during the latest Miocene (Flynn *et al*., 1991; Rook, 1992). This genus might be expected, with further research, to be discovered at Aṣ Ṣaḥābī.

Proboscidea

Three proboscidean taxa are described from Aṣ Ṣaḥābī. The best known among the fossil proboscideans from this site is the primitive elephantid *Stegotetrabelodon syrticus*, represented by abundant material, including a complete skull with mandible, isolated molars and post-cranials (Petrocchi, 1941, 1943, 1954; Gaziry, 1987a). We agree with Maglio (1973) that the specimens Petrocchi (1943, 1954) perceived as belonging to different taxa, namely the skull with mandible, the right lower M3 and the left upper M3 upon which he established respectively the species *Stegotetrabelodon syrticus*, *Stegotetrabelodon lybicus* and *Stegolophodon sahabianus*, represent actually the same species. In fact, taking into account the degree of individual morphological variation of proboscidean molars, the difference between upper and lower molars and that resulting from occlusal wear (Gaziry, 1987a), the variability displayed by these specimens conforms to that of a single species. In this case, as already stressed by Tassy (1986, 1999), the specific name with priority over the others is *Stegotetrabelodon syrticus* Petrocchi, 1941 and not *Stegotetrabelodon lybicus* as stated by Maglio (1973:17, note 6) and successively accepted by Tobien (1978) and Gaziry (1987a).

The fossil record of the genus extends from the late Miocene to early Pliocene. In agreement with Tassy (1985, 1999), and *contra* Tobien (1978) and Gaziry (1987a), we believe that only material from Afro-Arabia (included in *Stegotetrabelodon syrticus* and *Stegotetrabelodon orbus* from East Africa) should be referred to the genus *Stegotetrabelodon* Petrocchi, 1941. We thus exclude the European and Asian forms, referred by Tobien (1978) to the "*grandincisivus"* group ("*Mastodon*"*grandincisivus*, "*Mastodon" longirostris* forma *gigantorostris*). All these taxa seem actually to represent distinct elephantoid lineages that developed similar mandibular morphologies. According to this interpretation, stegotetrabelodonts represent a monophyletic elephantoid group (coincident with the subfamily Stegotetrabelodontinae Petrocchi 1943), which likely represents the sister group of the Elephantinae (*Stegodibelodon*, *Loxodonta*, *Primelephas*, *Elephas*, *Mammuthus*).

A large amebelodontid is represented by isolated molars and tusk fragment (Gaziry, 1987a). Gaziry (1987a) reports the occurrence at Aṣ Ṣaḥābī of a large amebelodont gomphothere (shovel-tusker), unknown to Petrocchi. The Aṣ Ṣaḥābī amebelodont is characterized by large, flat lower incisors, with the internal dentine showing a tubular structure. The first molar is typically trilophodont, while the second molar is tetralophodont. The third molar possesses six lophids and a distal talonid. All teeth are relatively high-crowned and covered by abundant dental cement. Gaziry (1987a), based on the proportion of the lower tusk, attributed the Aṣ Ṣaḥābī material to a new species of *Amebelodon*, *A. cyrenaicus*. Tassy (1999), however, considered it a junior synonym of "*Mastodon*" *grandincisivus*. Indeed, the combination of characters displayed by the Aṣ Ṣaḥābī amebelodon is known in a number of Eurasian elephantoid samples included in the taxon "*Mastodon*" *grandincisivus*, considered by Tassy to represent a derived amebelodontid species. A clear amebelodontid apomorphy shared by "*Mastodon*" *grandincisivus* is the tubular structure of the internal dentine of the lower tusks. "*Mastodon*" *grandincisivus* has been recorded from the Late Miocene of East Europe (Hungary, Bulgaria, and Ukraine), Asia (Iran, Pakistan; Tassy, 1983), and possibly from Jabal Barakah (Abu Dhabi; Madden *et al*., 1982; Tassy, 1999), where, as at Aṣ Ṣaḥābī, it is associated with *Stegotetrabelodon*. The record of this taxon at Aṣ Ṣaḥābī is thus of key importance in defining the relationships of this peculiar amebelodontid to other members of the clade (Amebelondontinae), and its palaeobiogeographic history.

The third taxon present at Aṣ Ṣaḥābī is a derived species of the gomphothere genus *Anancus* (Petrocchi, 1954; Tassy, 1986), known from several mandibles and isolated lower teeth, but some of the undetermined postcranials described by Petrocchi (1943) could also pertain to this taxon. At present, the figures provided by Petrocchi are the only sources of information concerning the morphology of the species represented at Aṣ Ṣaḥābī, the sample collected by Petrocchi being "missing" (Gaziry, 1987a). Only M2 and M3 are known, thus limiting the comparisons with other samples.

The molars of the form present at Aṣ Ṣaḥābī are relatively large with respect to East African *Anancus* samples, and are characterized by derived morphological traits, namely pentalophodon second molar, marked anancoidy, and well-developed accessory cusps. Coppens (1965) erected on the Libyan material the species *A. petrocchi*. Tassy (1986, 2003), however, using a more conservative approach, considered the Aṣ Ṣaḥābī sample as a morphotype ("*petrocchi*" morph) of the widespread East African species *A. kenyensis*. The simpler dental morphology shown by the type population of *A. kenyensis* from Kanam (Kenya) would represent the opposite morphological extreme of the species (*kenyensis* morph). Tassy (1986, 2003), nevertheless, does not exclude the possibility, that the two morphs might correspond to two successive evolutionary stages within the *A. kenyensis* lineage. Indeed, current dental evidence from Ethiopia and Kenya (Kalb and Mebrate, 1993; Tassy, 1986, 2003) seems to delineate an increase of the mean morphological complexity of successive *Anancus* samples in the time span 7-4 ma. The complex "*petrocchi*" morph is, in fact, common at early Pliocene sites (e.g. Apak Member at Lothagam, Aterir, and the Chemeron Formation) while it is extremely rare or unknown from late Miocene localities (e.g. Lukeino, Mpesida, Nawata Formation at Lothagam). In Ethiopia, the latest occurrence of *Anancus* is in the upper Sagantole Formation (ca. 4 ma), with a form showing a very derived dental morphology (Sagantole type; Kalb and Mebrate, 1993), exceeding the complexity characterizing the "*petrocchi*" morph. The complex morphology of the *Anancus* sample from Sahabi would be at odds with this pattern of evolutionary change, if a late Miocene age for the entire fossil assemblage is confirmed. On the other hand, this would support the hypothesis of Tassy (2003) that the two *A. kenyensis* morphs have no evolutionary significance. However, without a more complete dental sample, including also the upper dentition, it is not possible to fully evaluate the morphological variability of the Aṣ Ṣaḥābī *Anancus*, and its relationships with East African and Eurasian forms.

The exclusive Afro-Arabian distribution of stegotetrabelodonts is not challenged by the recent recovery of a *Stegotetrabelodon syrticus* mandible from Southern Italy (Ferretti *et al.*, 2003), as currently available evidence suggests that Calabria was part of the North African emerged platform during the late Miocene.

The early age of the Cessaniti *Stegotetrabelodon* (Tortonian) is comparable to that proposed by Tassy (1999) for the *Stegotetrabelodon syrticus* from Abu Dhabi, and to that one recently proposed for Aṣ Ṣaḥābī (Agusti *et al*., 2000). Thus, there is evidence that *Stegotetrabelodon* was already widespread both in northern Africa and eastward to the eastern shore of the Arabian platform during the Tortonian, around 7 ma. The occurrence of a primitive *Stegotetrabelodon* species in the Kakara and Oluka formations of Uganda (9 to 6 ma; Tassy, 1995) would suggest an even wider geographic range of the genus in the late Miocene.

Equidae

Bernor *et al*. (1987) recognized two sizes of hipparionine horses at Aṣ Ṣaḥābī and referred these to a larger species, "*Hipparion"* cf. *africanum*, and a smaller and more gracile species, *"Hipparion"* cf. *sitifense*. Twenty years of subsequent systematic research on North American and Old World hipparionine horses suggested to Bernor that a re-evaluation of Aṣ Ṣaḥābī hipparion systematics and biogeographic relationships was needed. This re-evaluation requires extensive analysis and comparison of both dental and postcranial evidence. Bernor and Scott (2003) have recently re-evaluated the postcranial evidence as represented by metapodial and phalangeal elements, while the dental record is currently being re-evaluated by Bernor and Kaiser.

Bernor and Scott (2003) found evidence for at least two hipparion species in the Aṣ Ṣaḥābī fauna which they referred to *"Cremohipparion"* aff. *matthewi* and *"Hipparion"* (*Sivalhippus*) sp. *"Cremohipparion"* aff. *matthewi* is represented by elongate-slender metapodials and compares most closely to *Cremohipparion matthewi* represented from the late MN 12 quarries at Samos (Greece) and the MN 13 locality of Maramena (Greece). *Cremohipparion* is a lineage of late Vallesian (MN 10, 9.7 – 8.7 ma) – late Turolian (8.7-5.3 ma) hipparions that likely arose in the Eastern-Mediterranean – Southwest Asian Subparatethyan Province and extended its range into East and South Asia as well as North Africa. One radicle of *Cremohipparion*, including *Cremohipparion matthewi*, underwent progressive size reduction with accompanying evolution of elongate and slender limbs adapted for cursorial behavior.

Limited dental evidence from Aṣ Ṣaḥābī suggests that yet a second species of *Cremohipparion*, possibly referable to *C. nikosi* (= *periafricanum*) is also present at Aṣ Ṣaḥābī. This second *Cremohipparion* species is tiny, with very small and elongate metapodials. If Aṣ Ṣaḥābī is found to have this species, its occurrence at Aṣ Ṣaḥābī would suggest a late Turolian (= MN 13) correlation with localities in Arabia, Greece, Italy and Spain.

The third species, also recognized by Bernor and Scott (2003), and referred to *"Hipparion"* (= *Sivalhippus*) sp. is a member of the *Sivalhippus* Complex. The *Sivalhippus* Complex would appear to have arisen by 8 ma and is known to occur from 8-5 ma only in the Indian Subcontinent and East Africa. By 6.5 ma there was an apparent biogeographic disjunction of this clade into an Indian Subcontinent clade (species belonging to *Sivalhippus* spp.) and an East and South African clade (*Eurygnathohippus* spp.). The Aṣ Ṣaḥābī species belonging to this clade has heavily developed postcrania that compare well in their size and proportions with specimens from the Lower Nawata Member at Lothagam, but unlike the Lothagam form it lacks any evidence of ectostylids.

Our current understanding of the Aṣ Ṣaḥābī hipparion fauna suggests that Sahabi best correlates with early MN 13, circa 6.7 ma. Biogeographically, Aṣ Ṣaḥābī exhibits temporally proximate relationships with the Eastern Mediterranean Greek faunas and more temporally distant relationships with South Asia and East Africa. Collection of more equid material from Aṣ Ṣaḥābī is crucial for refining our understanding of the age and timing of palaeogeographic connections with peri-Mediterranean, South Asian and East African bioprovinces.

Anthracotheriidae

Petrocchi (1943:8, 1952:23) reports the discovery of anthracotheres at Aṣ Ṣaḥābī but, as in the case of the hippopotamid remains, these were never described. They are now lost. In 1947 G. Bonarelli discovered an anthracothere partial cranium 40 km north of Qaṣr

Aṣ Ṣaḥābī and, thinking that he was in Cretaceous deposits and that he had discovered a dinosaur, named it *Libycosaurus petrocchi* (Bonarelli, 1947). Black (1972) corrected the error and assigned anthracothere fossils from the late Miocene of Tunisia to *Merycopotamus anisae*, suggesting that *M. petrocchii* was representative of a younger descendent species. Gaziry (1987b) published a preliminary report on the abundant remains of anthracotheres recovered by the ISRP from the Sahabi Formation, assigning them to *Merycopotamus petrocchii.* Vignaud *et al*. (2002) assigned anthracotheriid remains found at Toros-Menalla, Chad to this same species reverting to use of the original genus name *Libycosaurus petrocchii*. These authors accept a biostratigraphic age for the Chadian deposits of between 6 and 7 ma.

It is significant that the Baynunah Formation of Abu Dhabi does not preserve anthracotheres, although as pointed out above, it does share the presumably similarly semi-aquatic *Hexaprotodon*. The Mio-Pliocene site of Wadi Natun, Egypt, with hippopotamids and a fauna otherwise quite similar to Aṣ Ṣaḥābī, also lacks a record of anthracotheres (Bernor and Pavlakis, 1987), suggesting that the Eonile River may have acted as a selective faunal barrier for dispersal of anthracotheres east of the Eosahabi Channel. Neither the Lothagam Nawata Formation (Leakey and Harris, 2003) nor any other late or middle Miocene sites in eastern and northeastern Africa preserve anthracotheres. As noted above, these striking zoogeographic differences seem to differentiate the late Miocene Eosahabi Basin (Libya and Chad) from penecontemporaneous Eonile, eastern and northeastern sub-Saharan African, and circum-Mediterranean sites.

Suidae

Cooke (1987) recognized three species of tetraconodont pigs at Aṣ Ṣaḥābī: *Nyanzachoerus kanamensis, Nyanzachoerus* cf. *syrticus* and *Nyanzachoerus* cf. *devauxi*. He cited a correlation with Lothagam 1 C, or latest Miocene age. Harris and Leakey (2003) have recently cited the occurrence of *Nyanzachoerus* cf. *devauxi* and *Nyanzachoerus* cf. *syrticus* from the lower and upper members of the Nawata Formation. Harris and Leakey (2003) have essentially concurred with Cooke in correlating Aṣ Ṣaḥābī with the latest Miocene based on its larger size than the Lothagam Nawata forms.

The late Miocene witnessed an extensive turnover in Eurasian and African suid faunas. Western Eurasian late Miocene faunas included diverse suine (*Hippopotamodon antiquus, Propotamochoerus palaeochoerus, Microstonyx major* and *Microstonys erymanthius*), tetraconodont (*Parachleuastochoerus crusafonti, Parachleuastochoerus* sp., *Conohyus huenermanni*) and the latest survival of the listriodontine, *Listriodon splendens* in MN 9. There would appear in the earliest portion of the late Miocene interval to be a palaeogeographic connection between the Siwaliks and central-western Europe with the appearance (in latest MN 8) of *Propotamochoerus palaeochoerus* and *Hippopotamodon antiquus*.

The latest Miocene witnessed a dramatic turnover in peri-Mediterranean and South Asian-African suid faunas. In Italy, the Tusco-Sardinian faunas record the turnover from endemic MN 12 suid faunas that include only *Eumaiochoerus etruscus* to those that include the generalized suine *Korynochoerus* (= *Propotamochoerus*) *provincialis*. Indo-Pakistan, Arabia and East Africa all record a suine similar, or identical to *Propotamochoerus* in later-to-latest Miocene horizons.

While Aṣ Ṣaḥābī has no record of a suine, its recorded occurrence of *Nyanzachoerus* cf. *devauxi* and *Nyanzachoerus* cf. *syrticus* compares closely with Arabian and East African records of this species. *Nyanzachoerus devauxi* likely evolved from South Asian tetraconodonts, larger than *Conohyus sindiensis* and *Conohyus indicus*, and probably closest in morphology to *Sivachoerus prior*. As such, the Aṣ Ṣaḥābī suid fauna has a close biogeographic relationship with South Asia, Arabia, and in particular, East Africa. The suid fauna from Sahabi Formation suggests an MN 13 correlation.

Hippopotamidae

Petrocchi (1943, 1952) first mentioned the discovery of hippopotamids at Aṣ Ṣaḥābī, but these remains were never formally described or taxonomically identified. At least one cranium of a hippopotamid with six incisors and a mandible were excavated in 1939 but these fossils have yet to be located and studied. Gaziry (1987b) erected the new taxon *Hexaprotodon sahabiensis* to accommodate the new specimens collected by the International Sahabi Research Project. He compared this species to *Hexaprotodon harvardi* from Lothagam, Kenya (Coryndon, 1977) but noted the more primitive and longer premolar row in the Sahabi species. Gentry (1999) assigned new hippopotamid remains from the late Miocene Baynunah Formation of Abu Dhabi to *Hexaprotodon* aff. *sahabiensis*. Boisserie *et al*. (2003) reported a new species of hippopotamid from the Pliocene of Chad, *Hexaprotodon mingoz*. This species has molar morphology and dimensions similar to *Hex. sahabiensis* but its lower P4 is shorter and its premolar row overall is substantially reduced in comparison with the Sahabi species. Although more remains of hippopotamids from Aṣ Ṣaḥābī are needed to more fully characterize *Hex. sahabiensis*, at present this taxon is most supportive of a late Miocene age for the Sahabi Formation.

Ruminantia (Giraffidae and Bovidae)

Giraffids are not well represented at Aṣ Ṣaḥābī, contrary to what is observed in other late Miocene peri-Mediterranean localities. At this site these ruminants are documented by scarcely diagnostic fragmentary remains, essentially postcranial bones and very few dentitions, which have been referred to *Samotherium* sp. by Harris (1987). This attribution however is subject to revision since the only ossicone found at Aṣ Ṣaḥābī (and considered evidence of the occurrence of a palaeotragine) has been referred instead to a bovid horn core ("*Miotragoceros*" *cyrenaicus)* by Geraads (1989). Moreover, a referral of the giraffid remains from Aṣ Ṣaḥābī to *Samotherium* sp. is in disagreement with the latest Miocene age of this site as indicated by the bulk of the fauna. Indeed, this genus disappears in Europe and northern Africa before the end of the Turolian. *Paleotragus* and small- and middle-sized *Samotherium* are documented in mammal assemblages dated to the late middle Miocene and beginning of the late Miocene (Churcher, 1970). According to Geraads (1989) the giraffid remains from Aṣ Ṣaḥābī could belong to a sivatheriine form. Such a hypothesis is based on the size and proportions of postcranial remains. Giraffids from northern Africa around the Mio-Pliocene transition have been referred to this subfamily. The Aṣ Ṣaḥābī giraffid could be related to the species from Douaria, Tunisia (Geraads, 1986; 1989) which represents the oldest African sivatheriine.

The Bovidae represent the most diversified mammal group at Aṣ Ṣaḥābī with at least 8 different taxa, belonging to 6 size classes: *Leptobos syrticus*, *Miotragoceros cyrenaicus*, *Redunca* aff. *darti*, ?*Hippotragus* sp., *Prostrepsiceros libycus,* cf. *Damalacra*, *Raphiceros* sp., *Gazella* sp. (Lehmann and Thomas, 1987).

The systematics of bovids from Aṣ Ṣaḥābī have been extensively discussed in the literature. Some authors (e.g. Geraads, 1989) cast doubts on the homogeneity of this assemblage suggesting that at least the remains recovered during the Italian expedition (Petrocchi, 1951, 1956) and referred to *Leptobos syrticus* and *Redunca* aff. *darti,* were collected from Pliocene deposits. We are inclined to agree with this suggestion, which needs further detailed investigation.

The bovid assemblage from Aṣ Ṣaḥābī is dominated by the species *Prostrepsiceros libycus. Prostrepsiceros* is the most prominent genus of the "spiral-horned" antilopes of the late Miocene; it disappears from the Eastern Mediterranean and Southeast Asian region after the middle Turolian (= MN12; Bouvrain, 1982). Another genus which has a late Miocene affinity is the boselaphine *Miotragoceros* (a synonym of *Tragoportax*) according to Geraads (1989) and Gentry and Heizmann (1996). The Boselaphini is a particularly difficult group from a taxonomic standpoint and there are many problems with generic distinctions. The more advanced forms of this tribe were extremely successful and widespread in the late Miocene and became extinct at the end of that period or in the earliest Pliocene. According to Moya-Solà (1983) and Bouvrain (1988) the generic name *Miotragocerus* should be used only for the remains of central Europe (e.g. *M. pannoniae*), leaving the name *Tragoportax* for all the other boselaphines occurring in late Miocene elsewhere. The occurrence of a boselaphine taxon (*Tragocerina* indet.) is reported by Thomas and Petter (1986) from the Algerian late Miocene site Menacer. However, it is smaller than all the other known forms referred to this group.

Another intriguing bovid at Aṣ Ṣaḥābī is cf. *Damalacra.* The occurrence of an alcelaphine in North Africa during the late Miocene is discussed by Vrba (1984) who suggests that the divergence of this subfamily may have occurred during this time. The occurrence of ?*Hippotragus* at Sahabi is a matter of debate. Gentry (1994) believes that most occurrences of hippotragines from late Miocene localities should be revised since they could actually belong to caprines, identifiable by features of horn cores, pedicles and frontals.

Integration of historical collections

As the International Sahabi Research Project moves forward with new research, it is crucial to integrate the important historical collections made at Aṣ Ṣaḥābī, namely the "Petrocchi material". It is unclear in fact where much of this collection is currently located. Some important specimens (e.g. the type specimen of *"Stegotetrabelodon syrticus"* Petrocchi 1941) are in the Tripoli Museum of Natural History, while others (e.g. type specimens of *"Sivachoerus" syrticus* Leonardi 1954 or *Miotragocerus cyrenaicus* Thomas 1979) are kept in the Geo-Palaeontological Museum of the University *"La*

Sapienza" in Rome (Italy). However most of the fossils collected by the Italian team directed by Carlo Petrocchi between 1934 and 1939 are yet to be located. They may be still in Italy but most probably they were sent back to Tripoli where they are still stored. Locating and studying these specimens and establishing their exact geographic and stratigraphic proveniences will be important in resolving a number of the outstanding biostratigraphic questions relating particularly to the upper Sahabi Formation.

CONCLUSIONS

Several dated stratigraphic sections around the Mediterranean Basin now indicate that deposition during the Messinian Stage (6.8 to 5.3 ma) was more complex than a single major desiccatory event associated with a single "salinity crisis." In view of these new data, it is apparent that Formation P exposed at Aṣ Ṣaḥābī is not uniquely to be identified with the entire Messinian stage, as earlier interpreted by us. Thus, the Mio-Pliocene boundary is not represented by the interface of Formation P and the Sahabi Formation and would instead be found somewhere higher in the section. Our review of mammalian fauna argues for a late Miocene rather than a basal Pliocene age for the Member U (primarily Unit U 1) Sahabi Formation fauna. Thus, we would infer stratigraphic placement of Member U of the Sahabi Formation below the Mio-Pliocene boundary as well. Evidence for such a boundary in the sediments overlying Member U is not compelling and will require further fieldwork and laboratory analysis. Nevertheless, there are mammalian faunal indicators from earlier collections made at Aṣ Ṣaḥābī in the 1930s that sampled sediments in the western areas of outcrop, primarily if not exclusively from Member V, that do in fact correlate best with sites dated elsewhere to the early Pliocene. We thus posit that the Mio-Pliocene boundary, or a lapse in sedimentation at that time (that may correlate laterally with the incision of the Eoshabi Channel), may be seen at the Member U-Member V interface within the Sahabi Formation. Further testing of this hypothesis will be undertaken by renewed geological investigations and palaeontological collection in the field and by recovery and re-analysis of the early Italian collections, if they can be located.

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