JJEES

JJEES (2021) 12 (2): 113-121
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Depositional environment, microfacies analysis and planktonic foraminifera of oil shale deposits in the Wadi Al-Shallala Area, NW Jordan.

Hanan Al-Soud and Habes Al-Mashakbeh*

Department of Applied Earth and Environmental Sciences, Institute of Earth and Environmental Sciences, Al al-Bayt University, Jordan.

Received 4 May 2020; Accepted 15 October 2020

Abstract

This paper discusses the depositional environment, microfacies analysis and planktonic foraminifera of oil shale deposits exposed in the Wadi Al-Shallala area. The study is based on the analysis of 29 samples collected from a 7 m thick section. The data obtained from the microfacies analysis and the micropaleontological study of the Wadi Al-Shallala section shows that oil shale occurs within the Muwaqqar Chalk-Marl Formation (MCM). Four microfacies associations MF1 to 4 are recognized; Foraminifera-Bioclastic, Mudstone/Wackestone (MF1), Bioclastic-Foraminifera-Wackestone/Packestone (MF2), Subbotina-Foraminifera Packestone (MF3), and Peloidal Wackestone (MF4).

The benthic and planktonic foraminifera that were recognized in the studied thin sections are *Nodosaria* sp., *Subbotina* sp., *Lenticulina* sp., *Acarinina* sp., *A.soldadoensis*, and *A. aspensis*.This study identifies nine species of planktonic foraminifera that belong to five genera, and the Paleocene-Eocene age is assigned to the studied section based on the occurrence of certain planktonic foraminifera, e.g. (*Acarinina esnaensis*, *A. strabocella*, *A. interposita*, *A. soldadoensis*, *A. aspensis*, *Pearsonites broedermanni*, *Turborotalita carcoselleensis*, *Praemurica pseudoinconstans*, *Morozovella praeangulata*, *Subbotina cancellata*, *Planorotalites capdevilensis*, and *P. pseudoscitula*). In comparison, the variation in the index of oceanity shows that the sea level (continental shelf) slightly fluctuated over the time of the deposition of the oil shale. The bathymetry's average (water paleodepth) of the exposed oil shale section is about 120 m.

The current study indicates that the Paleocene-Eocene oil shales were deposited in a shallow-water carbonate to moderate circulation of the open shelf.

Keywords: Microfacies, Oil Shale, Foraminifera, Planktonic Percentages (P/B), Index of Oceanity, Jordan.

1. Introduction

Oil shale deposits in Jordan are grey to dark-grey fine-coloured, well-bedded sedimentary rocks of Late Cretaceous to Early Cenozoic age, containing organic matter that produces a significant amount of oil and gas upon destructive distillation. Numerous geological studies have shown that there are several oil shale deposits within the country (Alali, 2006, and Alali et al., 2015). The most significant oil shale deposits exist in 26 different locations throughout the country, with the 8 most important deposits located in the west-central area of the country. Other significant deposits are located in the Yarmouk area near the northern border, and the Ma'an district in southern Jordan (Hamarneh et al., 2006).

The Wadi Al-Shallala oil shale deposits were not analyzed in detail, most of the research concentrated on the oil shale microfacies. In this research, in support of microfacial analysis, the contents of oil shale microfossils in the Wadi AL-Shallala area (Figure 1) were extracted and described. Microfacies and micropaleontological analyses of source rocks are an essential method for studying sediment deposition environment like oil shale.

In Wadi Ashajara, northern Jordan, Al-Atawneh (2018) studied the depositional environment of the Eocene oil shale. Jarrar (1989) provided ideas on the sources of organic matter and the depositional setting. Other studies focused on the sources, depositional environment, quality, geochemistry and commercial production of Jordanian oil shales (Abed, 1982; Abed and Amireh, 1983; Hufnagel, 1985; Abed et al., 2005; Mehdawi and Mustafa, 2008; El-Hasan, 2008; Jaber et al., 2008; Ali Hussein et al., 2015; Hakimi et al., 2016; and Beik et al., 2017).

Ahmad et al., 2020 studied the stratotype section of the Wadi Shallala Formation, including the upper part of Umm Rijam Chert Limestone Formation and Wadi Shallala Formation from the northwestern part of Jordan for their contents of calcareous nannofossils and isotopes for the first time. Forty-two calcareous nannofossil species belonging to the Nannotetrina fulgens (NP15/CP13) Zone assigned to the Middle Eocene age where determined.

The main objective of the present study is to investigate the depositional environment, and microfacies analysis, coupled with the foraminifera of oil shale deposits in the Wadi Al-Shallala area.

* Corresponding author e-mail: Habes2819@aabu.edu.jo

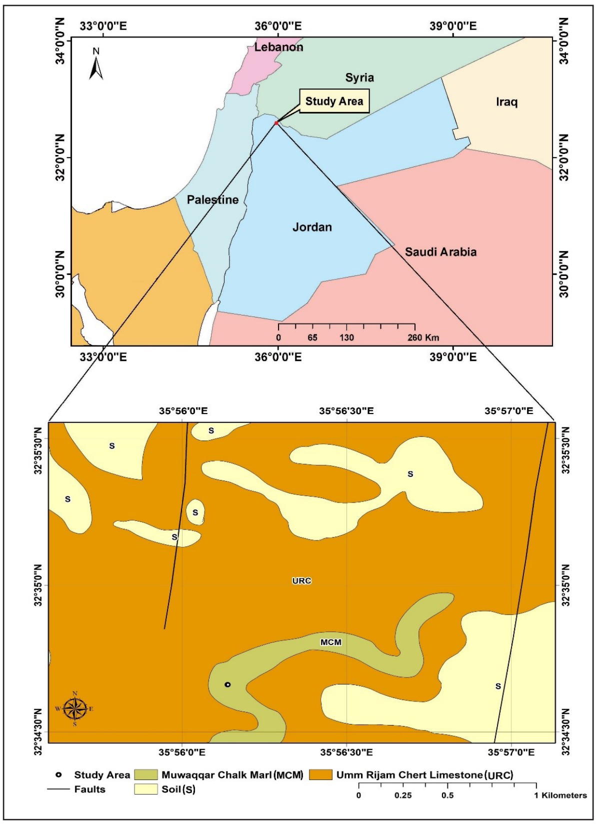

Figure 1. Location of study area (Modified after Moh'd, 2000).

2. Geological setting

Jordan was located at the Neo-Tethys Ocean's southern edge in the Cretaceous to Eocene. During that time interval, the sedimentation took place on a broad, shallow shelf that covered the northern edge of the Arabian Plate (Martin, 2001; Powell and Moh'd, 2011). A thick sequence of chalk, marl, and limestone is accumulated over the northern and central parts of Jordan. This sedimentary system, influenced by the subsequent closure of Neo-Tethys, associated with the continuous shifting of the African Arabian Plate toward the Eurasian Platelet to the formation of basins proper for oil shales deposition (Barjous and Mikbel, 1990).

Furthermore, tectonic movements along with broad structural features such as the Syrian Arc (Mart, 1987) and shifts in eustatic sea level (Haq and Al-Qahtani, 2005) also influenced the depositional environment.

The Jordanian oil shale is considered to be naturally bituminous marls with variable colours of grey to black with typical rather blue colour when weathered, in addition to the light content of fine-grained foraminifera content.

The exposed rocks in the present study are the Muwaqqar Chalk Marl Formation (MCM) and Umm Rijam Chert Limestone Formation. MCM is the oldest rock unit exposed in the study area and has a steeped topographical slope, high escarpments and flat bottom wadis with a dendritic drainage pattern (Moh'd, 2000). It is composed of yellowish marl, pale chalky marl, chalk and marly limestone with some carbonate concretions from bottom to top.

The thickest oil shale intervals occur in the lower part of the MCM and are typical for the Late Cretaceous to early Paleogene (Hamarneh et al., 1998).

3. Materials and Methods

The research area is Wadi Al-Shallala, which is situated in the north of Jordan, where it forms an extension of the Yarmouk River Basin (Thnebat, 2003).

The present study is based on one exposed oil shale section in the area, which estimated to be about 7 m thick. It is about 12 km northeast of Irbid City and about 5 km northwest of A-Ramtha City between 32° 34' 28" N; 35° 55' 6" E and 32° 35' 32" N; 35° 57' 8" **(**Figure 1**)**.

Twenty-nine samples were collected at regular distances of 25 cm from bottom to top for laboratory analysis, and 29 thin sections were made for petrographical analysis. The petrographic and microfacies study was conducted using a Nikon light microscope in the Department of Applied Earth and Environmental Sciences, Al al-Bayt University. The oil shale in the exposed section of the Wadi Al-Shallala consists of a sequence of grey to dark-grey-coloured marls, chalky marls and marly limestones, while the weathered surface gives light-blue colour **(**Figure 2**)**. The allochemical constituents were identified and classified based on Dunham (1962) and Flügel (1982). Microfacies are named according to Dunham's (1962) classification and are compared with the Ramp Microfacies (SMF) of Wilson (1975) and Flügel (2004) for the interpretation of the depositional environments. Samples were treated with a 3% hydrogen peroxide (H_2O_2) solution then washed over a 63 µm sieve for foraminifer analysis and dried at 50° C in an oven. The samples were sieved using a series of sieves after further drying. Foraminifera was picked from a specified fraction under a binocular microscope. Calculation of the index of oceanity carried out mathematically for each sample, then averaged for each microfacies type. The mean values of each microfacies type were represented on the Gibson graph to estimate the bathymetry of the oil shale deposition.

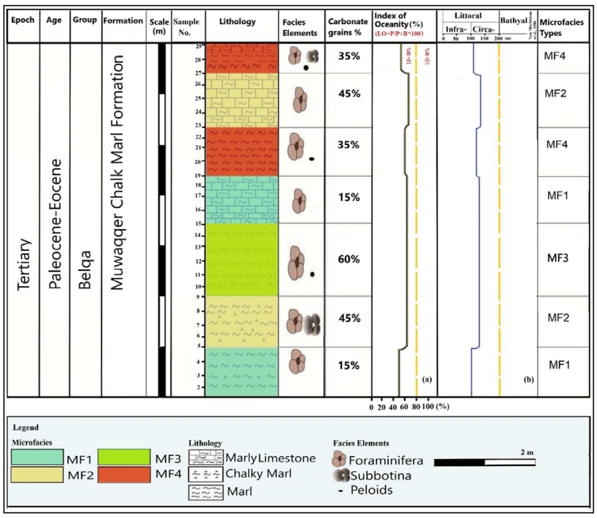

Figure 2. Lithological columnar section including curve of the variation of the oceanity index (a) and the bathymetry (b) of the Wadi Al-Shallala oil shale section.

In this article, the foraminifer taxonomy and descriptions are based on Brasier (1980), Loeblich et al. (1994), Olsson et al. (1999), Berggren et al. (2006) and Wade et al. (2011). Thin sections, labelled s-mf1-29, used for this study are deposited in the Department of Applied Earth and Environmental Sciences, Al al-Bayt University.

4. Results and Discussion

4.1. Microfacies Analysis:

Four major microfacies types were identified from bottom to top in the section of Wadi Al-Shallala:

MF1: Foraminifera-Bioclastic, Mudstone/Wackestone (Figures 3 a-d)

The Foraminifera-Bioclastic, Mudstone/Wackestone Microfacies **(**Figure 3a**)** consists of thin-bedded dark grey marls and marly limestone. This microfacies is represented by nine thin sections of the studied section. The total thickness of the microfacies is 2m (ca. 28% of the section) repeated two times from the base at samples no. 1–5 and 16–19 of the studied section, respectively (Figure 2). This type of microfacies is dominated by a lime-mud matrix, including 15% of carbonate grains. Bioclastic and mostly foraminifera are the dominant grains. This facies is mainly composed of fine- to medium-grained bioclastics in a micrite matrix: *Nodosaria* sp. (Figure 3b) and *Lenticulina* sp. (Figure 3c). Owing to cementation, the influence of diagenesis processes is well defined (Figure 3d). Röhl et al. (1991) interpreted the type of this microfacies type as being primarily deposited in a low-energy lagoon. Also, the Mudstone to Wackestone microfacies is interpreted as a restricted lagoon to the marine shelf, according to Wilson (1975) and Flügel (1982).

MF2: **Bioclastic-Foraminifera-Wackestone/Packestone (**Figures 4 a-d)

This microfacies type comprises chalky marl with some marly limestone levels consisting of 45% carbonate grains, represented by nine thin sections of the studied section. The total thickness of the Bioclastic-Foraminifera-Wackestone/Packestone microfacies is 2 m (ca. 28% of the section) repeated two times from the base at samples no. 6–9 and 24–27 of the studied section respectively (Figures 2,4a). The well-preserved carbonate grains predominantly include foraminifera bioclastic fragments, fragmented bones (Figure 4b); *Acarinina* sp., and *Subbotina* sp. (Figure 4c). Most of the grains are rounded to subrounded and incorporated in the micrite matrix. This microfacies type is characterized by different assemblages of skeletal debris.

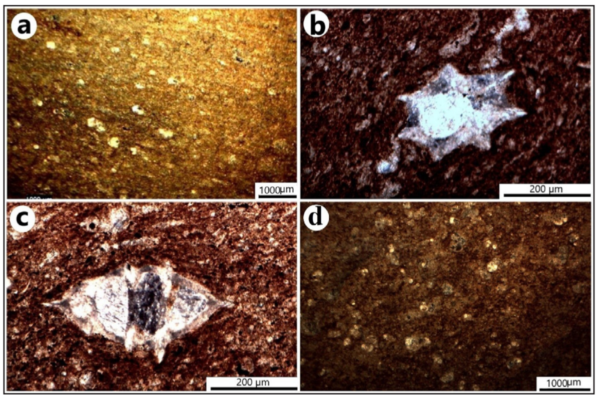

Figure 3. A. MF1-Foraminifera-Bioclastic, Mudstone-Wackestone. B. MF1-*Nodosaria* sp. C. MF1-*Lenticulina* sp. D. MF1-Well defined cementation.

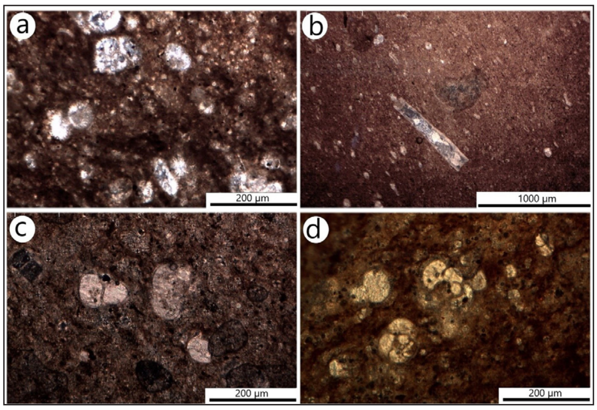

Figure 4. A. MF2-Bioclastic-Foraminifera-Wackestone/Packstone. B. MF2-Fragmented bones; C. MF2-*Acarinina* sp. D. MF2-*Acarinina soldadoensis* (Brönnimann 1952).

Acarinina soldadoensis (Brönnimann 1952) (Figure 4d) is a planktonic foraminifer, recognizing in this type of microfacies. This *Acarinina soldadoensis* (Brönnimann 1952) was identified by comparing the image of the thin section with all the nearby external morphology depicted through the images and it turned out that it is similar to the image of the species *Acarinina soldadoensis* mentioned in page 159 of Postuma (1971). The first occurrence of *Acarinina soldadoensis* (Brönnimann 1952) is at the base of the P4c subzone, Thanetian, 57.8Ma (Olsson et al. 1999), and the last occurrence is within the E7 zone, 45.72–50.20Ma, Lutetian (Wade et al. 2011). The suggested depositional environment for this type of facies is shallow neritic waters of moderate open circulation; it may have been formed in swales in the proximity of shoals in a high-energy environment.

MF3-Subbotina-Foraminifera Packestone(Figures 5a-b)

This facies type (Figure 5a) primarily consists of marlstone, light-brown to dark-grey, dull to light-grey, thin to medium-bedded, interbedded with greenish marl. *Subbotina*-Foraminifera Packestone microfacies is represented by six thin sections in the studied section. The total thickness of the microfacies is 1.5 m (ca. 21% of the section) recognized at samples no. 10–15 of the studied section, respectively (Figure 2), consisting of 60% carbonate grains.

The well-preserved grains are mainly comprised of rounded *Subbotina* sp. and *Acarinina* sp. *Acarinina aspensis* (Colom, 1954) (Figure 5b) is a planktonic foraminifera that identifies in this type of microfacies. This *Acarinina aspensis* (Colom, 1954) was identified by comparing the image of the thin section with all the nearby external morphology depicted through the slides and it turned out that it is similar to the image of the species *Acarinina aspensis* mentioned in Figure No. 7, page 175 of Postuma (1971). The first occurrence of *Acarinina aspensis* is at the base of the E7a subzone,50.2Ma, Ypresian, and the last occurrence was in the middle part of the E7a subzone,49.3Ma, Ypresian (Berggren et al., 2006). Owing to cementation, the influence of the diagenesis processes is well depicted (Figure 5b).

These microfacies are believed to have deposited in a shallow subtidal lagoonal environment of the inner shelf as indicated by the restricted faunal assemblage. Such microfacies are identical to those described by Wilson (1975) and Flügel (2004).

MF-4: Peloidal Wackestone (Figures 5c-d)

The Peloidal Wackestone Microfacies (Figures 5c, 5d) comprises thin-bedded dark-grey to dark grey to green marl. This microfacies is represented by six thin sections from the studied section. The total thickness of the microfacies is 1.5 m (ca. 21% of the section) repeated two times from the base at samples no. 20–23 and 28–29 of the studied section, respectively (Figure 2). This facies consists mainly of micritic limestone with 35% carbonate grains, often sub sorted peloids, bones, bioclastics and some foraminifera; typically, reasonably retained. These are usually the result of indurated carbonate mud due to erosion. The marl is greenish-grey to dark-grey, locally red-brown and cream to dark-brown. A few fossils were recognized in some shale beds such as; foraminifera, ostracods, and pelecypods. Owing to dissolution, the influence of diagenesis processes is well defined (Figures 5c, 5d). The proposed environment for this facies type is shallow neritic water of open circulation at or just below wave base.

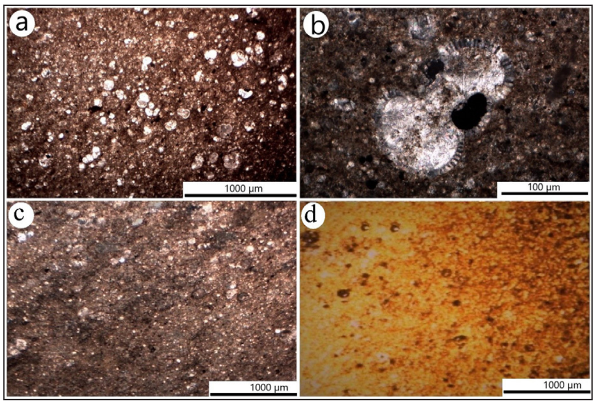

Figure 5. A. MF3-Foraminifera Packstone Subbotina sp. B. MF3-*Acarinina aspensis* (Colom 1954). C and d. MF4-Peloidal Wackestone.

The rock facies changes vertically in the exposed oil shale deposits from foraminifera-bioclastic, mudstone/wackestone in the lowermost part to peloidal wackestone in the uppermost part. Therefore, it is divided into seven units, based on the lithology and fossil contents; from the bottom to top, it begins with the marly unit (Unit 1) containing mainly benthonic and planktonic foraminifera. The marly unit composed of foraminifera-bioclastic, mudstone/wackestone microfacies represented by samples no. 1-5. Chalky marl (Unit 2) immediately above the marly unit is existed comprising predominantly of foraminifera and bioclastic fragments. The chalky marl composed of dominantly Bioclastic-Foraminifera-Wackestone/Packestone microfacies represented by samples no. 6-9.

The following upwardly unit is marl (Unit-3) consisting mainly of *Subbotina* sp. and *Acarinina* sp. The marly unit composed of *Subbotina*-foraminifera packstone represented by samples no. 10-15.

Marly limestone (Unit 4) immediately above the marly unit is existed comprising predominantly of benthonic and planktonic foraminifera. The marly limestone composed of dominantly foraminifera-bioclastic, mudstone/wackestone microfacies represented by samples no.16-19.

The following unit is marl (Unit-5) consisting mainly of sub sorted peloids, bones, bioclastic, and some foraminifera. The marly unit composed of peloidal wackestone microfacies represented by samples no. 20-23. Marly limestone (Unit 6) immediately above the marly unit is existed comprising of foraminifera and bioclastic fragments. The marly limestone composed of dominantly bioclastic-foraminifera-wackestone/packstone microfacies represented by samples no. 24-27. The uppermost unit is marly to marly limestone (Unit-7) composed dominantly of peloids, bones, bioclastic, and some foraminifera. The marly and marly limestone unit includes peloidal wackestone microfacies represented by samples no. 28-29.

4.2. Index of Oceanity (I.O)

Benthic and planktonic foraminifera are typical constituents of a broad variety of shallow to deep-water marine environments. The proportion of planktonic foraminifera in the sediment to the total amount of foraminifera referred to as the plankton/benthos ratio. The quantitative relationship between the number of plankton to the total number of individuals in the sediment (benthic + plankton) is also known as oceanity index (Gibson, 1989). The proportion of the planktonic foraminiferal assemblage usually increases with the depth of water (De Swaaf et al. 1999). This proxy may be used as a fundamental and effective method to estimate the paleo-water depth at deposition and/or the distance from the shore (Gibson, 1989; Van der Zwaan et al., 1990).

The (I.O) allows for the evaluation of bathymetry because in the marine waters the maximum productivity for planktonic foraminifers is far from a coast, but on the continental platforms, the benthic foraminifers proliferate. Foraminiferal planktonic and benthic abundances were counted and planktonic percentages (P/B) were calculated from the section studied in the oil shale deposits. The calculated values of the (I.O) for each sample and the mean for each microfacies type were shown in (Table 1) and (Figure 2a). The mean values of each microfacies type were correlated and compared with the Gibson graph (Figure 6) to assign approximately the bathymetry of the oil shale deposition (Figure 2b).

The mean values of the (I.O) of the studied section from the bottom are MF1= 53%, MF2= 62%, MF3 = 62%, MF1 = 62%, MF4 = 61%, MF2 = 63%, MF4 =57%. The mean of (I.O) in all samples from the studied section is about 60%. As a consequence of the relative sea-level changes, the I.O probably records slight variations in the oil shale samples.

Table 1. The mean values of the I.O and the estimated bathymetry of each recognized Microfacies types of study area.

MF types (Top)	I.O	Bathymetry(m)
MF4	57	110
MF2	63	132
MF4	61	124
MF1	62	128
MF3	62	128
MF2	62	128
MF1	53	105
Mean	60	120

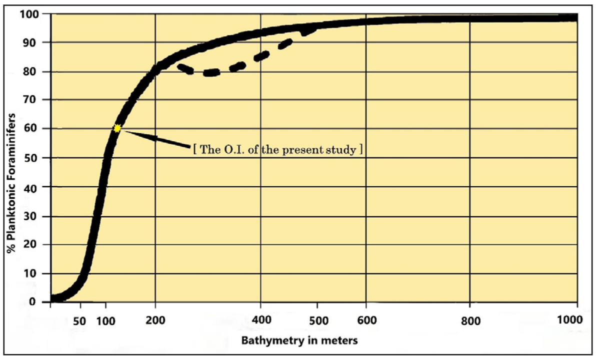

Figure 6. Index of oceanity (after Gibson, 1989).

The (I.O) from several depths transects across the United States shows that the middle-to-outer neritic transition at ~100 m is marked by 20–60% planktonic foraminifera and increases at ~200 m to 60–90% planktonic foraminifera (Gibson, 1989). The (I.O) at depth ~200 m is marked by 80% planktonic foraminifera and increases at > 200 m to 80–100% planktonic foraminifera based on the Gibson graph. Karoui-Yaakoub et al. (2016) used the Gibson model to reconstruct the bathymetry or the bottom water conditions of the Nukhul section (Egypt).

The approximate values of the bathymetry of the studied section from the bottom are MF1= 105 m, MF2= 128 m, MF3 = 128 m, MF1 = 128 m, MF4 = 124 m, MF2 = 132 m, MF4 =110 m. The mean of the bathymetry in the whole samples of the present section is about 120 m.

4.3. Planktonic Foraminifera

In the present study, the Cretaceous scheme of Caron (1985), the Palaeocene–Eocene scheme of Olsson et al., (1999) and new planktonic Foraminifera of (Hemleben et al., 1989) are adopted and the classification of the foraminifera is based on Loeblich and Tappan (1964). Fourteen species of planktonic foraminifera belong to nine genera are identified in this study;

(*Acarinina esnaensis*, *A. strabocella*, *A. interposita*, *A. soldadoensis*, *A. aspensis*, *Pearsonites broedermanni*, *Turborotalita carcoselleensis*, *Praemurica pseudoinconstans*, *Morozovella praeangulata*, *Subbotina cancellata*, *Planorotalites capdevilensis*, and *P. pseudoscitula*, *Planoglobanomalina* sp., *Globanomalina* sp.).

The most important identified planktonic Foraminifera species were photographed by a Scanning Electron Microscope (SEM) and are illustrated in (Figure 7).

Based on the range of the studied fourteen species of planktonic Foraminifera, the Paleocene to Eocene age were assigned as follows: Paleocene: (*Acarinina esnaensis*, *A. strabocella*, *Pearsonites broedermanni*, *Praemurica pseudoinconstans*, *Morozovella praeangulata*, and *Subbotina cancellata*) and Eocene: (*Acarinina esnaensis*, *A. interposita*, *A. soldadoensis*, *A. aspensis*, *Pearsonites broedermanni*, *Turborotalita carcoselleensis*, *Planorotalites capdevilensis*, *P. pseudoscitula*, and *Subbotina corpulenta*).

The study of (Futyan, 1976) determines the age of the oil shale deposits in Jordan somewhat differently, he assigned its age from Turonian, Santonian, Campanian, Maastrichtian, Paleocene to Eocene. Yassini, (1979) reported that the Muwaqqar Formation was deposited during the period of Maastrichtian-Late Eocene age. They are as follows: Maastrichtian: (*Globotruncana* zone); Paleocene: (*Morozovella*, *Planorotalites*, *Subbotina*, *Globoconusa*); Lower Eocene: (*Morozovella* zone). Al-Mashakbeh, (2012) identified three zones from the oil shale deposits in central Jordan during the Maastrichtian-Eocene age. The zones are: Maastrichtian: (*Pseudoguembelina*, *Racemiguembelina* and *Gansserina* zone); Paleocene: (*Morozovella*, *Praemurica*, *Subbotina*, and *Parvularugoglobigerina* zone); Lower Eocene: (*Acarinina*, and *Morozovella* zone).

4.4. Depositional Environments:

Oil shale originates in anoxic environments where the need for oxygen in the water column is greater than the availability (Demaison and Moor, 1980; Hay, 1995). Jordanian oil shales were deposited under restricted conditions of circulation. It is proposed that a set of physical barriers developed during the period of oil shale deposition, that enhanced the restricted conditions. The anoxic conditions that contributed to the deposition of Wadi Al-Shallala oil shale in the Yarmouk sub-basins may have resulted from syndepositional subsidence of fault bound throughout. The low diversity in the benthonic foraminiferal assemblage implies a low-oxygen environment, deposited under low-energy conditions. The variability in P/B ratios indicates fluctuations in sea level and that demonstrates the variation of the environment from shallow to open sea (Figure 8).

Microfacies diversity suggests a sea-level fluctuation from a shallow, restricted marine to an open marine depositional environment. The Mudstone/Wackestone Microfacies was deposited on the continental shelf. The Wackestone Microfacies type was deposited in open marine, shallow water. The Wackestone/Packstone microfacies was deposited in a shallow, restricted marine environment with limited water circulation and low energy. The Packestone Microfacies type concurrently accumulated in areas with similar quiet water sedimentation to those found in open sea shelf environments, and these conditions were ideal for retaining organic matter.

According to the aforementioned microfacies types, the depositional environment of the Wadi Al-Shallala oil shale can be attributed to a shallow continental shelf in a restricted marine and an open marine environment (Al-Soud, 2020). The present study confirms the results of previous studies that the Jordanian oil shales were deposited in a shallow, calm restricted environment, with limited open water circulation (e.g. Abed and Amireh, 1983; Mehdawi and Mustafa, 2008; Alqudah et al., 2014; Khrewesh, 2014; Ali Hussein et al., 2015; Beik et al., 2017, Al-Atawneh, 2018). Many authors have linked deposits of oil shale to MCM (Bender, 1974; Powell, 1989; Abed et al., 2005; Mihdawi and Mustafa, 2007). The age assignment of the MCM in previous studies are ranging from Maastrichtian to Paleocene age (e.g. Bender, 1974; Yassini, 1980; Powell, 1989), whereas Khrewesh (2014) used ammonites for assigning the MCM in Jebal Khuzayma in southeastern Jordan a Maastrichtian age. Basha (1982) gave an Eocene age based on foraminifera to the bituminous marl layers of central east Jordan. The variations of the age assignment of MCM in Jordan may be due to the different geographic locations of the studied sections or attributed to the materials used for age determination.

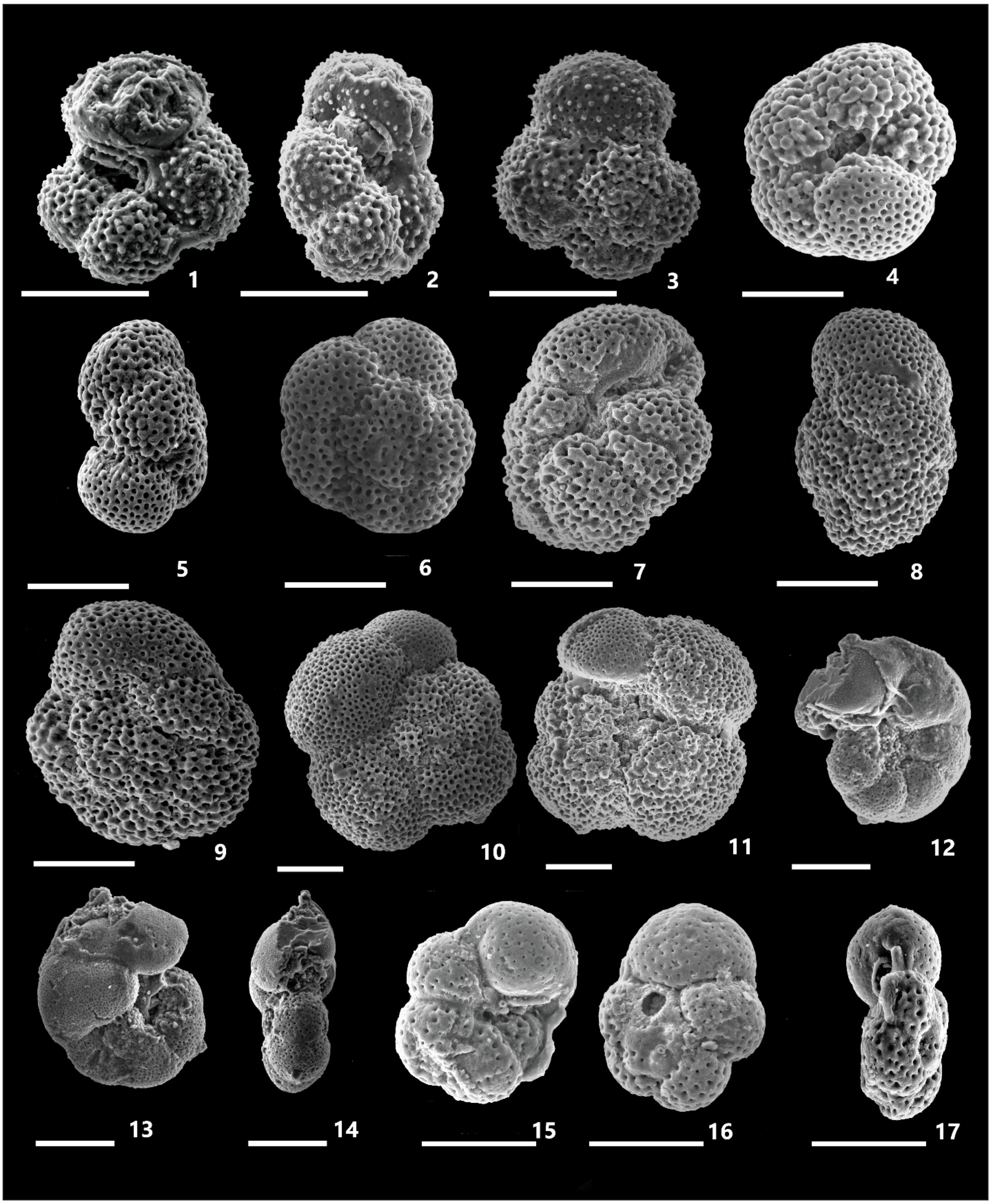

Figure 7. SEM photographs of selected planktonic foraminiferal species from the studied section.The scale barsof all Figures equal 100 µm. 1-3: *Acarinina esnaensis* (LeRoy 1953). 4-6: *Acarinina strabocella* (Loeblich and Tappan 1957). 7-9: *Pearsonites broedermanni* (Cushman and Bermudez 1949). 10-11: *Turborotalita carcoselleensis* (Toumarkine and Bolli, 1975). 12-14: *Planoglobanomalina* sp. 15-17: *Globanomalina* sp.

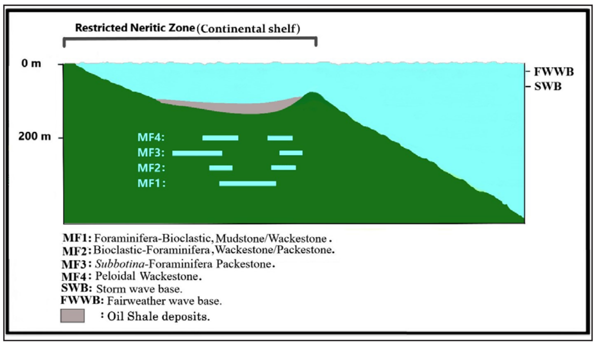

Figure 8. Depositional model of the study.

The average depth in all samples of the present section was around 120 m. Analysis based on planktonic percentages (P/B) or I.O indicated that oil shale deposition occurred in the continental shelf environment, which is following the results of the microfacies analysis (Al-Soud, 2020).

5. Conclusions

Four main microfacies types are distinguished and described; Foraminifera-Bioclastic, Mudstone/Wackestone (**MF1**), Bioclastic-Foraminifera-Wackestone/Packestone (**MF2**), Subbotina-Foraminifera Packestone (**MF3**), and Peloidal Wackestone (**MF4**). The average water depth of the exposed oil shale section is about 120 m.

The benthic foraminifera that was recognized in the present study are Nodosaria sp., and Lenticulina sp. The planktonic foraminifera that was recognized in the present study are; Acarinina esnaensis, A. strabocella, A. interposita, A. soldadoensis, A. aspensis, Pearsonites broedermanni, Praemurica pseudoinconstans, Morozovella praeangulata, Subbotina cancellata, S. corpulenta, Turborotalita carcoselleensis, Planorotalites capdevilensis, P. pseudoscitula, Planoglobanomalina sp., and Globanomalina sp. The Paleocene-Eocene age is assigned to the studied oil shale section. Microfacies analysis and I.O or planktonic percentages (P/B) indicate that the exposed oil shale section was deposited within a shallow marine and moderate circulation of an open marine shelf.

Acknowledgements

The authors would like to thank Prof. Abdalla Abu Hamad (University of Jordan) and Prof. Hendrik Klein (Saurierwelt Paläontologisches Museum, Germany) for the review of the manuscript and their suggestions and useful amendments. This article is part of the M.Sc thesis of the first author.

References

Abed, A.M. (1982). On the hydrocarbons of some Jordanian oil shales. Dirasat 9: 63-79.

Abed, A.M. and Amireh, B.S. (1983). Petrography and geochemistry of some Jordanian oil shales from north Jordan. Journal of Petroleum Geology 5(3): 261-274. http://dx.doi.org/10.1111/j.1747-5457.1983.tb00571.x.

Abed, A. M., Arouri, K. R., Boreham, C. J. (2005). Source rock potential of the phosphorite–bituminous chalk–marl sequence in Jordan. Marine and Petroleum Geology 22(3): 413-425. https://doi.org/10.1016/j.marpetgeo.2004.12.004.

Ahmad, F., Faris, M., Farouk, S. (2020). Calcareous Nannofossil Biostratigraphy and Carbon Isotopes from the Stratotype Section of the Middle Eocene Wadi Shallala Formation, Northwestern Jordan. Jordan Journal of Earth and Environmental Sciences 11 (2): 103-112.

Alali, J., Abdelfattah, A. S., Yasin, S. M., Al Omari, W. (2015). Oil Shale in Jordan. Natural Resources Authority of Jordan, 26 pp.

Alali, J. (2006). Jordan oil shale, availability, distribution, and investment opportunity. In International Conference on Oils Shale: Recent Trends in Oil Shale pp. 7-9.

Al-Atawneh, M. S. (2018). Depositional Environment of Eocene Oil Shale from Wadi Ashajara. M.Sc. Thesis, Yarmouk University, Jordan.

Ali Hussein, M., Alqudah, M., Blessenohl, M., Podlaha, O. G., Mutterlose, J. (2015). Depositional environment of Late Cretaceous to Eocene organic-rich marls from Jordan. GeoArabia 20(1): 191-210.

Al-Mashakbeh, H. (2012). Micropaleontology and Biostratigraphy of Some Oil Shale Deposits in Jordan, Ph.D. Thesis, University of Jordan, Jordan.

Alqudah, M., Hussein, M. A., Podlaha, O. G., den Boorn, S. V., Kolonic, S., Mutterlose, J. (2014). Calcareous nannofossil biostratigraphy of Eocene Oil shales from central Jordan. GeoArabia 19(1): 117-140.

Al-Soud, H. (2020). Microfacies analysis, Micropaleontology and Paleoenvironment of Oil Shale Deposits in Wadi Al-Shallala – Jordan. M. Sc. Thesis, Al al-Bayt University, Jordan.

Barjous, M. and Mikbel, S. (1990). Tectonic evolution of the Gulf of Aqaba-Dead Sea transforms fault system. Tectonophysics 180(1): 49-59. https://doi.org/10.1016/0040-1951(90)90371-E.

Basha, S. (1982). Stratigraphy, palaeogeography and oil possibilities of the Azraq Sirhan Turayf basin (Jordan-Saudi Arabia). Dirasat 9: 85-106.

Beik, I., Gómez, V.G., Podlaha, O.G., Mutterlose, J. (2017). Microfacies and depositional environment of Late Cretaceous to Early Paleocene oil shales from Jordan. Arabian Journal of Geosciences 10(15): 346. https://doi.org/10.1007/s12517-017-3118-6.

Bender, F. (1974). Geology of Jordan. Supplementary Edition in English with Minor Revisions. Gebrueder Borntraeggger, Berlin, 196pp.

Berggren, W.A., Pearson, P.N., Huber, B.T., Wade, B.S. (2006). Taxonomy, biostratigraphy and phylogeny of Eocene Acarinina. Atlas of Eocene Planktonic Foraminifera. Cushman Foundation Special Publication 41: 257-326.

Brasier, M.D. (1980). Microfossils. George Allen and Unwin, London, 193 pp.

Brönnimann, P. (1952). Trinidad Paleocene and lower Eocene Globigerinidae. Bulletin of American Paleontology 34(143): 1-34.

Caron, M. (1985). Cretaceous Planktonic Foraminifera. In: Bolli, H. M., Saunders, J. B. and Perch-Nielsen, K. (Eds), Plankton Stratigraphy. Cambridge University Press, Cambridge: 17- 86.

Colom, G. (1954). Estudio de las biozonas con foraminíferos del Terciario de Alicante. Boletín del Instituto Geológico y Minero de España 66: 1-279.

Cushman, J. A. and Bermudez, P. J. (1949). Some Cuban species of Globorotalia. Contributions from the Cushman Laboratory for Foraminiferal Research 25: 26-45.

De Swaaf, M. E., De Rijk, T. C., Eggink, G., Sijtsma, L. (1999). Optimisation of docosahexaenoic acid production in batch cultivations by Crypthecodinium cohnii. Journal of Biotechnology 70(1-3): 185-192. https://doi.org/10.1016/S0079-6352(99)80111-8

Demaison, G.J. and Moore, G.T. (1980). Anoxic environments and oil source bed genesis. AAPG Bulletin 64(8): 1179-1209. https://doi.org/10.1306/2F91945E-16CE-11D7-8645000102C1865D.

Dunham, R.J. (1962). Classification of Carbonate Rocks According to Depositional Texture. In: Ham, W.E. (Ed.), Classification of Carbonate Rocks, AAPG, Tulsa, 108-121.

El-Hasan, T. (2008). Geochemistry of redox-sensitive trace elements and its implication on the mode of formation of the Upper Cretaceous oil shales, Central Jordan. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 249(3): 333-344. https://doi.org/10.1127/0077-7749/2008/0249-0333.

Flügel, E. (1982). Introduction to facies analysis. In Microfacies Analysis of Limestones (pp. 1-26). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-68423-4_1.

Flügel, E. (2004). Microfacies analysis of carbonate rocks. Analysis, interpretation and application. Springer, Berlin. https://doi.org/10.1007/978-3-662-08726-8

Futyan, A.I. (1976). Late Mesozoic and early Cainozoic benthic foraminifera from Jordan. Paleontologie (Prague) 13: 517–537.

Gibson, T. G. (1989). Planktonic benthonic foraminiferal ratios: modern patterns and Tertiary applicability. Marine Micropaleontology 15(1-2): 29-52. https://doi.org/10.1016/0377-8398(89)90003-0.

Hakimi, M. H., Abdullah, W. H., Alqudah, M., Makeen, Y. M., Mustapha, K. A. (2016). Reducing marine and warm climate conditions during the Late Cretaceous, and their influence on organic matter enrichment in the oil shale deposits of North Jordan. International Journal of Coal Geology 165: 173-189. https://doi.org/10.1016/j.coal.2016.08.015.

Hamarneh, Y., Alali, J., Sawaged, S. (1998). Oil shale resources development in Jordan. Natural Resources Authority, Hashemite Kingdom of Jordan, Amman.

Hamarneh, Y., Jamal, A., Suzan, S. (2006). Oil shale resources development in Jordan (PDF). Natural Resources Authority of Jordan.

Haq, B.U. and Al-Qahtani, A.M. (2005). Phanerozoic cycles of sea-level change on the Arabian Platform. GeoArabia 10(2): 127-160.

Hay, W.W. (1995). Paleoceanography of Marine Organic Carbon-Rich Sediments. In A.-Y. Huc (Ed.), Paleogeography, Paleoclimate, and Source Rocks. AAPG Studies in Geology Series no. 40: 21-59. https://doi.org/10.1007/978-3-642-68423-4_1.

Hemleben, C., Spindler, M., Anderson, O. R. (1989). Modern planktonic Foraminifera. New York: Springer Verlag, 363 pp. Free-floating forms are the worldwide markers in the geological time scale. https://doi.org/10.1007/978-1-4612-3544-6

Hufnagel, H. (1985). Oil shale in Jordan. Natural resources and development 22: 46-62.

Jaber, J.O., Sladek, T.A., Mernitz, S., Tarawneh, T. M. (2008). Future policies and strategies for oil shale development in Jordan. Jordan Journal of Mechanical and Industrial Engineering 2(1): 31-44.

Jarrar, M. (1989). Composition, Stratigraphy and depositional environment of kerogenous limestone of Wadi AL-Shallala. Master thesis, Yarmouk University, Jordan.

Karoui-Yaakoub, N., Mtimet, M.S., Grira, C., Guesmi, W., Bejaoui, S. (2016). Planktonic foraminiferal biostratigraphy and paleoenvironment of the Danian/Selandian in west-central Sinai (Egypt), implications from the Nukhul section. Arabian Journal of Geosciences 9(7): 1-15. https://doi.org/10.1007/s12517-016-2513-8

Khrewesh, A.M., Hamad, A.A., Abed, A.M. (2014). Late Cretaceous Muwaqqar Formation Ammonites in Southeastern Jordan. Jordan Journal of Earth and Environmental Sciences 6(2): 77-83.

LeRoy, L.W. (1953). Biostratigraphy of the Maqfi Section, Egypt. Memoir Geological Socity of America 54: 1-73. https://doi.org/10.1130/MEM54-p1

Loeblich Jr., A.R. and Tappan, H. (1994). Foraminifera of the Sahul Shelf and Timor Sea. Cushman Foundation for Foraminiferal Research. Special Publication 31: 661.

Loeblich, A.R. and Tappan, H. (1957). Planktonic foraminifera of Paleocene and early Eocene Age from the Gulf and Atlantic coastal plains. In: Loeblich, A.R., Jr., Tappan, H., Beckmann, J.P., Bolli, H. M., Montanaro Gallitelli, E. Troelsen, J.C. (Eds.), Studies in Foraminifera. U.S. National Museum Bulletin 215: 173-198.

Loeblich, A.R. and Tappan, H. (1964). Treatise on Invertebrate Paleontology (Vol. 1 and 2). The Geological Society of America and The University of Kansas Press, Lawrence.

Mart, Y. (1987). Superpositional tectonic patterns along the continental margin of the southeastern Mediterranean: a review. Tectonophysics 140(2-4): 213-232. https://doi.org/10.1016/0040-1951(87)90230-7

Martin, A.Z. (2001). Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences. GeoArabia 6(3): 445-504.

Mehdawi, H. and Mustafa, H. (2008). Geochemistry and evaluation of organic matter of the oil shale from Muwaqqar formation (Maastrichtian- Paleocene) in the area between Wadi Zahar and Wadi Abu Ziyad , NW- Jordan. Abhath AL-Yarmouk 17 (1B): 233-257.

Moh'd, B. K. (2000). The Geology of Irbid and Ash Shuna Ash Shamaliyya (Waqqas): Map Sheets No. 3154-II and 3154-III. Hashemite Kingdom of Jordan, Natural Resources Authority, Geology Directorate, Geological Mapping Division.

Olsson, R. K., Berggren, William A., Hemleben, C., Huber, Brian T. (1999). "Atlas of Paleocene Planktonic Foraminifera." Smithsonian Contributions to Paleobiology 1 -252. https://doi.org/10.5479/si.00810266.85.1.

Postuma, J. (1971). Manual of Planktonic Foraminifera. Elsevier Publishing Co. Amsterdam 420.

Powell, J. H. (1989). Stratigraphy and sedimentation of the Phanerozoic rocks in central and south Jordan, part B: Kurnub, Ajlun and Belqa Groups. (Geology Directorate, Natural Resources Authority, Amman, Jordan), Bulliten 11, 130 pp.

Powell, J.H. and Moh'd, B.K. (2011). Evolution of Cretaceous to Eocene alluvial and carbonate platform sequences in central and south Jordan. GeoArabia 16(4): 29-82.

Röhl, U., Dumont, T., von Rad, U., Martini, R., Zaninetti, L. (1991). Upper Triassic tethyan carbonates off northwest Australia (Wombat Plateau, ODP Leg 122). Facies 25(1): 211-251. https://doi.org/10.1007/BF02536760

Thnebat M.A. (2003). Hydrological study of Wadi Al-Shallala Yarmouk Basin, Master thesis. University of Jordan, Amman, Jordan.

Van der Zwaan, G. J., Jorissen, F. J., De Stigter, H. C. (1990). The depth dependency of planktonic/benthic foraminiferal ratios: constraints and applications. Marine Geology 95(1): 1-16. https://doi.org/10.1016/0025-3227(90)90016-D

Wade, B.S., Pearson, P.N., Berggren, W.A., Pälike, H. (2011). Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. Earth-Science Reviews 104(1-3): 111-142. https://doi.org/10.1016/j.earscirev.2010.09.003

Wilson, J.L. (1975). Carbonate Facies in Geologic History. Springer, Berlin, pp. 471. https://doi.org/10.1007/978-1-4612-6383-8

Yassini, I. (1979). Maastrichtian-Lowe Eocene biostratigraphy and the planktonic foraminiferal biozonation in Jordan. Revista española de micropaleontología 11: 5-57.