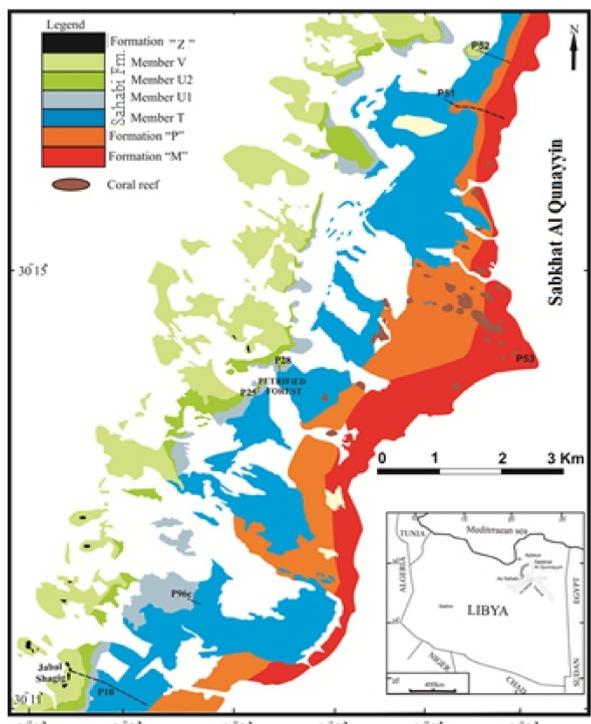




Chronology	Formation	Member	Lithology	Thickness (m)
Late Neogene	Messinian-? Pliocene	V	10-40	10
		U-2	4-10	4-10
		U-D	3	3
		U-1	2-25	2-25
		T	10-45	10-45
	Tortonian	M	>10	>10

- Dolomite
- Clay-Shale
- Sand/Sandstone
- Coral reef
- Fracture filled with gypsum
- Gypsum
- Dolomitic
- Burrows
- Cross bedded



ABSTRACT

As Sahabi area is one of famous vertebrate African localities situated in northern Africa, at the northern Sirt Basin of Libya. Its scientific value is due to the diverse and high abundance of vertebrate fossil remains. Hence, the dating of the exposed vertebrate-bearing member "U1" of Sahabi Formation in As Sahabi area using micro-macro invertebrates is the primary objective of this work. The data base is quite large including eight profiles and two subsurface shallow drilled wells from As Sahabi. Stratigraphically, the Late Neogene rock units of As Sahabi area are well differentiated and correlated by means of both biofacies and lithofacies changes as much as possible. The youngest Quaternary rock unit (Formation "Z") is raised herein to be Formation rather than Member on the basis of the newly recognized unconformity. Whereas, the mineralogical and geochemical analyses are applied to the non-fossiliferous clayey intercalations in Sahabi Formation searching for any datable minerals or microfossil to solve the age enigma of Sahabi Formation, also implemented to understand the source area of the Sahabi clays. The mineralogical and geochemical study of clayey sediments from the vertebrate fossiliferous member of the As Sahabi Formation, using XRD and XRF analyses proved a continental origin from Neogene mega-Lake Chad. Paleontologically, several species have been described and illustrated for the first time from five macrofossils phyla (echinodermata, mollusca, corals, bryozoa and arthropoda) have been described in more detail to a species level in As Sahabi area particularly from formation "M". Thirty-five foraminiferal species have been documented from As Sahabi area during this study, mostly from the Pre-Sahabi formation "M", from which two assemblage biozones are established. Whilst, Sahabi Formation itself yields mainly shallower foraminiferal elements, with very low diversity and bad state of preservation. Seventeen ostracodes species from the pre-Sahabi rock unit (i.e. formation "M") in As Sahabi area have been identified. In addition to that the Pre-Sahabi formation "M" from the subsurface data yielded diagnostic calcareous nannofossils, on which the dating is based. Integrated age of Late Tortonian age is assigned to the Pre-Sahabi Formation "M" based on the above-mentioned tools. Meanwhile the Sahabi Formation, Member "T" which is shallow marine deposits is dated as (post-Tortonian - ? Messinian). Meanwhile the terrestrial-marginal marine deposits (Member U1, U2, U3 and V) are of Messinian or younger, base on Foraminiferal contents. Formation "Z" is of Quaternary age.

INTRODUCTION

The As Sahabi area has attracted not only paleontologists for its natural museum of Neogene vertebrates, but also tourists for its fascinating scenery and impressive desert landscape panorama. During the nineteen twenties, Italian soldiers noted by accident the presence of mammal fossil bones in the vicinity of the Qasr as Sahabi, a now-runned fort dating from Roman times, located at the southern end of the present paleontological site. In the early nineteen thirties, the famed Italian geologist and paleontologist Ardito Desio, with Professor G. D'Erasmus from Naples and geologist G. Stefanini from the University of Pisa, conducted the first geological and paleontological investigation in the As Sahabi area (Petrocchi, 1934). Carlo Petrocchi, a young paleontologist recruited in the 1930s by Desio to study As Sahabi, would become involved for decades in As Sahabi (and Libya), and make discoveries that rendered As Sahabi the most famous Libyan fossil site. Among his first finds (via excavations also), were the skull of the four-tusked elephant *Sogropotobolus gregoryi* at (now) locality P18, and the skull and the *in situ* skeleton of a cetacean, a whale, at locality P8 (Petrocchi 1934, 1936 and 1941). For more on the discovery of the As Sahabi site, see Rook (2008); for a general presentation of the paleontological site, see Boaz (2009); and for a brief history of As-Sahabi research and collections, see Boaz, et al., (2008b).

LOCATION

The As Sahabi study area is located in the northeastern part of Sirt Basin, covering an area of about 375km². It is bounded by longitudes 20° 48' 08" to 20° 54' 45" E and latitudes 30° 10' 58" to 30° 17' 36" N, within a tectonic province called the Ajdabiya Trough. The studied samples came from scattered exposures aligned in a N30E-trending manner and bounded by the Sabkhat al Qunayyin from the west.

LITHOSTRATIGRAPHY

Four instead of three formations are differentiated in this work. Three of these rock units bear the same informal names, from bottom to top: Formation "M", Formation "P", and Sahabi Formation. Sahabi Formation, however, is divided into five instead of six members (T, U1, U2 and V) and the old member "Z" of Sahabi Formation is revised to the new formation "Z" based on two important criteria: observed unconformity and the lithological nature, to be explained further in section formation "Z". caps the Sahabi Formation at some profiles, as in P10. All these formations are separated by unconformity surfaces (De Heinzelin and El-Armani, 1987).

Formation "M": It consists of semi-consolidated sandy bioclastics with maximum exposed thickness reaching up to 12 m. Few patches of coral reef are sporadically exposed as isolated reef building. Petrographically formation "M" is differentiated into the following five microfacies, on the basis of the lithology, texture and fossil content, from bottom to top they are: 1) Foraminifera-sclerodermata packstone microfacies; 2) Sandy-pelletal packstone microfacies; 3) Gypsiferous dolomite unit; 4) Clay unit and 5) Fossiliferous limestone microfacies.

Formation "P": The exposed gypsum deposits of Formation "P" at As Sahabi area are interpreted by previous workers, including De Heinzelin and El-Armani (1983, 1983, 1987), as a result of Mediterranean sea recession of the Messinian Crisis. The field investigations of this study suggest that the gypsum of formation "P" represents a subsequent infilling depositional event (i.e. Gypsum crystals filled the large polygonal-shaped cracks into dark silty clay mixed with sand). The cracks are extending down to more than 5 m depth. This is a very characteristic phenomenon, which probably indicates that during the deposition of these sediments they became exposed, dried out and cracked and were filled later by sheet-like gypsum called Solonch. This phenomenon seems to be repeated at least twice in this particular formation.

Sahabi Formation: It was introduced by the Heinzelin and El-Armani (1982), who divided it into six members (T, U1, U2, U3, U4 and V). This Formation consists in this paper of five members since the Z is excluded as mentioned earlier. Sahabi Formation is bounded by two unconformity surfaces. The lower one is with the underlying formation "P", meanwhile the upper unconformity surface is with the overlying formation "Z", which is similarly defined by the noticeable zone of root casts. The five members are summarized from bottom to top as follows:

Member "T": It consists of sands grading to highly cross bedded sandy dolomite upwards, with gypsum filled cracks locally in the lower part of the section as such in P52. The presence of common porcellaneous foraminifera (*Borelis melo cruda*) as well as *Lithothamnium rhodoliths* and *Ophiomorpha* traces are indication of shallow shelf marine conditions. Meanwhile, the presence of the gypsiferous clay is probably attributed to lagoonal depositional affinity. In the southern part however, common *Gryphaea* sp. with sparse aquatic vertebrate remains (sirenian bones and teeth) are present.

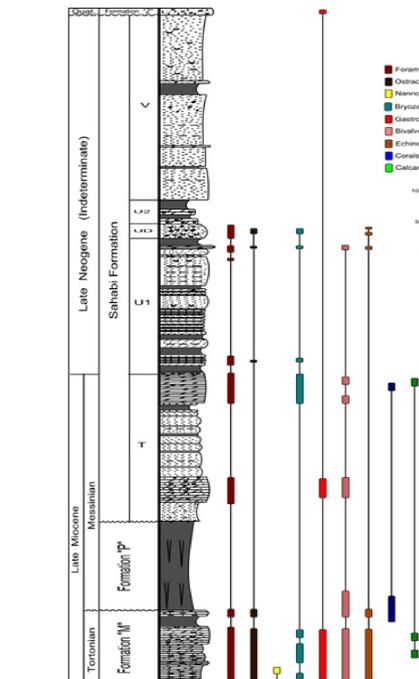
Member U-1: This rock unit consists of rhythmic intercalations of sand and clay sequence interrupted locally by thin intercalation of dolostones. The sand is usually clean, ferruginous, with clay clasts in parts and locally cross bedded (De Heinzelin and El-Armani, 1982). On the other hand, the clays at P25 and P28 have been analyzed mineralogically by means of XRD and found to be dominated by Quartz, followed by few kaolinite while, in the frame of this study the phyllosilicates kaolinite, dickite, illite, chlorite, smectite and montmorillonite are represented by low percentages (Mufahh et al., 2011). Pyrite is present locally indicating reduction conditions at this locality. Paleontologically, this member is the most productive rock unit in terms of vertebrate fossils (including postcranial, teeth, and some complete skulls) as well as coprolites. In few localities such as P25, this unit displays in-situ internal sandstone casts of large tree trunks that are aligned in E-W direction. This sandstone casts are made of clean, white and coarse grained quartz, exhibiting tough and planar cross bedding. Fossil wood is also found commonly preserved as silicified fossil wood (e.g. the famous petrified wood at P28, Fig. 3.17), and in rare cases as gypsified fossil wood. Laterally in the southern part of the study area this unit gradually changes into silts and sands intercalated with clay inclusions, as in the case of locality P96c.

Member "U-2": This Member is represented by a narrow discontinuous strip, extending between the older member "U1" or "U1P" and the younger member "U3" of Sahabi Formation. It is in most cases bounded by two dolomite horizons. It is considered as a marker bed for the whole region by De Heinzelin and El-Armani (1983). It consists of sands intercalated with clay, interrupted upwards by thin dolomitic crusts. The mineralogical analysis of these clays by X-ray diffraction indicates mainly montmorillonite with subordinate amounts of kaolinite, chlorite and illite.

Member "U-D": Although this rock unit is displaying a discontinuous occurrence in As Sahabi area, it is considered as a marker bed by De Heinzelin and El-Armani, (1982). It consists of sandy dolostones with highly cross bedded planar and herringbone types, which are obviously overprinted by the extensive bioturbation.

Member "U-1P": This Member is considered herein as the topmost member of the Sahabi Formation. It is represented by intermittent few exposures occupying the area beyond the older member "U2" of Sahabi Formation. It consists of variable white to green sands and sandy mudstone with lenses of gray dolomite, gypsiferous, (at some places rose gypsum reported), and with frequent clay balls. Common presence of root casts was reported as well. The sand grains are usually medium to coarse in size, and gravely at some places. The lower part is characterized by mammal bones, such as a *Stegotetrabelodon* skull which was excavated by Petrocchi (1934) at locality P19 (De Heinzelin and El-Armani, 1983). Fossil wood has also been reported in a few places, such as at locality P10.

Formation Z: This rock unit is considered herein as a separate formation rather than a Member of the Sahabi Formation, due to the unconformity with the underlying member "V" discovered in this study. It forms the youngest rock unit in the study area, with 82m thickness. This soil complex sequence is exposed as a remnant crust, capping the topmost of few hills with a distributional pattern aligned in N20E (Fig. 2). In Jabal Shaqib (P10), for example, but not exclusively there, this rock consists of brecciated calcareous with the presence of the terrestrial land snail *Helix cf. melanostoma*. The presence of *Helix*, a monospecific genus, confirms a sub-areal continental affinity. The presence of paleo-caliche precipitation, with brecciation, as well as of root casts in this rock unit, permit the elevation of this Member to an independent formation. De Heinzelin and El-Armani, (1987) suggested previously to consider this Member a Formation. The scattered distribution of *H. melanostoma* with common liberated shells in the vicinity of these exposures is probably due to the extensive erosion of this rock unit in the surrounding outcrops.

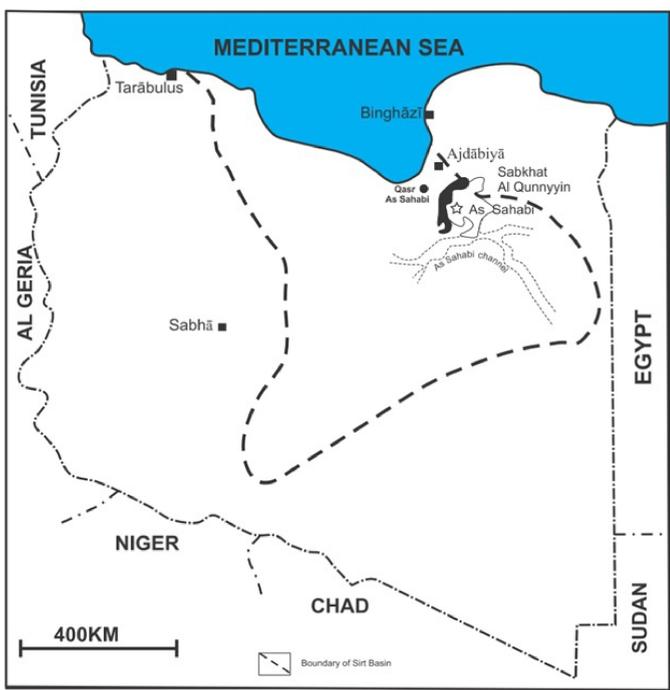
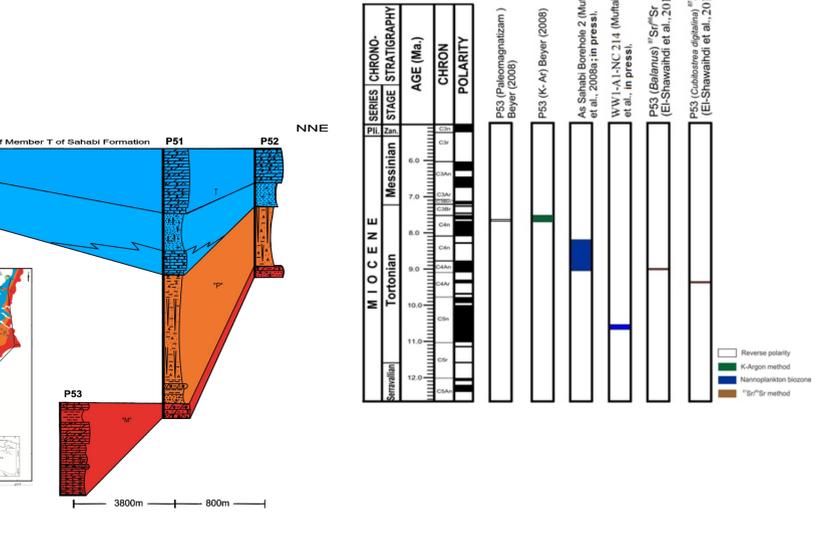
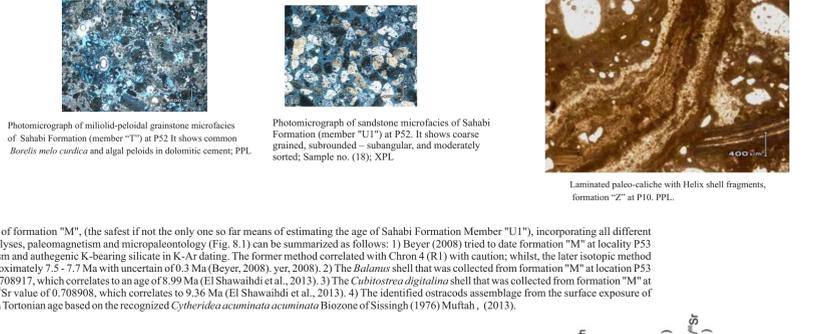
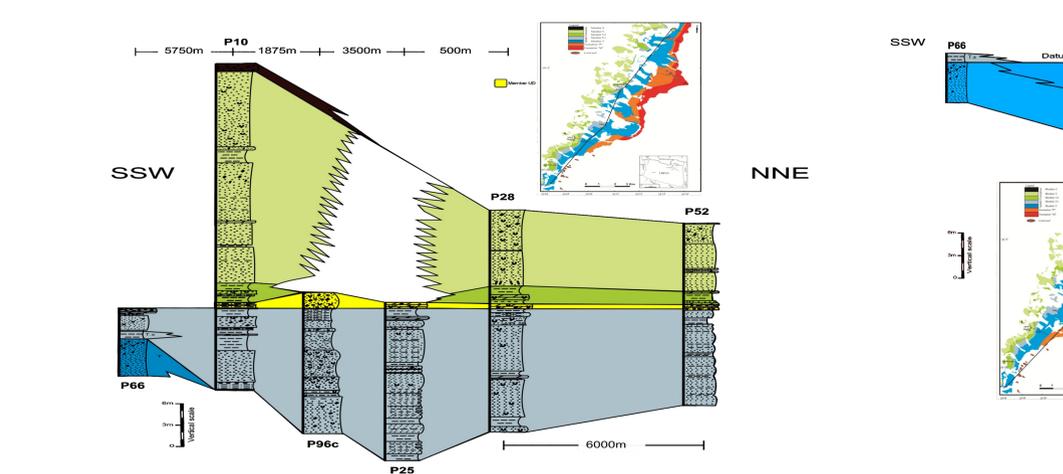


Age	Formation	Member	Sample no.	Lithology	Microfossils
LATE NEOGENE	SAHABI	V	40	Foraminifera, mollusca, bryozoa, echinodermata, sclerodermata, corals, bryozoa, arthropoda, and gastropods.	P52
			39	Sandstone. White, cream, soft, fine-medium grained, silty, moderately sorted and moderately well-sorted. Contains coarse and cross bedded laminae. Turbidite upwards.	
			38	Sandstone. White, cream, fine grained, occasionally medium, silty, moderately sorted and occasionally well-sorted.	
			37	Limestone. White, medium hard-hard, slightly sandy.	
			36	Sandstone. White, soft-medium hard, fine-medium grained, silty, moderately sorted and gypsiferous.	
			35	Sandstone. White, medium hard-hard, slightly sandy, silty, moderately sorted and gypsiferous.	
			34	Sandstone. Yellow, medium hard-hard, fine-medium grained, silty, moderately sorted and gypsiferous.	
			33	Sandstone. Yellow, medium hard-hard, fine-medium grained, silty, moderately sorted and gypsiferous.	
			32	Sandstone. Yellow, medium hard-hard, fine-medium grained, silty, moderately sorted and gypsiferous.	
			31	Sandstone. Yellow, medium hard-hard, fine-medium grained, silty, moderately sorted and gypsiferous.	
Tortonian	M	T	2	Dolomite. Cream, soft-medium hard, fine-medium grained, silty, moderately sorted and gypsiferous.	P51
			3	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			4	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			5	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			6	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			7	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			8	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			9	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			10	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	
			11	Gypsiferous and silty clay. Moderately sorted and gypsiferous. Contains large gypsum crystals.	

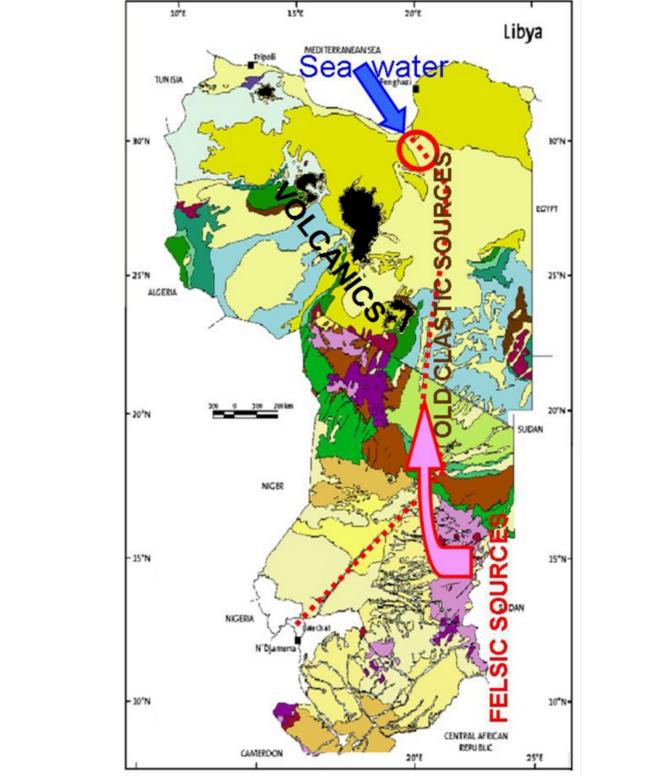
Photomicrograph of multi-lobed dolomite microfacies of Sahabi Formation (member "T") at P52. It shows common *Borelis melo cruda* and algal peloids in dolomitic cement. PPL.

Photomicrograph of sandstone microfacies of Sahabi Formation (member "U1") at P52. It shows coarse grained, subangular, and moderately sorted. Sample no. (18), XPL.

Laminated paleo-caliche with *Helix* shell fragments, formation "Z" at P10. PPL.



Mineralogical and geochemical investigation, performed for first time in the literature, of clayey sediments from three localities, P25, P28 and P96c, from vertebrate fossiliferous member "U1" of the As Sahabi area, robustly showed very mature and re-processed sediments of continental origin, and felsic sources, with no influence from Libyan volcanic (basaltic) rocks. According to our data, the studied As Sahabi sediments can originate in Precambrian continental sources in northeastern Chad. Another scenario could be that the As Sahabi fossiliferous rocks are related Precambrian outcrops in Ethiopia through an east-west river connection with the Nile. We argue this suggestion unfavorable, since it is supported mainly by remote sensing data, and there is no time control and geological data. The abundant vertebrate fauna from the Sahabi Formation is associated to penecontemporaneous fossil faunas in Chad and gives evidence for an Eosahabi River connection to Neogene mega-Lake Chad.



Proposed origin of sediments of the fossiliferous Member U1 of As Sahabi Formation (the geological formations of Libya and Chad were taken by Schlueter (2008)).