Contribution to the taphonomic significances of the Eocene marine mammals in Wadi El-Hitan and northern Lake Qaroun sectors, Fayoum,Egypt.

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Abstract

The present work aims to study the taphonomic significances of the middle and late Eocene skeletal remains ofmarine mammals in the Wadi El-Hitan and Jebel Qatrani areas of Fayoum, Egypt. These richly fossiliferous bone-bearing horizons include well preserved skeletons of primitive whales (Archaeoctes) and sea cows (Sirenians). The controlling factorsaffectingthe concentrationand mode of the skeletons in each horizon are discussed. Taphonomic data including mode of articulation, fragmentation, abrasion, polishing and bio-erosion are recorded and interpreted. The taphonomic interpretation is supplemented by the lithologic data to reconstruct physical and biological events. It is observed that most of the skeletal remains occurinstratigraphic horizonswith particular characteristics within the different levels of the Eocene rock units of the studied areas. The remains show varying degrees of articulation (complete, partially articulated and disarticulated skeletonsofwell-preserved bones). Thismay indicate thatthe skeletons were rapidly buried on sea floor. Most of the bone fossils show very low degrees of abrasion, indicating little movement by sea currents.Marks compatible with shark-like bites werealso observedonthefossilized bones. Bio-erosion evidence is clear on many bones from some horizons of the Eocene formations in the northern Lake Qaroun, indicating somewhat longer exposure before the remains were covered. However, taphonomic and sedimentological characteristics indicate a short period of time between death and burial of the bones

Key words: Taphonomy, Eocene, Archaeocete, Wadi El Hitan**,** Egypt**.**

Introduction

Marine mammals (Archaeocetes and Serinians) of the Fayoum province are concentrated in the Middle and Late Eocene layers (Gehannam, Birket Qaroun and Qasr El Sagha formations) in Wadi El Hitan and northern lake Qaroun, (Fig. 1). This natural heritage site in the north and northwest of Fayoum depression was discovered at the beginning of nineteenth century. Schweinfurth (1879) discovered the first Archaeocete fossil in Fayoum at Gezerit el Qarn within Lake Qaroun. Dames (1883a, b) described the first well preserved dentary of *Zeuglodon osiris* (now *Sagahcetus osiris*) in the north of Lake Qaroun. Beadnell (1905) discovered a large dentary of *Zeuglodon isis*(now *Basilosaurus isis*). Andrwes (1906) discovered a well preserved skeleton skull of *Prozeuglodon osiris* (now *Dorudon atrox*).

Dart (1923) defined the species of *Zeuglodon sensitivus* and *Zeuglodon intermedius* and he thought that the vertebrate fossils were extracted from the Gehannam Formation. Gingerich *et al*. (1990) described for the first time the hind limb of the *Basilosaurus isis* in Wadi El Hitan, includes the foot bone. Doming *et al.* (1994) described the *Protosirens mithae* as a new Protosirenidae on the basis of associated cranial and postcranial from the Late Middle Eocene (Latest Bartonian), the Gehannam Formation of Wad El Hitan, Fayoum Province. Gingerich *et al.* (1996) discovered and described the new species of Archaeoctes, *Ancalectus simonsi* from the Birket Qaroun Formation. Zalmout *et al.* (2008) described a new species of Sirenians that collected from the cliffs of the Northern shore of Qaroun Lake. Peters *et al*. (2009) made a focus study on the north of Wadi El-Hitan area, as sedimentation and preservation of the

Eocene marine vertebrates, controlling by physical processes for sequence stratigraphic architectures on siliciclastics shelf. They mentioned that the marine vertebrate are concentrated in stratigraphic intervals, and the taxonomic composition of whales changes with sequence position, *Basilosaurus isis* skeletons are concentrated in offshore marine flooding surface and *Dorudon atrox* skeletons are concentrated in foreshore sediments. Antar *et al.* (2011) studied the anatomy of *Basilosaurus isis* skeleton, which collected from the Wadi El-Hitan. Abu El Kheir *et al* (2013) described for the first time the dentary of *Masracetus markgrafi* from the north of Qaroun Lake. The most abundant whale skeletons in these areas are *Basilosaurus isis* and *Dorudon atrox* with *Masracetus markgrafi* and *Saghacetus osiris* less numerous. Whale and sea cow skeletons are found in bone horizons of Gehannam, Birket Qaroun and Qasr El Sagha formations. Most of the bone horizons are concentrated in the lower parts of Gehannam and BirketQaroun formations inehtWadi El Hitan and Northern Lake Qaroun sectors.

The aim of the present study is to describe the taphonomic characteristics of marine mammals (Archaeocetes and Serinians), association with other fossilized remains and the characteristics of the horizons in relation to the distribution of the stratigraphic facies of the exposed Birket Qaroun and Qasr El Sagha formations) of the Fayoum Depression. Environmental characteristics are also reported.

Materials and Methods

Fifteen stratigraphic sections were measured and stratigraphically and paleontologically described with recognizing of particular sedimentary structure(s) and lithological properties in addition to vertebrate taphonomic horizons, (see plates 1, 2 and 3).

More than 500of whales and about 50 sea cow specimens were recorded and photographed in situ. Many specimens were damaged and scattered by recent erosion while others remained within the associated layer and almost covered with sediments.

The studied marine mammal are recorded with G.P.S(using a handheld GPS unit), depending on the taxonomic composition and the distribution of the stratigraphic facies.

The recorded taphonomic data include: degree of articulation, degree of abrasion, fragmentation, association with other fossilized fauna, orientation of the skeletons, evidence of bio-erosion and the lithostratigraphic characteristics of each bone horizons. According to Fiorillo (1988) and Bossencker subdivision in 2011, these data are classified as follows:

Articulation of the skeletal remains was classified into three intervals1= articulated skeleton, 2= disarticulated skeleton, 3= partially articulated elements, 4= isolated elements.

Abrasionwasclassifiedinto three stages, un-braded, very angular (stage 0), lightly abraded, sub-angular (stage 1) and heavily abraded, sub-rounded (stage 2).

Fragmentation was classified into three intervals, un-fragmented, (stage 1), slightly fragmented, (stage 2) and highly fragmented (stage 3).

Bio-erosionand bio-encrustation was classified bythe type of the bio-erosion as boring, shark biting or shark biting and the presence or absence of invertebrate encrusting.

Polishing was classified into three stages, unpolished (stage 1) slightly polished (stage 2), and highly polished (stage 3).

Results

Occurrence and distribution of marine mammals

Fossilized whale remains are present, including *Basilosaurus isis*, *Dorudon atrox*, *Masracetus markgrafi*, *Anclacetus simonsi* and *Saghacetus osiris*. Remains of other marine vertebrates, such as sea cows, crocodiles, turtles and fishes are also present and are abundant in the north-northwest side of the Fayoum Depression. These vertebratemarine fossils are located in several successive, distinct bone beds or “horizons”. Whales and sea cows occur frequently in Wadi El Hitan and north of Lake Qaroun, within Eocene strata of the Gehannam and Birket Qaroun formations.

The present study recorded the lithology and primary sedimentary structures associated with each horizon, together with taphonomic features affecting marine vertebrate bones, including degree of articulation, abrasion (following Fiorillo, 1988), bio-erosion and bio-encrustation.

Sectors and horizons / Taphonomic features	North Qaroun Lake sector														Wadi El Hitan sector											
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H 12	H 13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24	H25	H26
Articulation	4	4	2	1	4	2-3	3-4	3-4	2-3	3-4	3-4	3-4	4	3	4	4	2-3	4	1-2	1	1	2-3	2-4	4	1	2-3
Abrasion	2	2	1-2	0	2	2	2.	2	1	1	2	1	2	2	2	0-1	0-1	0	0-1	0	1	1	1	2	1	3
Fragmentation	3	3	2	1	3	2	2	2	2	2	2-3	2	2	2-3	3	3	2-3	3	1-2	1	1	1-2	2	3	2	3
Polishing	-	-	-	-	3	-	3	3	2	2	-	-	3	-	3	-	-	0-1	3	1	2	2	-	3	-	3
Bio-erosion deformation	-	Enc bit		Enc Bit sqz	-	enc	enc	enc	enc	-	enc	-	-	-	-	-	Bit Bor.	-	Enc Bor.	-	Sqz	Enc Bit	Enc Scrat	-	-	Bit Enc Bor
Recent weathering & erosion	1	3	3	3	3	1	-	1	1	-	2	-	-	-	-	-	-	-	1	-	-	1	-	2	-	-
Taxonomic composition	Cr M D B Sh	Cr M D B Sh	M D B Sh	B Sh	M B Sh	Cr M B Sh O	D B Sc Sh	B D M Cr Sh O	B D M Sh O	D B Sc	D Sc	Sc Sh	D Sh	Cr Sh O	B D	B D Sc	B D Sh	B Sh	B, D Sh Cr O	B D	B	B D M	B D M Cr	B D Cr Sh O	B	Sc Sh

Table (1) Distribution of the taphonomic features and the taxonomic composition along the different vertebrate horizons. H: horizon, Bit: shark Biting, Bor: borings, Enc: encrusting, Sqz: squeezed, Scrat: scratching, B: *Basilosaurus isis*, D: *Dorudon atrox*, M: *Masracetus markgrafi*, Sc: sea cow, Sh: shark teeth, Cr: crocodile, O: others.

The following paragraphs describe the lithological characteristics andvertebrate preservation (e.g.the taxonomic composition and taphonomic characteristics) for each defined stratigraphic horizon (bone bearing layer) in the North Lake Qaroun and the Wadi El Hitan areas.

Horizons of the North of Lake Qaroun

Four horizons referred to as 1st to4th(Figs. 3 to 8) were found in the Gehannam Formation. Ten horizons, referred to as 5th to 14th (Figs. 9 to 16) were found in the Birket Qaroun Formation in the North of Qaroun Lake.

The first horizon:

This horizon of the Gehannam Formation is represented in the North Ghard, the Qaret Umm Regl and the Qaret Mizar sections which is mainly mudstone to fossiliferous sandstone. In the Qaret Mizar for instance, it detected above the base of the section by about 26 m within the massive mudstone. The bone bearing layer is composed of grayish white, gypsiferous, calcareous, fossiliferous mudstone with whale and fish bones, crocodile bone fragments and shark teeth.

The vertebrate fossils are mainly represented by crocodile bone *Masracetus markgrafi*, some scattered vertebrae of *Dorudon atrox* and *Basilosaurus isis*, shark teeth and *Pristis* sp. teeth (Figs.4&5 inclusive). These bones are heavily abraded (stage 2), heavily fragmented (stage 3), scattered (stage 4) and highly affected with the recent erosion activities. Some whale skeletons are covered with thin layer of conglomeratic, highly fossiliferous, calcareous sandstone, which is full of crocodile and shark teeth. The bones are also affected by the recent weathering as the sand polishing and the heat shattering.

The second horizon

The second horizon of the Gehannam Formation is located above the first horizon by about 7 m thick of dark, gray laminated shale. It is very similar to the first horizon, consisting of 1 m thick of grayish white, massive, fossiliferous, mudstone. It is highly affected by the recent weathering activities. Most of the marine vertebrates are *Masracetus markgrafi, Basilosaurus isis* and *Dorudon atrox* (Fig. 6). Their bones are heavily abraded (stage 2), heavily fragmented (stage 3) and scattered (stage 4). The encrusting by some pelecypods and biting by sharks are

observed in the whale bones. The shark and crocodile teeth are accumulated around the fragmented whale skeletons.

The third horizon

The third horizon is separated from the second horizon by about 2.5 m. This horizon is formed of 2 m thick of grayish white calcareous massive mudstone. Most of the marine vertebrates are *Basilosaurus isis* skeletons and some bones of *Dorudon atrox*, *Masracetus markgrafi* and *Pristis* sp. and other fishbones (Fig. 7). The whale skeletons are disarticulated (stage 2); slightly abraded (stage 1) and some are slightly fragmented (stage 2). Many skeletons of this bed have squeezed vertebraethat may be affected by the load of upper mudstone layer. The encrusting by some shells and the shark biting are well observed in the whale bones.

The fourth horizon

The fourth horizon is located in the Gehannam Formation above the third horizon by about 6 m. This horizon is formed of grayish white calcareous mudstone. Most of this horizon is covered with Pleistocene deposits and talus. Few Complete and articulated (stage 1) skeletons of *Basilosaurus isis* are found in the top of the horizon. Shark teeth andfish bones are also found in this horizon. It is well preserved due to its covering with sediments and less affected by the recent erosion activities (Fig. 8).

The fifth horizon

The fifth horizon is well observed at Qaret El Beni in the lower unit of the Birket Qaroun Formation. It is formed by 2 m thick of grayish yellow, calcareous, highly fossiliferous sandstone and banded sandy mudstone. Most of the preserved vertebrates in the fifth horizon are *Basilosaurus isis*, *Masracetus markgrafi* and shark teeth. These bones are highly fragmented (stage 3), isolated elements (stage 4), and they are heavily abraded (stage 2) and slightly polished (stage 2). These bones are highly affected by the ancient lake Qaroun flooding.

The sixth horizon

The sixth horizon of the Birket Qaroun Formation is well exposed at Qaret El Beni section. The horizon is formed of about 2 m thick of grayish white, burrowed, conglomeratic, ferruginous, highly fossiliferous, thalathinoidal, bioturbated with oyster bank sandstone. It is characterized by the presence of thin band of iron oxide and eolian deposits at the upper surface (Fig. 9).Most of the vertebrate fossils are *Masracetus markgrafi*, *Dorudon atrox* and *Basilosaurus isis*, shark teeth, turtle, crocodile and fish bones.The *Basilosaurus isis* bones are found as scattered vertebrae (stage 4) on the upper surface of this bed. *Dorudon atrox* bones are found as partial skeletons (stage 3) and scattered vertebrae (stage 4) on the upper surface of this horizon. The *Masracetus makgrafi* bones are found as disarticulated skeletons (stage 2) to scattered vertebrae (stage 4) in the middle and the top of this bed. In general, the whale bones of this horizon are slightly abraded (stage 1) and slightly polished (stage 2) (Fig.9). The encrusting of the pelecypods is well observed on the surface of the whale bones. The concentration of the whale fossils in this bed is low and highly affected by recent erosion activities.

The Seventh horizon

The seventh horizon is located above the sixth horizon by about 10 m thick of gray shale, north ofQaret El Beni section. It is composed of reddish white, conglomeratic, burrowed, bioturbated and highly fossiliferous sandstone. It is cliff forming with oyster bank on the upper surface of the bed and irregular lower surface. This has a long extension and exposure in the west direction, where it is affected by the recent flooding streams (Fig. 10). The presence of the vertebrate fossils is very rare in this horizon. Most of the vertebrate fossils are partial skeletons (stage 3) of *Dorudon atrox*, scattered vertebrae (stage 4) of *Basilosaurus isis***,** partial skeletons of sea cows (stage 3), shark teeth and fish bones. Some partial skeletons of *Basilosaurus isis* and *Dorudon atrox* in the opposite side of Gezerit El Qarn El Zahabi are moved from their places by the recent flooding streams. These vertebrate bones are heavily abraded(stage 2), slightly polished (stage 2) and encrusted by some shells.

The eighth horizon

The horizon is well observed in the opposite side of Gezerit El Qarn. It located in the lower unit of the Birket Qaroun Formation. It is formed of about 2 m thick of yellow, friable, very

fine grained, ferruginous, calcareous, burrowed, highly fossiliferous, thalathenoidal and bioturbated sandstone with the presence of the fragmented shells in the upper surface of the bed(Figs. 11&12, inclusive). It is covered by the Holocene deposits and affected by the flooding of the Qaroun Lake, with the presence of many tnecerfish, crocodile and turtle bones and some traces of the prehistoric and Grecco-Roman human activities. Most ofthe vertebrate fossils in the eight horizons are *Basilosaurus isis, Dorudon atrox, Masracetus markgarfi*, *Pristis* sp. rostrum, turtle, crocodile and fish bones and shark teeth. Most of these bones are slightly fragmented (stage 2), heavily abraded (stage 3), slightly polished (stage 2), and slightly fragmented (stage 2). The whale skeletons are found as separated vertebrae (stage 4). The encrusting by shells is observed in the whale bones. The shark teeth are concentrated around the whale bones. The vertebrate fossils in this bed are affected by the Lake Qaroun flooding. There are many encrusting of some shells from the Pliocene period.

The ninth horizon

The ninth horizon of the Birket Qaroun Formation is located above the eighth horizon in the opposite site of Gezerit El Qarn by about 7 m. It is formed of about 1 m thick of grayish brown, conglomeratic, calcareous, burrowed, Thalathenoidal, fossiliferous sandstone. The lower surface is irregular with the presence of globular shaped concretions (Fig. 13). This horizon is highly ferrugenated at the top. It is characterized by the presence of high accumulations of shell fragments at the upper surface of this bed. This horizon is not well exposed. It is covered by the Holocene deposits and the overlain weathered layers. Most of the vertebrate fossils in the ninth horizon are *Dorudon atrox*, some vertebrae of *Basilosaurus isis* and *Masracetus markgrafi*, turtle and fish bones, *Pristis* sp. and shark teeth. The *Dorudon atrox* and *Basilosaurus isis* are found as disarticulated, partial skeletons and (stage 2 to 4), slightly abraded (stage 1), slightly polished (stage 2). There is some encrusting by pelecypod shells on the surfaces of the whale bones. The bones are highly affected by the recent erosion activities. Some *Dorudon atrox* vertebrae are very light in weight than the others found in the other beds that may be due to dissolve of some minerals of the bones, which caused by the fossilization process.

The tenth horizon

The tenth horizon of the Birket Qaroun Formation in the North of Lake Qaroun is well observed at the mainland opposite of Gezerit El Qarn and in the east of Dime. This horizon contains some whale and fishbones.Most of the vertebrate fossils in this horizon are *Dorudon atrox*, *Basilosaurus isis* and some bones of sea cow. The whale bones are partial skeletons to isolated elements (stage 3 to 4). These bones are slightly removed by the incised valley fill in this area and are slightly abraded (stage 1) and slightly polished, (Fig. 14).

The eleventh horizon

The eleventh horizon of the Birket Qaroun Formation at the North of Lake Qaroun is formed of about 1 m thick of grayish yellow, fossiliferous sandstone. This horizon is observed in the mainland opposite side of Gezerit El Qarn, east of Dime and El Kanays areas. The *Dorudon atrox* and sea cow are the most abundant vertebrate fossils in this horizon. The whale bones are scattered (stage 4) to partial elements (stage 3) and are slightly to highly fragmented (stage 2 to 3), heavily abraded (stage 2) with some shell encrusting. These bones are highly affected by the erosion of the Lake Qaroun.

The twelfth horizon

The twelfth horizon of the lower unit of the Birket Qaroun Formation is well observed at mainland opposite side of Gezerit El Qarn, east of Dime and Qum Oshim areas. The vertebrate fossils in this horizon are very little. Some scattered bones and partial skeletons of sea cows and shark teeth are only existed. These bones are slightly abraded (stage 1) and highly fragmented (Stage 3)

The thirteenth horizon

The thirteenth horizon is located in the upper unit of the Birket Qaroun Formation is recorded at Qaret Umm Regl and Qaret Mizar sections. The contained vertebrate fossils in this horizon are very little. Partial skeletons (stage 3) of sea cows, fragmented turtle bones, some scattered vertebrae of *Dorudon atrox* and shark teeth are only existed. These bones are highly fragmented (stage 3), scattered (stage 4) and slightly abraded (stage 1).

The fourteenth horizon

This horizon is located at the basal part of the Qasr El Sagha Formation at Qum Oshim section, which includes the famous site of Sieffert (2008) (Figs. 15&16). This horizon is formed of about 1 m thick of limy conglomeratic, friable, ferruginous, highly fossiliferous sandstone. This horizon is characterized by the presence of fragmented pieces of petrified wood logs and thin bands of ferruginous sandstone. It is covered with spherical and biscuit shaped concertinos with the *Trypaite* trace fossils. The horizon is not continuous along the extension of the layer. It is replaced in some places by marine shale. It is well exposed at the north of Dime ruins. A new location is recorded by the present author at about 2 km to the south of the Qasr El Sagha temple. Most of the vertebrate fossils are highly fragmented (stage 3) including parts of sea cow bones and terrestrial vertebrate remains of Probosideans (*Moeritherium* and *Barytherium*. This horizon includes also small mammals, ranging from primates (*Karanisia* and *Saharagalago*), hyracoids, herodotines, potolemaiids, rodents, creodonts, bats and insectivores (Sieffert, 2008). There are also many fragmented bones of crocodiles and turtles. These bones are highly fragments (stage 3), heavily abraded (stage 2), cracked and scattered (stage 4). There are no complete or partial skeletons of any terrestrial or marine animals in this horizon.

6.1.2 Horizons of the Wadi El Hitan.

The Gehannam, Birket Qaroun and Qasr El Sagha formations are represented by 3, 8 and 1 horizons, respectively. In Wadi El Hitan, they contain the famous well preserved whale and sea cow skeletons. These skeletons are existed in the detected horizons, referred to as fifteen to twentieth six, which are described as below.

The Fifteenth horizon

The horizon is located in the Gehannam Formation at the Qaret Gehannam section. This horizon is formed of grayish gray, calcareous mudstone. Most of the frequent types of vertebrate elements are whale skeletons; mainly belong to *Basilosaurus isis* and *Dorudon atrox*. The whale bones are slightly fragmented (stage 2) and scattered referable to stage 4 (isolated elements) and slightly polished (stage 2). They are also affected by the recent weathering as the sand polishing and the heat shattering.

The sixteenth horizon

The horizon is located in the lower third of the exposed part of the Gehannam Formation and is well exposed at Qaret Gehannam and Minqar El Hut sections. This horizon is formed of about 0.5 m thick of yellow, marly, conglomeratic, fossiliferous sandstone(Fig.17). The lower surface is irregular with the presence of burrows, *Ophiomorpha* and rootlets. This horizon contains *Nummulites,* shell fragments, fish fragments, echinoid spines and barncles (*Balanus* sp.)encrusting the whale bones and crabs of the genus *Lobocarcinus*. The lower surface of this horizon is characterized by the presence of paleosols of grayish white, sandy limestone. The bed is topped by fine to medium grained, fossiliferous sandstone with fragmented shells and remains of echinoid spines and skolithos trace fossils. It contains whale skeletons (*Basilosaurus isis* and *Dorudon atrox*). The most frequent types of vertebrate elements are whale skeletons, mainly belonging to *Basilosaurus isis*, which are grouped in clusters. Parts of sirenian ribs and shark teeth are sometimes associated. The whale bone in this horizon is fragmented and scattered, referable to stage 4 (isolated elements) of the articulation stages. The level of their abrasion is between unabraded (stage 0) and slightly abraded (stage 1). The bones are also affected the recent weathering as the sand polishing and the heat shattering.

The seventeenth horizon

The horizon is located about 3 m above the sixteenth horizon. It is well exposed at Qaret Gehannam and Minqar El Hut in the Gehannam Formation. This horizon is formed of about 0.5 m of grayish white coarse-grained, fossiliferous sandstone with the presence of *Skolithos*, which extend vertically to the lower bed by about 20 cm. This bed is also characterized by the presence of paleosols formed by recrystallized calcareous sandstone from the underlying bed. The lower surface of this layer is irregularly eroded. This horizon contains different forms of shark teeth and skeletons of different species of whales. Shell fragments and articulated shells of lucinid bivalves are abundant around the skeletons of the whales. Other invertebrate fossil associated with whale bones are turritellid gastropods and hemiasterid echinoids (Figs. 18 to

21). The upper part of this bed is characterized by the presence of a network of *Thalassinoids* at the top. The sandstones associated with the whale bones are characterized by red color due to the iron oxide pigmentation. The species of *Basilosaurus isis* and *Dorudon atrox* represent more than 90% of vertebrate bones. Some whale skeletons are disarticulated to isolated elements (stage 4). The isolated heavy elements are close to each other in an anatomically-consistent way, (e.g., thoracic vertebrae are close to the ribs of the correspondent whale skeleton), while the broad and light elements (e.g. lower jaws and scapulae) are located somewhat further away from the backbones. Whalebones are unabraded (stage 0) to slightly abraded (stage 1), sometimes highly fragmented (stage 3). Some invertebrate casting is observed around the whalebones(Fig. 21). The largest number of skeletons, among which a semi-complete specimen of *Dorudon atrox*, is found in the A-interval that designed by Bossenecker *et al*., (2011).

Eighteenth horizon

This horizon is observed at Sandouk El Bornitta section. The whale bones are located in 0.5 m thick of yellowish white, fossiliferous, calcareous sandstone horizon. Most frequent type of vertebrate elements is whale skeletons, mainly belonging to *Basilosaurus isis*, with some shark teeth association. The whale bones are scattered, isolated elements stage 4). These elements are unabraded (stage 0).

Nineteenth horizon

This horizon represents the top of the upper unit of Gehannam Formation and is represented by root bearing-burrowed limey sandstone-mudstone. The lower part of this horizon is rich in *Nummulites* and mollusks including *Lucina* sp., teredolited, shark teeth, crabs fragments dna fish bones There is a large tree trunk (about 18 m) in the same level of this layer, covered with *Teredolites*, which is filled with celestite. This layer is one of the most important layers containing whale skeletons of the Wadi El Hitan area. The *Basilosaurus isis* and *Dorudon atrox* are the most abundant species in this layer. Shark teeth of different species are occurred abundantly. dna eltrut ,elidocorCfish bone sare less common. The exposed upper parts of the skeletons are heavily weathered; however, the lower covered parts of skeletons are well preserved and not polished. The whale skeletons are articulated (stage 1) to disarticulated (stage 2). The ribs and lower jaws are separated from the whole skeleton and the skull by few meters. Some skulls are overturned and articulated with the skeletons. The forelimbs, scapulae, humerus, ulna and radius are quiet arranged regularly to each other systematically with the skeletons, but in some other specimens these bones are occurred randomly and separated. Exposed whalebone skeletons in this horizon are unabraded, (stage 0) to slightly abraded (stage1) and un fragmented (stage 1) (Figs. 22 to 26). Some borings of molluscan shells are observed in the bone remains. Some Arthropods (*Balanus* sp.) that built its shell on the whale bones are observed with some worms burrowing (Fig. 26). The exposed skeletons in this layer are also affected by the recent weathering as sand polishing and the heat shattering.

The twentieth horizon

This horizon is composed of 0.5 m of pale yellow, fossiliferous, burrowed sandstone with shell fragments and whale skeletons. It is well exposed in the lower unit of the Birket Qarun at Sandouk El Bornitta section. The *Basilosaurus isis*, *Dorudon atrox* and some sea cow skeletons are the most abundant marine vertebrate remains. The skeletons are very well preserved, articulated (stage 1) to disarticulated (stage 2) and unabraded bones, (stage 0).

The twentieth first horizon

This horizon is composed of 0.5 m thick of grayish yellow, highly gypsiferous, highly burrowed, and fine cross bedded, argillaceous, fossiliferous sandstone, shell fragments and whale skeletons. The horizon is exposed in the lower part of the Birket Qaroun Formation at the Northern side of the Wadi El Hitan. The *Basilosaurus isis* skeletons are observed in the horizon (Fig. 27). These whale skeletons are located in the upper part of this horizon. The whale skeletons are articulated (stage 1) to disarticulated (stage 2), slightly abraded (stage 1), slightly polished (stage 2). The whale vertebrae are squeezed by the loading of the shale bed of the upper shale beds above the skeletons, (Fig. 28). The bones are occasionally deformed by Gypsum inter pore spaces filling. The shark biting in bones are also observed (Fig. 29). Fragmented, unabraded (stage 0), partial skeleton (stage 3) of sea cow is existed at the top of

this horizon. The exposed skeletons are also affected by the recent weathering as heat shattering and the sand polishing.

The twentieth second horizon

This horizon is formed of 0.5 m thick of grayish yellow, argillaceous, calcareous, burrowed, ferruginous, fossiliferous sandstone. Fossilized whale skeletons, bone fragments of sea cow and shark teeth are observed (Figs. 30&31). The horizon extends to the north and north east side of the Wadi El Hitan with some lateral variations into more argillaceous and highly burrowed at the top, fossiliferous sandstone with weathered surfaces. The *Basilosaurus isis, Dorudon atrox,* and *Masracetus markgrafi* are abundant skeletons. Some partial skeletons of sea cow are also observed. There are many species of shark teeth and other fish and turtlebones are included. The whale skeletons are located at the bottom of the horizon.They are disarticulated (stage 2) and slightly fragmented (stage 2). The bones are slightly abraded (stage 1) and slightly polished (stage 2). The shark teeth and some Pelecypods are concentrated around the whale skeletons. Some shark biting and encrusting are observed on the surface of the whale bones by the pelecypods and the Barnacles. The whale bones are covered with thin coating of iron oxides and black spots.

Twentieth third horizon

This horizon is located at the lower unit of the Birket Qarun Formation. It is formed of about 1 m thick of conglomeratic, calcareous, ferruginous, fossiliferous, rippled sandstone with shell fragments. It contains whales, other fish fragments and shark teeth (Fig. 32). *Basilosaurus isis* and *Dorudon atrox* are the most common whale skeletons of the horizon with the presence of some skeletons of *Masracetus markgrafi*. There are also some crocodile fragmented skeletons, different species of shark teeth and saw fish rostrum and other *enob hsif* fragments. Hermit crabs are also existed in this bed. The whale skeletons are disarticulated (stage 2), partial skeletons (stage 3), isolated elements (stage 4) and slightly abraded (stage 1). There are many juvenile whale skeletons of *Dorudon atrox* are observed as isolated elements (e.g scapula, mandible, and some ribs). The scratching of the shark bitingand encrusting of invertebrate shells are observed in the whale bones in this horizon. The skeletons are also affected by the recent weathering.

The twentieth fourth horizon

The horizon is located in the upper unit Umm Regl member (Qasr El Sagha Formation in northern the Wadi El Hitan section. It is composed of about 30 cm of conglomeratic, friable, highly fossiliferous, coarse grained sandstone, which represent the basal bed of the incised valley fill subsequence. The vertebrate fossils are abundant and highly diverse. The whale bones of *Basilosaurus isis* and *Dorudon atrox* as well as fish, turtle, crocodile bones and Probosideans and shark teeth associated with some land vertebrates are the most isolated bone elements (stage 4). These bones are heavily abraded (stage 2), highly polished (stage 3), highly fragmented (stage 3), scattered (stage 4), badly weathered. The mixing of the land (e.g. *Moeritherium* and *Baratherium*) and marine mammals indicates the vertebrate remains were eroded from marine sediments and transported short distance as fluvial clasts in the system the removing of these fossils by the fluviomarine systems.

Thetwentieth fifth horizon

The horizon is located in the basal part of the upper unit of the Birket Qaroun Formation at the Wadi El Hitan area. It is observed in Minqar El Hut and Sandouk El Bornitta sections. The *Basilosaurus isis* skeletons are the most abundant whale, in addition to some enob hsif*s* (saw fish bone and shark teeth). The *Basilosaurus isis skeletons* are partially skeletons (stage 3) to isolated elements (stage 4), slightly fragmented (stage 2) and slightly abraded (stage 1).

Thetwentieth sixth horizon

The horizon is located inthe base of the Qasr El Sagha Formation of the Wadi El Hitan area. It is formed of 2 m thick of grayish white, very hard, burrowed, highly fossiliferous limestone with banks of oysters and *Carolia placinoids*. This horizon extends in all sectors of the Wadi El Hitan. It is very rare to find the vertebrate fossils of this horizon. The whale skeleton of *Saghacetus osiris*, sea cow skeletons and shark teeth are the most abundant vertebrate fossils. These skeletons are disarticulated (stage 2), partial elements (stage 3) and some are highly fragmented (stage 3), heavily abraded (stage 2), and slightly polished (stage 2). The shark

biting is not observed but the encrusting of pelecypods is well observed. The Mollusca shells are accumulated around the whale and sea cow skeletons.

Taphonomic significances

As previously mentioned in Peters *et al.* (2009), sedimentation and fossil preservation are both influenced by balance between sediment supply and formation and destruction of sediment accommodation. For this reason, the processes that control sequence stratigraphic architecture often determine apparent timing of biological origination and extinction in the fossil record, as well as the abundance, distribution, composition, and taphonomy of fossils within individual stratigraphic sections and sequences. In agreement with the conclusion of Peters *et al.* (*op cit*) that the extent to which processes that govern macro-invertebrate preservation can be extrapolated to vertebrate is uncertain because shelly macro-invertebrates differ substantially from marine vertebrates in chemical composition, size and skeletal durability, as well as in life history modes and standing population sizes. The following paragraphs discuss the taphonomic significances of the fossil preservation and distribution in relation to their controlling factors (e.g. paleobiological patterns, taxonomic composition changes with sequence position and paleoecological setting as well as diagenetic modification and surface weathering effects.

Sedimentological evidences

The taphonomic modification (e.g. the degree of articulation and abrasion) and patterns of bone dispersion, orientation, alignment and position (stratigraphical interval) of the bone horizon within the bearing bed may indicate several, sedimentological evidences. These evidences may include rate of sedimentological and paleoenvironmental conditions and, mode of bone transportation and deposition, time of exposure and burial, as well as the association of skeletal elements based on the previous taphonomic description of vertebrate horizons. The following sedimentological evidences could be interpreted

1- Some whale skeletons and isolated bone elements are deposited in A- interval (at the top of layer) that designed by Bossenecker *et al*. (2011) indicate low rate of sedimentation, which may attribute to storm currents or high agitated water. These sedimentological conditions may have played an important role in disarticulating complete whale skeletons and dispersing bones on the sea floor. The low net rate of sediment accumulation may lead to increase the exposure times of skeletons and consequently result in poor preservation and disarticulation. Obvious cases of poorly preserved bone remains are located in horizons H1, H2, H15, H16, H18 and H24.

2- Contrarily, the well preserved and complete articulated whale and sea cow remains in some horizons (despite their paucity in number) may indicate a large increase in average rates of sediment accumulation (high sedimentation rates). In this case the bone remains are deposited in B-interval (in the middle of the layer) of the Boessencker *et al*. (2011). Examples of the well preserved and complete articulated vertebrate remains are located in horizons H19, H20, H21 and H25 which are belonging to different facies parasequences of different sequence systems tracts (Table 1). However, H20 and H21 are lithologically very similar faunal contents that indicating low net rate of sedimentation. This mains that the degree of preservation depend on other controlling factors, e.g. mode of bone deposition and burial condition as well as the biological factors more than the rate of sedimentation.

3- The unabrasion and slightly abrasion of the vertebrate bones indicate that they were not transported for long distance, but may be not more than few meters on the sea floor, (Zeigler*et al*. 2005). Indeed, most moved and broken elements as scapulae, ribs and lower jaws are found very close to the whale skeleton, and also the presence of well-preserved transverse processes and the neural spines of the whale vertebrae, examples of the case are horizons H3, H4, H9, H16, H17, H18, H19, H20, H21, H22 and H25. On the other hand, the heavily abraded bone remains indicate long distance of their transportation on the sea floor which may be subjected to strong subsea currents; examples of the highly abraded bone remains are located in horizons H1, H2, H5, H7, H8, H15, and H24.

4- Some horizons as horizon H24 of the basal conglomeratic sandstone of the fluvial system, of Birket Qaroun Formation contain marine and continental vertebrate remains. They are heavily abraded and fragmented to various degrees, indicating that the transportation of these remains was carried out by strong fluvial current for a long distance. However, the marine isolated bones and teeth were eroded from older marine deposits and transported short distances as sedimentary clasts in the fluvial system which this horizon (H24) belongs. The marine remains are thus, allochtonous and represent reworked and eroded fossils left behind as erosional lags at the base of fluvial channels (Peters *et al*. 2009). Continental vertebrate remains derived directly from animal that lived in and adjacent to the fluvial system and were therefore subjected to less taphonomic and meteoric diagenetic modification during subaerial exposure (Peters *et al*. 2009).

5 - Some horizons are arranged above each other with intervals 0.5 m to 2 m in the Gehannam and the lower unit of the Birket Qaroun formations. Such vertical sequence of the horizons may indicate passive accumulation of bone remains due to their skeletal characteristics. The whale skeletons are distributed on the plain of the bed in separate locations with no active accumulations, which means the transporting of the different individuals and accumulated above each other, (Lyman, 1994). The most of whale skeletons would be too large to be carried as stream bed load, which means that these skeletons could not have been transported for long distance. Many of these skeletons have a passive accumulations, which means a very slight movements of some elements but very close to the skeleton itself, as the movements of some light elements as the limbs, some ribs cervical vertebrae and the posterior caudal vertebrae. This passive accumulation of the bone remains may have happened by physical effectiveness as tidal or wave currents or by biological effectiveness as scavengers like sharks.

6 - The alignments of the whale skeletons in the horizon H15 and the horizon H16 are not clear because there is not well exposed surface of this bed and the most of the whale skeletons are disarticulated and fragmented bones, but in some associated skeletons, they seem to be oriented to the North and to the south. The *Basilosaurus isis* skeletons of the horizon H19 are oriented to the north-northeast and south-southwest with some oriented wood trunks and *Tredolites* as a main direction. This direction of the whale skeletons may be parallel to the unidirectional flow of stream water near the mangrove shoreline. Voorhies (1969) who mentioned that the linear skeletal elements will tend to align parallel to the currents if they are submerged. These whale skeletons are presented in nearly horizontal position, the heavy anterior and light posterior elements are located in the same horizontal level, indicating that the sea floor of this bed was hard (mangrove calcareous sandstone), which were not allowed for the anterior heavy parts of the skeleton to sink in the sediments. The alignment of the whale skeletons of the horizons H21, H22 and H23 in the lower unit of the Birket Qaroun Formation are not clear (similar to H15 and H16) because the most of the whale skeleton are disarticulated but in the articulated *Basilosaurus isis* skeletons, they are oriented to the north and the south as a main direction as in horizon H19, which may be parallel to the unidirectional flow. Some of the skeletons were also affected by the Pliocene Tethyan Sea, which covered this area at that time and some Pliocene shells are built on some whale vertebra, besides the flooding of the ancient lake during the Holocene time.

Biological evidences

The biological evidences include the significances of the Skeleton composition and nature of the marine vertebrate muscles as well as the bio-erosion evidences.

Bio-erosion is defined as the process by which animals, plants and microbes penetrate surfaces of hard substrates (Bromley, 1992; Taylor and Wilson, 2003). The marine hard substrates comprise both a biogenic (sediments and rocks) and biogenic (shells, wood and bones) substrates. Despite the extensive studies on the marine bio-erosion on invertebrate skeletons

and inorganic hard grounds (Taylor and Wilson, 2003; Bromley, 2004) there are relatively little and sporadic literatures that discuss the marine bio-erosion on bones and especially cetacean bones.

Based on the type of the suspected borers, the reported bio-erosive structures in the bones of the Middle to Upper Eocene whales are subdivided into three main types:

a) bivalve-bone borings. b)worm-bone borings; and c) shark marks (scratching and biting). The following observations could be concluded:

1-The bivalve borings are rare bio-erosive structures in the studied fossil-whale bones. The morphological characteristics of these borings (Fig. 33 B& C) are attributed herein to those of the ichno genera *Gastrochaeonolites* Leymerie, 1842. The type ichno species *Gastrochaenolites lapidicus* is designated by Kelly and Bromley, 1984. This clavate borings are common in lithic and biogenic (e.g. shells and bones) substrates. Circular to oval aperture is usually narrower than the main chamber, which varies from subspherical to elongate shape (see Kelly and Bromley, 1984). In spite of the rare occurrences and relatively poor preservation status, two types of *Gastrochaenolites* borings (G1 and G2) can be easily differentiated.

Ichno species *Gastrochaenolites* are typically associated with the actions of endolithic boring bivalves (e.g. mytilid borers *Lithophaga* sp.) under shallow-water conditions. The crowded individuals mark only a few meters of water depth (Bromley, 1994). The mechanism of borings occurs by means of an acid organic secretion, bore holes to dwell inside. Moreover, similar borings are also excavated by recent *Coralliophilid* gastropods and some Sipunculan worms (Bromley, 2004).

2- Sporadic bio-erosive worm structures in the bones of the middle to Upper Eocene whales are reported. Two types of worm borings are reported. Worm-boring type 1 is rare in the study fossil-whale bones (Fig. 33 B, D) and assigned herein to the Osedax-like borings. The suspected borers are polychaetes and/or sipunculans (see Bromley, 1994) as the result of chemical and/or mechanical erosion.

Type-2 worm boring type is reported only from the vertebra of the *Basilosaurus isis* in the Gehannam Formation. It is only a single but a unique sample because of the partial cast preservation of its tracemaker (Figs.33C, E &F). The boring is cylindrical with circular cross-section, straight, but curvilinear at one end. It is horizontal, and lacks pouches and vanes. This sample has a length of 3 cm and a diameter of 1.5mm.

3- Scavenging of whale carcasses by sharks and other whales is also likely to have been an important disarticulation and dispersal mechanism. The presence of disarticulated, partial elements and fragmented bones, which may indicate that the skeletons are not rapidly buried and are affected by the predation of the scavengers as sharks and some marine crocodiles. The shark biting traces are observed in the whale bones (Figs, 34 B to D &35, inclusive).

4- The adult skeletons of *Dorudon atrox* are fossilized in circle shaped while the adult skeletons of *Basilosaurus isis* are fossilized in a snake or "S" shaped which may be reflected to the desiccation of the powerful back and tail muscles of the skeletons before it was buried (Dolson *et al*. 2002, Abu El Kheir 2010).

5- The whale bones of the Gehannam Formation in the North of Lake Qaroun are not well preserved and very low density as in those horizons equivalent at the Wadi El Hitan. The whale skeletons in these beds are not accurately distributed in restricted zones, but there are some whales skeletons are observed around the horizon. The whale skeletons are covered with thin layer of calcareous, conglomeratic, highly fossiliferous sandstone, including many shark and crocodile teeth. This indicates that the whale carcasses were as barriers in the sea floor, many organisms, worms, some molluscan shells, fish, crocodiles and sharks are accumulated above these carcasses for feeding (Fig. 34).

6- The skull and the anterior part of the skeleton are sunk more deep in the bed and the posterior part of the skeleton and the caudal are presented on the surface of the bed. The most of the caudal vertebrae in the *Basilosaurus isis* skeleton in this bed are missed which may be caused by not covering with sediments and removing by currents or by predators. This

indicates that the sea floors of these beds were soft or muddy, which allowed to the anterior heavy parts of the carcasses to sink in the sea floor.

7- The fragmentation and the disarticulation of the whale skeletons are evidences that the carcasses were not whole before buried, may have happened during decaying stages or during scavenging. The most of whale skeletons of the third horizon have a well preserved articulated state, indicating that these skeletons had rapidly buried. The lower jaws and the forelimbs are found very close to the skeleton, which means that these elements were associated with the skeleton before buried. The most of the whale skeletons of the H20, H21, H22 horizons in the lower unit of the Birket Qaroun Formation are disarticulated skeletons and have many fragmented elements, which mean that are affected by the storm action during the deposition or by scavengers as sharks which are concentrated around the whale skeletons.

Discussion

Based on the distribution of the taphonomic modification and taxonomic composition along the different vertebrate horizons, the following observations can be concluded.

1- The generalized interpretation of Peters *et al*. (2009) who suggested that the preservation of the study vertebrates in the North the Wadi El Hitan section is controlled primarily by the physical processes of the sequence stratigraphic architecture cannot be accepted for the study Late Bartonian–Priabonian succession in the study the Wadi El Hitan and the North Lake Qaroun sectors. Furthermore, no consistent relationship was found between the inferred durations of the erosional omissional hiatuses and the degree of the concentration or state of preservation of vertebrate remains as indicated from the taphonomic characteristics of the horizon H24.

2- It was found that the stratigraphical distribution of the marine vertebrate fossils (as given in Table 3) shows superimposed variation in the concentration and state preservation of vertebrate remains in some horizons (e.g. H21, H22, H23, H25 and H26). It was found that the dominant taxon is shifted from *Basilosaurus isis* with few specimens of *Dorudon atrox* at the lower unit of the Birket Qaroun Formation at the H21, H22 and H23 to *Dorudon atrox* in the upper unit of the Birket Qaroun Formation, that represented by H25 and more recent, it is shifted to dugong – dominated assemblages at the top horizon (H26) near the base of Qasr El Sagha Formation with few exceptions. However, this vertical succession in relative abundance of the vertebrate species (taxonomic composition) cannot be applied in all stratigraphic sections and consequently may not be indicative of a true temporal biological trend. Instead, it could be controlled by a sea level forced environmental stacking pattern that resulted in the vertical stratigraphic juxtaposition of an original onshore – offshore faunal gradient (i.e. habitats tacking, (Peters *et al*., *op cit*.), which main that the big marine animals are deposited in deeper areas than the small animals, which may be deposited onshore than offshore areas. In this respect, it was suggested that the *Basilosaurus isis*, the largest bodied whale, may have been more prevalent than *Dorudon atrox* (the relatively smaller bodied whale in deeper water, offshore environments, even though both whales occurs across the same range of environments.

3- The vertebrate horizons H18 within the mangrove limy sandstone- mudstone straddling low sea stand, is more or less similar to horizon H24 in having mixed types of marine vertebrates, however, it includes articulated and disarticulated complete whale skeletons and dispersing bones on/or near the valley floor within or nearby the mangrove beds. It includes thetype and many referred specimens of *Basilosaurus isis* and *Dorudon atrox* as well as specimens referred to *Eotheroides* sp. and *Protosiren* sp. in addition to diverse segments and parts of sharks and sea turtles with rare crocodile. The paleoenvironment (as mentioned before) is a shallow marine shelf with evidence of restricted circulation and chemical precipitation of celestite.

4- The *Basilosaurus isis* skeletons are co-occurred with the *Dorudon atrox* skeletons in the horizons H1, H2, H3, H15, H16, H17, H4, H18 and H19, which showed that no direct relation between their sequence position and taxonomic composition change as mentioned in horizons H20, H21, H22. Nearly all skeletons are found on or within the tops of the coarsening upward mudstone – limey sandstone cycles.

5- The dominance of well-preserved articulated and nearly complete *Basilosaurus* skeleton within the mangrove parasequence which represents a sea level fall does not support the hypothesis of Peters *et al*. (2009) that *Basilosaurus* dominant in deeper water of transgressive phase sequence. The sea level fall, through the modification of shallow shelf habitats, could cause a true decline in the abundance of *Basilosaurus*. However, the dominance of *Basilosaurus* may indicate either it was a shallow marine specialist or it may have been generally adapted to the expansive, epeiric sea environments in which whales first evolved (Gingerich, 1992). Contrarily to the Peters *et al*. (op cit) hypothesis, the low sea stand condition during the deposition of the top of the upper unit of the Gehannam Formation may help greatly in explaining why so many vertebrate skeletons have been preserved in Wadi El-Hitan area. Some skeletons may have beached on shallow shoals by retreated tides contrarily to Peters *et al*. hypothesis (Gingerich 1992). However, the quiet shallow brackish, partially open marine restricted (lagoonal) environment which favored the development of the mangrove may trap the whale skeletons of different generations. The vertebrate remains of the horizons H18, H19 seem to be subjected to a digenetic and weathering modification (e.g. celestite filling and cementation, iron staining indicating subaerial exposure and meteoric diagenesis.

6- Supported to the present suggestion, particularly with the mangrove local environments, the whale carcasses were deposited in a shallow marine environment (like the case of the mangrove horizon in the Wadi El Hitan sector), which is not quite suitable for living and movement for this big animal. It thought that the whales were lived and died in deeper water than the carcasses position. By the decomposition of the carcasses by bacteria, the abdomen was bloated by gasses and floated up to the surface of the water, so the bloated whale will almost always upside down (Esperante, 2002). The tidal and wave currents moved these carcasses to the shallow water near the shoreface. When the gasses were escaped of the abdomen or the carcasses were exploded, the carcasses went into a free-fall and landed at any position. The most of the whale skull are found upside down positions and the vertebral columns are presented in the left or right side, indicating the upside down position of the carcasses before burial. The lower jaws are found articulated or very close to the skull of the skeleton, indicating the rapid burial of the carcasses, (Esperante *op. cit*.). In other skeletons the lower jaws are missed, may be disarticulated rapidly in floating decaying whale carcass, (Schafer, 1972). Indeed, some lower jaws are found as an isolated element and far from any skeleton.

The dominant of the dugong remains in shoreface and embayment environments is consistent with their subsistence on sea grasses which have been found as fossils in dugong – bearing horizons. It is worth to mention that the only dugongs have been found in the Qasr El Sagha Formation in the horizon H26.

Summary and conclusion

The taphonomic significances of the study vertebrate fossils preservation and distribution including sedimentological and biological evidences along different horizons (26 horizons) were discussed. The relation of these horizons to sequence systems tracts was discussed with the previous related studies. It was no relation between the inferred duration of the erosional omissional hiatuses and the degree of concentration or state of preservation of the vertebrate remains.

The description of the taphonomic features and their significances of the study marine vertebratemammals (especially the whale and seacow) skeletons were documented along the recognized horizons. The vertebrate remains (fossils) were described and recorded in each horizon for the comparative taphonomic analysis in relation their depositional environments.

The taphonomic features include the degree of articulation, fragmentation, abrasion, polishing, bio-erosion and recent weathering. These features with the taxonomic composition were tabulated and interpreted. The taphonomic significances include sedimentary and biological evidences as well as relation of bone preservation to sequence system tract. The sedimentological evidences contain rate of sedimentation, mode of bone deposition, distance of transportation of the skeletons on the sea floor, passive and active accumulation of bone remains and current direction. The biological evidences include the significance of skeleton composition, nature of the marine vertebral muscles and bio-erosion evidences. The bio-erosion evidences include scavenging whale carcasses by sharks and other whales. The adult skeletons of *Dorudon atrox* are fossilized in circle shaped while the adult skeletons of *Basilosaurus isis* are fossilized in a snake shaped, which may be reflected to the desiccation of the powerful back and tail muscles of the skeletons before it was buried.

It is suggested that the whale skeletons are deposited in a shallow marine environment, which is not quiet suitable for living and movements for these big animals, such as *Basilosaurus isis* which is dominant in the mangrove horizon. It thought that the whales were lived and died in deeper water than the skeleton position. By the decomposition of the carcasses by bacteria, the abdomen was bloated by gasses and floated up to the surface of the water, so the bloated whale will almost always upside down. The tidal and wave currents moved these carcasses to the shallow water near the shoreface. When the gasses were escaped of the abdomen or the carcasses were exploded, the carcasses went into a free- fall and landed at any position. The most of whale skull are found upside down positions and the vertebral columns are presented in the left or right side, indicating the upside down position of the carcasses before burial. The lower jaws are found articulated or very close to the skull of the skeleton, which indicate the rapid burial of the carcasses. In other skeletons the lower jaws are missed, may be disarticulated rapidly in floating decaying whale carcass. Indeed some lower jaws are found as an isolated element and far from any skeleton.

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