A rich fish assemblage from the Miocene Al Jaghboub Formation, Marmarica Area, NE Libya.

By

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DEDICATION

This thesis is dedicate to the soul of my beloved brother Toha, also to the soul of my late uncle Dr. Abdelwahed El Gaziry, to my mother, father, my sister and my fiancé

Mohammed.

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This Thesis (**A rich fish assemblage from the Miocene Al Jaghboub Formation, Marmarica Area, NE Libya**.) was Successfully Defended and Approved on 24-9-2017.

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List of abbreviations

aff. – affinity: indicates a specimen or specimens believed to be closely related to but not exactly the same as the named species.

cf. to compare; used in paleontology to indicate that a specimen or specimens are closely comparable to but not the same as a named species.

e.g. abbreviation meaning "for example".

ESEM-EDX: abbreviation for environmental scanning electron microscope with an energy dispersive X-ray system.

et al. abbreviation for and others.

Fig. abbreviation for figure.

HREE: abbreviation for heavy rare earth elements.

ICP-MS: abbreviation for inductively coupled plasma-mass spectrometry.

i.e. abbreviation meaning "that is".

indet. abbreviation meaning Indeterminate**.**

LREE: abbreviation for light rare earth elements.

Ma: abbreviation for million years ago.

PAAS: abbreviation for Post-Archean Australian Shale.

Pl. abbreviation for plate.

REE: abbreviation for rare earth elements.

SEM: abbreviation for scanning electron microscope.

sp. abbreviation for species.

spp. abbreviation indicating that more than one species is present.

WHJ: abbreviation for Wadi Al Hash-Al Jaghboub Formation.

†. mark stands for extinct species or genus.

Abstract

A vertebrate fossils site has been discovered in Wadi Al Hash, 20 Km east of Tobruk city, NE Libya. This fossiliferous outcrop is the lower most horizon of Al Jaghboub Formation which was dated herein as early Miocene, late Burdigalian (17.25 Ma.) using ($^{87}Sr/^{86}Sr$) radioactive isotopes for a *Balanus* shell, and the presence of some elasmobranches teeth remains. More than fifteen elasmobranch species and six teleost taxa were identified from the concerned horizon. Among the identified species such as *Megascyliorhinus* sp., *Scyliorhinus* sp., *Paragaleus pulchellus, Rhizoprionodon fischeuri, Negaprion eurybathrodon, Rhynchobatus pristinus, Dasyatis* aff. *rugose, Dasyatis* cf. *gigas*, *Dasyatis* cf. *serralheiroi*, *Gymnura delpiti, Myliobatis* sp., *Mobula* sp., cf. *Epinephelus* sp., *Sparus* sp., *Diplodus* aff. *intermedius*, *Pagrus* sp., cf. *Dentex* sp. and cf. *Sphyraena* sp. Most of the identified ichthyofauna herein are reported elsewhere around the Tethys and Paratethys (e.g. France, Portugal, Germany, Italy and India) confirming the connection between the Mediterranean and the Indian Ocean in that slice of time. This association clearly suggests that this facies was deposited in more or less deep marine environment under fairly subtropical climatic conditions. While the contemporaneous fossil site elsewhere in the Sirte Basin further southwest were deposited in shallow to marginal marine environments (e.g. Jabal Zaltan), this clearly suggests that the coastal shoreline was located further south during the early Miocene.

Acknowledgements

Before even thinking to thank anyone or anything, I would like to thank "Allah", who created everyone and everything, and guided us to meet some extraordinary people, and interact with them in the field of earth sciences, and from whom we gained a lot of interest and passion to have a career in geology.

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Chapter 1

Introduction

The study of fossilized ichthyofaunas (fish faunas) from sediments associated with Oligo-Miocene transition particularly important, as this was a time of major climatic turnover (Zachos *et al*., 2001) and paleogeographical reordering in what is today the eastern Mediterranean region, including the collision between Eurasia and Afroarabia (Argyriou *et al*., 2015). Before this collision seaways enabled faunal exchange between the Tethys and the Indian Ocean. The Tethyan gateway was closed following the collision between Eurasia and Afroarabia, in the middle Miocene, leading to the formation of the Mediterranean Sea (Karami *et al*., 2011). The rich fossil fish record of the circum-Mediterranean region has been the subject of numerous scientific works. However, most of the studied fossil fish localities are of late Miocene (e.g., Gaudant, 1987) and Pliocene (e.g., Pawellek, *et al*., 2012), while deposits with an age proximal to that of the Oligo-Miocene transition are rare and/or understudy. These deposits are critical for understanding the origins and evolution of the Mediterranean ichthyofauna and the impact of the Eurasia-Afroarabia collision on aquatic life (e.g., Argyriou *et al*., 2015). Few of the rare Oligocene–early Miocene fish assemblages known from several sites on the Arabian plate (Otero and Gayet, 2001) and one assemblage from the early Miocene of Jabal Zaltan, Libya (Argyriou *et al*., 2015). Other known localities in North Africa may help fill this gap in our knowledge of Oligo–Miocene fish evolution, including Moghra (Egypt, Priem, 1920; Cook *et al*., 2010).

1.1. **Location of study area**

The most recent study on these deposits at Wadi Al Hash which has been carried out by team of geologists from the University of Benghazi in 2013 who discovered this unknown vertebrate rich horizon and recommended to be handled by a vertebrate specialist, to identify their taxonomic groups and their geological implications (Muftah *et.al*., in press). The study area is very hard to access even by 4 wheel drive vehicle (because of its ruggedness and long distance from the main road), as it is located close to the mouth of Wadi Al Hash which is about 20 Km east of Tobruk city in the northeastern corner of

Cyrenaica between longitudes 24° 07' 10" and 24° 07' 50" E and latitudes 32 00' 00" and 32° 00' 30" N (Fig. 1.1).

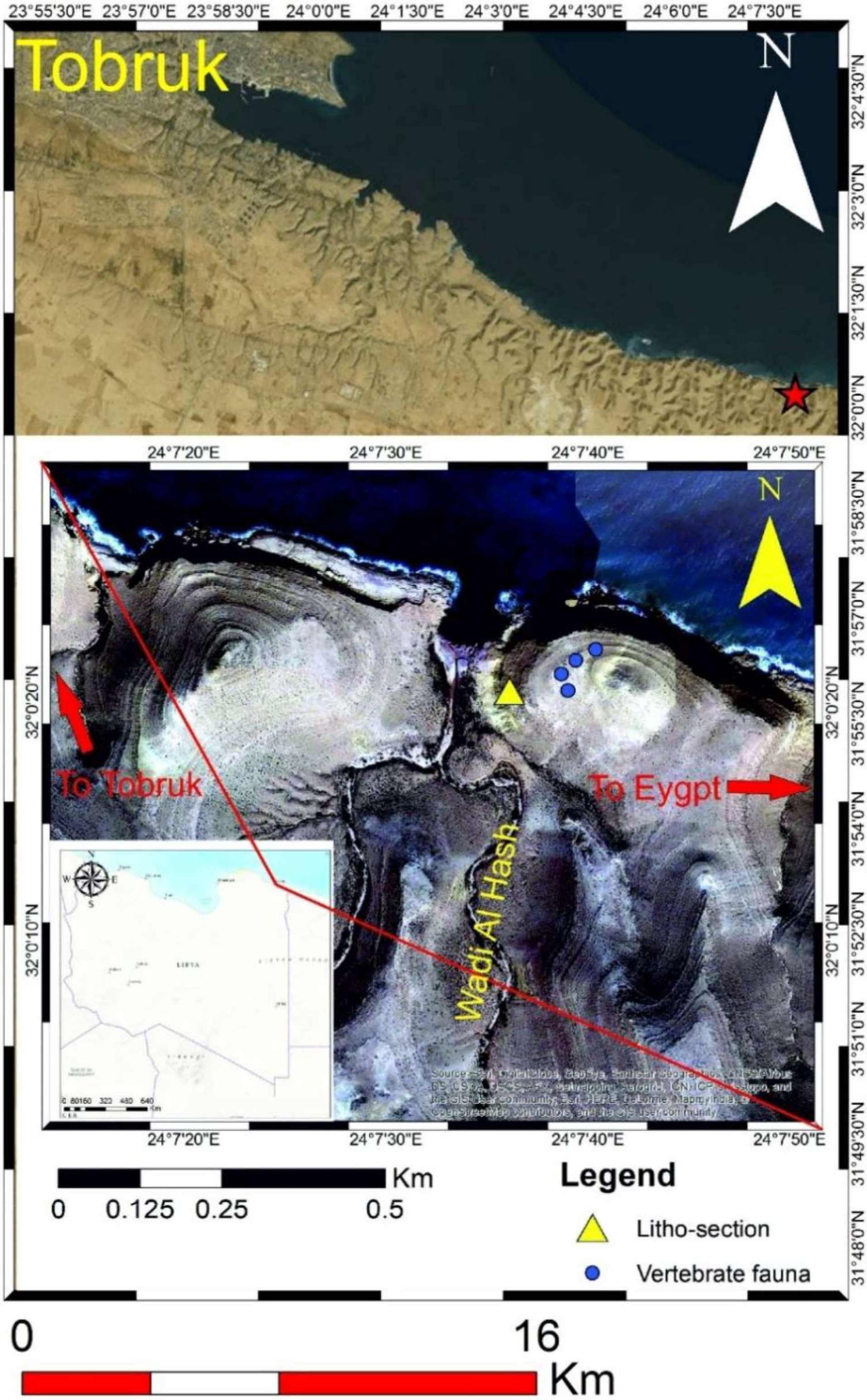


Fig.1.1. Landsat image of the study area of Wadi Al Hash, NE Libya.

1.2. Objectives

The present study is centered on the description and taxonomic identification of fossil chondrichthyan and actinopterygian fishes from Wadi Al Hash (early Miocene). The attributions are expected to help address a variety of secondary goals including:

1) Paleoenvironmental reconstruction of the region during early Miocene using fossil Ichthyofauna.
2) Inter-regional assemblages comparison with neighboring basins to clarify the paleobiogeographical scenario.
3) Bridging the gap between the well-known Paleogene faunas and those from the Miocene.
4) Creating a solid foundation for further regional comparative studies by providing adequate descriptive and pictorial documentation of fossils.

1.3.Problem Statement

Bony and cartilaginous fishes are the most important vertebrate components of all aqueous bodies. Also they have an excellent fossil record and specific biological/ecological traits. Therefore, they can be used to address a variety of issues pertaining to paleoenvironments, paleobiogeography, evolution, faunal turnover etc. Most fishes found in Neogene deposits have living counterparts whose biology (includes preferred habitats, temperatures etc.) can help in providing an independent check on previous interpretations about the depositional environment, and compare with other faunas for paleobiogeographic purposes.

1.4.Methods

A- Fieldwork

Three field trips to the study area were organized, supported and performed by the Earth Sciences Department, University of Benghazi during April 2016, which helped to achieve the following goals.

- Rock sampling of a new stratigraphic column of the Wadi Al Hash locality from the sea level to the top of the cliff (Fig. 1.2), from which ~17 selected rock samples from the Al Faidiyah Formation were processed for petrographic examinations.

- The vertebrate-bearing clay at the Paleogene/Neogene boundary (i.e. early Miocene), which forms the primary target of this research, has been subjected to extensive sampling. About 51 kg of sediments were collected from these visited localities, from which the fossil fish remains were retrieved (Fig. 1.3).

Fig. 1.2. General view of Wadi Al Hash, Looking NE.

Fig. 1.3. Collecting samples from the Paleogene/Neogene boundary exposed at Wadi Al Hash

B- Laboratory Investigation

Geochemical analysis was performed on two samples (Phosphate nodules 17_1 and shale sample 17_2) from the early Miocene horizon of the Al Jaghboub Formation. The technique used herein is the inductively coupled plasma-mass spectrometry (ICP-MS) technique which is widely used for the determination of elements in various materials with high precision. About 11 major oxides and 22 trace elements, were analyzed in order to investigate various parameters such as paleooxygenation levels, paleohumidity.

Furthermore age dating using $^{87}Sr/^{86}Sr$ ratio was applied during this study on *Balanus* shell, which recovered from the top of the measured Al Jaghboub Formation in attempt to deduce the age of the studied horizon, on stratigraphic basis.

The screen-washed materials were obtained by washing 51 kg of sediments, using standard sieves of 3.5 mm and 5 mm mesh. The coarse sieved residue was then examined under binocular microscope at different magnification levels. Microvertebrate remains (i.e. teeth, vertebrae, coprolites and bone fragments) were picked using a fine brush.

The fossil vertebrate materials consisted exclusively of teeth (isolated selachian and actinopterygian elements), fragmentary bones, vertebral centra and shark coprolites. The selachian teeth, particularly those of sharks, were often in good state of preservation, where smaller teeth were the most complete. All studied elements are housed in the Vertebrate Museum of the Earth Sciences Department at University of Benghazi (Collection number with abbreviation WHJ). The generic identification of selachian taxa is based on the scheme of Compagno (1984), and Cappetta (1987, 2012). Geographic and stratigraphic distribution data for each extinct taxa were taken, from the Paleobiology Database [http://fossilworks.org]. Furthermore, distribution and habitat for extant selachians were taken from Cappetta, 2012 and FishBase [http://www.fishbase.org]. Meanwhile, the recognition of Actinopterygian materials would be attempted using a number of dry skeletons of recent fishes from the local fish market (Bankeena), also by comparing with materials from neighboring sites. Shark coprolites classification is based on the scheme of Diedrich and Felker (2012).

Selected representative teeth and other selected skeletal elements were photographed using a digital camera and binocular microscope. This setup required a camera mount and specimens photographed directly through the ocular and scope tube. This provided adequate results for larger specimens. However, smaller specimens ware imaged using a Scanning Electron Microscope (ESEM-EDX) in the Nuclear Materials Authority in Cairo, Egypt.

1.5. Literature Review

D'Erasmo (1934) was the first to study fossil ichthyofaunas in Libya, material from Libya which were collected by the Italian geologist Desio (1935), from different exposures of the Maradah Formation. Different fish taxa belonging to sharks, rays, and actinopterygians have been identifiable by D'Erasmo from the collection. Arambourg and Magnier (1961) reported actinopterygian fossils attributed to "silurids'' and *Lates* sp. from Jabal Zaltan site (Libya). Savage and Hamilton (1973) however, reported elasmobranchs from the same site and recognized the following taxa: *Carcharias acutissima*, *Carcharodon* sp., *Hemipristis serra*, *Pristis* sp. and *Myliobatis* sp. On the other hand the late Neogene fossiliferous localities in Sahabi (Libya) have yielded numerous osteichthyan and chondrichthyan remains (D'Erasmo, 1951 and Gaudant, 1987). D'Erasmo (1951) described chondrichthyan and osteichthyan fossils recovered from fossiliferous clay in northeast part of Sahabi, Libya. Gaudant (1987) reported nine taxa of fossil osteichthyans, six of them identified as *Polypterus*; *Clarias* or *Heterobranchus*?; *Clarotes*; *Synodontis*; *Arius*?; and *Lates*. These fossils interprets the depositional environment of Sahabi Formation as fresh water environment with relative proximity of the seashore, which can be confirmed by the presence of molariform teeth of sparid fishes. Pawellek, *et al.,* (2012) discovered a rich marine tropical fish fossils of lower Pliocene deposits, at a vertebrate bearing sediments along the coast between the cities of Tripoli and Al Khums NW Libya, where 24 selachian species and 4 actinopterygians species were identified. The presence of various sharks and rays with Indo-Pacific characters during the Early Pliocene indicates that they may inherited from the Paleogene Tethys, long after its closure. Otero *et al.* (2013) described and attributed fossil remains of *Argyrosomus* (Sciaenidae) from the late Miocene deposits of Sahabi, Libya. Argyriou *et al.* (2015) studied the fossil fish assemblage collected from a lower Miocene deposits of Jabal Zaltan, Libya. The fauna they described contains 18 marine and freshwater taxa. These kind of assemblages can provide a clear picture of the early Miocene fish remains from the North African coast.

Otero and Gayet, 2001, studied the lower Oligocene and Miocene ichthyofaunas from Oman and Saudi Arabia. The fossil ichthyofauna reported from these localities includes freshwater and marine taxa, the later taxa being of major paleobiogeographic importance, as they include Eurasian taxa that migrated to Afroarabia before the collision of the two continents.

Vertebrate remains mostly belong to marine and largely fossil fishes from early Miocene deposits of Montagna della Maiella, Italy, were described by Marsili *et al.* (2007).

Cook *et al*. (2010), described the ichthyofaunas extracted from the lower Miocene fluviomarine sediments of Moghra site (Egypt). Abundant selachian remains were recovered from the site, they included the genera *Carcharias*, *Megaselachus*, *Cosmopolitodus*, *Hemipristis*, *Galeocerdo* and *Carcharhinus*, *Myliobatis*, *Pteromylaeus* and *Aetobatis*. These fauna show some similarity with the sites from circum-Tethys (particularly France, Malta, and Italy), at least at the generic level.

Chapter 2

Geology

2.1. Tectonic setting

The study area is considered as a part of Marmarica Uplift, this tectonic element extends along the coastline of northeast Libya and probably continues eastwards into the coastal area of the Western Desert of Egypt (El Arnauti *et al.* 2008) (Fig. 2.1).

The structural pattern of Al Bardia area is mainly determined by tensional faults. These are mostly confined to the northern part of the area studied. The fact that no faults were observed from the southern part of the area does not exclude their presence in this southern flat area. The plateau is covered by the Al Jaghbub limestone which is generally flat with no scarps or cuts which permit observing dislocations of one side against the other. A fault might have 'crossed the limestone country in post Miocene times and the higher upthrown side was later beveled and thus both sides of the fault assume now the same level of limestone. The problem is complicated more by silt spreads covering the limestone country (El Deftar and Issawi 1977).

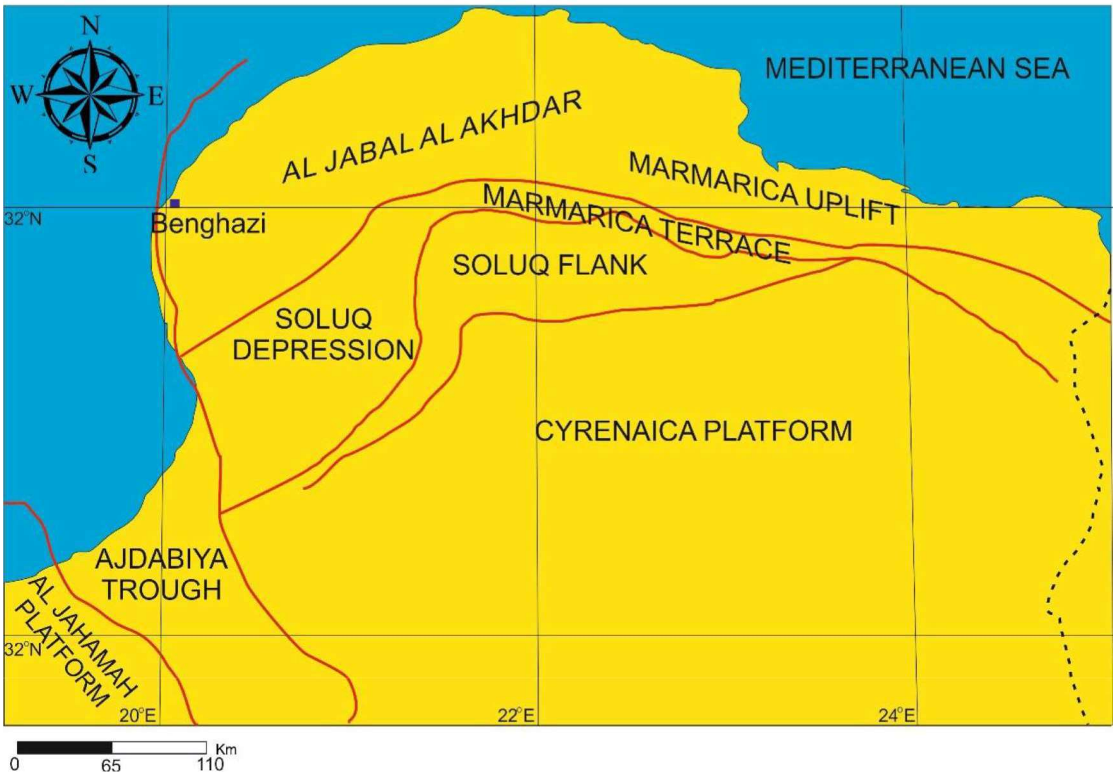


Fig. 2.1. Major structural elements of NE Libya. Modified after El Arnauti *et al.,* (2008).

2.2. Stratigraphy and Sedimentology

Al Burdia area (including Wadi Al Hash) is considered to be a very difficult area to understand stratigraphically, a fact reflected in the long list of studies concerning the subject. One of the first detailed studies was carried out by El Deftar and Issawi (l977), who subdivided the stratigraphical units in the study area to the Al Khowaymat Formation (lower member of middle Eocene and upper member of early Oligocene), the Al Faidiyah Formation (late Oligocene-early Miocene) and the Al Jaghboub Formation (middle Miocene). Megerisi and Mamgain (1980) proposed to replace the term Al Khowaymat Formation with Al Majahir, Darnah and Al Abraq formations, based on age difference. Imam (1999), studied the area biostratigraphically using foraminifera and recognized nine biozones, ranging from late Eocene to middle Miocene in age. Muftah *et al.* (in press), reviewed the stratigraphy and spatial distribution of rock units of Tobruq-Al Burdia area, using lithology and foraminiferal content, replaced the term lower Member of Al Khowaymat Formation with Darnah Formation; and the upper Member of Al Khowaymat with Al Faidiyah Formation for the western part of the study area. Also, Al Majahir Formation replaced the term Lower Member of Al Khowaymat Formation at Wadi Al Rahib section.

One stratigraphic section was selected and measured in the studied area (Fig. 2.2 and 2.3) (32° 00' N and 24° 07' E), at the mouth of Wadi Al Hash near Tobruk City. This section was investigated for their lithological characteristics as well as paleontological contents. The succession of this stratigraphic section revealed three main superposed stratigraphic formations of different sedimentary facies ranging in age from middle Eocene – early Miocene.

Fig. 2.2. General view of the studied lithological section at Wadi Al Hash, Looking NE.

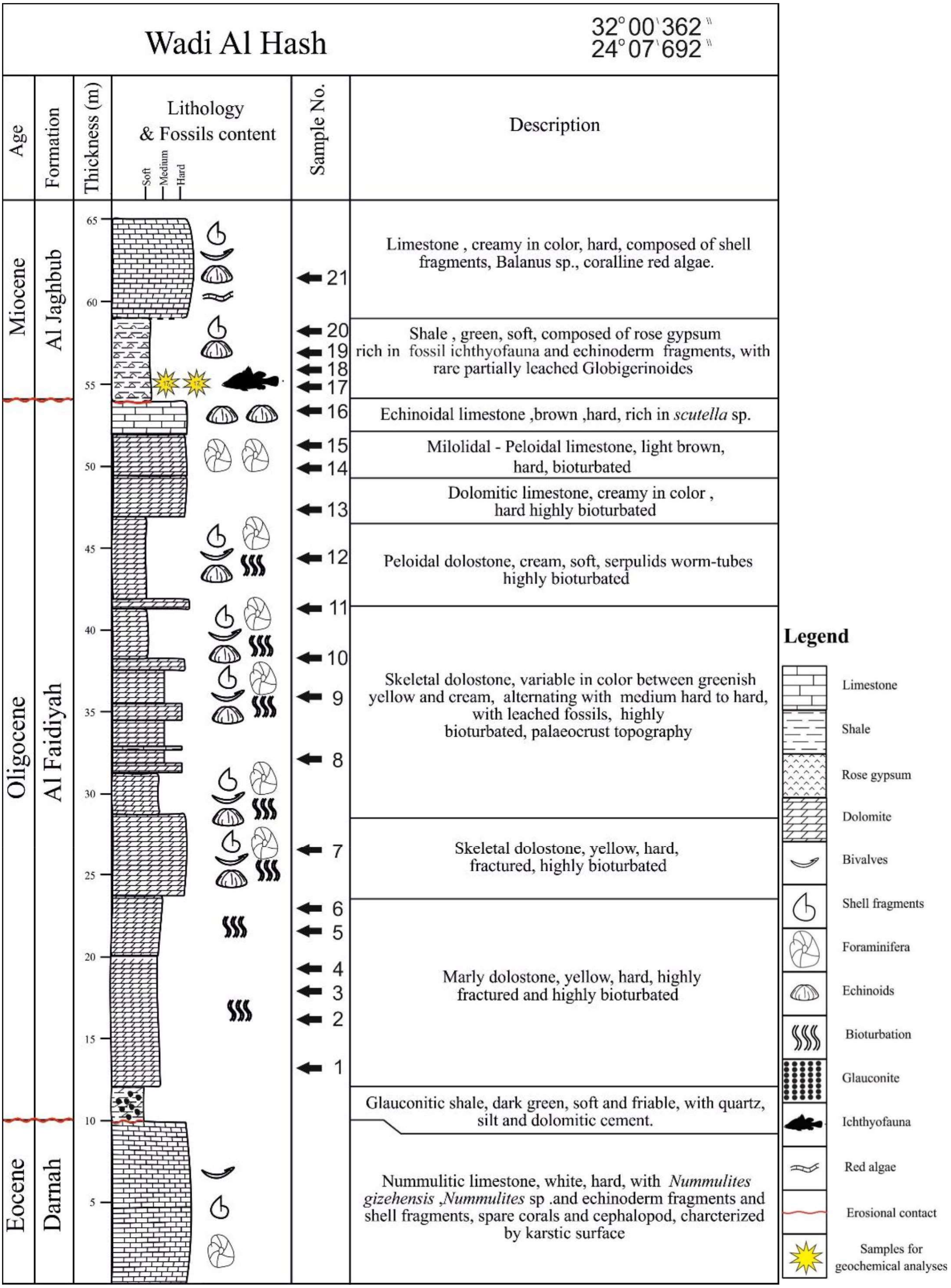


Fig. 2.3. Lithostratigraphic column of the exposed Paleogene/Neogene sediments at Wadi Al Hash.

2.2.1. Darnah Formation (Middle – Late Eocene)

Gregory (1911) was the first to describe Darnah Formation. The type locality of the Darnah Formation lies in Wadi Darnah, near Darnah city. This Formation consists of white to yellowish white, mostly massive limestone, fossiliferous, mainly *Nummulites*. Darnah Formation in the central part of Al Jabal Al Akhdar may be disconformably underlain by different rock units such as Cretaceous formations (e. g. Wadi Dukhan Formation) or with the Paleocene Al Uwayliah Formation or Eocene Apollonia Formation, depending on paleorelief, due to local structure framework. While the upper contact is disconformable with the Oligocene Al Bayda Formation. The total thickness of the Darnah Formation in the type locality is about 270 m (Rohlich, 1974).

In Wadi Al Hash, the Darnah Formation consists of white nummulitic limestone enriched with *Nummulites gizehensis* and characterized geomorphologicaly by bogaz karstic feature (Fig. 2.4) with a total thickness of about 10 m, (Fig. 2.3).

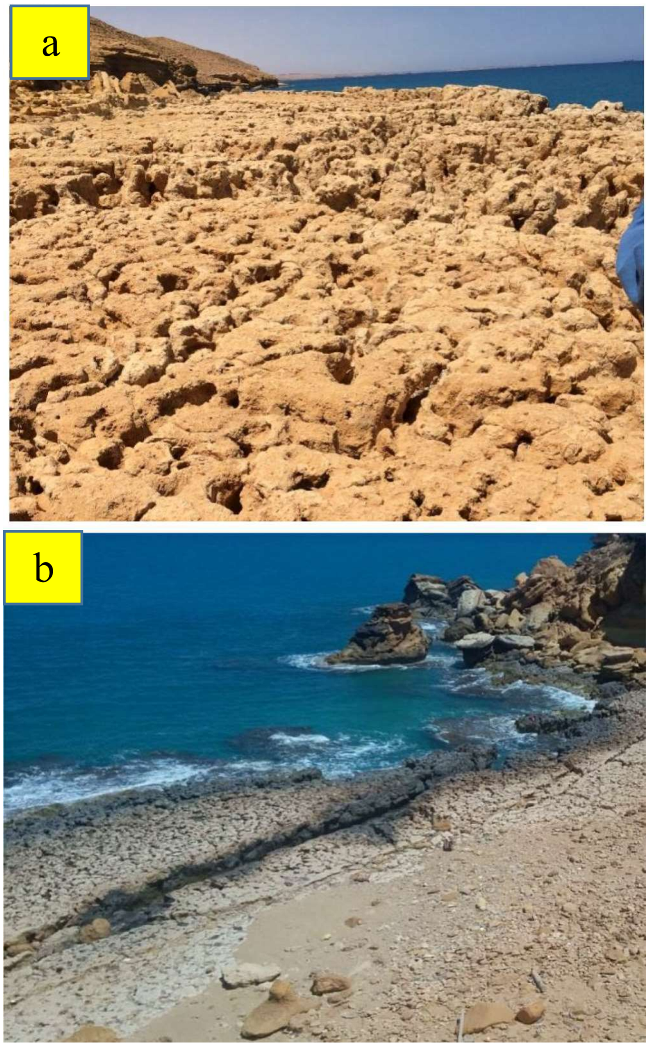


Fig. 2.4. Bogaz karst topography of the Darnah Formation at Wadi Al Hash, a) close view, looking NW, b) General view of the mouth of Wadi Al Hash, looking NE.

2.2.2. Al Faidiyah Formation (Late Oligocene):

Al Faidiyah Formation as defined by Pietersz (1968) who described its type locality along the road cut near Al Faidiya village. The formation is composed mainly of calcareous clay and marly limestone, which is white to yellowish white and thick-bedded to massive. Some fossiliferous horizons contain algae, benthic foraminifers, corals and oysters. Glauconitic marl with recognizable glauconite grains (a typical sediment of marine transgression) occurred at the formation base (Rohlich, 1974). Al-Faidiyah Formation in the study area is unconformably overlain the Middle Eocene Darnah Formation, which is represented by a sequence of dolomitic glauconitic shale (at the base) (Fig. 2.5), dolomitic limestone and echinoidal limestone (at the upper part near the disconformity), yellow, varying hardness (soft to hard), fossiliferous and bioturbated at places, with a total thickness of about 43 m and its divided into eight units (Fig. 2.3) from the oldest to youngest as follows:

Unit (1):

This unit is composed of dolomitic glauconitic shale, dark green, soft and friable, with abundant coarse glauconite grains of irregular shape, quartz, silt and dolomite cement, the total thickness of this unit reaches 2 m, in places this unit is consisted as a marker bed to the base of the Al Faidiyah Formation in the region (Fig. 2.5).

Fig. 2.5. Glauconitic shale at the disconformity surface between the Al Faidiyah Formation and Darnah Formation at Wadi Al Hash, looking NE.

Unit (2):

This unit is made of marly dolostone, yellow, hard, highly fractured and highly bioturbated, the total thickness of this unit is 12 m.

In thin section this unit is characterized by a mudstone texture with clear rim and euhedral fine dolomite crystals hematic in places with rare presence of anhydrite cement, yielded few algal mat remnant, (Fig. 2.6).

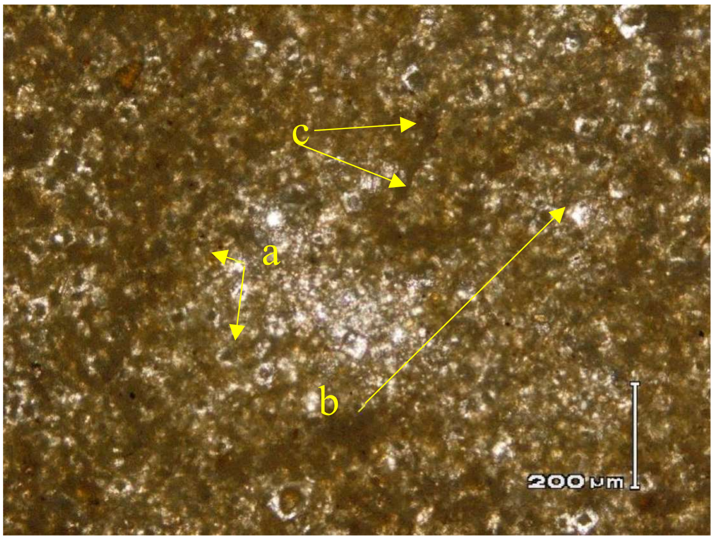


Fig. 2.6. Photomicrograph of marly dolostone, unit 2 (mudstone texture) of the Al Faidiyah Formation. Euhedral dolomite crystals (a), anhydrite cement (b), hematite cement (c). (XPL).

Unit (3):

Characterized by skeletal dolomitic limestone, yellow, hard, with debris of oysters and echinoids the total thickness of this unit is 5 m.

In thin section this unit is characterized by a wackestone texture, also by presence of echinoid, plecypods fragments (oysters), foraminifera (*Operculina complanata*, *Amphistegina* sp. with rare *Nummulites*), (Fig. 2.7).

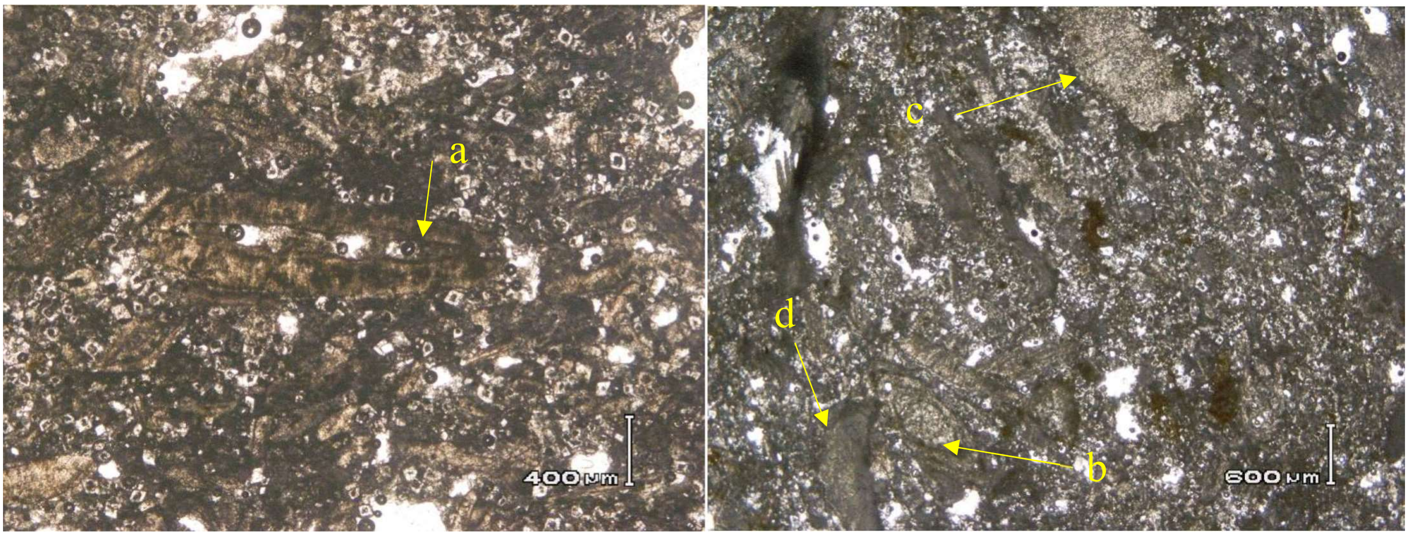


Fig. 2.7. Photomicrographs of skeletal dolomitic limestone, unit 3 (wackestone texture) of the Al Faidiyah Formation. *Operculina complanata* (a), *Amphistegina* sp. (b), echinoid fragment (c), oyster fragment (d), (XPL).

Unit (4):

This unit is made of skeletal dolostone, variable in color between greenish yellow and cream, alternation between medium hard to very hard due to iron oxide cementation, highly bioturbated and leached fossils, also characterized by paleocalcrate topography, the total thickness of this unit is 13 m.

In thin section this unit shows wackestone texture and largely compose of euhedral dolomite crystals, with micritic matrix and cemented by anhydrite and hematite, leached fossils (e.g. echinoids, *operculina*), also algal mat remnant (Figs. 2.8 and 2.9).

Fig. 2.8. Paleocalcrate topography and alternation between medium hard and very hard lithology of unit 4 within the Al Faidiyah Formation at Wadi Al Hash, looking N.

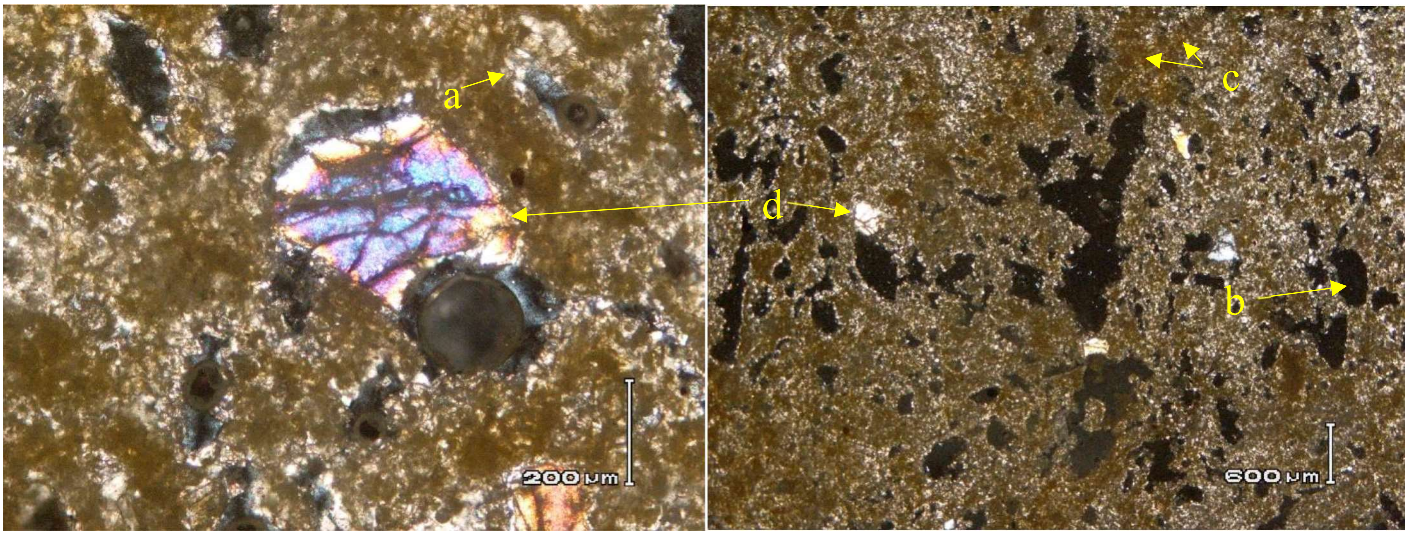


Fig. 2.9. Photomicrograph of skeletal dolostone, unit 4 (wackestone texture) of the Al Faidiyah Formation. Euhedral dolomite crystals (a), Algal mat remnant (b), Hematite cement (c), Anhydrite (d). (XPL).

Unit (5):

Peloidal dolostone, cream, soft, highly bioturbated the total thickness about 4 m.

In thin section this unit is characterized by wackestone to packstone texture with euhedral crystals of dolomite, also presence of common algal peloids, some serpulids worm tubes, (Fig. 2.10).

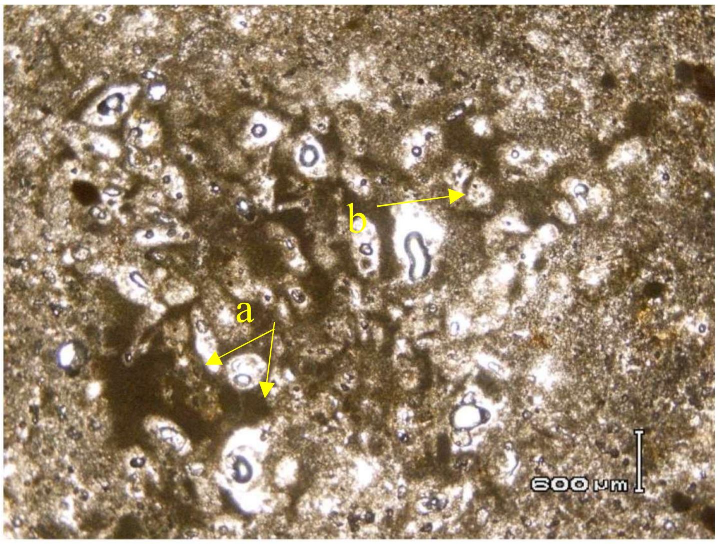


Fig. 2.10. Photomicrograph of Peloidal dolostone, unit 5 (wackestone to packstone texture) of the Al Faidiyah Formation. Algal peloids (a), micrite matrix (b). (XPL).

Unit (6):

Dolomitic limestone, cream, hard, highly bioturbated, with total thickness about 2 m.

In thin section this unit is characterized by wackestone texture, also by the presence of euhedral dolomite crystals and common algal mat, Porosity types are represented by intergranular and intragranular porosities which partly filed with dolomite crystals, (Fig. 2.11).

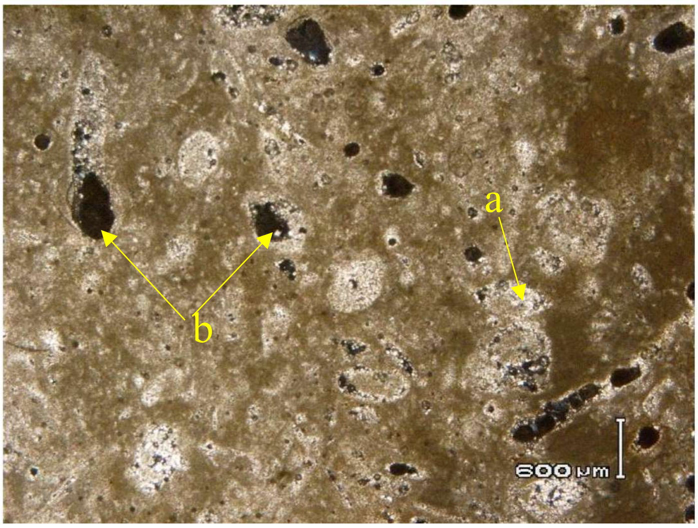


Fig. 2.11. Photomicrograph of Dolomitic limestone, unit 6 (wackestone texture) of the Al Faidiyah Formation. Euhedral dolomite crystals (a), pelloids, intragranular porosity (b), (XPL).

Unit (7):

This unit is made of miliolids – peloidal limestone with packstone to grainstone texture, light brown, hard, bioturbated, with total thickness about 3 m.

In thin section this unit is micritic in places and cemented by anhydrite and calcite cement is the dominant cementation mode as isopachous cement, characterized by packstone - grainstone texture, also by the presence of miliolids, highly porous and the porosity represented by intergranular and intergranular porosities (Fig. 2.12).

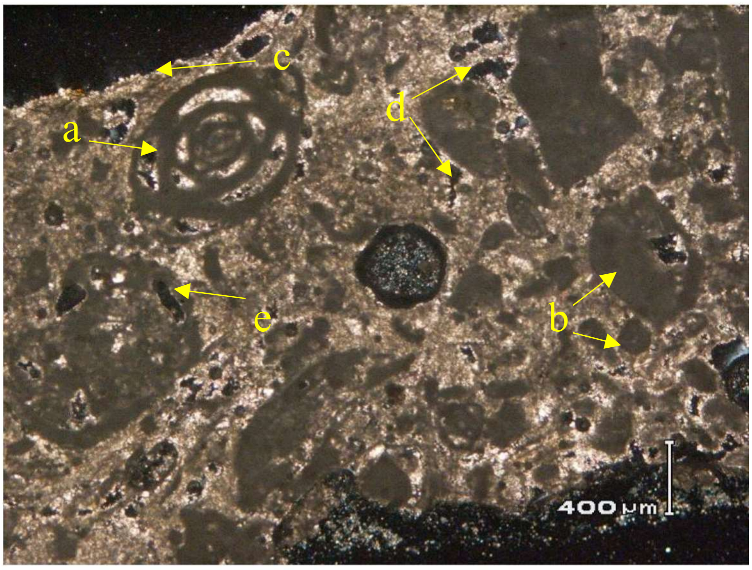


Figure 2.12. Photomicrograph of miliolids – peloidal limestone, unit 7 (packstone - grainstone texture) of the Al Faidiyah Formation. Exhibits tests of miliolids (a), algal pelloids (b), isopachous cement (c), intergranular porosity (d), intragranular porosity (e). (XPL).

Unit (8):

This unit is characterized by echinoidal limestone, brown, hard, with total thickness about 3 m. Fossil content is mainly *Scutella* sp. It is the youngest unit of the Al Faidiyah Formation and lies just below the disconformity surface with the Al Jaghboub Formation, (Fig. 2.13).

Fig. 2.13 Close up view of echinoidal limestone (unit 8) of Al Faidiyah Formation at Wadi Al Hash, note Dominance of Echinoclasts and *Scutella* sp.

2.2.3. Al Jaghboub Formation (Early-Middle Miocene):

Desio (1928) was the first to introduce this term to describe the fossiliferous interbedded sandy limestone, soft limestone, green shales and gypsum outcrops in Al Jaghbub Oasis. The formation in the study area is probably of early to middle Miocene age, as estimated by contained fossils such as *Echinolampus amplus* Fuches, *pecten cristato-costatus* Sacco, *Balanus* sp., *Amphistegina* cf. *radiata* Fichtel and Moll. The Al Jaghboub Formation outcrops in the investigated area (at Wadi Al Hash) compose of yellowish green shale at the base, and are rich in microvertebrate remains (fossil ichthyofauna) and echinoid fragments with small rose gypsum its lower part (Fig. 2.14), also characterized by presence of common concentration of phosphates, while fossiliferous limestone in upper section mostly contains *Balanus* sp. and coralline red algae, with a total thickness of 12 m.

The Al Jaghboub Formation in the study area is unconformably overlain the late Oligocene Al Faidiyah Formation, this unconformity is evidenced by the obvious break in the slope, the presence of reworked echinoid fragments, sudden change in lithology from hard echinoidal limestone into soft shales and clays and the presence of rare altered globigerinoides tests.

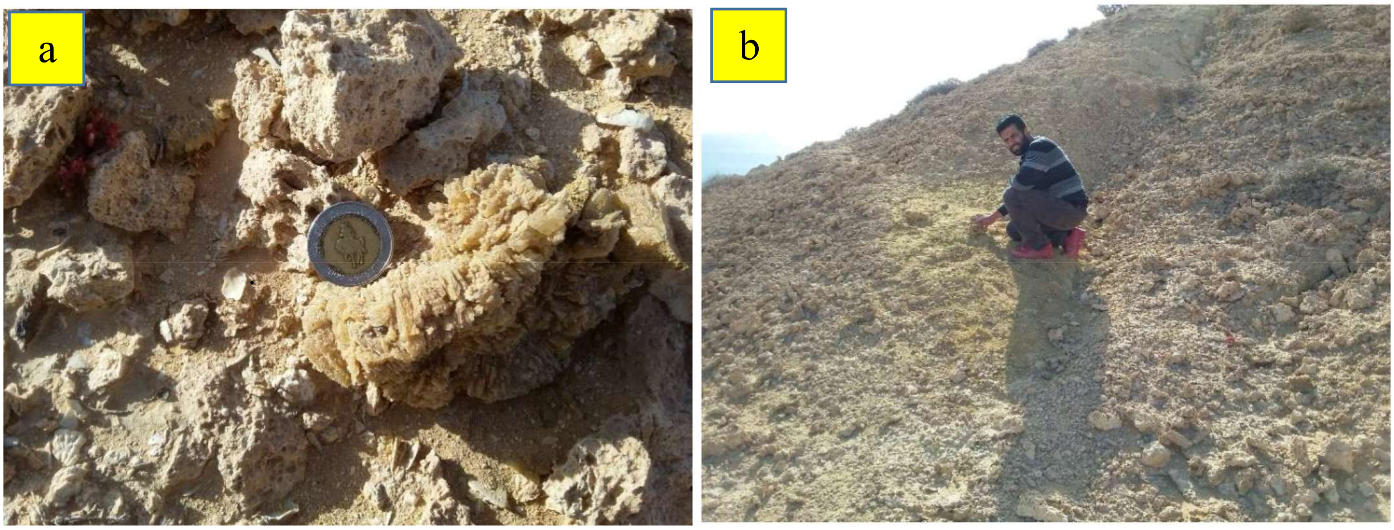
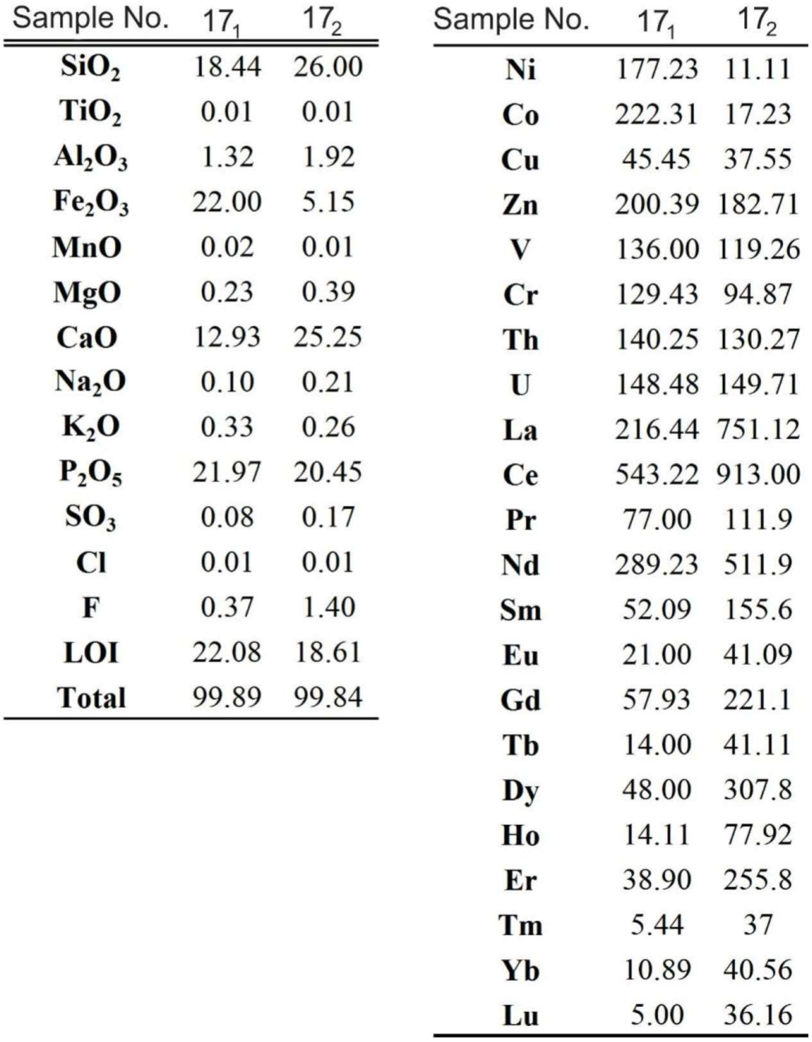


Fig. 2.14 Shows Al Jaghboub Formation at Wadi Al Hash. (a) Rose gypsum, (b) gypsiferous clays at the base of the Al Jaghboub Formation at the study area, looking NE.

2.3. Geochemistry

The analysis of major oxides and trace elements have been carried out using inductively coupled plasma-mass spectrometry (ICP-MS) technique (Table 2.1) in order to indicate the depositional parameters.

Table 2.1 Chemical analysis data (major oxides in wt%, trace elements in ppm) of the studied samples.



Sample No.	17_1	17_2
SiO_2	18.44	26.00
TiO_2	0.01	0.01
Al_2O_3	1.32	1.92
Fe_2O_3	22.00	5.15
MnO	0.02	0.01
MgO	0.23	0.39
CaO	12.93	25.25
Na_2O	0.10	0.21
K_2O	0.33	0.26
P_2O_5	21.97	20.45
SO_3	0.08	0.17
Cl	0.01	0.01
F	0.37	1.40
LOI	22.08	18.61
Total	99.89	99.84

Sample No.	17_1	17_2
Ni	177.23	11.11
Co	222.31	17.23
Cu	45.45	37.55
Zn	200.39	182.71
V	136.00	119.26
Cr	129.43	94.87
Th	140.25	130.27
U	148.48	149.71
La	216.44	751.12
Ce	543.22	913.00
Pr	77.00	111.9
Nd	289.23	511.9
Sm	52.09	155.6
Eu	21.00	41.09
Gd	57.93	221.1
Tb	14.00	41.11
Dy	48.00	307.8
Ho	14.11	77.92
Er	38.90	255.8
Tm	5.44	37
Yb	10.89	40.56
Lu	5.00	36.16

The rare earth elements (REE) are normalized to Post-Archean Australian Shale (PAAS, Taylor and McLennan, 1985, Fig. 2.15). In general, the studied samples are enriched in the HREE over the LREE. The concentration of REE is less in sample 17_1 (phosphate nodules) than in sample 17_2 (shale). The PAAS-normalized REE patterns indicate that the studied samples are mainly of marine origin. This interpretation is further supported by the $(La/Sm)_N$ vs. $(La/Yb)_N$ bivariate plot (Fig. 2.16).

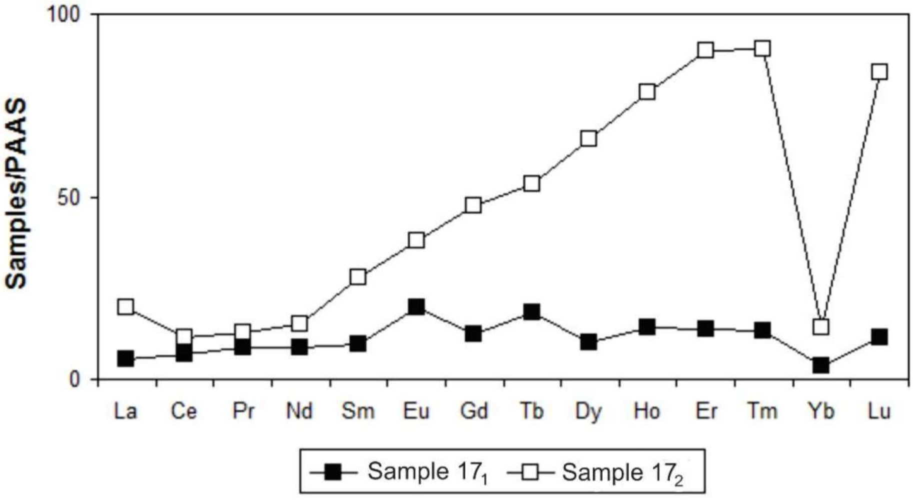


Fig. 2.15 PAAS normalized REE diagram for the studied samples

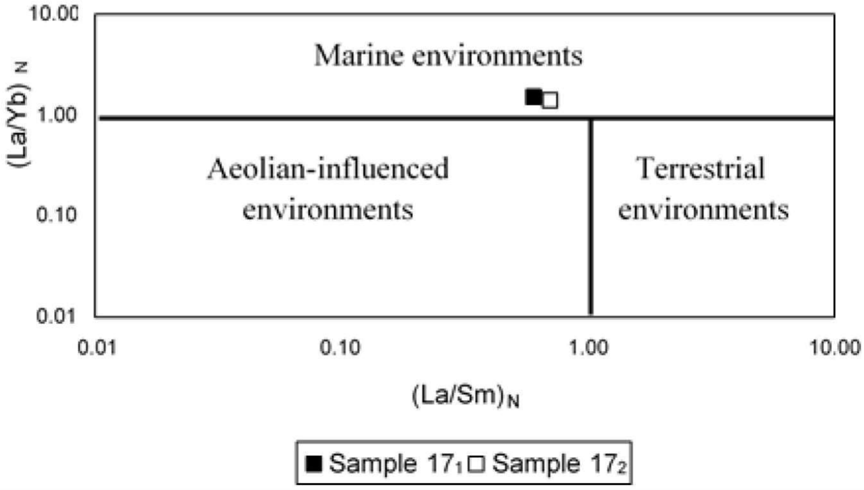


Fig. 2.16 Relationship between $(La/Sm)_N$ vs. $(La/Yb)_N$ in the studied samples (fields after Cook and Trueman, 2009)

Furthermore, the studied clayey bed of the Al Jaghboub Formation is considered to be an early Miocene in age (Burdigalian age) based on the $^{87}Sr/^{86}Sr$ ratio method applied on *Balanus* shell (the value of the isotope analysis is 0.708689) (fig. 2.17), which give an age of 17.25 Ma within the bed laying just above the bed of focus.

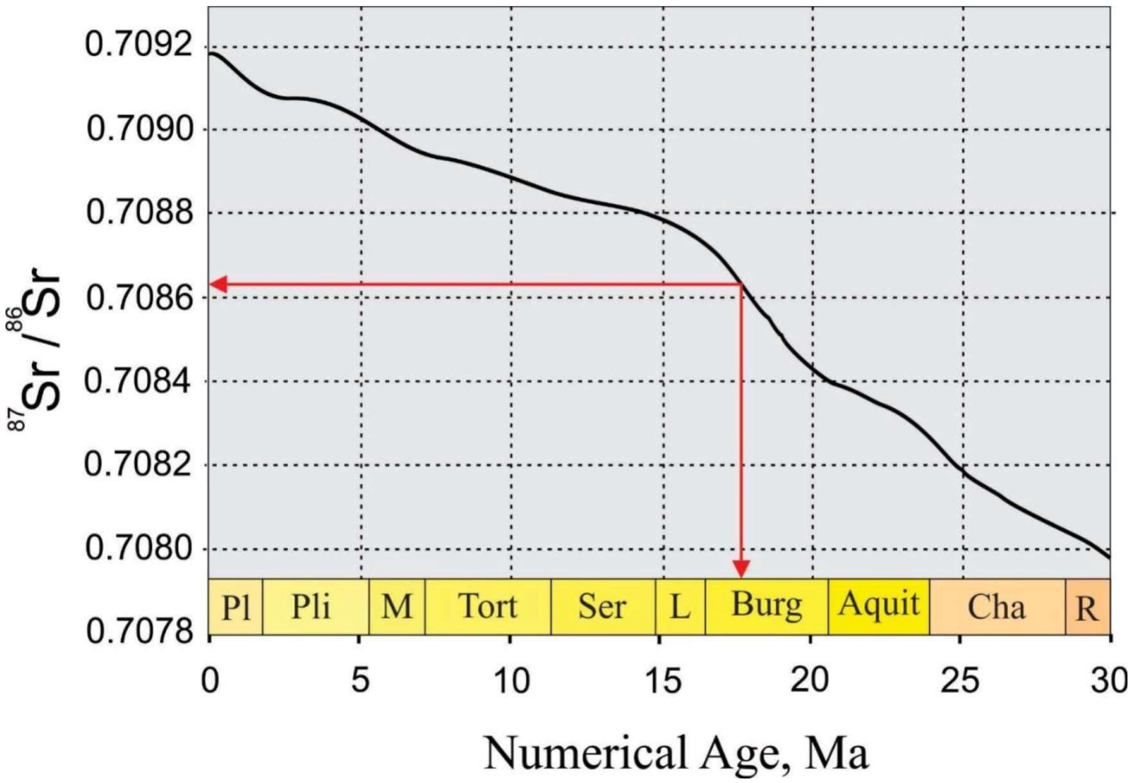


Fig. 2.17. Plot of inferred strontium isotope value during early Miocene time. The $^{87}Sr/^{86}Sr$ value of *Balanus* sp. (0.708689) corresponds to an age of 17.25 Ma. Note, the red line and star represents the age determinations, taking possible errors into account. Modified after, McArthur *et al*., (2001).

Chapter 3
Systematic paleontology

3.1. Sharks and Rays

Class Chondrichthyes are characterized by the absence of bony tissue in their skeleton. They are also characterized by having a chondrocranium braincase, placoid scales; jaws with teeth restricted to the jaw margins, which are constantly replaced; soft fin rays, biting edge of jaws formed by the palatoquadrate and Meckel's cartilage; absence of a swimming bladder; presence of a spiral or scroll valve in the intestine; internal fertilization; and generally long gestation periods (Nelson, 2006). Chondrichthyes (Figure 3.1) are subdivided into two subclasses, Elasmobranchii (plate + gills) including all modern and fossil sharks and rays; the second is Holocephali containing chimaeroids and rat fishes. Modern sharks and rays are primarily marine fishes but some also inhabit brackish and fresh waters, such as estuaries, rivers and lakes. They reach their greatest diversity in tropical and warm temperate waters and are found worldwide at all latitudes and at depths ranging from abyssal to intertidal (Welton and Farish, 1993).

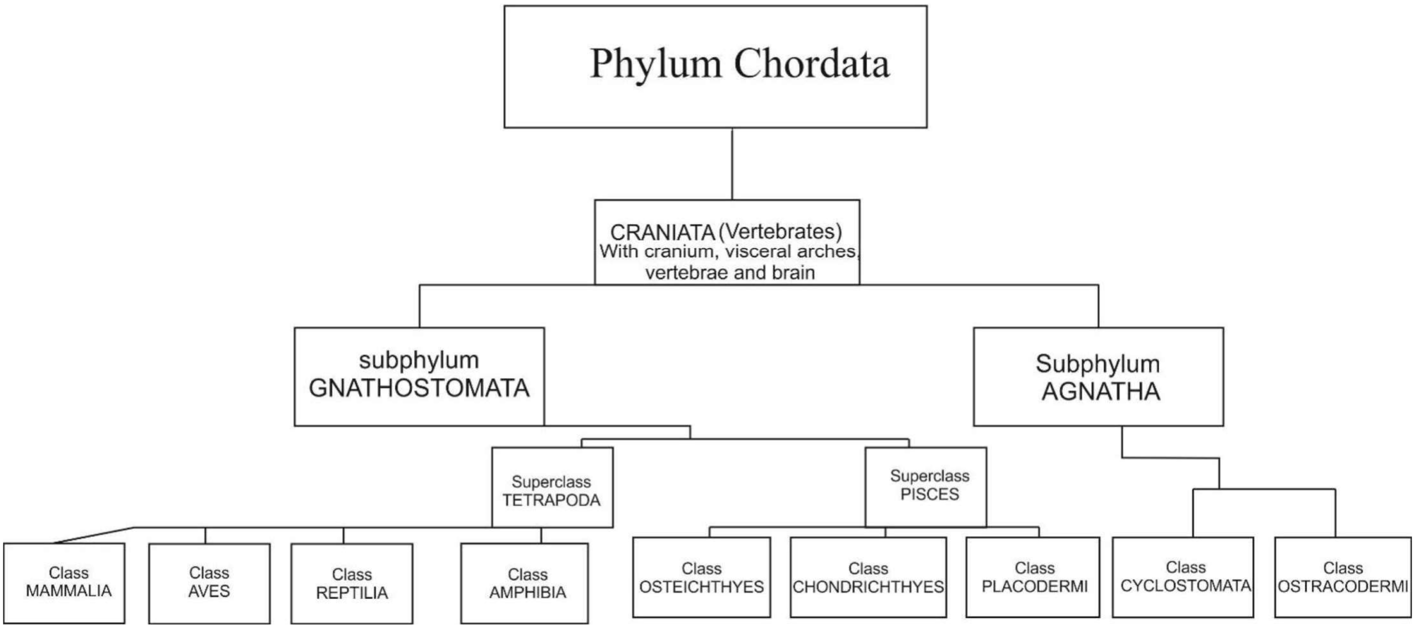


Fig. 3.1. Phylogenetic relationships of phylum chordata. Modified after Kardong, (2011).

Class Chondrichthyes from the bulk volume of the sample is forming about 33% (Fig. 3.2), where the shark teeth is comprising about 21% of the total Chondrichthyes sample and the ray teeth is forming the majority of Cartilaginous Fishes teeth by about 79%.

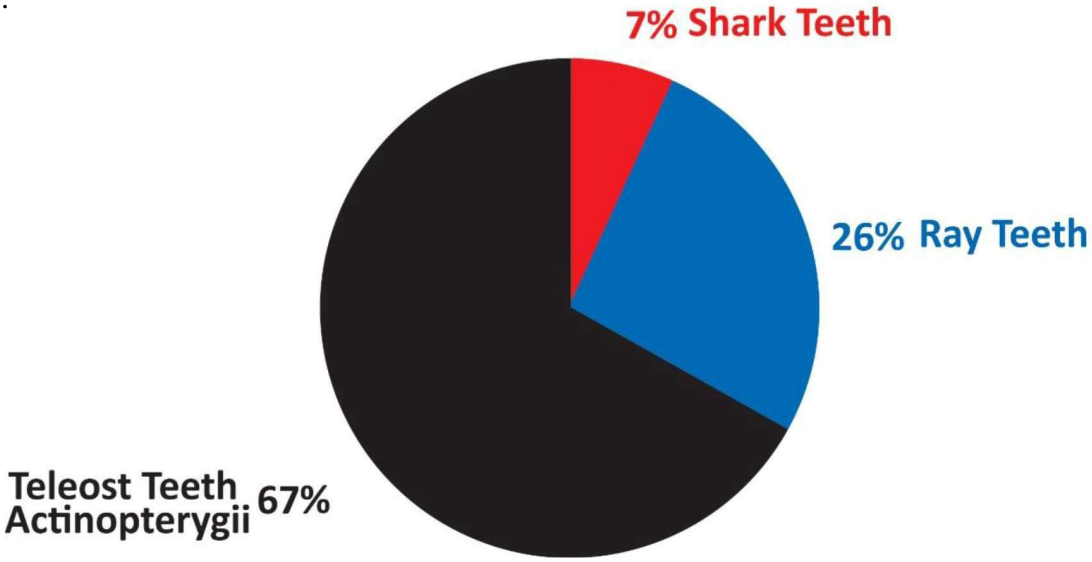


Fig. 3.2 Pie diagram shows relative Abundance of different classes of teeth elements in the studied sample.

Systematic Paleontology

Several hundred microscopic shark and ray teeth were collected from the lower Miocene clays at the basal part of the Al Jaghboub Formation, their taxonomic documentation is presented below. The systematics dental terminology of selachian taxa is based on the scheme of Cappetta (1987, 2012) (see appendices A and B). Over nine species of rays and nearly six species of sharks were recorded, most of them are documented for the first time from Libya.

Class Chondrichthyes Huxley 1880

Subclass Elasmobranchii Bonapart 1836

Subcohort Neoselachii Compango 1977

Superorder Galeomorphii Compagno 1973

Order Carcharhiniformes Compagno 1973

Family Scyliorhinidae Gill 1862

Subfamily Megascyliorhininae Pfeil 1984

Genus *Megascyliorhinus* Cappetta & Ward 1977

† *Megascyliorhinus* sp.

Fig. 3.3

Material: One anterior tooth WHJ 1.

Description: The tooth is small (up to 2.5 mm high and 2 mm wide), broad, compressed in profile, with an angulated and lingually and slightly distally bent cusp. The crown is devoid of cutting edges and has a practically circular cross-section. The labial face is slightly convex, showing no folds, it slightly overhangs the root. There is only one damaged distal lateral cusplet.

The root is high, rather thick, and wider than long, exhibiting a bulging lingual protuberance. The lobes bear a slightly convex basal face and are separated by a slightly deep furrow with main foramen opening lingually. There is a pair of rather large marginal-lingual foramina.

Remarks: This specimen designated to species of *Megascyliorhinus* according to the similarities in the cusp shape, lateral cusplet, the strong similarity in the root region with the location of central foramen and the large marginal-lingual foramina.

Stratigraphic and Geographical Distribution:

Megascyliorhinus is known from the Eocene (England, France, Egypt and Jordan), Oligocene (New Zealand), Oligo-Miocene (Argentina and Czech Republic), Miocene (Chile), Middle Miocene (Japan), Late Miocene (Portugal and France); Pliocene (France, Italy and Tunisia), Mio-Pliocene (New Zealand) (Cappetta, 2012; http://fossilworks.org, 10 March 2017, using the name *Megascyliorhinus sp.*).

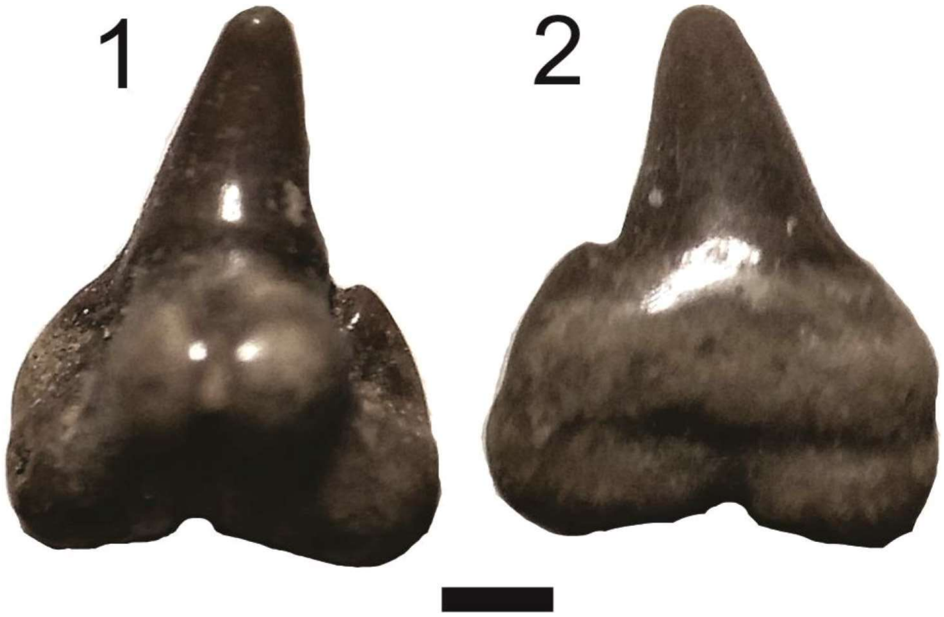


Fig. 3.3. †*Megascyliorhinus* sp. from the lower Miocene Al Jaghboub Formation, NE Libya. 1-2, anterior tooth; 1, lingual view; 2 labial view, (WHJ 1). Scale bar 500 µm.

Subfamily Scyliorhininae Gill 1862

Genus *Scyliorhinus* Blainville 1816

Scyliorhinus sp. morphotype 1

Fig. 3.4

Common name: Cat shark**.**

Material: Eighteen teeth WHJ 2.

Description: Teeth of small size (up to 1.5 mm high and 1 mm wide), show more or less sharp cusp, which is broad at its base. There is a pair of lateral cusplets. Teeth are bend distally (Fig. 3.4). The labial face of the crown clearly overhangs the root by a more or less cut out bulge and bears strong folds restricted to the base and parallel to the main cusp. The cutting edge is not so clear at the cusp, due to preservation conditions. The root is bulky with a well-marked lingual protuberance and flat basal face. The marginal-lingual foramina, generally a pair, are well developed.

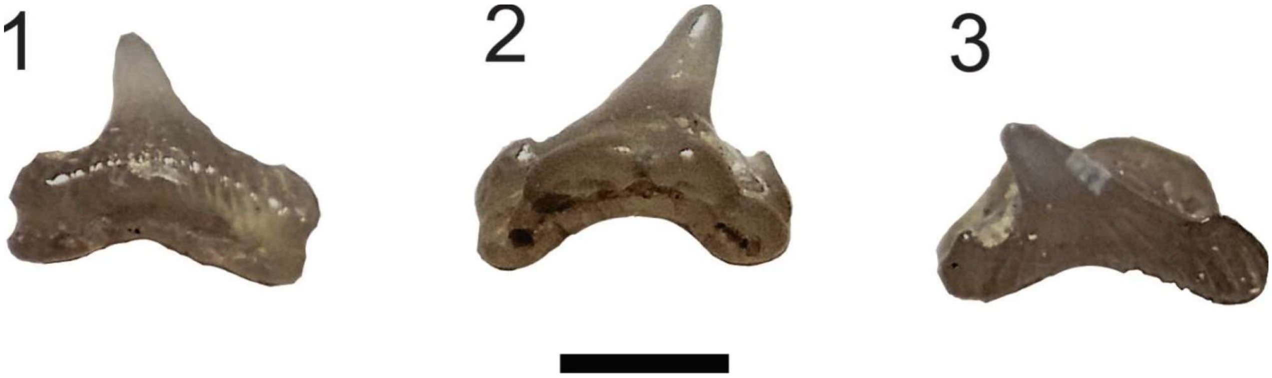


Fig.3.4. *Scyliorhinus* sp. morphotype 1 from the lower Miocene Al Jaghboub Formation, NE Libya. 1-3, antero-lateral tooth, 1, labial view; 2, basal-lingual view, 3, occlusal view, (WHJ 2). Scale bar = 500 µm

Scyliorhinus sp. morphotype 2

Figure 3.5

Material: One tooth WHJ 20.

Description: The teeth are stout, triangular, very small (0.8 mm high and 1 mm wide), sharp main cusp with a pair of cusplets well separated from the base of the cusp. The enamel of labial face free of folds. The cutting edges are well developed and runs along the crown and cusplets. The root is not very thick with a well-marked lingual protuberance, without median furrow. The basal face is flat and somehow concave with a kidney-shaped outline.

Remarks: The labial smooth and flat face character is similar to that of *Scyliorhinus joleaudi* from the Langhian deposits of Hérault (Cappetta, 1970) and from Portugal (Antunes *et al*., 1999), which expressed as intraspecific variation in tooth morphology. Determination of this specimen as *Scyliorhinus joleaudi* is questionable so far until more precise work using more specimens in future.

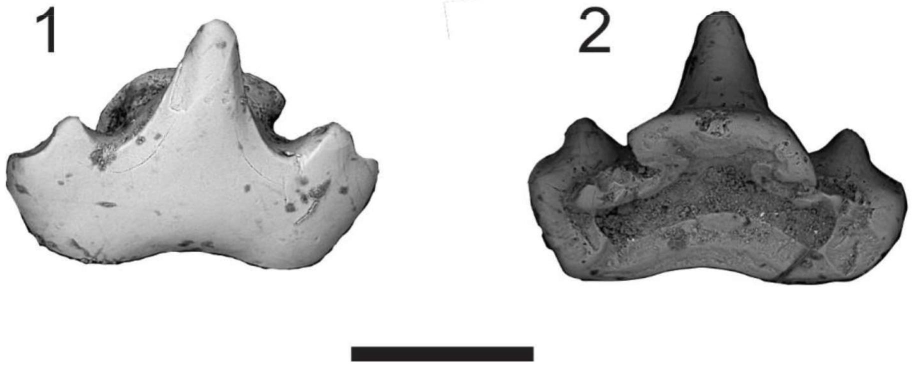


Fig. 3.5. SEM image of *Scyliorhinus* sp. morphotype 2, from the lower Miocene Al Jaghboub Formation, NE Libya, 1, occlusal view; 2, basal view, (WHJ 20). Scale bar = 500 µm.

Scyliorhinus sp. morphotype 3

Figure 3.6

Material: One tooth WHJ 21.

Description: Robust teeth, very small (600 µm high and 800 µm wide), a triangular in shape. The massive circular main cusp is not very high and flanked by two pairs of rather broad lateral cusplets. The enamel of labial face bears numerous strong folds. The cutting edges are well developed and runs along the crown and cusplets. The root is medium thick with a well-marked lingual protuberance and median furrow. The basal face is flat with a kidney-shaped outline.

Remarks: More detailed investigation is needed to determine its precise taxonomy; however *Scyliorhinus* sp. morphotype 3 maybe belong to the abovementioned species or maybe belong to another species, this cannot be decided until further detailed study take place in the future.

Distribution and habitat: Cat sharks are mainly nektonic marine carnivore, live near the bottom, ranging from shallow intertidal zones to depths of more than 2000 m and this deep-water habitat makes many catsharks difficult to observe and collect. They most frequently live in temperate to tropical; continental and insular shelves and slopes; circum-global, Atlantic, Indian, and Pacific (http://www.fishbase.org, 18 march 2017, using the name *Scyliorhinus*).Some catsharks are adapted to live in wide range of benthic environments, evolving larger branchial (gill) regions, which allow them to survive very low oxygen levels, higher temperatures and higher salinity (Compagno, 1988).

Fig.3.6. SEM image of *Scyliorhinus* sp. morphotype 3, from the lower Miocene Al Jaghboub Formation, NE Libya, occlusal view, (WHJ 21) .Scale bar = 500 µm.

Family Triakidae Gray 1851

Subfamily Galeorhininae Gill 1862

Tribe Galeorhinini Gill 1862

Genus Galeorhinus Blainville 1816

cf. *Galeorhinus* sp.

Figure 3.7

Common name: School shark.

Material: Eleven teeth WHJ 25.

Description: They are small teeth (1 mm high and 1.7 mm wide) and partly damaged. They are mainly represented by isolated crowns. The main cusp is high, bending backward. The mesial cutting edge is not serrated and slightly convex. The distal heel is high and well developed and bears two to three strong cusplets decreasing in size toward the distal edge. The first lateral cusplet is well separated from the main cusp. The labial face of the crown slightly overhangs the root. The root is generally thin with slightly convex basal face without distinct furrow.

Remarks: Because most of the recovered teeth are very fragmentary, the recognition of the species is relatively difficult. There is always a mix up when it comes into the nomenclature stage for species or even the genus, for example, *Galeorhinus affinis* and *Galeorhinus latus*, were reported by Cappetta (1970) in the Miocene of Hérault. Currently the former species is assigned to *Chaenogaleus affinis* and the later to *Physogaleus latus* (see Cappetta, 2006).

Stratigraphic and Geographical Distribution:

Upper Cretaceous (Russia, Poland, Morocco, Sweden, Belgium and U.S.A), Paleocene (Morocco and U.S.A), Eocene (France and Morocco), Oligocene (Japan, Netherlands and U.S.A), Miocene (France and Portugal), upper Miocene/lower Pliocene (Costa Rica), Pliocene (U.S.A, Belgium and Italy) (Cappetta, 2012; http://fossilworks.org, 11 March 2017, using the name *Galeorhinus* sp.).

Distribution and habitat: The school shark is a nektonic carnivore which is found mainly near the seabed around coasts in temperate waters (up to 21 °C), down to depths around 1057 m. It has a widespread distribution in the Northeast Atlantic and Mediterranean Sea, also found around the coast of South and West of Africa. It is present in the Northeast Pacific where it occurs off the coast of Eastern Canada and U.S.A., and in the Southeast Pacific off South America. Also it can be found around the Australian south coast, including Tasmania, and New Zealand (http://www.fishbase.org 10 March 2017, using the name *Galeorhinus*).

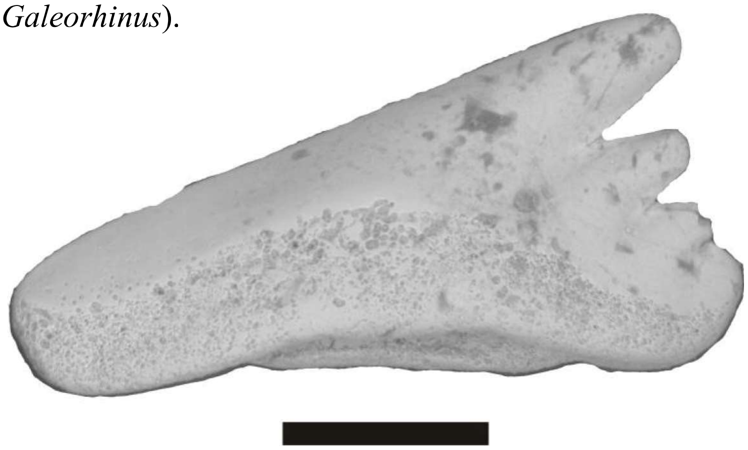


Fig. 3.7. SEM image of cf. *Galeorhinus* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, antero-lateral tooth, lingual view, WHJ 25. Scale bar = 1 mm.

Family Hemigaleidae Hasse 1879

Genus *Paragaleus* Budker 1935

† *Paragaleus pulchellus* Jonet 1966.

Fig. 3.8

Common name: Sharpnose weasel shark.

Synonymy:

-*Carcharias* (*Scoliodon*) sp., Leriche (1926, page 432, fig. 196).

-Eugaleus aff. *Minutissimus* Onset, Zbyszewski & Moitinho d'Alemeida (1950, pl. VII, fig. 126-132).

- *Galeorhinus pulchellus* Jonet (1966, pl. IV, fig. 11-16, non fig. 17-25).

- *Galeus* Cappetta *et al*., (1967, page 292, Name only).

- *Paragaleus pulchellus* (Jonet, 1966), Cappetta (1969, pl. X, fig. 6-18).

Material: One lower lateral tooth WHJ 33.

Description: *Paragaleus pulchellus* is represented by one lower lateral tooth, (height up to 5 mm high and 4.5 mm in width), their cusp is more erect, bent little lingual and more distally with a concave mesial cutting edge. The mesial heel is most evident. The distal heel is shorter than the mesial one and bears five cusplets that decrease in size backward; the distal cutting edge of the cusp often has a convex outline. The labial face of the crown is flat and overhangs the root by a labial bulge. The root is low with a flat basal face bearing a distinct furrow and the lingual protuberance is evident.

Remarks: The recovered lower tooth of *Paragaleus* in this study is very important differentiating the genus *Paragaleus* from genus *Chaenogaleus* because of its morphological characters. The first can be distinguished from the later by the following characters: 1- cusp is more erect and bent distally and lingually, 2- The distal heel is shorter than the mesial one and bears several cusplets, 3- the distal cutting edge of the cusp often has a convex outline (Cappetta, 2012).

Stratigraphic and Geographical Distribution:

Upper Miocene of Portugal by the presence of large number of *Paragaleus*-like teeth *(Paragaleus antunesi*) from the Esbarrondadoiro Formation, (Balbino and Cappetta, 2000)

Distribution and habitat: Marine, commonly found inshore to offshore of the continental shelves; eastern tropical Atlantic (and possibly New England) and Indo-West Pacific (Nelson, 2006). The Atlantic weasel shark ranges from depths of a few meters down to more than 160 m, while the temperature ranges from 10 – 25 °C (http://www.fishbase.org, 9 March 2017, using the name Sharpnose weasel shark, *Paragaleus*).

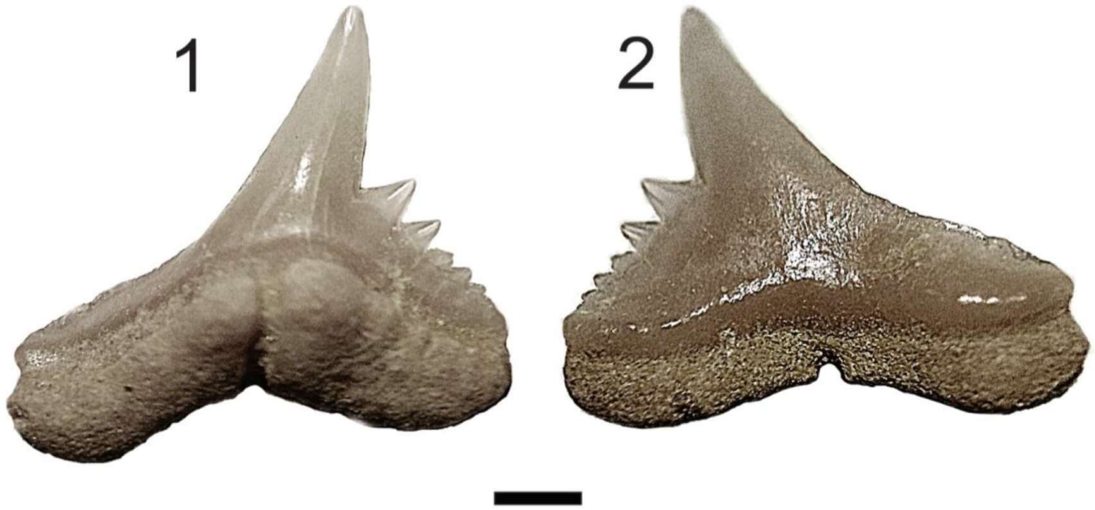


Fig. 3.8. † *Paragaleus pulchellus* from the lower Miocene Al Jaghboub Formation, NE Libya, 1-2, lower lateral tooth, 1, lingual view; 2, labial view, (WHJ 33). Scale bar = 1 mm

Family Carcharhinidae Jordan & Evermann 1896

Subfamily Carcharhininae Jordan & Evermann 1896

Tribe Rhizoprionodontini Compagno 1988

Genus *Rhizoprionodon* Whitley 1929

† *Rhizoprionodon fischeuri* Joleaud 1912

Fig. 3.9

Common name: Sharpnose shark

Synonymy:

-*Carcharias* (*Physodon*) *ficheuri* Joleaud (1912, pl. VI, fig. 4-11, non fig. 1-3).

-*Physodon miocanenicus* Jonet (1966, pl. III, fig. 3, 4, 7, 8, non fig. 5, 6 and 9-12).

-*Scoliodon dentatus* Jonet (1966, pl. IV, fig. 3-10, non fig. 1-2).

-*Scoliodon taxandriae* (Leriche, 1926), Jonet (1966, pl. III, fig. 16-17, non fig.14-15 and 18-22).

Material: Forty two teeth.

Description: The teeth are small (3 mm high and 3.5 mm wide). The cusp is strongly bent backward; the base of the crown is really extended especially on the mesial edge with a high, rounded and smooth distal heel; the labial face of the crown slightly overhangs the root. The root is low and the basal edge is rectilinear, very stocky, with a very strong lingual protuberance bearing a deep furrow; the antero-lateral and lateral teeth have a rather narrow and erect cusp with a distinctly concave mesial cutting edge.

Remarks: This species is relatively abundant in the middle and the late Miocene of southern France (Cappetta, 1970; Vaucluse, Joleaud, 1912; Brisswalter, 2009 and Mazan, Vaucluse, Vialle *et al*., 2011). The examined teeth show similar morphological characters of *Rhizoprionodon ficheuri* of Langhian, middle Miocene, Loupian, Hérault, southern France (Cappeta, 1970, 2012).

Stratigraphic and Geographical Distribution:

Middle Miocene of the Avignon region, middle and upper Miocene (South France, Portugal), Miocene (Belgium) (Cappetta, 2012; http://fossilworks.org, 11 March 2017, using the name *Rhizoprionodon fischeuri*).

Distribution and Habitat: The requiem shark *Rhizoprionodon*, commonly known as Sharpnose sharks because of their long, pointed snouts, preferably found in the subtropical waters of the Indo-Pacific Ocean and Atlantic Ocean, it found in water with depth ranges from the surface level up to 740 m and water temperature up to 29 °C. The diet of the Sharpnose shark consists of crustaceans, fishes, and cephalopods. (http://www.fishbase.org, 11 March 2017, using the name Sharpnose shark, *Rhizoprionodon*).

Fig. 3.9. SEM images of † *Rhizoprionodon fischeuri* from the lower Miocene Al Jaghboub Formation, NE Libya, 1, lower antero-lateral tooth, male; lingual view, (WHJ 37); 2, lateral tooth, lingual view, (WHJ 39); F, lower lateral tooth, lingual view, (WHJ 41). Scale bar = 1 mm.

Tribe Carcharhinini Jordan & Evermann 1896

Genus *Negaprion* Whitley 1940

†*Negaprion eurybathrodon* Blake, 1862

Fig. 3.10

Common name: Lemon shark

Synonymy:

-*Negaprion kraussi* (Probst, 1878): Cappetta (1970, p. 52, pl. 15, figs 1-10, 12, 14-17)

-*Hypoprion acanthodon* (Le Hon, 1871): Menesini (1974, p. 148, pl. 4, figs 15-22)

-*Carcharhinus egertoni* (Agassiz, 1843): Menesini, (1974, p. 144, pl. 7, figs 7-10, 15).

- *Sphyrna prisca* (Agassiz, 1843): Menesini (1974, p. 152, pl. 7, figs 17-19).

Material: Two upper teeth WHJ 76; WHJ 77 and one lower tooth WHJ 78.

Description: The species is represented by two upper teeth and one lower teeth. The upper tooth is relatively large (12.5 mm high and 15 mm wide) have a rather high, triangular cusp, which is slightly bent toward the rear and characterized by the presence of two well-marked coarsely serrated lateral heels; the cutting edges of the cusp are well-developed and never serrated; the labial face of the crown is flat and slightly overhangs the root by a basal bulge. It has small vertical folds along the bulge; the lingual face is slightly convex. The branches of the root are extended; the basal face is rather broad and flat with a distinct furrow.

The lower tooth is smaller in size (5.5 mm high and 6.25 mm wide), characterized by fairly tall, acute cusp, and slightly bent lingually with smooth heels. The cutting edges of the heels are separated from the cusp by a shallow notches. The labial face of the crown is flat, very weakly overhangs the root. The lingual face of the crown is slightly convex. The root is straight, where the lobes are well developed and asymmetric; the nutritive groove or the axial furrow is shallow and narrow in lingual.

Remarks: It must be noted that the recovered *Negaprion* in this study maybe considered to be the third record of this genus in the Libyan Neogene after the first record by Argyriou *et al.*, (2015). *Negaprion* aff. *N. brevirostris* teeth also have been recorded in the Early Pliocene of Sabratah Basin, Libya (Pawellek *et al.*, 2012). The recent *Negaprion* live today is represented by two species, *Negaprion brevirostris* of Atlantic and *Negaprion acutidens* of Indian and Pacific Ocean (Compagno, 1984 and Argyriou *et al.*, 2015). *Negaprion* can be easily confused with the genus *Carcharhinus*, but there are several characters to distinguish the first from the second as follows: 1- The cutting edges are never serrated, while the cutting edges of *Carcharhinus* are always serrated in Neogene and Recent forms (Cappetta, 2012), 2- the mesial and distal heels bears very coarse serrations. Consist of number of denticles of decreasing size moving away from the main cusp (Cappetta, 1970 and Marsili *et al.*, 2007).

Stratigraphic and Geographical Distribution:

Eocene (Pakistan and USA, Georgia), lower Miocene (Italy, Malta, Saudi Arabia and Venezuela), middle Miocene (Costa Rica), upper Miocene (Portugal and Malta). Pliocene (Ecuador) (http://fossilworks.org, 12 March 2017, using the name *Negaprion eurybathrodon*).

Distribution and Habitat

The lemon sharks *Negaprion*, are often found in shallow subtropical waters of coral reefs, mangroves, enclosed bays, and river mouths, also been found in the open ocean down to depths of 92 m and water temperature up to 28 °C, and are known to inhabit and return to specific nursery sites for breeding. Often feeding at night, like all chondrichthyans these sharks use electroreceptors to find their main source of prey. Lemon sharks are found across the East coast of North and South America in the tropical western Atlantic Ocean. They also live off the coast of West Africa in the southeastern Atlantic. In addition, they have been found in the eastern Pacific (http://www.fishbase.org, 11 March 2017, using the name Lemon Shark, *Negaprion brevirostris*).

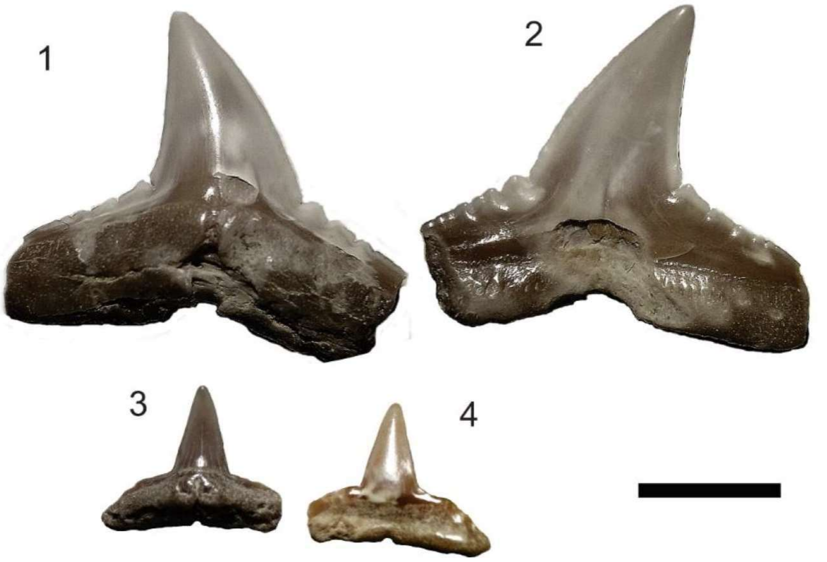


Fig. 3.10. 1-4, † *Negaprion eurybathrodon* from the lower Miocene Al Jaghboub Formation, NE Libya, 1-2, upper tooth, 1, lingual view; 2, labial view, (WHJ 76); 3-4, lower tooth, 3, lingual View; 4, labial view, (WHJ 78). Scale bar = 5 mm.

Superorder Batomorphii Cappetta 1980

Order Rajiformes Berg 1940

Suborder Rhinobatoidei Fowler 1941

Family Rhynchobatidae Garman 1913

Genus *Rhynchobatus* Müller & Henle 1837

† *Rhynchobatus pristinus* Probst 1877

Fig. 3.11

Common name: Wedgefish

Synonymy:

- *Rajidé* Delfortrie (1872, pl. IX, fig. 6-13).
- *Cestracionte* Delfortrie (1872, pl. IX, fig. 10).
- *Pristis pristinus* Probst (1877, pl. I, fig.17-18).
- *Pristis angustior* Probst (1877, pl. I, fig.19-20).
- *Rhynchobatus pristinus* (Probst, 1877), Joleaud (1912, pl. VIII, fig. 25-30).
- *Rhynchobatus pristinus* (Probst, 1877), Cappetta *et al*. (1967, page 292, name only).

- *Rhynchobatus* sp*.,* Jonet (1968, pl. I, fig. 14).
- *Rhynchobatus pristinus* (Probst, 1877), Cappetta (1969, pl. XII, fig. 1-12).

Material: Two lateral teeth WHJ 79 and WHJ 80.

Description: *Rhynchobatus pristinus* here is represented by one massive lateral tooth (2.3 mm high and 2.7 mm wide). The oral face of the crown may be differentiated into three different areas, the labial area is more or less convex, the occlusal area has a triangular shape and is separated from the labial one by slightly convex-transverse keel. These two areas are characterized by ornamented surfaces. However, the lingual face of the crown is smooth and can be easily seen a well-developed enameled protuberance forming a long central uvula. On the lingual face of the root, the root appears to be massive with two lobes well separated by a deep furrow with a big margino-lingual foramina and on each side of the uvula.

Remarks: The only described tooth of genus *Rhynchobatus* in this study was confidently assigned to *Rhynchobatus pristinus,* as compared to species from Neogene sediments (Cappetta, 1970 pl. 23, fig.17-23; Vialle *et al*., 2011, fig. 4. 2).

Stratigraphic and Geographical Distribution:

Oligocene (Oman, Summerville of USA and Pakistan), lower Miocene (southern Germany), Miocene (southern France, USA and Malta), middle Miocene (Austria, Czech Republic), upper Miocene (Costa Rica and Portugal) (Cappetta, 2012; http://fossilworks.org, 12 March 2017, using the name *Rhynchobatus pristinus*).

Distribution and Habitat

Rhynchobatus is a genus of rays and the sole genus in the family Rhynchobatidae. They are mainly reef-associated found in wide range of water salinity from marine to brackish, they exist in tropical and subtropical Indo-Pacific Ocean with a single species (*Rhynchobatus luebberti*) in the eastern Atlantic; the depth range for the genus is 8 - 157 m, while the preferred temperature is 28°C (http://www.fishbase.org, 12 March 2017, using the name *Rhynchobatus*).

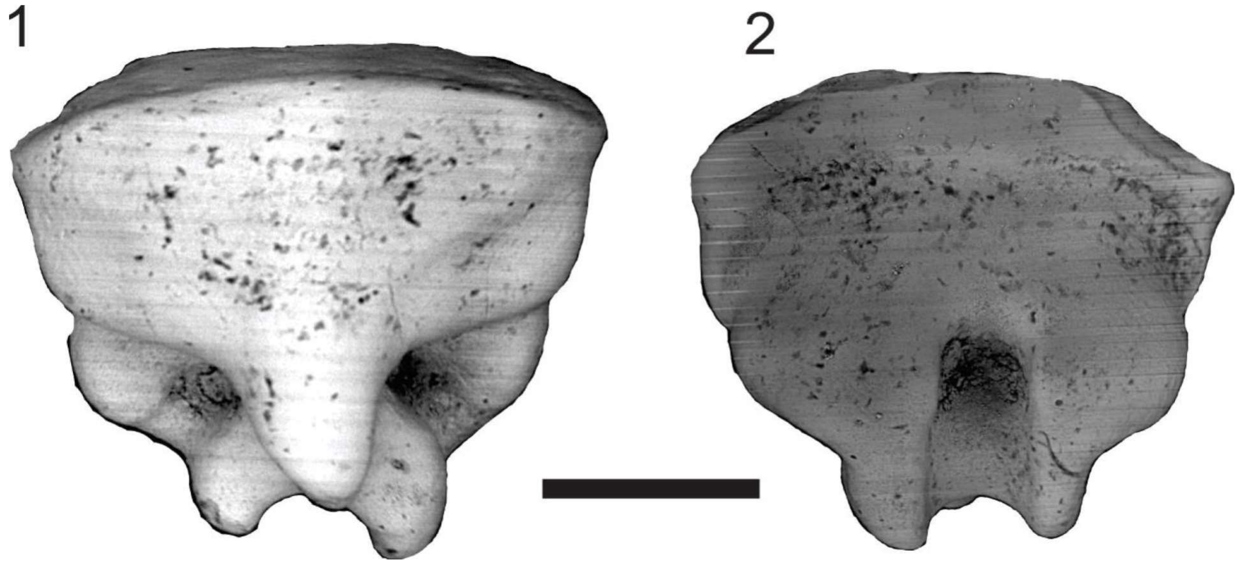


Fig. 3.11. SEM images of † *Rhynchobatus pristinus* from the lower Miocene Al Jaghboub Formation, NE Libya, 1-2, lateral tooth, 1, occlusal view; 2, basal view, (WHJ 80). Scale bar = 1 mm.

Family Rhinobatidae Muller & Henle 1838

Genus *Rhinobatos* Linck 1790

Rhinobatos sp.

Fig. 3.12

Common name: Guitarfish

Material: Ten teeth WHJ 84.

Description: Teeth (0.9 mm high and 0.75 mm wide). It has massive and high crown that is mesio-distally wide; the contour of the labial visor is convex in occlusal view. The lower part of the visor is convex in profile. Three parts can be distinguished on the crown in occlusal view; a labial part slightly developed and confined lingually by a distinct transverse keel; the median part with more or less triangular outline and the margino-lingual limits of the median part are strongly curved crests. The basal contour of the crown shows a prominent median uvula with a rounded tip. The lingual face of the crown is slightly concave in profile. The marginal uvulae are hardly marked with a pair of foramina in the margino-lingual faces. In basal view, a triangular massive root is well-developed, placed lingually narrower than the crown, with a deep nutritive groove that contains a central basal foramen.

Stratigraphic and Geographical Distribution:

Lower Cretaceous (Spain, France: Italy and U.S.A., Texas), upper Cretaceous (Lebanon, U.S.A., South Dakota & Texas, Morocco, Kazakhstan and Germany), Paleocene (Morocco and France), lower Eocene (Morocco, France, Belgium, Egypt and U.S.A., Texas), upper Eocene (Jordan); lower Miocene (India), middle Miocene (France), upper Miocene (Portugal), Pliocene (France) (Cappetta, 2012; http://fossilworks.org, 12 March 2017, using the name *Rhinobatos* sp.).

Distribution and Habitat

The common guitarfish (*Rhinobatos rhinobatos* Linnaeus, 1758) is found within subtropical climate in the western North Atlantic Ocean. Its range extends from the southern end of the Bay of Biscay to Angola, including the Mediterranean Sea. Inhabits sandy and muddy bottoms, from the intertidal zone to about 100 m. Sometimes near rocky reefs, it swims around just above the seabed, sometimes resting on the sand or mud and partially buried within sediments. Feeds on benthic invertebrates and fishes (Michael, 1993, http://www.fishbase.org, 14 March 2017, using the name *Rhinobatos rhinobatos*).

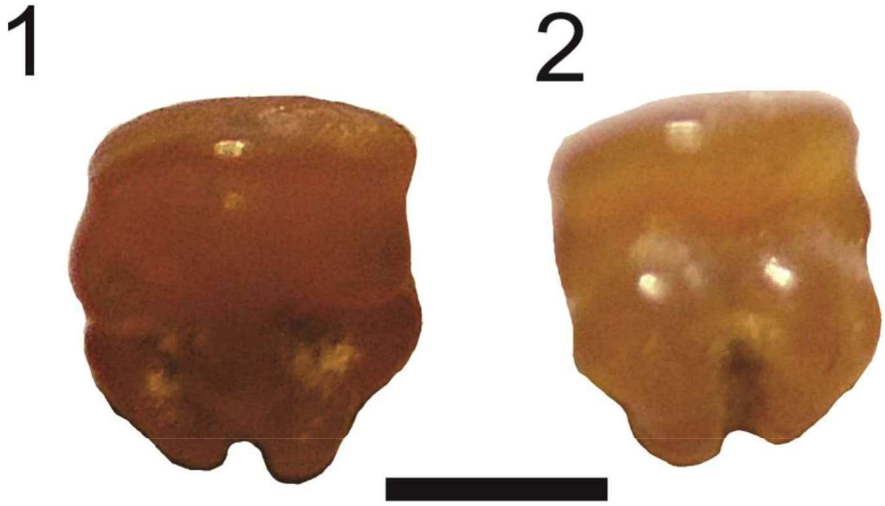


Fig. 3.12. *Rhinobatos* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, 1-2, lateral tooth, 1, occlusal view; 2, basal view, (WHJ 84). Scale bar = 500 µm.

Order Myliobatiformes Compagno 1973

Superfamily Dasyatoidea Whitley 1940

Family Dasyatidae Jordan 1888

Genus *Dasyatis* Rafinesque 1810

† *Dasyatis* aff. *rugose* Probst, 1877

Fig. 3.13 A & B

Common name: Whiptail Stingray

Synonymy:

- *Raja rugose* Probst (1877, pl. I, fig. 5, 8, 9 non fig. 6, 7).
- *Raja Strangulata* Probst (1877, pl. I, fig. 10-13).
- *Trygon jaekeli* Leriche (1954, pl. II, fig. 85-86).

Material: Two hundred and twenty nine teeth.

Description: The teeth have more or less globular form (1 mm high and 1.1 mm wide). In occlusal view, the labial face of the crown is strongly ornamented by coarse shallow pits. The marginal angles are distinct. The crown bears a high and nearly wide transverse crest. Although the lingual visor is convex in outline, the labial visor is convex and wide in outline. The lower part of the labial visor is angular in outline. The lingual face of the crown is depressed with smooth surface; median lingual ridge is weakly developed or sometimes not found. The root is bilobed, massive and short. The basal surface is wide and convex. The lobes are separated by deep nutritive groove with a central foramen.

In male teeth, the crown is high (1 mm high and 1.25 mm wide), with the transverse crest crown develops into a long and pointed cusp. The cusp bears a slight longitudinal depression or concave labial face that is strongly ornamented by closely spaced deeper pits. The labial visor of the crown is well developed and semi-circular in outline. On the other hand, the root is similar to that of the female teeth.

Remarks: The most obvious character of this genus is the sexual or gynandric heterodonty, females have teeth with a rounded crown (Fig. 3.13-1), whereas the teeth of males arc more or less strongly cuspidate (Fig. 3.13-2 and 3). The described fossil teeth of *Dasyatis rugose* are quite similar to those described by Cappetta, 1970 (pl. 21, fig. 2, 4 for female and 12 for male).

Stratigraphic and Geographical Distribution:

Upper Oligocene (U.S.A., South Carolina), Miocene (Austria and Germany) (Cappetta 2012; http://fossilworks.org, 14 March 2017, using the name *Dasyatis rugose*).

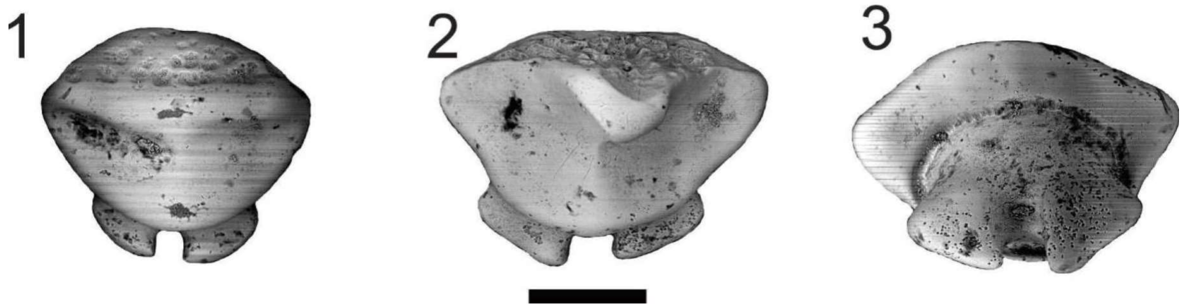


Fig. 3.13. 1-3 SEM images of †*Dasyatis* aff. *rugose* from the lower Miocene Al Jaghboub Formation, NE Libya, 1, lateral tooth, female; occlusal view, (WHJ 124); 2, male teeth, 2, occlusal view; 3, basal view, (WHJ 175). Scale bar = 500 μm.

†*Dasyatis* cf. *gigas* Günther, 1870

Fig. 3.14

Material: Five teeth WHJ 322.

Description: Teeth are rather large (1.5 mm high and 1.75 mm wide). In occlusal view, the crown has an ornamented labial surface. The marginal angles are very clear. There is a broad well-marked transverse crest separating the labial face from the lingual face of the crown. The labial face of the crown is slightly hollowed and strongly roughened. The labial visor is wavy in outline. The lingual face of the crown is smooth and concave, with no distinct median lingual ridge. The root is bilobed, the lobes are narrow placed labio-lingually. The basal surface is slightly convex. The lobes are separated by slightly deep groove with a central foramen, plus three foramina located in the labial face of the root.

Remarks: The recovered *Dasyatis gigas* teeth are of great similarity to those from described by Balbino and Antunes (2006). However, differences in the outline of the labial visor of the crown, as well as shape of the transverse crest, making the level of uncertainty in attribution to *Dasyatis gigas* is slightly higher.

Stratigraphic and Geographical Distribution:

Upper Miocene (Portugal) (http://fossilworks.org, 14 March 2017, using the name *Dasyatis gigas*).

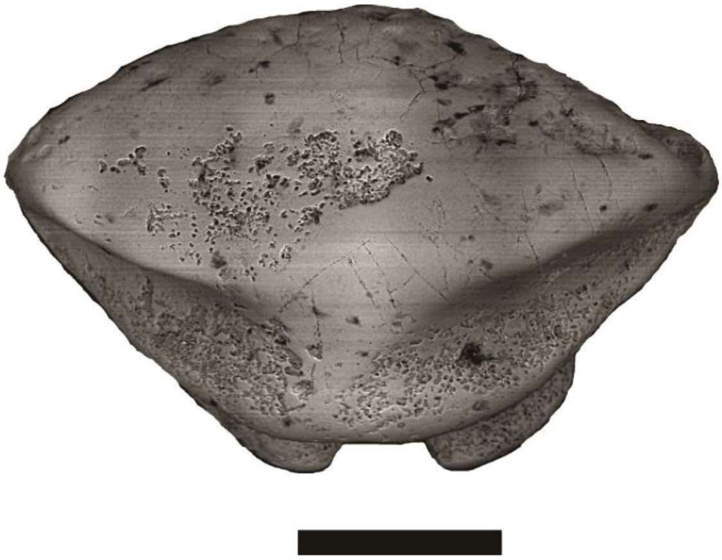


Fig. 3.14. SEM images of †*Dasyatis* cf. *gigas* from the lower Miocene Al Jaghboub Formation, NE Libya, lateral tooth, female; occlusal view, (WHJ 322). Scale bar = 500 µm.

†*Dasyatis* cf. *serralheiroi* Cappetta 1970

Fig. 3.15

Material: Three lateral teeth WHJ 327; WHJ 328 and WHJ 329.

Description: The teeth are relatively large (1.3 mm high and 1.9 mm wide), broad and have more or less a rectangular outline. In occlusal view, the labial face of the crown has more or less lozenge shape, flat and slightly ornamented, the lower part of labial visor is wide and concave. The marginal angles are well marked. The lingual face of the crown is separated from the labial face by a less marked transverse crest. The lingual face of the crown is wide, smooth and concave, the median lingual ridge is obvious. The lingual visor is exceptionally concave revealing a wide the lingual notch of the root. The root is wide and positioned lingually, the lobes are asymmetrical and separated by a wide furrow which bears a well-marked central foramen.

Remarks: The retrieved teeth have been assigned to *Dasyatis serralheiroi* according to several morphological similarities such as, 1- the rectangular crown outline, 2- the slightly ornamented labial face, 3- the concave shape of the lingual visor and 4- wide lingual notch (see Cappetta, 1970 pl. 20, fig. 1-11).

Stratigraphic and Geographical Distribution:

Lower Miocene of France (Cappetta, 1970; http://fossilworks.org, 14 March 2017, using the name *Dasyatis serralheiroi)*.

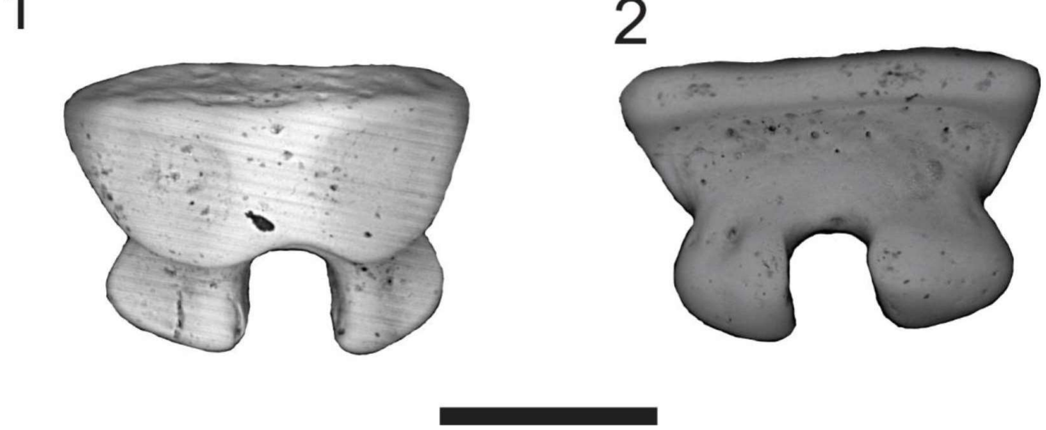


Fig. 3.15. SEM images of †*Dasyatis* cf. *serralheiroi* from the lower Miocene Al Jaghboub Formation, NE Libya, lateral tooth; 1, occlusal view; 2, basal view, (WHJ 327). Scale bar = 1 mm.

Dasyatis sp.

Fig. 3.16

Material: Two lateral teeth WHJ 330 and WHJ 331.

Description: Teeth has a very distinctive triangular shape (1.5 mm high and 1.5 mm wide). In occlusal view, the crown has a smooth labial face. The marginal angles are distinct and making obtuse angles. The transverse crest has an arrow outline pointing down to the lingual face of the crown. The labial visor has wavy outline. The lingual face of the crown is smooth and concave and more or less wide; the median lingual ridge is weakly distinct. The root is bilobed, but one of the lobes is missing probably due to postmortem process. The lobes are separated by a clear nutritive groove with a central foramen.

Remarks: *Dasyatis* sp. teeth are closely similar to the extinct *Dasyatis hexagonalis* defined by Arambourg (1952). However, the recovered specimens are incomplete which make the identification as open name.

Distribution and Habitat

The common stingrays is found in all temperate and warm seas from the Mediterranean and Black Seas. They also occurs, in the northeastern Atlantic Ocean (Serena *et al*., 2003). They typically inhabits sandy or muddy habitats in coastal waters and is also sometimes encountered near rocky reefs or in estuaries, as it is tolerant of low salinity. The depth ranges from 0 to 479 m. While the temperature preference is up to 28 °C. (http://www.fishbase.org, 14 March 2017, using the name *Dasyatis*).

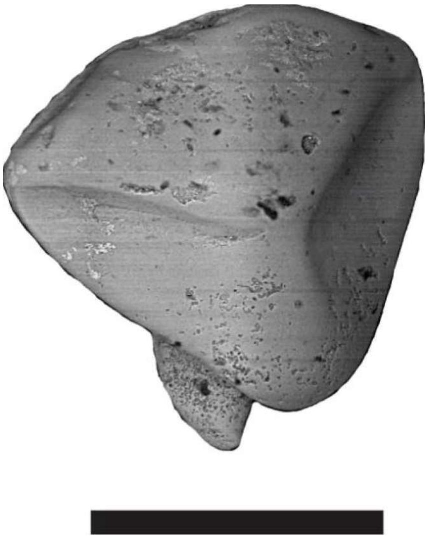


Fig. 3.16. SEM images of *Dasyatis* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, lateral tooth, occlusal view, (WHJ 330). Scale bar = 1 mm.

Family Gymnuridae Fowler 1934

Genus *Gymnura* Van Hasselt 1823

† *Gymnura delpiti* Cappetta 1984

Fig. 3.17

Common name: Butterfly ray

Material: Twelve teeth WHJ 333 and WHJ 335.

Description: The crown of anterior teeth (1.1 mm high and 1.5 mm wide) (fig.3.17 A1 and A2) is symmetrical, with long, straight sharp cusp bent lingually. The lateral angles are highly developed and joined by the well-marked transverse keel, which are acute and directed labially forming true margino-labial protuberances. The root is incomplete due to fragmentation. In Posterior teeth (1.4 mm high and 1.2 mm wide) (fig. 3.17 B1 and B2) the cusp is shorter curves towards the commissure and the teeth become asymmetrical; the mesial cutting edge of the crown is long and straight, while the distal is shorter. The root is massive, high, and wide; the groove is deep and separating the root to two will developed lobes the root is still clearly separated from the Crown on its whole circumference by a depressed area. The main foramen is in central position.

Stratigraphic and Geographical Distribution:

Paleocene (Morocco), lower Eocene (France), middle Eocene (France and western Africa of Togo and Guinea-Bissau), upper Eocene (Jordan), upper Oligocene (Germany), Miocene (France and Portugal), Pliocene (France and Italy) (Cappetta, 1987, 2012).

Distribution and Habitat

It occurs in warm and shallow waters of the Pacific, Indian and Atlantic oceans and Mediterranean Sea and rarely in estuaries. It occur in relatively shallow waters (176 m) with water temperature ranges from 8 – 28°C (Cappetta, 2012, http://www.fishbase.org, 12 March 2017, using the name *Gymnura*).

Fig. 3.17. †*Gymnura delpiti* from the lower Miocene Al Jaghboub Formation, NE Libya, A, lateral tooth,; A1, occlusal view; A2, basal view, (WHJ 333); B, Posterior tooth, B1, lingual view; B2, labial view, (WHJ 335). Scale bar = 1 mm.

Superfamily Myliobatoidea Compagno 1973

Family Myliobatidae Bonaparte 1838

Genus *Myliobatis* Cuvier 1816 & 1817

Myliobatis sp.

Fig. 3.18

Common name: Eagle rays

Material: Five teeth WHJ346.

Description: This family is represented by one complete tooth and several damaged elements. The described specimens is the only complete tooth (0.3 mm high and 1.5 mm wide). It has a hexagonal or chevron contour and mesio-distally elongated. The mesial and distal ends of the teeth are triangular in shape. The crown is markedly separated from the root by a minor groove. The crown is flat, whereas the basal attachment surface of the root is flat or slightly concave and crossed labio-lingually by numerus deep nutrient grooves separating multiple root lobes (polyaulacorhizous root).

Remarks: This tooth is assigned to *Myliobatis* based on the chevron contour of the crown. Milankumar and Patnaik (2013), described a pretty much similar specimen under the name *Myliobatis* sp. indet. 3 from the Miocene Deposits of Baripada Beds of India. The described specimen also shows a similar morphology to that figured by Cappetta (1970), as *Rhinoptera* cf. *studeri* from the Miocene of France. Species of *Rhinoptera* can be differentiated from *Myliobatis* by smaller size, and more closely spaced root lobes for *Myliobatis* (Case and West, 1991).

Stratigraphic and Geographical Distribution:

Paleocene (Morocco, Enclave of Cabinda and Nigeria), Eocene (Enclave of Cabinda, Tunisia, India, U.S.A., New Jersey, South Carolina, Texas, England, Morocco, Nigeria, Spain, France, Italy, Germany and Egypt), Oligocene (Italy and Germany), Miocene (Democratic Republic of Congo, U.S.A., South Carolina, Maryland, New Jersey, California, Brazil, Sri Lanka, France, Germany, Switzerland, Hungary, Italy; Portugal), Pliocene (Italy, Japan; France and Libya). (Cappetta, 2012).

Distribution and Habitat

The eagle ray *Myliobatis*, is a Marine, brackish; benthopelagic creature found mainly throughout the Eastern Atlantic, north to the western coasts of Ireland and British Isles and the southwestern North Sea, South Africa. Also can be found throughout the Mediterranean. *Myliobatis* species lives in warm, shallow waters. Adults prefer sandy shores, while juveniles can usually be encountered offshore. The depth range for this genus was deduced based on 1986 specimens in 11 taxa, and it reaches up to 1183 m, while the water temperature can reach 26 °C (McEachran and Séret, 1990, http://www.fishbase.org, 15 March 2017, using the name *Myliobatis aquila*).

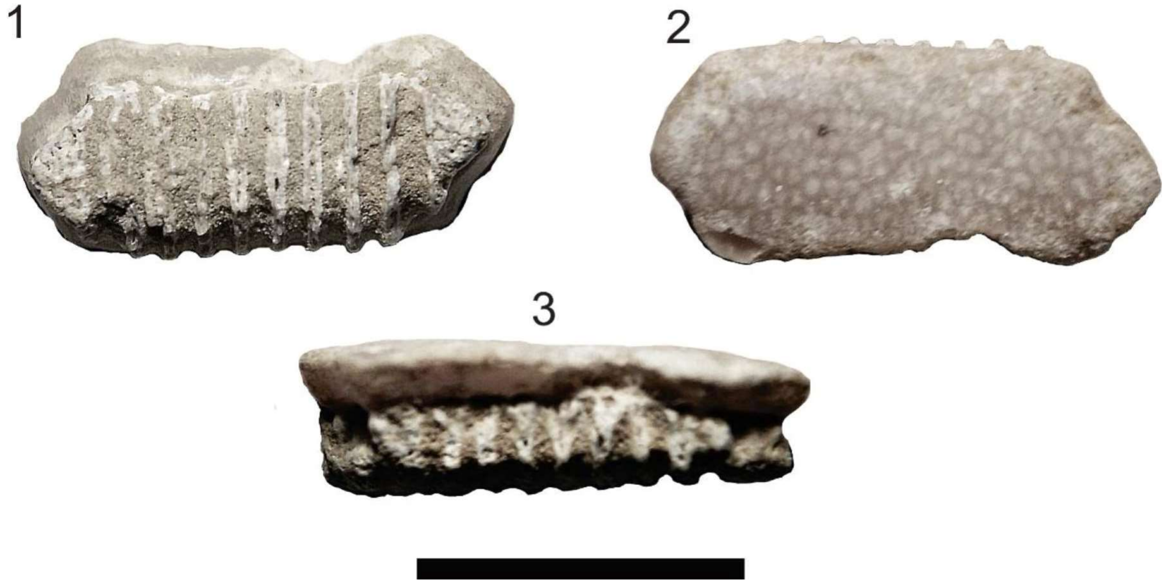


Fig. 3.18. *Myliobatis* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, 1-3, median tooth,1, basal view; 2, occlusal view; 3,lingual view, (WHJ 346). Scale bar = 1 mm.

Superfamily Mobuloidea Whitley 1936

Family Mobulidae Gill 1893

Genus *Mobula* Rafinesque 1810

Mobula sp.

Fig. 3.19

Common name: Devil rays

Material: One lateral tooth WHJ 347.

Description: This species is represented by only one tooth. It's relatively small (1.2 mm high and 2.6 mm wide), with high crown. The occlusal face is broader than long and relatively flat with a concave labial edge, having strong granular ornamentation. The lingual edge is rather sharp and has a simple wavy obtuse multi-cusp. The lingual face is wide and shows two concave areas. The labial edge generally straight and rounded over the root. The root is narrower than the crown and is multilobate; the furrows are shallow and the laminae rather broad.

Stratigraphic and Geographical Distribution:

Eocene (Germany; U.S.A., South Carolina), Miocene (France, Poland; Portugal; India as *Narcine* sp.), Upper Miocene-Lower Pliocene (Costa Rica) (Cappetta, 2012).

Distribution and Habitat

Mobula, or Devil rays are found mainly in the Mediterranean Sea and in the East Atlantic Ocean, and possibly in the northwest Atlantic. They predominantly prefer deep waters ranging in depth from a few tens of meters to several thousand meters. Devil fish inhabit offshore areas to the neritic zone, while the water temperature can reach 26 °C. (http://www.fishbase.org, 15 March 2017, using the name *Mobula mobular*).

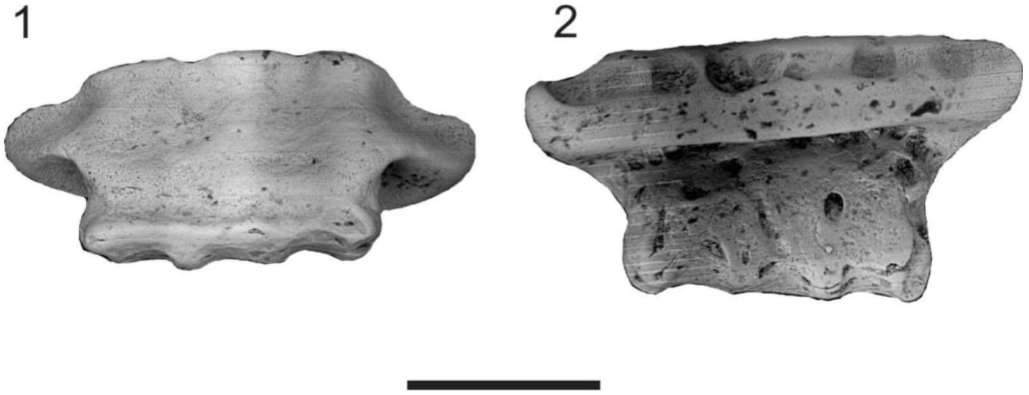


Fig. 3.19. SEM images of *Mobula* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, 1-2, lateral tooth, 1, lingual-basal view; 2, labial view, (WHJ 347). Scale bar = 1 mm.

3.2. Other Hard Parts:

3.2.1. Placoid Scales

Placoid scales cover the entire external surface of the shark and rays, also line the inside of the mouth, pharynx and branchial arches. Placoid scales are found only in sharks and histologically similar to teeth by having a central pulp cavity through which nerves and blood vessels enter and surrounded by dentine, while the outer surface of the scale is covered with enameloid (Fig. 3.20). As the animal grows, placoid scales are replaced serially by larger ones (Welton & Farish 1993).

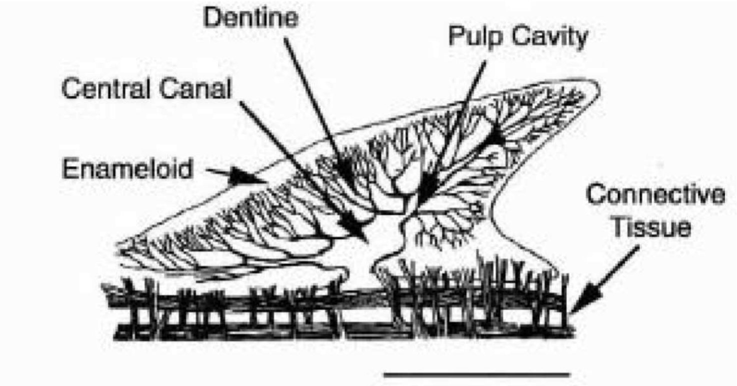


Fig. 3.20. Sagittal section of *Dalatias licha* placoid scale showing detailed histology. Scale bar = 0.5 mm. (after Welton and Farish, 1993).

Several placoid scales of undetermined shark or ray taxa are collected during picking process of the washed sample, as association miscellaneous elements. They are very small elements, all of them has the same morphology. They are more or less has a bulky cusp with a rhombic outline with many longitudinal ridges (Fig. 3.21).

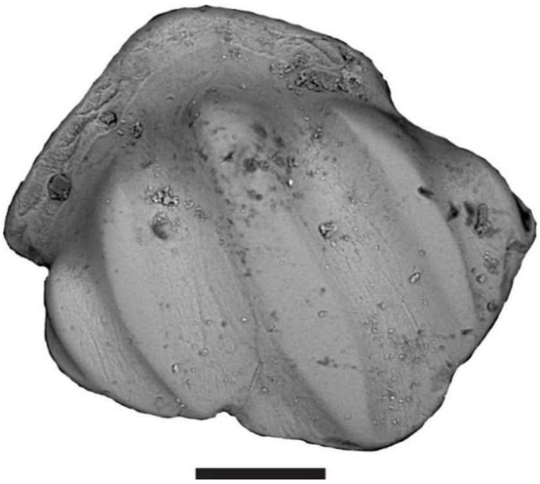


Fig. 3.21. SEM image of placoid scale of indet. Chondrichthians from the lower Miocene Al Jaghboub Formation, NE Libya, dorsal view, (WHJ 351). Scale bar = 200 µm.

3.2.2. Vertebrae

Vertebrae are very common type of Selachian fossils, they consist of a series of externally simple disks called amphicoelous centra that are anteroposteriorly biconcave and hour-glass shaped. The centrum represents the main body of the vertebra after all the projecting cartilaginous parts (arch cartilages and ribs) are removed. These centra are aligned antero-posteriorly in a series held together by connective tissue and have projecting neural and hemal arches composed of cartilaginous plates (Welton and Farish 1993).

Vertebra of chondrichthyes are fairly common in the examined Al Jaghboub sediments (about 167 elements have been picked). The disk-shaped centra exhibit two pairs of foramina, one dorsal and one ventral (Fig. 3.22).

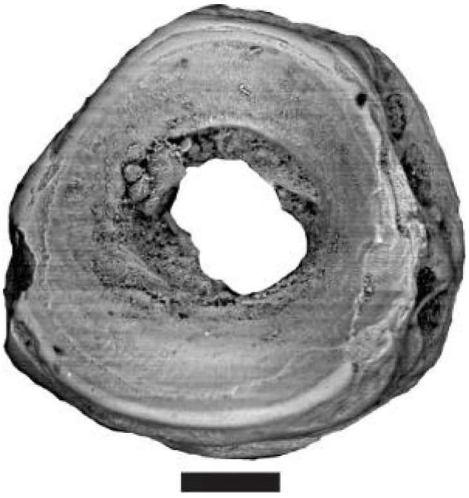


Fig. 3.22. SEM image of indet. Chondrichthians vertebra from the lower Miocene Al Jaghboub Formation, NE Libya, (WHJ 501). Scale bar = 200 μm.

3.3. Chondrichthyan Ichnofossils:

Coprolite

Extant Chondrichthyes produce helical or spiral shaped feces, due to the presence of a spiral valve in the posterior part of the intestine (Fiedler, 1991). Diedrich and Felker (2012), tried to classify shark coprolites based on their external morphological features. They recognized five distinct forms, (A, B, C, D, E) as follows:

Type A: They are up to 70 mm in length and can reach a maximum width of 50 mm. The coils are not more than three. Proximally the spiral folds and groves are less clearly developed.

Type B: They have 4-20 short-distance coils, are highly variable in their width and length, which is certainly also a result of coprolite growth.

Type C: A rare form is elongated and only 5 mm in width and has an indeterminate maximum length. The coils are not spindle – like they cross each other at about 45° angles.

Type D: Round-oval to high-oval shaped feces that reach maximum sizes of 20 mm in length and 8 mm in width. The surfaces lack clear, distinct coils, but surface ornamentation is quite similar to type E.

Type E: A last and most tiny round-oval form is only 3 mm in length and width. These also those have some spiral-like folding as in the above mentioned type D.

In total, 251 shark coprolites of small sizes have been collected during the course of this study, they are characterized by almost same morphology, an elongated form with 0.5 mm in width and has a variable length due to postmortem displacement (Fig. 3.23). The coils are cross each other at acute angles. (It must be noted that this morphology correspond to type-C of coprolite as suggested by Diedrich and Felker, (2012). The homogeneity in shape and size of these coprolites of the retrieved elements are strongly indicative of in situ assemblages, although, the coprolites are the only trace elements rarely found as in situ due to wave drifting activities.

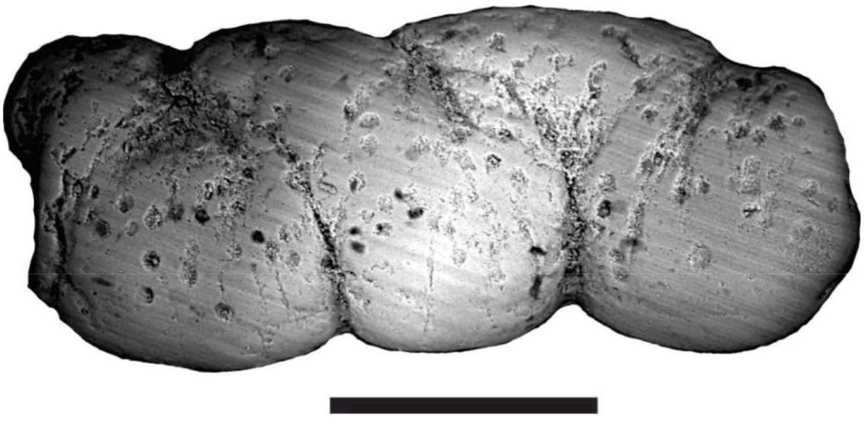


Fig. 3.23. SEM image of Coprolite of indet. Chondrichthians from the lower Miocene Al Jaghboub Formation, NE Libya, lateral-side view, (WHJ 604). Scale bar = 200 µm.

3.4. Actinopterygii

Bony fishes or Osteichthyes, from their name are a diverse group of fishes that have bony skeletons. It is the largest taxonomic group of vertebrates alive today. The group Osteichthyes is divided into the ray-finned fish (Actinopterygii) and lobe-finned fish (Sarcopterygii) (Fig. 3.1). The oldest known fossils of bony fish are about 420 million years ago. Osteichthyes known also as Euteleostomi (in paleontology) which means that the two terms are synonymous (Betancur-R. *et al*., 2013). Actinopterygians, or 'ray-finned fishes,' are the largest and most successful group of fishes and make up half of all living vertebrates. Actinopterygii mainly characterized by the presence of ganoid, cycloid, or ctenoid scales (scales absent in many groups); internal nostrils absent; nostrils relatively high up on head. At present, approximately 44 orders, 453 families, and nearly 27,000 species are recognized within this class but there are bound to be taxonomic revisions as research progresses. (Nelson, 2006).

The teleosts or Teleostei are the largest infraclass in the class Actinopterygii, and make up 96 percent of all fish. This diverse group arose in the middle or late Triassic period about 220–200 million years ago and their members are arranged in about 40 orders and 448 families and over 26,840 species have been described. Teleosts dominate the seas from pole to pole and inhabit the ocean depths, estuaries, rivers, lakes and even swamps (Nelson, 2006). The difference between teleosts and other bony fish lies mainly in their jaw bones; teleosts have a movable premaxilla and corresponding modifications in the jaw musculature which make it possible for them to protrude their jaws outwards from the mouth. This is of great advantage, enabling them to grab prey and draw it into the mouth. In more derived teleosts, the enlarged premaxilla is the main tooth-bearing bone and the maxilla, which is attached to the lower jaw, acts as a lever, pushing and pulling the premaxilla as the mouth is opened and closed. Other bones further back in the mouth serve to grind and swallow food. (Benton, 2005).

Class Actinopterygii is the main constituent of the retrieved taxa where it form about 67% of the bulk sample, (Fig. 3.2). The majority of the bony fishes belong to the Family Sparidae (93.5%), while the families Scombridae; Sphyraenidae; Serranidae and Acanthuridae are the minority (3%; 2%; 1% and 0.5% respectively) (Fig. 3.24).

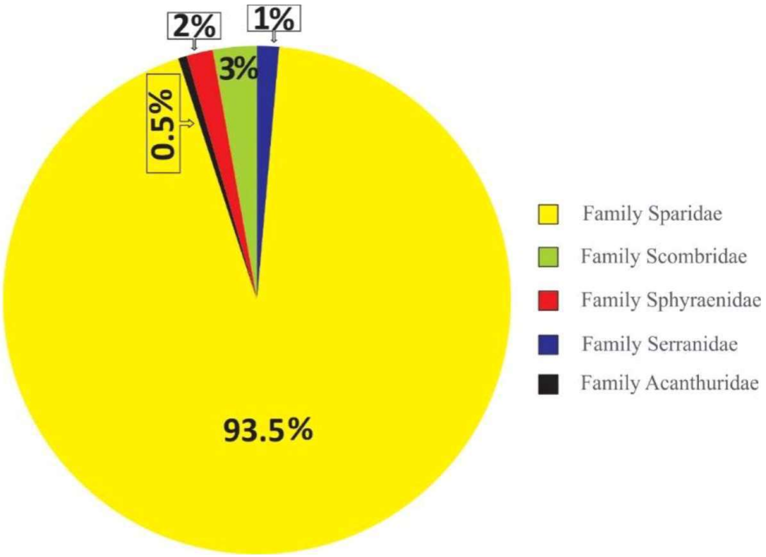


Fig. 3.24 Pie diagram of relative Abundance of different families of Class Actinopterygii in the studied sample.

Systematic Paleontology

More than two thousand teeth in association with some bone fragments have been recovered and assigned to Actinopterygians. Several hundred microscopic teleost teeth have been extracted during the lab work from the collected materials. Over six species belonging to five different families were identified here in. Their systematics will follow the classification scheme of Nelson, 2006.

Class Actinopterygii Klein, 1885

Division Teleostei Müller, 1846

Order Perciformes Bleeker, 1859

Family Serranidae Swainson, 1839

Subfamily Epinephelinae sensu Jordan and Eigenman, 1890

Genus *Epinephelus* Bloch, 1793

Cf. *Epinephelus* sp.

Fig. 3.25

Common name: Grouper

Material: Ten teeth WHJ 775.

Description: The crown with cylindrical shaft, the upper part is conical with pointed apex and slightly inclined towards inner margin. The apical part of the crown is compressed, while the basal part is thicker, well defined enameloid crown. The surface of the whole tooth is smooth. The basal section is sub-circular with an opening for pulp cavity.

Remarks: The crowns characters are closely similar to now a day's groupers (East and Southwest Atlantic; Western Indian Ocean and Mediterranean Sea *Epinephelus marginatus* and East Atlantic and Mediterranean Sea *Epinephelus aeneus*. The lower specific classification cannot be determined from the collected teeth, because it needs more comparative materials, further data and study.

Distribution and habitat:

Epinephelus is considered a marine; brackish, demersal fish. Found at depths from 0 to 200 meters with some species can reach a depth to 300 m, it also prefer the Subtropical environment with temperature up to 27°C. It inhabits the Mediterranean, East and Southwest Atlantic and Western Indian Ocean, between longitude 17°W - 60°E and latitude 39°N - 16°S (http://www.fishbase.org, 20 March 2017, using the name *Epinephelus*).

Fig. 3.25. Cf. *Epinephelus* sp. from the lower Miocene Al Jaghboub Formation, NE Libya, lateral view, (WHJ 775). Scale bar = 1 mm.

Family Sparidae Bonaparte, 1831

Genus *Sparus* Linnaeus, 1758

Sparus sp.

Fig. 3.26

Common name: Gilt-head bream

Material: One hundred and twenty teeth.

Description: Different tooth morphotypes are represented in our material, ranging from Canineform to low-crowned molariform, varying in accordance to jaw positions. Molariform teeth can exhibit different crown contours, ranging from oval to reniform, to circular and to sub circular depending on their as the position in the jaw. Smaller elements might either derive from a different species of *Sparus* (*Sparus* spp.) or a younger ontogenetic stage (juvenile forms) of the genus .

Canineform teeth of Sparus are also retrieved from the sample of the Miocene Al Jaghboub Formation. The teeth show sub-cylindrical high basal part with strongly conical upper part. The conical apical part is slightly inclined towards its inner margin of the shaft. The basal section of the shaft is circular with a central cavity.

Remarks: The Canineform teeth are very similar to *Sparus agarwali* from the Miocene of India (Mehrotra 1981). These similarities include: i) having somewhat thick, conical apical part of the shaft and inclined towards inner margin; 2- It differs from *Sparus auratus* described from the Miocene of Portugal (Jonet, 1975) by having much wider basal part of the shaft than the upper part. The present sample cannot been assigned to *Sparus agarwali* because the lack of more materials.

Distribution and habitat:

Sparus belongs to Sparidae (Porgies) family, it distributed in Eastern Atlantic and in the Mediterranean. It's a Marine or brackish water fish, demersal and can be found in beds of seagrass and sandy bottoms, usually can be found at depths of about 30 m and even reach a maximum depth of 150 m for the adults (http://www.fishbase.org, 20 March 2017, using the name *Sparus*).

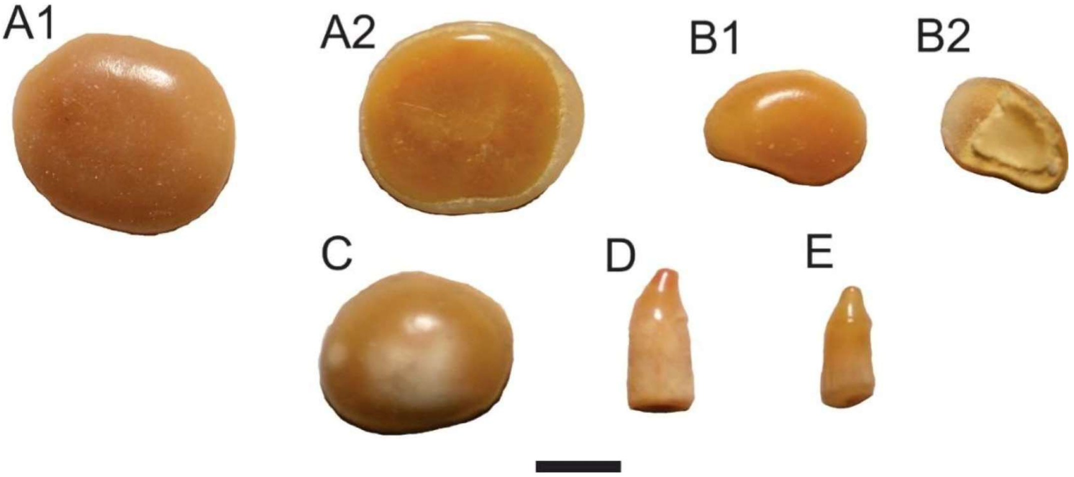


Fig. 3.26. *Sparus* sp. from the lower Miocene Al Jaghboub Formation, NE Libya. A-C, molariform; A1, B1, C, occlusal view (WHJ 780, 801 and 804 respectively); A2, B2, basal view, D-E, Canineform; lateral view, (WHJ 809 and 815). Scale bar = 1 mm.

Genus *Diplodus* Rafinesque, 1810

† *Diplodus* aff. *intermedius* Jonet, 1975

Fig.3.27

Common name: Seabream**.**

Material: Twenty seven teeth WHJ 1040.

Description: The species *Diplodus* aff. *intermedius* is defined here according to the recognition of Posterior teeth " i.e. Incisiform teeth", which yield two parts: more or less Flat crown, strongly convex on the outside and concave on the inside with a rather sharp upper crest. The tooth‹ when it is complete, is somewhat similar to Spoon (Jonet, 1975), but the present studied materials shows an absent root, maybe because the material of which the root made of is so fragile and eroded. The upper edge is very sharp, it inclines more and more towards the inner margin.

Remarks: The described incisiform Teeth (fig.3.25) is more or less similar to the teeth described by Jonet (1975). They show similar characters of having two parts, the flat crown and sharp crest, inclined more towards the commissure. Thickening at their base, the lateral and lower edges, and the spoon -like tooth.

Distribution and habitat:

Diplodus is mostly found in Subtropical regions of Eastern Atlantic; Mediterranean and Black Sea, between latitude 48°N - 36°S and longitude 18°W - 42°E. The seabream fish habitat is mainly demersal marine: brackish and oceanodromous (Riede, 2004); found usually at depth ranges from the surface level to 50 m (Lenfant and Planes, 1996 and Sala and Ballesteros, 1997). Their preferred water temperature is about 23°C (http://www.fishbase.org, 20 March 2017, using the name *Diplodus sargus sargus*).

Fig. 3.27. †*Diplodus* aff. *intermedius* from the lower Miocene Al Jaghboub Formation, NE Libya. lateral view, (WHJ 1040). Scale bar = 500 µm.

Genus *Pagrus* Cuvier, 1817

Pagrus sp.

Fig. 3.28 A and B

Common name: Seabream.

Material: Three hundred and twenty unnumbered teeth and two jaw fragments WHJ 1203 and WHJ 1204.

Description: Canineform teeth with a smooth; massive and cylindrical shaft. The apical part of the crown is not sharp with flat apex and slightly inclined towards its inner margin. The basal section of the crown is circular with a central pulp cavity surrounded by thick radial wall.

The specimen numbered WHJ 1203 corresponds to a jaw fragment bearing an attached molariform tooth, and exhibiting to it with tooth impression belongs to unknown species of *Pagrus*, as mentioned earlier the species may belongs to one species that have been described above or maybe another one but it firmly considered as a species of *Pagrus*.

Remarks: the described tooth was found to be more or less similar to the *Pagrus robustus* described by Mehrotra (1981, page 83, Pl. I, fig. 15), also similar to Sparidae indet. morphotype 2. described and illustrated by Marsili *et al*. (2007, page 37, Pl. 2, fig. 9) of probable an anterior jaw position.

Distribution and habitat:

Pagrus is a marine; oceanodromous fish, found in Eastern Atlantic; Mediterranean and Western Atlantic. It's a bentho-pelagic fish found above rocky or sandy bottoms; their depth range is from 0 - 250 m, its environment is subtropical with preferred water temperature of 24°C (http://www.fishbase.org, 20 March 2017, using the name *Pagrus*).

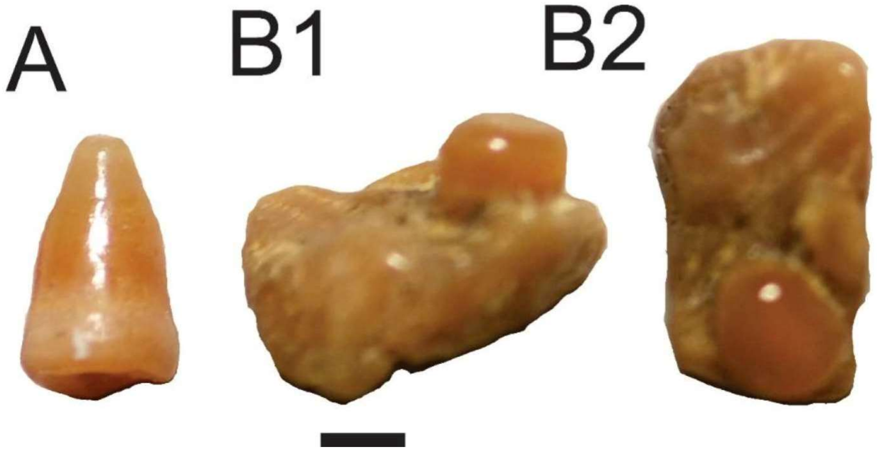


Fig.3.28. *Pagrus* sp. from the lower Miocene Al Jaghboub Formation, NE Libya. A, Canineform teeth; lateral view, (WHJ 1121). B, jaw fragment; B1, side view, B2, dorsal view (WHJ 1203). Scale bar = 1 mm.

Genus *Dentex* Cuvier, 1817

Cf. *Dentex* sp.

Fig. 3.29 A and B

Common name: Dendshy**.**

Material: Two hundred and three teeth.

Description: The teeth are of varying sizes, the described material (Fig. 3.29 A) considered to be lateral teeth, with strongly curved crown and slightly flat sides with triangular sharp apex. The apex is inclined towards inner margin. The basal section is much wider and circular in shape with a central pulp cavity.

Fig. 3.29 B shows another canineform morphotype of cf. *Dentex* are, which is cylindro-conical with sharp pointed apex. The crown is curved towards inner margin and on its surface it bears fine longitudinal striations. The basal face of the crown is circular with a central pulp cavity.

Remarks: The genus *Dentex* is paleobiogeographically important because it can be found in the Miocene deposits of India (Mehrotra, 1981, Austria (Schultz, 2001, Gregorová *et al*., 2009), Italy (Girone, *et al*., 2010) and Algeria (Arambourg, 1927).

Distribution and habitat:

Dentex dentex (Linnaeus, 1758) is a Marine fish distributed along the Eastern Atlantic and in the Mediterranean between latitude 56°N - 12°N and longitude 23°W - 42°E . Its benthopelagic, which inhabit hard bottoms to 200 m deep, subtropical with preferred water temprature19°C (http://www.fishbase.org, 21 March 2017, using the name *Dentex dentex*).

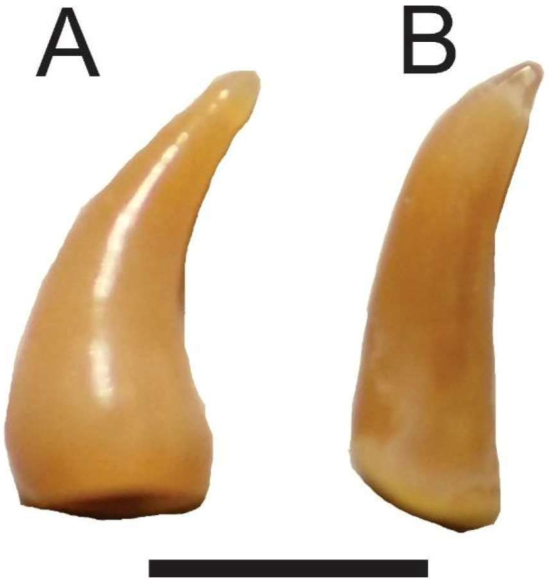


Fig.3.29. Cf. *Dentex* sp. from the lower Miocene Al Jaghboub Formation, NE Libya. A; lateral view, (WHJ 1240). B; lateral view, (WHJ 1320). Scale bar =1 mm.

Sparidae indet.

Fig. 3.30

Material: 1 fragmented premaxilla WHJ 1700.

Description: The nasal process of the premaxilla is broken off. The mesial surface of the bone distinct circular tooth attachment surfaces (fig. 3.30 A2). The latter bear radiations run towards a central cavity. In lateral view (fig. 3.30 A3), there is still a replacement tooth embedded in the posterior part of the jaw. The tooth has a low, conical apex and stout circular base.

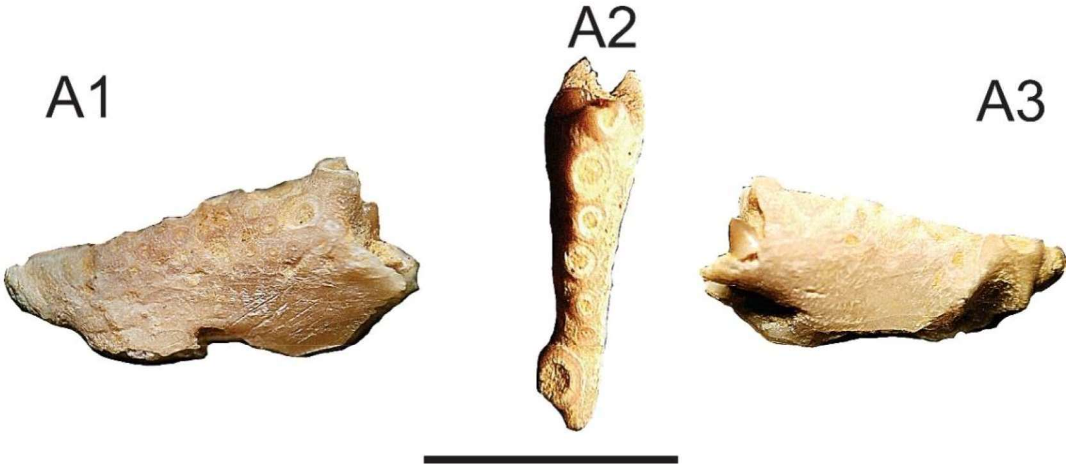


Fig. 3.30. Fragmented premaxilla of sparidae indet. from the lower Miocene Al Jaghboub Formation, NE Libya. A1, internal view, A2, dorsal view, A3, external view, (WHJ 1700). Scale bar =5 mm.

Family Sphyraenidae Rafinesque, 1815

Genus Sphyraena Walbaum, 1793

Cf. *Sphyraena* sp.

Figure 3.31

Common name: Barracuda

Material: Twelve teeth WHJ 2004.

Description: The teeth exhibit long, triangular crowns with sharp apices. The teeth are labiolingually compressed and weakly biconvex. The basal section is sub-circular to ellipsoid in shape with a central pulp cavity. In some specimens the apex is gently inclined posteriorly.

Remarks: The genus *Sphyraena* has been recorded in many Miocene deposits in various localities around the Tethys; India (Mehrotra, 1981 as *Sphyraena* sp.), Portugal, (Antunes *et al*., 1981 as *Sphyraena olisiponensis* and *Sphyraena* aff. *gracile*).

Distribution and habitat:

Sphyraena is mainly distributed in the Subtropical Eastern Atlantic; Mediterranean and Black Sea between longitude 14°E - 65°W and latitude 48°N - 24°S. It's essentially a marine fish Found in coastal and offshore waters; pelagic-neritic with depth ranges between 0 to 100 m. Feeds mostly on fish, less often on cephalopods and crustaceans (http://www.fishbase.org, 21 March 2017, using the name *Sphyraena*).

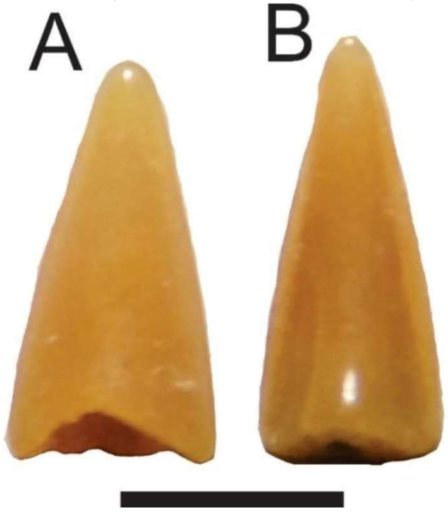


Fig.3.31. Cf. *Sphyraena* sp. from the lower Miocene Al Jaghboub Formation, NE Libya., A and B lateral view, (WHJ 2004). Scale bar =1 mm.

Family Acanthuridae Bonaparte, 1832

Acanthuridae indet.

Fig. 3.32

Common name: Surgeonfishes

Material: Four teeth WHJ 2041.

Description: The morphology of tooth is leaf-shaped, with the cutting edges forming nine lobe-like cusplets. The apical cusplet is the smallest, while the lateral cusps are larger.

Remarks: Multicuspidate teeth, with lobe-shaped cusplets are distinctive of Acanthuridae. Most living members of the family exhibit teeth of this morphology, except *Naso* and *Ctenochaetus* (Tyler, 1970). Acanthuridae are interesting paleogeographically because they are absent from modern Mediterranean (Nelson, 2006). But abundant in the Indian Ocean. In the Miocene they reflect the signature of the Tethyan Ocean.

Distribution and habitat:

Acanthuridae are exclusively marine-dwelling and can be found in all tropical and subtropical seas but are absent from the Mediterranean. (Johnson and Gill, 1998; Nelson, 2006). Acanthuridae inhabit offshore coral reefs as adults but larvae are carried by the currents inshore where they quickly sink to the bottom and begin transformation to the juvenile form. Acanthurids have small mouths and incisor-like, lobate teeth used to probe the reef for small animals and plants. (Allen and Robertson, 1994; Johnson and Gill, 1998)

Fig. 3.32. SEM image of Acanthuridae indet. tooth from the lower Miocene Al Jaghboub Formation, NE Libya. lateral view, (WHJ 2041). Scale bar =200 µm.

Suborder Scombroidei Bleeker 1859

Family Scombridae Rafinesque, 1815

Scombridae indet.

Fig. 3.33

Common name: Mackerels, tunas, bonitos.

Material: Twenty teeth WHJ 2053.

Description: The teeth are conical and compressed laterally with sharp lateral edges which bear very fine serrations. The surface of the crown mostly flat but sometimes bears longitudinal striations, which are very distinct at the crown's base. The basal section of the crown is biconvex and there is no opening for pulp cavity.

Remarks: This family is very common in the Miocene. It was reported from early Miocene deposits of Portugal, Italy (Jonet, 1967) and India (Mehrotra, 1981, 1982).

Distribution and habitat:

Scombridae can be found worldwide (cosmopolitan) in tropical and subtropical seas, with many species traveling periodically into cool temperate waters (Johnson and Gill, 1998; Nelson, 2006). They also, pelagic (open-ocean) fishes. Many groups within Scombridae tend to remain near the surface and over the continental shelf. (Nelson, 2006)

Fig. 3.33. Scombridae indet. tooth from the lower Miocene Al Jaghboub Formation, NE Libya., lateral view, (WHJ 2053). Scale bar =1 mm.

Chapter 4

Paleoecology and Paleogeography

4.1. Introduction:

Early studies of the Al Jaghboub Formation show that the associations of biosparite rich in biohermal fossils such as bryozoa, algae, miliolidae, echinoids and molluscan fragments. On the other hand, the presence of cross bedded limestone near the lower part of the Al Jaghboub Formation as recorded in Wadi Al Hash, indicates that it was deposited in fluviomarine conditions (El Deftar and Issawi, l977). Previous studies show no specification concerning the paleoecological conditions during deposition of the Al Jaghboub Formation, especially the lower most part of it at Wadi Al Hash.

4.2. Paleoecology:

Paleoecology is known as the science that study all aspects that govern the relationship between the fossil taxa and their ancient life environment, especially the relation of organisms with sediments (Lapidus, 1990). Interpreting the paleoecology can be done by comparing the living and fossil life form and their favorite habitats. The ichthyofaunal fossil taxa recovered from the lower horizon of the Al Jaghboub Formation at Wadi Al Hash, has been interpreted on the bases of their life style using their living analogous. The parameters investigated are: their depth preferences (palaeobathymetry), water temperature, water salinity and substrate.

4.2.1. Water Depth (Bathymetry):

Trying to establish the palaeobathymetry of ancient marine environment from fossil data is very important to most palaeoenvironmental analyses of marine sequences, although it is probably the hardest parameter to measure (Bosence and Allison 1995). The lower horizon of Al Jaghboub Formation at Wadi Al Hash has been concluded that it was deposited under fairly open marine environment based on the depth preferences of the living counterparts of the chondrichthyan and teleost taxa. Also, the majority of the ichthyofaunal taxa have benthopelagic life style with some percentage have nektonic lifestyle based on their living representatives (http://www.fishbase.org, 21 March 2017). The depth assigned to Al Jaghboub Formation is between 250 up to 479 m according to the majority of recovered taxa which inhabiting that range (Fig. 4.1). Taxa with larger depth ranges below the neritic zone of 200 m represent a large percentage of the total assemblage (61% of total of specimens) (Fig. 4.1) these include *Scyliorhinus* sp. (twenty-one specimens, 2%), *Galeorhinus* sp. (eleven specimens, 1%), *Rhizoprionodon longurio* (forty-two specimens, 4%), *Dasyatis* sp. (two hundred and fifty specimens, 23%), *Myliobatis* sp. (five specimens, 0.5%), *Mobula sp.* (one specimen, 0.1%), *Epinephelus* sp. (ten specimens, 1%), and *Pagrus* sp. (three hundred and twenty specimens, 30%). In the same context, the second most probable peleodepth ranges from 0 to 250 m based only on the teleost fossil taxa (*Sparus, Pagrus* and *Dentex* or 90% of the teleost taxa), the teleost fauna is used herein because of its abundance in the studied materials. Since there is a conflict concerning the depth of the water based on the recovered taxa and their counter parts, the two alternatives hypothesis have been addressed in order to explain the co-occurrence of fossil remains of two different ecological conditions in the same horizon: 1- Migrating up of deep water taxa into shallower depth by coastal upwelling through submarine canyons, or 2- Turbidity currents of shallow water taxa into deeper water (Besson *et al*., 2005 and Vialle *et al*., 2011). Additionally, the presence of few globigerinoides taxa. is considered as another support to the open marine environment.

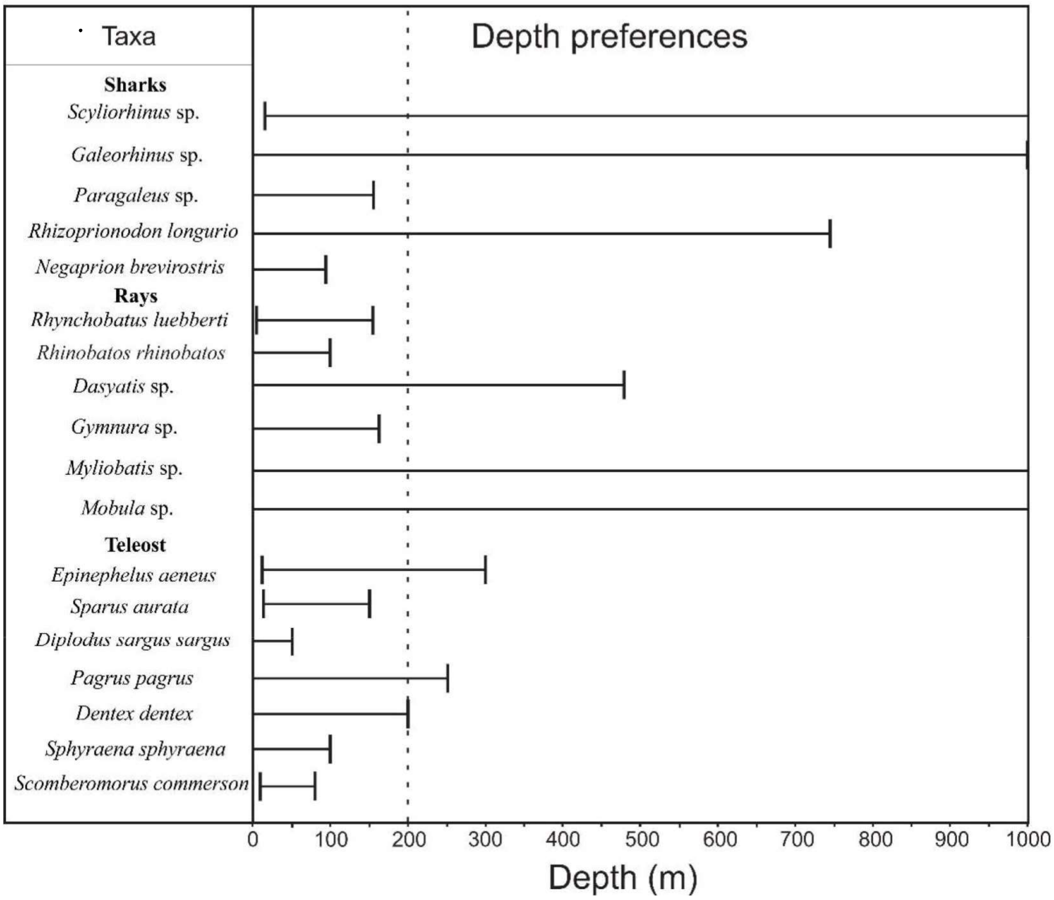


Fig. 4.1. Depth preferences of the recorded Ichthyofauna species from the Al Jaghboub Formation. after Pimiento *et al*., (2013).

Redox condition is very important for recognizing the sediment deposition in marine or non-marine environments. Moreover, the accumulation of certain trace elements in sediments is directly or indirectly controlled by redox conditions through either a change in redox state and/or speciation (McKay *et al*., 2007). In this case, the Ni/Co, Cu/Zn, V/Cr and U/Th ratios are significant paleochemical indicators of the redox conditions of the depositional environment (e.g., Nagarajan *et al*., 2007; Shaltami *et al.,* 2016). The studied samples display low Ni/Co, Cu/Zn, V/Cr and U/Th ratios (0.72, 0.22, 1.15 and 1.10, in average, respectively) which suggest that these sediments were deposited in a well oxygenated marine environment.

4.2.2. Water temperature and Paleoclimate:

The paleotemprature of water for the recovered taxa was interpreted using their living representatives. The majority or 73.3% of the taxa (e.g. *Rhizoprionodon*, *Myliobatis*, *Sparus, Pagrus* and *Dentex*) prefer subtropical conditions, while the second most probable temperature preferences is given for the temperate conditions based on the living taxa of the selachian fauna (e.g. *Dasyatis* and *Galeorhinus*).

From the above mentioned taxa, it can be deduce that the studied horizon was deposited under quite warm water temperature mostly between 24 to 26 °C (Fig. 4.2)

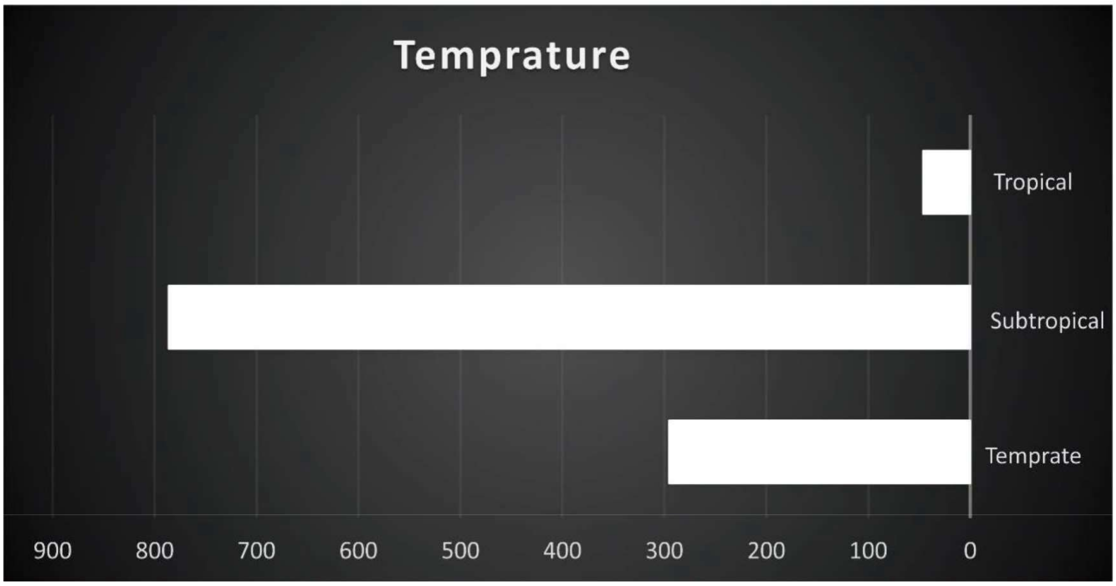


Fig. 4.2. Bar graph shows the temperature preferences of the Ichthyofauna from the Al Jaghboub Formation.

Geochemically, the applicability of the ratios of $SiO_2/(Al_2O_3+K_2O+Na_2O)$ for paleoclimatic condition (Suttner and Dutta, 1986) during deposition of the sediments in the basin is well recognized by many workers. The plot SiO_2 vs. (Al_2O_3+K_2O+Na_2O) (Fig. 4.3) shows semi-humid climatic conditions in the study area.

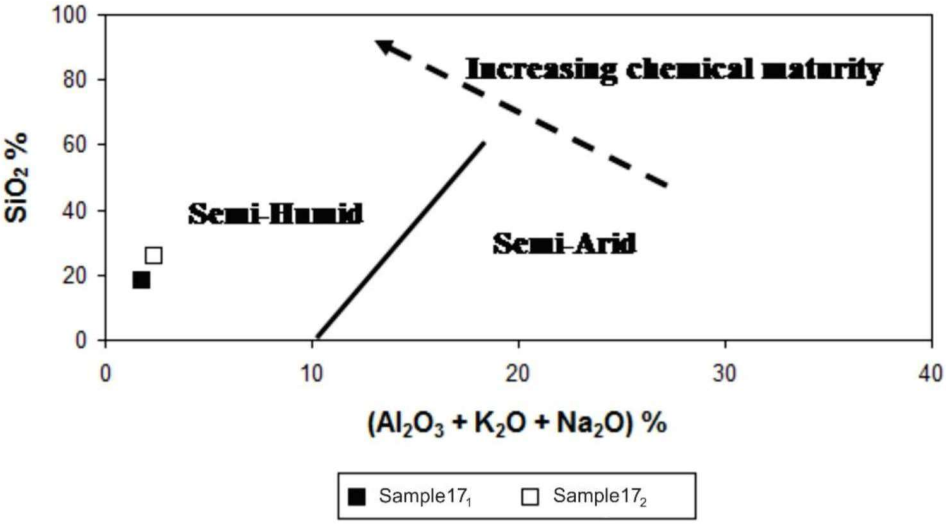


Fig. 4.3. Relationship between SiO_2 and (Al_2O_3 + K_2O + Na_2O) in the studied samples (fields after Suttner and Dutta, 1986).

4.2.3. Water salinity

The analysis of variable salinity (Fig. 4.4) based on the reported taxa shows that the normal salinity was attributed to the studied horizon of the Lower Miocene Al Jaghboub deposits, although some genera such as *Sparus* and *Dasyatis* sometimes inhabits brackish water; however the relatively high frequency of normal saline marine water (i. e. 35 g/L or 35 grams of dissolved salts in one liter of seawater) ichthyofauna support the possibility of purely marine conditions.

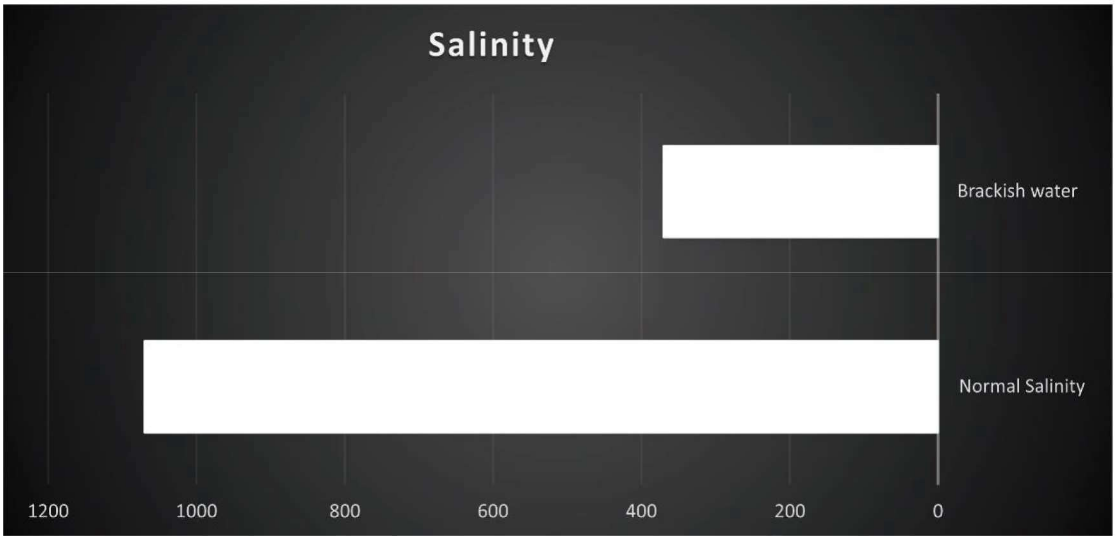


Fig.4.4. Bar graph shows the salinity preferences of the Ichthyofauna from the Al Jaghboub Formation.

4.2.4. Substrate

From the examination of the sample residue, a large quantity of white echinoids shell debris and maybe algae, in addition to the presence of some sand grains. The sand grains are more or less composed of detrital phosphate or fragments of bone elements belonging to the following genera on the bases of color affinity (*Galeorhinus*, *Dasyatis*, *myliobatis* and *Rhinobatos*). Actinopterygii debris elements however, such as *Dentex*, *Sparus, Pagrus, Diplodus* and Acanthuridae which are assumed to be co-exist with sandy materials and some algae communities which may provide shelter and protection for many of these fish.

4.3. Paleobiogeography

The Mediterranean Sea and Paratethys had gateways to both the Atlantic and the Indian Oceans during much of the Early and Middle Miocene (~ 23 – 13 Ma; Fig. 4.5) (Rögl, 1999). The Indian Ocean has gateways to the Mediterranean Sea and Paratethys which were closed sometime during the Middle Miocene (Rögl, 1999; Meulenkamp and Sissingh, 2003; Reuter *et al*., 2009). These passage ways have a great influence concerning water properties of both the Mediterranean and Paratethys, which controlled the floral and faunal exchange of both water bodies (Rögl, 1999; Latal *et al*., 2004; Harzhauser *et al*., 2002 and 2007, Harzhauser and Piller 2007). Most of the Lower Miocene sediments in study area were purely marine deposits because the area was submerged by the paleo-Tethys Ocean (modern Mediterranean Sea), while the paleo-shoreline was located further south.

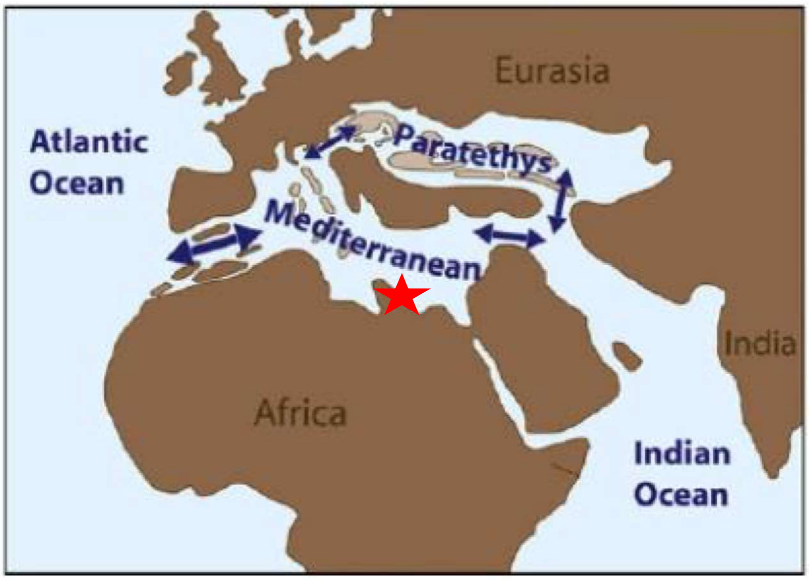


Fig. 4.5. A paleogeographic map of the Early to Middle Miocene Mediterranean Sea and Paratethys prior to closure of their connections to the Indian Ocean. after Rögl, (1999). Key: the red star infer to the study area.

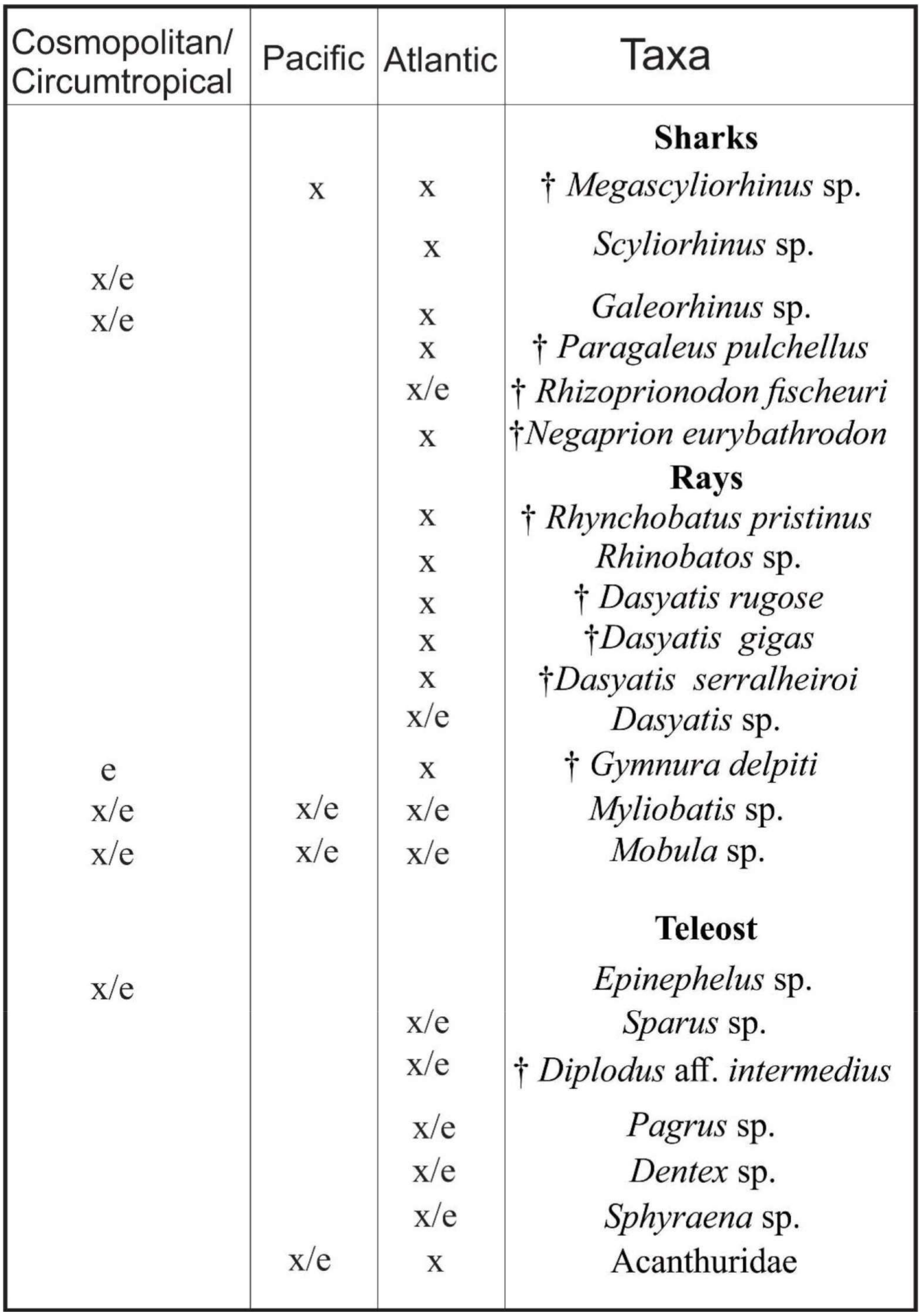
Nowadays the study area is overlooking the modern Mediterranean Sea, but this was not the story in the early Miocene time. The recovered fossil ichthyofaunas (Chondrichthyes and Actinopterygii) confirm that the studied horizon was deposited in fairly subtropical climate with more or less deep marine environment. From the study, the majority of the ichthyotaxa recovered and described from the Lower Miocene Al Jaghboub Formation have been also reported from the Lower Miocene deposits elsewhere of the Mediterranean Sea and Paratethys as marine assemblages, however, clearer picture about the possible migration routes and subsequently the paleogeography with paleoshorelins during the early Miocene (see Arambourg, 1927; Cappetta, 1970; Jonet, 1975; Antunes *et al*., 1981; Mehrotra, 1981; Schultz, 2001; Balbino and Antunes, 2006; Marsili *et al*., 2007; Gregorová *et al*,. 2009; Girone *at al*., 2010 and Vialle *et al*., 2011).

Most of the fossil chondrichthyan described herein have a living representatives at least at generic level inhabits different ocean realms, except *Scyliorhinus*, *Galeorhinus*, *Gymnura, Myliobatis* and *Mobula* which are of a cosmopolitan distribution in today's oceans (Table 4.1). The genus *Rhizoprionodon* has extant counterparts living mainly in the Atlantic Ocean (*Rhizoprionodon terranovae*, *Rhizoprionodon lalandii*, and *Rhizoprionodon porosus*, Compagno, 1984). The recent living representatives of the genus *Negaprion* are, *Negaprion brevirostris* of Atlantic and *Negaprion acutidens* of Indian and Pacific Ocean (Compagno, 1984, Argyriou *et al*., 2015). Rays living representative of genus *Rhynchobatus* is the *Rhynchobatus luebberti* which are currently restricted to the Atlantic Ocean, on the other hand, *Mobula hypostoma* colonized both the eastern Atlantic and the Indian Oceans; whereas, *Mobula mobular* colonized the Mediterranean Sea and the East Atlantic Ocean, and maybe further to the northwest Atlantic. While the genus *Gymnura* is found in warm oceans worldwide. (Table 4.1).

The teleost taxa have more or less the same paleogeographical scenario as the chondrichthyan fossils of the current study, and give almost similar pattern, because most the described materials show remarkable similarity with fossil marine teleost assemblages from different localities around the Tethys during the Early Miocene time (Portugal, Jonet, 1975; India, Mehrotra, 1981 and Italy, Marsili *et al*., 2007; Girone *et al*., 2010). Also their living counterparts (at least at generic level) almost have uniform distribution from Eastern Atlantic, Mediterranean Sea, and Indian Ocean, except of

Acanthuridae because they are absent in the modern Mediterranean Sea (Nelson, 2006). This similarity in the marine faunal content confirms that the connection between the Indian Ocean and the Mediterranean Sea as well as between Atlantic Ocean and Mediterranean Sea were prevailed during that slice of time, and by the time of its closing (the middle Miocene) the faunal content were exposed to extensive changes because of the isolation created by pre-mentioned disconnection.

Table 4.1. Biogeographical distribution of Ichthyofauna from the Lower Miocene Al Jaghboub Formation. Key: e. extant distribution; x, fossil occurrences. after Pimiento *et al*., (2013).



Cosmopolitan/ Circumtropical	Pacific	Atlantic	Taxa
			Sharks
	x	x	† *Megascyliorhinus* sp.
x/e		x	*Scyliorhinus* sp.
x/e		x	*Galeorhinus* sp.
		x	† *Paragaleus pulchellus*
		x/e	† *Rhizoprionodon fischeuri*
		x	†*Negaprion eurybathrodon*
			Rays
		x	† *Rhynchobatus pristinus*
		x	*Rhinobatos* sp.
		x	† *Dasyatis rugose*
		x	†*Dasyatis gigas*
		x	†*Dasyatis serralheiroi*
		x/e	*Dasyatis* sp.
e		x	† *Gymnura delpiti*
x/e	x/e	x/e	*Myliobatis* sp.
x/e	x/e	x/e	*Mobula* sp.
			Teleost
x/e			*Epinephelus* sp.
		x/e	*Sparus* sp.
		x/e	† *Diplodus* aff. *intermedius*
		x/e	*Pagrus* sp.
		x/e	*Dentex* sp.
		x/e	*Sphyraena* sp.
	x/e	x	Acanthuridae

Summary and Conclusions

The main purpose of the present study was to record, define and describe the retrieved Ichthyofauna taxa from the lowermost part of the Al Jaghboub Formation at Wadi Al Hash in Eastern Cyrenaica, NE Libya, and trying to understand their relation to the sediment they were found within, also to compile all available evidence and information in order to interpret the paleoenvironments during the early Miocene time in this area.

The results and conclusions are briefly summarized as follows:

1) Rock units at Wadi Al Hash are represented by a sequence of middle Eocene Nummulitic limestone of the Darnah Formation as the oldest exposed rock unit in the area, unconformably overlain by the upper Oligocene Al Faidiyah Formation, which consists of green glauconitic claystone and marly limestone, which unconformably overlain by the Al Jaghboub Formation of lower-middle Miocene (the upper facies dated as Burdigalian (17.25 Ma) using $^{87}Sr/^{86}Sr$ method), the lower vertebrate bearing clay (the main scoop of the study) is composed of yellowish green shale with rich content of micro-ichthyofauna fossils.
2) The diversity and richness of the identified Ichthyofauna found in the clayey portion of the Al Jaghboub Formation at the study area is employed to reconstruct the prevailed paleoenvironment, paleoecology and paleogeography.
3) Class Chondrichthyes forms about 33% of the whole recovered taxa. where the shark teeth is comprising about 21% of the total Chondrichthyes sample.Sharks teeth retrieved from this clay are belonging to four families, which are (Scyliorhinidae; Triakidae; Hemigaleidae and Carcharhinidae), and there are eight species belonging to these families which are (*Megascyliorhinus* sp.; *Scyliorhinus* sp. morphotype 1, morphotype 2 and morphotype 3; *Galeorhinus* sp.; *Paragaleus pulchellus*; *Rhizoprionodon fischeuri* and *Negaprion eurybathrodon*).
4) Rays taxa extracted from the study area are more divers than the sharks (about 79% of Cartilaginous Fishes teeth) and are belonging mainly to six different families which are (Rhynchobatidae; Rhinobatidae; Dasyatidae; Gymnuridae; Myliobatidae and Mobulidae), they include nine species, (*Rhynchobatus*

pristinus; Rhinobatos sp.; *Dasyatis* aff. *rugose*; *Dasyatis* cf. *gigas*; *Dasyatis* cf. *serralheiroi*; *Dasyatis* sp.; *Gymnura delpiti*; *Myliobatis* sp. and *Mobula* sp.).

5) Class Actinopterygii is the main constituent of the recovered taxa and forms about 67% of the studied sample. The studied elements are belonging to five families which are (Serranidae; Sparidae; Sphyraena; Acanthuridae and Scombridae) and there are nine species belonging to these families which are Cf. *Epinephelus* sp., *Sparus* sp., *Diplodus* aff. *intermedius*, *Pagrus* sp., Cf. *Dentex* sp., cf. *Sphyraena* sp. Acanthuridae indet. and Scombridae indet.
6) The paleo-bathymetry assigned to the Al Jaghboub Formation is probably ranging between 250 to 479 m according to the majority of recovered taxa, whereas the second most probable peleodepth ranges from 0 to 250 m based only on the teleost fossil taxa such as *Sparus*, *Pagrus* and *Dentex*.
7) The paleotemprature of water for the majority of the recovered taxa was interpreted as subtropical or semi-humid climatic conditions with temperature ranges mostly between 24 to 26 °C. This also was confirmed geochemically using plot SiO_2 vs. (Al_2O_3+K_2O+Na_2O)
8) Water salinity that was attributed to the studied horizon of the Al Jaghboub Formation is considered to be purely marine with normal salinity.
9) Paleogeographically, most of the fossil chondrichthyans described herein have a living representatives at least at generic level inhabits different ocean realms, except *Scyliorhinus*, *Galeorhinus*, *Gymnura*, *Myliobatis* and *Mobula* which are of a cosmopolitan distribution in present oceans. The teleost taxa have more or less the same paleogeographical patteren as the fossil chondrichthyans in the present study, Although, Acanthuridae are absent in the modern Mediterranean Sea, but abundant in the Indian Ocean, and that's confirm the signature of the Tethyan Ocean (i. e. the connection between Mediterranean Sea and the Indian Ocean) in the Miocene time.

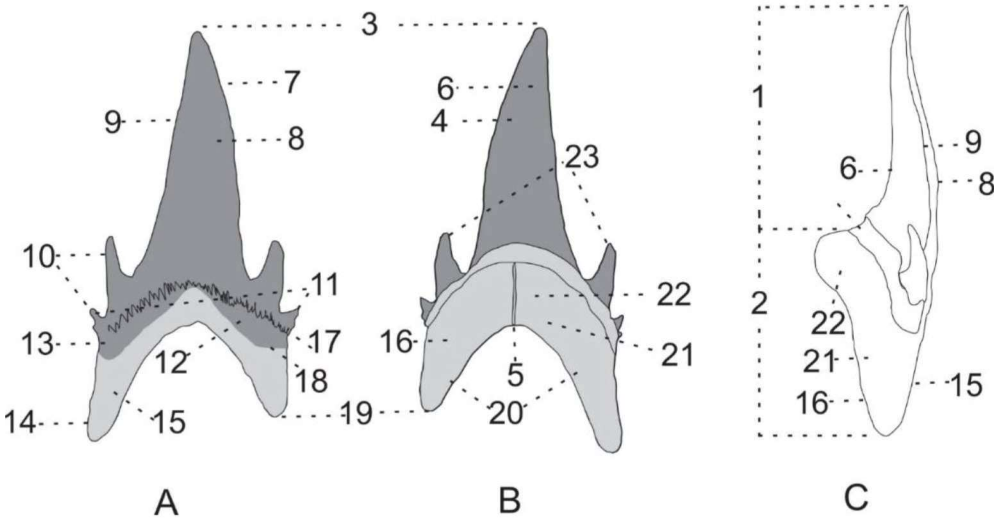
Appendices

APPENDIX A

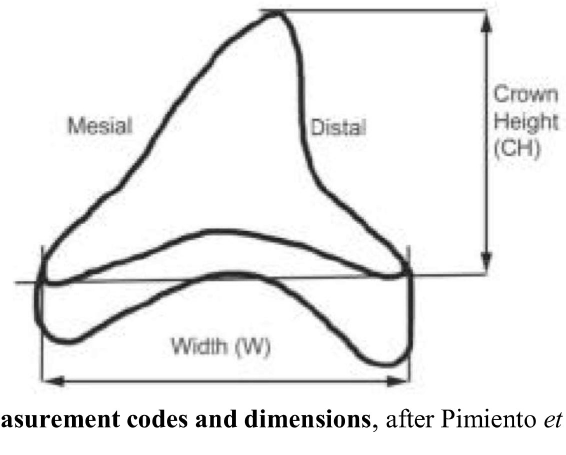
Shark Tooth Diagnostic Characters and Dimensions

In sharks (figure below), the crown generally forms a more or less sharp point, the cusp; the labial (external) and lingual (internal) faces are limited by more or less sharp cutting edges; these cutting edges may be blunt or can disappear on some anterior teeth. The enameloid may be smooth (Lamnidae) or puckered (= folded), either on the labial face of the crown (many Cretaceous Orecrolobiformes)، or on the lingual face (Mitsukurina), or on both faces (many Scyliorhinidae). On each side of the cusp there are often one to several pairs of more or less developed lateral cusplets that can be smooth or folded (Cappetta, 1987).

The term "lateral" is used for the location of teeth on the jaw. Therefore the term «marginal» is proposed to designate mesial and distal cusplets; yet the term "lateral" for cusplets seems of universal use amongst shark specialists and hardly lead to confusion (Cappetta, 1987).



Tooth terminology of sharks; anterior tooth of *Palaeohypotodus rutoti;* A, labial view; B, lingual view; C, mesial view. After Cappetta, (1987, 2012). 1, Crown; 2, Root; 3, Apex; 4, Cusp; 5, Nutritive groove; 6, Lingual face of the crown; 7, Distal cutting edge; 8, Labial face of the crown; 9, Mesial cutting edge; 10, Lateral cusplets (= denticles); 11, Marginal pair of cusplets; 12, Labial bulge of the crown; 13, Mesial crown tongue; 14, Mesial root lobe; 15, Labial face of the root; 16, Lingual face of the root; 17, Vertical ridges; 18, Distal crown tongue; 19, Distal root lobe; 20, Basal edge of the root; 21, Basal face of the root; 22, Lingual protuberance of the root and 23, Proximal pair of cusplets.



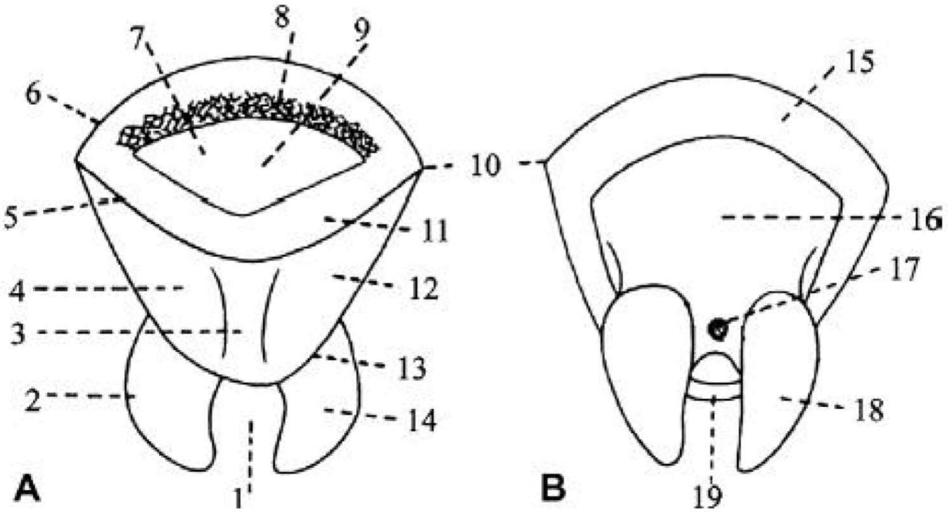
Tooth measurement codes and dimensions, after Pimiento *et al*., (2010)

APPENDIX B

Batoids Tooth Diagnostic Characters

In batoids with a crushing-type dentition, the teeth are rather different morphologically; in general, the crown lacks cusps except in the Torpediniformes and in the males of certain Rajiformes and of the Dasyaroidea. In the Dasyatoidea (Figure below), the crown is globular and bears a more or less high and sharp transverse crest separating the labial from the lingual face. The labial face of the crown may be convex or hollowed, and smooth or roughened with puckered enameloid. Generally, there are well marked marginal (= lateral sensu CAPPETTA 1970) angles. The labial edge of the crown is called the labial visor and strongly overhangs the labial face of the root; the lower part of the visor is more or less wide, sometimes Rat , sometimes convex. The lingual face of the crown is usually smooth, often with a centro-lingual ridge. The lower part of the lingual visor is narrow. The root is bilobed and often displaced lingually; the lobes can be narrow with a convex basal face‹ or wide with a flat basal face. The lobes are separated by a deep, labio-lingually directed groove, with a central foramen and/or two paracentral foramina opening marginally at the level of the central foramen. The labial face of the root is generally well developed and may bear small foramina. The lingual face of the root lacks foramina (Cappetta, 1987).

In the Rhinobatoidei, the crown is simpler and generally smooth apart from small wrinkles on the base of the lingual face of the crown. The lingual visor is indented by one or three protuberances or uvulae; the centro-lingual uvula is always present and is very distinct while the margino- lingual uvulae may be absent. The margino-lingual faces of the root generally bear one to several pairs of margino-lingual foramina (Cappetta, 1987).



Tooth terminology of Batoids (*Dasyatis* sp.): A, occlusal view; B, basal view (after Cappetta, 1987, 2012). 1, lingual notch of the root; 2, mesial root lobe; 3, median lingual ridge; 4, lingual face of the crown; 5, transverse crest; 6, labial visor; 7, labial face of the crown; 8, labial zone of the crown; 9, median labial hollow; 10, marginal angles (lateral angles); 11, lingual zone of the crown; 12, lingual marginal face of the crown; 13, lingual visor; 14, root lobe; 15, lower part of labial visor; 16, labial face of the root; 17, central foramen; 18, basal face of the root; 19, lower part of lingual visor.

Glossary:

Anterior: located forward.

Amphicoelus: hour-glass shaped vertebra.

Apex: the tip of the crown or cusp of a tooth.

Basal: toward the root.

Basal edge: an edge formed by the crown overhanging the root at the crown foot of a tooth.

Batoids: skates and rays.

Brackish: term applied to waters with salt content that is intermediate between that of fresh and sea water.

Centrum: main body of a vertebra.

Coprolite: petrified (fossilized) excrement. The undigestible residue of food eaten and passed through the alimentary canal of some animal.

Cosmopolitan: having worldwide distribution.

Crown: the enameloid-covered portion of the tooth which, unlike the root, is not anchored to the dental membrane.

Cusp: a major crown projection on a tooth.

Cuspate: having numerous crown projections (cusp and cusplets) on a tooth.

Cusplet: minor crown projection flanking a cusp on a tooth.

Cutting ridge: knife-like ridges found on cusps, cusplets, blades and occlusal crown surfaces of a tooth.

Demersal: Fishes and other aquatic organisms that live on or in close association with the ground whether it's the bottom of the sea or a lake.

Distal: The side of the tooth away from the midline of the jaws.

Dorsal: toward the top.

Elasmobranchs: sharks, skates and rays.

Fauna: animals collectively found in a geographic region.

Foramen: a hole.

Formation: the primary unit in stratigraphy consisting of a succession of strata useful for mapping or description.

Genus: a group of species believed to have descended from a common direct ancestor that are similar enough to constitute a useful unit at this level of taxonomy.

Ichthyology: branch of zoology specializing in the study of fish.

Labial: Lip side of tooth; it is usually flat or the flattest side.

Lateral: situated on the sides.

Lingual: Tongue side of tooth; it is usually rounded, and on the root, this side has a central Foramen (circular opening) or a transverse groove.

Lobate: a rounded tooth protuberance, usually refers to a root.

Meckel's cartilage: lower jaw cartilage in elasmobranchs.

Mesial: The side of the tooth toward the midline of the jaws where left and right jaws meet.

Pelagic: marine organisms that live free from direct dependence on bottom or shore.

Placoid scales: tooth-like scales found only on sharks and rays.

Polyaulacorhizous: roots having multiple nutrient grooves. e.g., *Myliobatis.*

Posterior: located rearward.

Ray: a cartilaginous fish belonging to the class Chondrichthyes, having a dorsoventrally flattened body and ventral gill slits.

Root: that portion of the tooth that in life is anchored to the dental membrane, is composed of osteodentine and lacks an enameloid covered surface.

Sagittal section: longitudinal vertical plane.

Selachians: cartilaginous fishes; sharks and rays.

Serrations: saw-toothed ornamentation of the cutting ridge of a tooth.

Subtropical: between the tropical and temperate zones.

Systematics: study of similarities and differences in organisms and their relations; includes taxonomy and classification.

Taxa (taxon): a group of organisms constituting one classified category.

Taxonomy: the principles and processes of classifying organisms into categories.

Teleosts: A large group containing most bony fishes; refers to the Teleostei, the highest superorder of the ray-finned bony fishes.

Tethys Ocean: Tethys Sea or Neotethys was an ocean during much of the Mesozoic era located between the ancient continents of Gondwana and Laurasia, before the opening of the Indian and Atlantic oceans during the Cretaceous period.

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الملخص

تم اكتشاف موقع حفريات الفقاريات في وادي الهاش، على بعد ٢٠ كم شرق مدينة طبرق، شمال شرق ليبيا. هذا النتوء الحفري هو أقل أفق لتشكيل الجغبوب الذي تم تأريخه هنا في وقت مبكر من ميوسين، في وقت متأخر من البورديجاليان (17.25 مليون سنة مضت) باستخدام النظائر المشعة ($^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$) لقشرة بالانوس، ايضا بسبب وجود بقايا للاسنان الغضروفيات. أكثر من خمسة عشر نوع من الغضروفيات و ستة اصناف من الاسماك العظمية (التيلوست) من الأفق المعني. من بين الأنواع التي تم تحديدها مثل ميغاسيليورهينوس sp.، سيليورهينوس sp.، بولاجيلوس باراغاليوس، ريزوبريونودون فيسشيوري، نيغابريون يوريباثرودون، رينتشوباتوس بريستينوس، داسياتيس روجوس، داسياتيس cf. جيغاس، داسياتيس cf. سيراليروي، غيمنورا ديلبيتي، ميليوباتيس sp.، موبولا sp.، cf. إبينيفيلوس sp.، سباروس sp.، ديبلودوس aff. إنترمديوس، باغروسس sp.، cf. دنتيكس sp. و cf. سفيرانيا sp. وقد تم الإبلاغ عن معظم الكائنات الحية التي تم تحديدها هنا في مكان آخر حول تيثيس وباراتيتيس (مثل فرنسا والبرتغال وألمانيا وإيطاليا والهند) تؤكد العلاقة بين البحر الأبيض المتوسط والمحيط الهندي في تلك الفترة الزمنية. هذا الارتباط يشير بوضوح إلى أن هذه الوجوه قد ترسبت في بيئة بحرية عميقة في ظل ظروف مناخية شبه استوائية إلى حد ما. وفي حين أن الموقع الأحفوري المعاصر في أماكن أخرى من حوض سرت في الجنوب الغربي قد ترسبت في البيئات البحرية الضحلة إلى الحافة البحرية (على سبيل المثال جبل زلطن)، فإن هذا يشير بوضوح إلى أن الشريط الساحلي كان موجودا في الجنوب خلال العصر الميوسيني المبكر.