Stratigraphy and Age of the Sahabi Formation, Libya

Moftah El Shawaihdi, Ahmed Muftah, Raymond Bernor, and Noel Boaz

Abstract

New data from lithostratigraphic and biostratigraphic research, sub-surface investigations, and remote sensing studies have allowed the formalization of lithostratigraphic nomenclature in the Sahabi area, North Central Libya. The base of sedimentation is the Late Miocene Benghazi Formation of the Ar Rajmah Group, formerly "Formation M." These sediments were deposited under shallow marine conditions and are of Tortonian age, ranging from biozones NN8 to NNl la, with an age range of 8.23–10.70 Ma. $^{87}Sr/^{86}Sr$ dates from these levels range from 8.99 Ma to 9.36 Ma. The pack of sediments lying unconformably above the Benghazi Formation comprises the Late Miocene Sahabi Formation, the Pliocene Qarat Weddah Formation, and the Pleistocene-Recent "Formation Z." The Sahabi The formation is divided into two members: the "Lower Member," including the gypsiferous former "Formation P" and lower portion of "Member T," and the "Upper Member," including the non-gypsiferous and fossil-rich Units U-1, U-D, and U-2. Vertebrate fossils from U-1 and U-2 represent a highly diverse mosaic of paleohabitats ranging from the steppe, savanna, forest, large river, and estuarine to marine offshore, which makes the Sahabi fauna more valuable for biostratigraphic comparison with a wide variety of penecontemporaneous sites. The open country fauna shows Sahabi to have been a crossroads fauna correlating to European mammalian biozones MN12 and MN13, with a best-fit age estimate of 6.8 Ma for Unit U-1 and 6.0 Ma for Unit U-2. The closed and water-tied faunal elements from Sahabi are more relictual and include a highly endemic anthracothere shared with the essential hominin-bearing site of Toros Menalla, Chad, correlating most closely with the Sahabi U-2 fauna. The Chorora and Adu-Asa Formations in the Awash Basin of Ethiopia, the Qaret El-Muluk Formation of Wadi El-Natrun, Egypt, and the Nawata Formation of Lothagam, Kenya, are close in biostratigraphic age to the "Upper Member" of the Sahabi Formation. Sahabi shows the closest similarity in Eurasia to the MN12/13 site of Baynunah, Abu Dhabi and the MN13 site of Maramena, Axios Valley, Greece. The upper age of the Sahabi U-2 fauna is constrained by the unconformity that forms a Margin Erosion Surface (MES) separating the Messinian-aged Sahabi Formation from the overlying Pliocene Qarat Weddah Formation, dated elsewhere in the Mediterranean Basin to 5.96 Ma to 5.33 Ma.

Keywords

Libya • Messinian • Miocene • Stratigraphy • Sahabi

1 Introduction

Sahabi is located on the northeastern flank of the Sirt Basin and covers an area of ~ 375km^2. It is bounded by longitudes 20° 48′ 08″ to 20° 54′ 45″ E and latitudes 30° 10′ 58″ to 30° 17′ 36″ N (Fig. 1). Strata are exposed along the western edge of the recent Sabkhat Al Qunnayyin, in a general NE-SW trend of elongated intermittent hills (De Heinzelin & El-Arnauti, 1987).

The area is known for both its important Neogene fossil vertebrates (Boaz et al., 1979, 1987) and the discovery of presumed Messinian-aged subsurface channels of over

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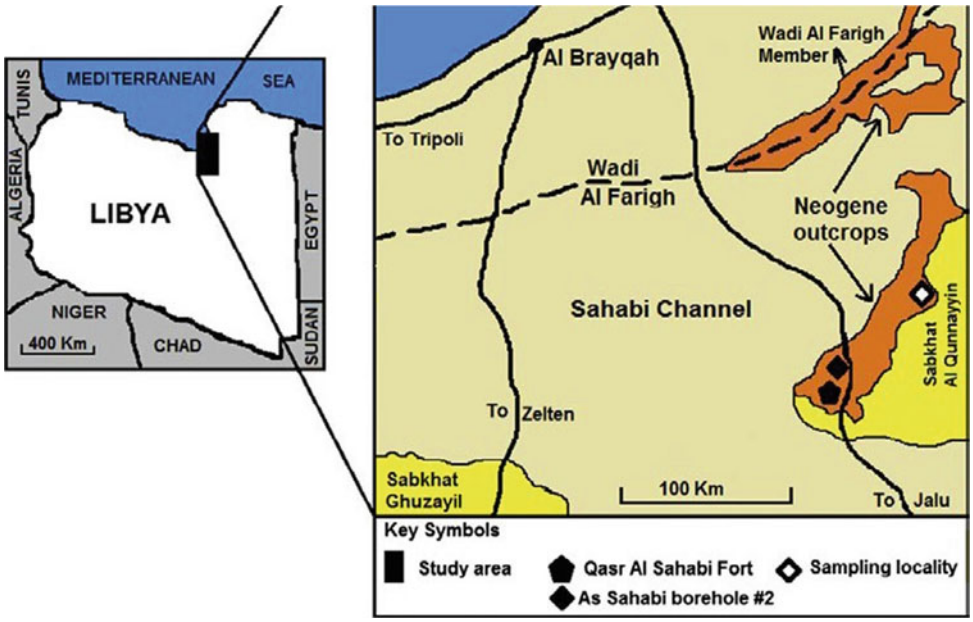

Fig. 1 Location of the Neogene sedimentary deposits in the As Sahabi area, north central Libya

400 m in depth detected by seismic studies (Barr & Walker, 1973). The As Sahabi area is composed of Upper Neogene sediments known as Benghazi Formation, Sahabi Formation, and Qarat Weddah Formation.

2 Materials and Methods

103 stratigraphic exposures were investigated during field seasons between 1977 and 2010. Fieldwork resulted in the lateral tracing of the recognized Sahabi rock units based on lithological descriptions and macro/micropaleontological contents. Standard preparation techniques for age-dating using stable strontium isotopes ($^{87}Sr/^{86}Sr$), foraminifera, and calcareous nannofossils have been followed. Thin sections were studied for petrographical examination. All materials including micropaleontological slides and vertebrate fossils are stored at the Earth Sciences Department and Museum of Vertebrate Paleontology of Benghazi University, Benghazi, Libya. All locality data and specimen identifications are maintained in the master catalog of the East Libya Neogene Research Project (ELNRP) database.

3 Results–Lithostratigraphy of As Sahabi Area

The paper integrates the most recent lithostratigraphic studies by the ELNRP team (El-Shawaihdi et al., 2014, 2016; Muftah et al., 2013, 2018). We identify an unconformable Margin Erosional Surface (MES) (Roveri et al., 2014), dating to 5.33 Ma–5.96 Ma, that resulted from Messinian down-cutting of the Eosahabi paleoriver. This unconformity separates the Miocene Sahabi Formation from the Pliocene Qaret Weddah Formation. This revised lithostratigraphy is supported by vertebrate biostratigraphy, nannoplankton biostratigraphy of intercalated marine sediments, strontium dating, and subsurface studies, and refines earlier studies by De Heinzelin and El-Arnauti (1987) and Giglia (1984) (Fig. 2).

Formerly termed "Formation M," the Benghazi Formation is a ~ 12 m thick dolomitic limestone that forms the lowest stratigraphic level of the sediments exposed in the As Sahabi area. Its lower contact is not exposed, and its upper contact is an unconformity underlying the Sahabi Formation. It consists of highly gypsiferous, halite-containing sandy, and clayey bioclastic sediments. There is a rich marine invertebrate fauna including echinoids, pelecypods, bryozoans, barnacles, foraminifera, and ostracods. The calcareous nannofossils indicate a Tortonian age (ca. 8.23 Ma), supported by $^{87}Sr/^{86}Sr$ isotope studies on a fossilized shell providing ages of 8.99 Ma to 9.36 Ma. The macro/microfossils suggest a depositional environment of transgressive inner neritic marine conditions, indicative of shallow water deposition with a low rate of sedimentation.

The Sahabi Formation is composed of two members. The "Lower Member" is up to 25 m thick and is composed of gypsiferous dark clay and sand, previously termed "Formation P" and the "Member T" portion of the Sahabi Formation. It contains a network of 5 m-deep polygonal cracks filled with selenite gypsum. The upper contact is an unconformity delineated by gypsum-filled cracks. This

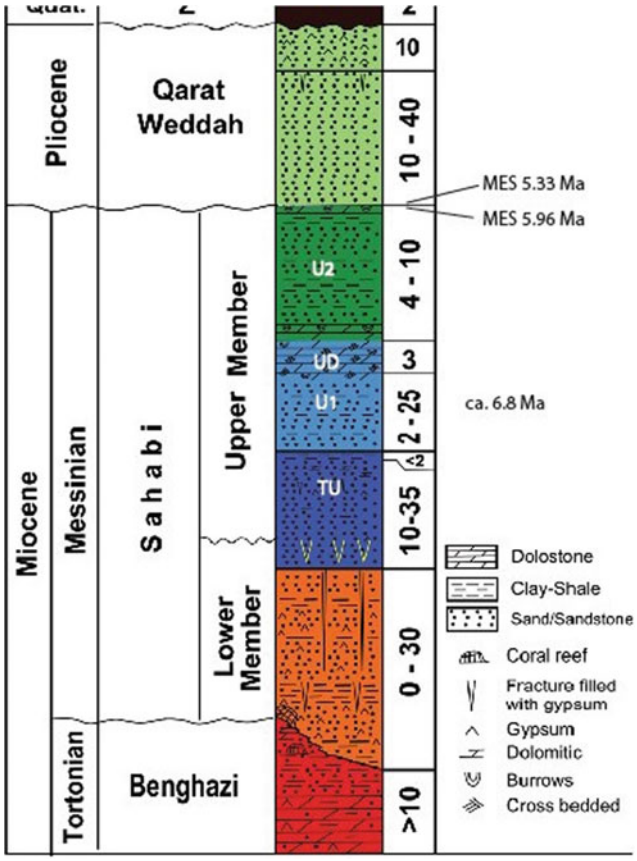

Fig. 2 Chrono/lithostratigraphic columnar section showing the exposed Neogene rock units in the As Sahabi area, northeast Sirt Basin

stratum was interpreted by De Heinzelin and El-Arnauti (1987) to be terminal Miocene in age and correlative to the Messinian Salinity Crisis, but lithologic and fossil content indicate a shallow marine depositional environment and evaporitic conditions within a sabkha or hypersaline lagoon. The age of this Unit is Late Miocene (Messinian Stage) (El-Shawaihdi et al., 2016).

The "Upper Member" of the Sahabi Formation includes the upper part of the member T (TU), and Units U-1, U-D, and U-2. Clay and sands grade upwards into peloidal sandy dolostone, followed by arrhythmic intercalations of sand and clay locally interrupted by thin dolostones. Vertebrate fossils are abundantly preserved in Units U-1 and U-2. This member has been dated to the Late Miocene using benthic foraminifera (*Borelis melo curdica*) and numerous vertebrate taxa at ca. 6.8 Ma (Bernor et al., 2020; Boaz et al., 2008). Depositional environments included a mosaic of paleohabitats, terrestrial (steppe, wooded savanna, and forest) and aquatic (large freshwater river, estuary, and offshore marine). The cross-bedded strata of unit U-D, earlier interpreted as a "dune," constitute a transgressive carbonate barrier bar (Muftah et al., 2008).

The Qarat Weddah Formation formerly termed "Member V," consists of variable white to green sands and sandy mudstones with lenses of gray, gypsiferous dolomite, with frequent clay balls. This unit unconformably overlies the "Upper Member" of the Sahabi Formation, and represents transgressive fluvio-deltaic deposition in tidal channels, fresh to brackish-water marshes, or sabkhas. This formation was deposited during the post-Messinian re-filling of the Mediterranean Basin, and its age is estimated as Early Pliocene based on its stratigraphic position. The upper contact is unconformable with overlying "Formation Z," a brecciated paleosol with root casts of Quaternary age (El-Shawaihdi et al., 2016).

4 Discussion

The regional stratigraphic framework in the As Sahabi area now provides a matrix for documenting earth history events and investigating biotic effects during the Messinian period in northern Africa and the eastern Mediterranean Basin. Among the questions that can be addressed here are the course, timing, and demise of one of Africa's great rivers, the Eosahabi, a significant source of fresh water emptying into the Mediterranean (Barr & Walker, 1973; Griffin, 2006, 2011; Nicolai, 2008). Questions surrounding the timing and origin of the Sahara Desert can also be effectively addressed in unexplored sedimentary deposits along the long Eosahabi valley stretching south to the Mega-Lake Chad Basin. Paradoxical aspects of Neogene As Sahabi, showing attributes of both a "crossroads" and endemic biota, remain to be explained (11).

5 Conclusions

Roveri et al. (2014) note that "a comprehensive stratigraphic scenario of Messinian events is still unavailable because of the difficulties in combining onshore and offshore observations." The Neogene stratigraphic record of sediments exposed at Sahabi represents just such a marine-terrestrial sequence. Reconstructing that record has required a methodical multidisciplinary program of fieldwork and lithostratigraphic correlation. The As Sahabi area holds great promise for interpreting the complex geological and paleoenvironmental phenomena preceding and following the Messinian Salinity Crisis.

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