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Oysters (Bivalvia-Pteriomorphia) of the Upper Cretaceous rocks of Jordan. Palaeontology, Stratigraphy and Comparison with the Upper Cretaceous oysters of Northwest Europe.

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With 7 plates and 53 text-figures

Contents

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Zusammenfassung

Austern (Bivalvia-Pteriomorphia) stellen eine der vielfältigsten und besterhaltenen Fossilgruppen in den mesozoischen Sedimentgesteinen Jordaniens dar. Ihre größte Verbreitung erreichen sie in den oberkretazischen Ablagerungen. Obwohl sie in der Literatur häufig erwähnt werden, werden sie in keiner dieser Arbeiten als eigenständige Gruppe betrachtet. Im Rahmen dieser Dissertation werden die Paläontologie, stratigraphische Verbreitung, Paläoökologie, Biostratigraphie, Paläobiogeographie und die Gehäusemikrostruktur der jordanischen Austern als Tethys Vertreter diskutiert und mit gleichaltrigen borealen Vertretern aus NW-Europa verglichen.

Die Lithologie und Stratigraphie von zwei Profilen in Wadi Salihi (nördlich von Amman) und in Wadi Mujib (Zentral-Jordanien) dienen als Referenzprofile für die stratigraphische Einordnung der Austern Jordaniens.

Die in dieser Arbeit verwendete Austern-Systematik stützt sich auf die neuesten Ansätze zur Klassifikation dieser Organismen-Gruppe. Die wichtigsten morphologischen Merkmale der Austern werden kurz beschrieben und diskutiert. Die systematische Einordnung der Arten dieser Arbeit erfolgt nach Größe, Gestalt, internen Merkmalen, externen Merkmalen und der Mikrostruktur der Schale.

Aus den oberkretazischen Schichten Jordaniens werden insgesamt 17 Arten aus 10 Gattungen und 6 Untergattungen beschrieben. Darunter wird eine neue Art *(Oscillopha wala* n. sp.) aus dem Turon in Wadi Wala (Zentral Jordaniens) beschrieben. 4 weitere Arten *(Osillopha figari* (FOURTAU), *Exogyra (Exogyra) italica* (SEGUENZA), *Laevigyra luynesi* (LARTET) und *Laevigyra dhondtae* (MALCHUS) werden zum ersten Mal aus Jordanien beschrieben. Zusätzlich werden noch zwei Arten (*Africogryphaea costellata* (DOUVILLÉ) und *Gryphaeligmus jabbokensis* (COX) aus dem Bathon (Mittel Jura) Zentral- und NW-Jordaniens beschrieben. Zum Vergleich wurden außerdem 15 Arten aus 8 Gattungen und 4 Untergattungen aus der Oberkreide NW-Europas untersucht.

Die stratigraphische Verbreitung der in dieser Arbeit untersuchten Austern zeigt, daß die Austern in Jordanien ihre artreichste Zahl im Cenoman/Unterturon und im Campan erreichten. In NW-Europa haben die Austern ebenfalls ihre größte Zahl in Cenoman/Turon und im Campan/Maastricht. Diese hohe Diversität ist möglicherweise auf die Cenoman- und Campan-Transgressionen zurückzuführen, die den Austern neue Lebensräume eröffneten.

Die Austern bilden sowohl in Jordanien wie auch in NW-Europa kleinere bis größere Gemeinschaften, die meist von einer oder zwei Arten dominiert werden. Die artliche Zusammensetzung variiert jedoch von Lokalität zu Lokalität. Daher ist es schwierig erfolgreiche regionale biostratigraphische Zonierungen mit Hilfe von Austern zu erstellen. Jedoch können einige jordanische Austern wie z.B. *Oscillopha. wala* n. sp., *O. figari* (FOURTAU), *Laevigyra. luynesi* (LARTET), *L. dhondtae* MALCHUS, *Ambigostrea villei* (COQUAND) und *P. (Costeina)* sp. als Leitfossilien für bestimmte Zeitabschnitte (in Jordanien) angesehen werden. Die großen Austernbioherme in der Al Hisa Phosphorite Formation, die entlang des Phosphatgürtel Jordaniens verbreitet sind, können jedoch als separate lithologische Einheiten kartiert werden.

In den oberkretazischen sedimentären Einheiten Jordaniens lassen sich zwei Haupt-Austernfazien unterscheiden. Die erste besteht aus flachmarinen Plattform-Karbonaten (Kalke, mergelige Kalke, Mergel, Dolomite), die sich mit Siliziklastika verzahnen. Diese Fazies wurde in der transgressiven Ajlun-Gruppe (Cenoman/Turon) gebildet. Die Ablagerung erfolgte in flachem, ruhigen und warmen Wasser. Die zweite Fazies besteht aus Austernschillen und Grainstones sowie großen Austernbiohermen. Die Austernschille und Grainstones weisen großmaßstäbliche Kreuzschichtungen auf. Sie entstanden wahrscheinlich im Folge der Änderung der Schelf-Konfiguration von einer Kabonatplattform zu einer Karbonatrampe während der Transgression im Oberen Coniac. Die Fazies-Verteilung weist auf ein Hochenergie-Environment hin. Sie können mit ähnlichen Austern-Fazien in Negev (S. Israel) und auf der Sinai-Halbinsel (Ägypten) korreliert werden. Die oberkretazische Austern-Fazien NW-Europas unterscheiden sich von den jordanischen. Die meisten der untersuchten Arten des Cenomans und des Turons kommen in mergeligen, glaukonitischen grünen Sanden vor, während die meisten Austern des Senoniens in tieferen marinen Kreidekalken gefunden werden.

Kosmopolitische Arten wie *Pycnodonte (Phygraea) vesiculare* (LAMARCK), *Pycnodonte (Phygraea) vesiculosum* (SOWERBY), *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS) und *Gryphaeostrea canaliculata* (SOWERBY) kommen sowohl in Jordanien wie auch in NW-Europa vor. Diese Arten sind nicht nur geographisch sondern auch zeitlich Durchläufer.

In Jordanien und in NW-Europa gehören die Austernfaunen hauptsächlich zur Familie Gryphaeidae, Unterfamilie Exogyreinae. In Jordanien dominieren jedoch Vertreter des Tribus Exogyrini *(Exogyra, Ilymatogyra, Laevigyra* und *Rhynchostreon),* während in NW-Europa, das Tribus Nanogyrini *(Amphidonte* mit den Untergattungen *A. (Amphidonte), A. (Ceratostreon), A. (Vultogryphaea)* vorherrscht. Die Gattung *Vultogryphaea* wurde auf Grund der amphidonten rechten Klappe und der fischgräten-kreuz-foliaten Struktur mit Mokret-Linsen als Untergattung zur Gattung *Amphidonte* gestellt. Vertreter des Tribus Exogyrini haben unterteilte Endostraca mit unterschiedlichen Strukturen, die gebogen-foliate Struktur ist für die Gattungen *Rhynchostreon* und *Laevigyra* charakteristisch, während die Arten der Gattung *Amphidonte* Schalen mit fischgräten-kreuzfoliaten Struktur mit Mokret-Linsen bilden.

Abstract

Oysters (Bivalvia-Pteriomorphia) are one of the most diversified and best preserved fossil groups in the Mesozoic sediments (mainly Upper Cretaceous) of Jordan. They were often mentioned in the old literature, but non of the studies treated them as a separate group. In this work, the palaeontology, stratigraphic distribution, biostratigraphy, palaeoecology, palaeobiogeography as well as the shell microstructure of the Jordanian oysters (as representatives of the Tethyan realm) are discussed and compared with Upper Cretaceous oysters from Northwest Europe which represent the North Temperate realm.

The lithology and stratigraphy of two compiled columnar sections in Wadi Salihi, north of Amman and in Wadi Mujib, central Jordan, are discussed and used as reference sections for this study.

Oysters were reviewed according to the latest systematic classification concerning this group. The important morphological characters of oyster shells are briefly described and discussed. They are subdivided into: size, outline, internal characters, external characters and shell microstructure. This subdivision is made to provide a simple presentation of the systematic palaeontology of this work.

Seventeen species belonging to ten genera and six subgenera from the Upper Cretaceous sediments of Jordan are described. Among which, one new species *(Oscillopha wala* n. sp.) from the Turonian of Wadi Wala in Central Jordan is erected, and four species, *Oscillopha figari* (FOURTAU), *Exogyra (Exogyra) italica* (SEGUENZA), *Laevigyra luynesi* (LARTET) and *Laevigyra dhondtae* MALCHUS, are reported for the first time from Jordan. In addition, two species belonging to two Jurassic genera, *Africogryphaea costellata* (DOUVILLÉ) and *Gryphaeligmus jabbokensis* (COX) from the Bathonian (Middle Jurassic) sediments of central and northwestern Jordan, are reported.

From Northwest Europe, fifteen species belonging to eight genera and four subgenera are reported. Among which *Oscillopha dichotoma* (BAYLE) is reported for the first time.

The stratigraphic distribution of the studied oysters shows that the Upper Cretaceous oysters from Jordan are concentrated in the Cenomanian-Lower Turonian and in the Campanian stages; and those of Northwest Europe are concentrated in the Cenomanian-Turonian and in the Campanian-Maastrichtian stages. Such concentrations in the distribution are possibly related to major transgressions which occurred at the beginning of the Cenomanian and in the Campanian stages which enabled oysters among other fauna to open new suitable environmental niches.

Jordanian and Northwest European oysters are generally found in small to large accumulations, mostly dominated by one or two species which vary from one locality to another. Therefore it is difficult to establish successful regional biostratigraphic zonation based on oysters. However, oyster species such as *Oscillopha wala* n. sp., *O. figari* (FOURTAU), *Laevigyra luynesi* (LARTET), *L. dhondtae* MALCHUS, *Ambigostrea villei* (COQUAND) and *Pycnodonte (Costeina)* sp. characterise certain intervals within the Upper Cretaceous System of Jordan. Also the large oyster-bioherms of Al Hisa Phosphorite Formation (Campanian) which are distributed along a the phosphate belt of Jordan can be mapped as separate units.

Two major oyster-facies patterns can be recognised within the Upper Cretaceous sedimentary sequences of Jordan. A shallow carbonate-platform facies pattern, where Cenomanian-Turonian platform-carbonate sediments (limestones, marly limestones, marls and dolomites) with minor tongues of siliclastics were deposited marking a series of pulses of transgression during the deposition of the Ajlun Group. Here oysters have generally lived in shallow, calm, warm-water. And an oyster-coquinal grainstone and oyster-bioherm facies pattern, where thick beds of large scale oyster-coquinal grainstone, large scale cross-stratified oyster-banks and large oyster-bioherms up to 30m thick were formed. It is possibly established as a result of a change in the configurations of the shelf from a platform to a ramp and of a concomitant rise in the sea level associated with the Late Coniacian transgression. These facies pattern indicate a high energy environment of deposition concomitant to local unconformities, they are successfully correlated with similar oyster-facies from the Negev, southern Israel and Sinai, Egypt. Northwest European Upper Cretaceous oysters reflect different facies patterns. Most of the Cenomanian and Turonian studied species occur in glauconitic marly green sand facies, while most of the Senonian oysters are found in deeper marine white chalk facies.

Cosmopolitan species such as *Pycnodonte (Phygraea) vesiculare* (LAMARCK), *Pycnodonte (Phygraea) vesiculosum* (SOWERBY), *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS) and *Gryphaeostrea canaliculata* (SOWERBY) are reported from Jordan as well as Northwest Europe.

Distribution of oysters in the different oyster-groups show that the Jordanian and the Northwest European ones are dominated by the family Gryphaeidae, subfamily Exo-

gyreinae. However, the Jordanian oysters are dominated by the tribe Exogyrini (*Exogyra, Ilymatogyra, Laevigyra* and *Rhynchostreon*), while the Northwest European ones are dominated by the tribe Nanogyrini (genus *Amphidonte*) with the subgenera *A. (Amphidonte), A. (Ceratostreon)* and *A. (Vultogryphaea)*, the latter is attributed to this genus according to the amphidontid right valve and to the herringbone-cross-foliated structure with mocret lenses. Members of the tribe Exogyrini have divided endostraca with different structures, among which bent-foliated structure is characteristic of the genera *Rhynchostreon* and *Laevigyra;* while species of the genus *Amphidonte* build herringbone-cross-foliated structure with mocret lenses.

1. Introduction

1.1. Statement of the problem

Upper Cretaceous carbonate rocks cover more than 2/3 of the outcroping rock surface of the Hashemite Kingdom of Jordan. These carbonates are rich in both micro- and macro-invertebrate fossils. Efforts made by previous authors were concentrated mainly on studies concerning microfossils and few reports were published on macrofossils from the Kingdom. Oysters represent one of the most frequent and best preserved group of fossils throughout the Jordanian Upper Cretaceous strata. In the few published studies, oysters were partly or briefly discussed. In this study, a serious attempt is made to discuss the palaeontologic, taxonomic and stratigraphic values of the Jordanian oysters based on the Upper Cretaceous species, since they form the majority of oysters in Jordan. Some Jurassic oysters are also included in this study.

Also Upper Cretaceous oysters of the North Temperate Realm from North Europe are systematically reviewed and compared with the Tethyan oysters from Jordan.

Shell microstructure has recently gained an increasing importance in the classification and interpretation of many fossil taxa. It is becoming an integral part of bivalve systematics. A contribution to this character is made by investigating shell microstructures of the Jordanian as well as the North European oysters.

1.2. Material and methodology

For the purposes of this study, oyster samples were collected and documented throughout the outcropping Upper Cretaceous strata in Jordan. Samples were collected by the author in the time between April and August 1988. Most of the samples were collected along the eastern side of the Jordan Rift Valley from Irbid in the North to Ras-El-Naqab in the South. Jurassic oysters were collected from Bajocian-Bathonian strata of Wadi Zerqa River, Arda, Deir Alla, Old Jerash Bridge and King Talal Dam. Additional Upper Cretaceous oyster samples were kindly provided by Prof. K. BANDEL (Geol.-Palaeontol. Institute of the University of Hamburg), they were collected from different localities along the eastern flank of the Jordan Rift Valley. Two compiled columnar sections were measured in Wadi Salihi north of Amman and in Wadi Mujib in Central Jordan. The section in Wadi Salihi is modified after BANDEL & GEYS (1985), the nomenclature used in their work is shown in tab. (1).

Most of the North European material of this study was loaned from fossil collections of the Geological and Palaeontological Institute and Museum of the University of Hamburg. A selected oyster collection was loaned from the Ruhrlandmuseum in Essen. Oyster fossil collections in natural history museums in Münster and Essen in Germany, Paris in France and Brussels in Belgium were visited.

Specimens described in this study are housed in the collection of the Geological-Palaeontological Institute and Museum of the University of Hamburg (GPIMH).

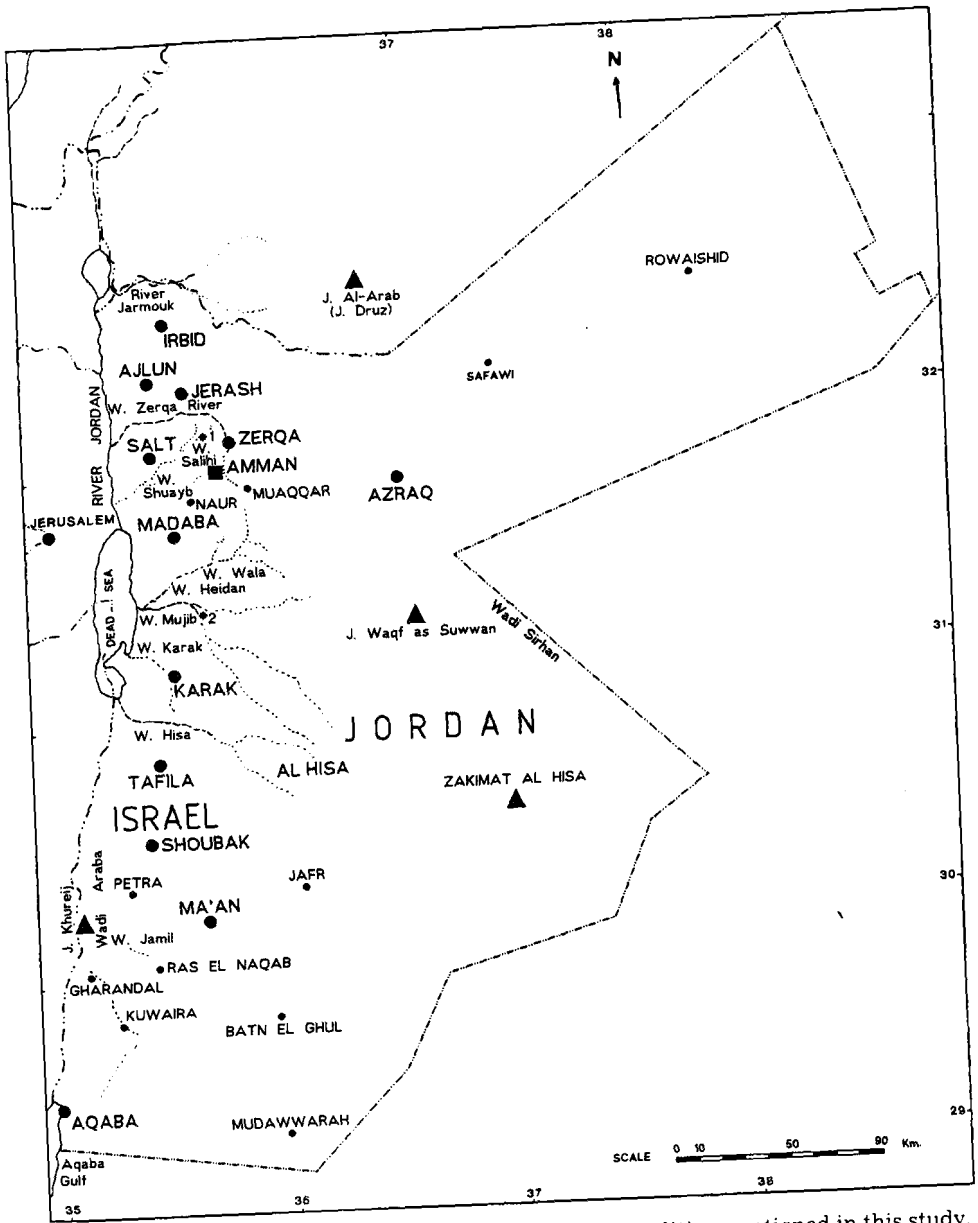

Fig. 1: Location map of Jordan showing the different localities mentioned in this study.

Samples of this study were cleaned by using hydrogen-peroxide (H_2O_2) method for the relatively soft samples and air-pressured sand technique for the hard samples. Over 100 thin-sections from oyster shells were made for the shell microstructure analysis of this study. These thin-sections were studied under the polarized microscope. Photos and drawings necessary for the photo-plates and for the different figures and maps of this study were also made.

2. General geological framework of Jordan

2.1. Geological setting

The Hashemite Kingdom of Jordan lies at the northwestern part of the Arabian Peninsula. It covers 89,544 km^2 between 29°30'–33°30' (Latitude) North and 35°–39° (Longitude) East. The Kingdom is bordered by Syria in the North, Iraq and Saudi Arabia in the East, Saudi Arabia and the Gulf of Aqaba in the South and the Dead Sea and Palestine in the West.

Sedimentation of the Mesozoic and early Cainozoic rocks was controlled by the configuration of the old Tethys Sea to the north and northwest of Jordan and the isostatic movement of the Arabian-Nubian Shield and its Palaeozoic rock cover in the south. Triassic and Jurassic sediments composed of alternating cycles of sandstones, carbonates, shales and some gypsum crop out in the central part of the Jordan Valley east of the Dead Sea and Wadi Zerqa River. These sediments reflect littoral, lagoonal and marine origin. They are restricted to the above mentioned localities and unconformably overlie Lower Palaeozoic sandstones, whereas further south the Palaeozoic strata are mainly overlain by Lower Cretaceous Kurnub Sandstones (see a. o: Cox, 1924, 1932; Wetzel & Morton, 1959; Parker, 1970; Basha, 1981; Bandel & Khoury, 1981; Aqrabawi, 1987; Shinaq, 1990).

Throughout the deposition of the Lower Cretaceous Kurnub Sandstone, the shore-lines lay off north Jordan with a NE-SW trend. Uplift of the hinterland of Jordan resulted in erosion and recycling of the Palaeozoic siliclastic sediments which were deposited on the pre-Kurnub peneplain as mature siliclastics in a fluvial braided stream environment (Powell, 1989). The Lower Cretaceous sandstones are unconformably overlain throughout most of Jordan by a thick Cenomanian- Turonian sequence of predominantly carbonate rocks of the Ajlun Group which reflect a major transgressive sequence as the Tethys Sea advanced southward across the coastal plain, situated adjacent to the present-day Mediterranean coast (Flexer et al. 1986). The Ajlun Group is unconformably overlain by another sequence of limestones, chalks, biogenic cherts and phosphorites with oyster bioherms (Belqa Group) of Coniacian-Eocene age. These sediments were deposited in inner- to midshelf environments during an extensive transgressive phase when the Tethys reached further south to Saudi Arabia (Powell, 1989). Erosion and uplift occurred during a number of phases at Upper Eocene to Pleistocene removed much of the Belqa Group in east and Southeast Jordan and produced fluvial, lacustrine deposits of Oligocene to Miocene- Pliocene age near the margins of the Jordan Rift system, or Quaternary fluvial and lacustrine in East Jordan. Throughout the Quaternary detritus was transported into the Rift Valley, and the extensive Azraq-Wadi Sirhan and El-Jafr depression of East Jordan. These depressions were partly covered by fresh and brackish water lakes during pluvial periods of the Pleistocene, while fluvial conglomerates of the same period spread over extensive areas along the eastern slope of the mountain ridges bordering the eastern flank of the Wadi Araba-Jordan Rift (see a. o.: Masri, 1963; Bender, 1968, 1975; Parker, 1970; Basha, 1979; Powell, 1989).

2.2. Lithostratigraphical nomenclature of the Upper Cretaceous rocks of Jordan:

Upper Cretaceous rocks crop out throughout most of Jordan overlying sediments of Lower Cretaceous Kurnub Sandstone Group. They are generally composed of limestones, marls, chalk, biogenic chert and phosphate of mainly marine origin. Age determinations of these rocks are based on the abundant micro and macrofossil contents. The different lithostratigraphical subdivisions

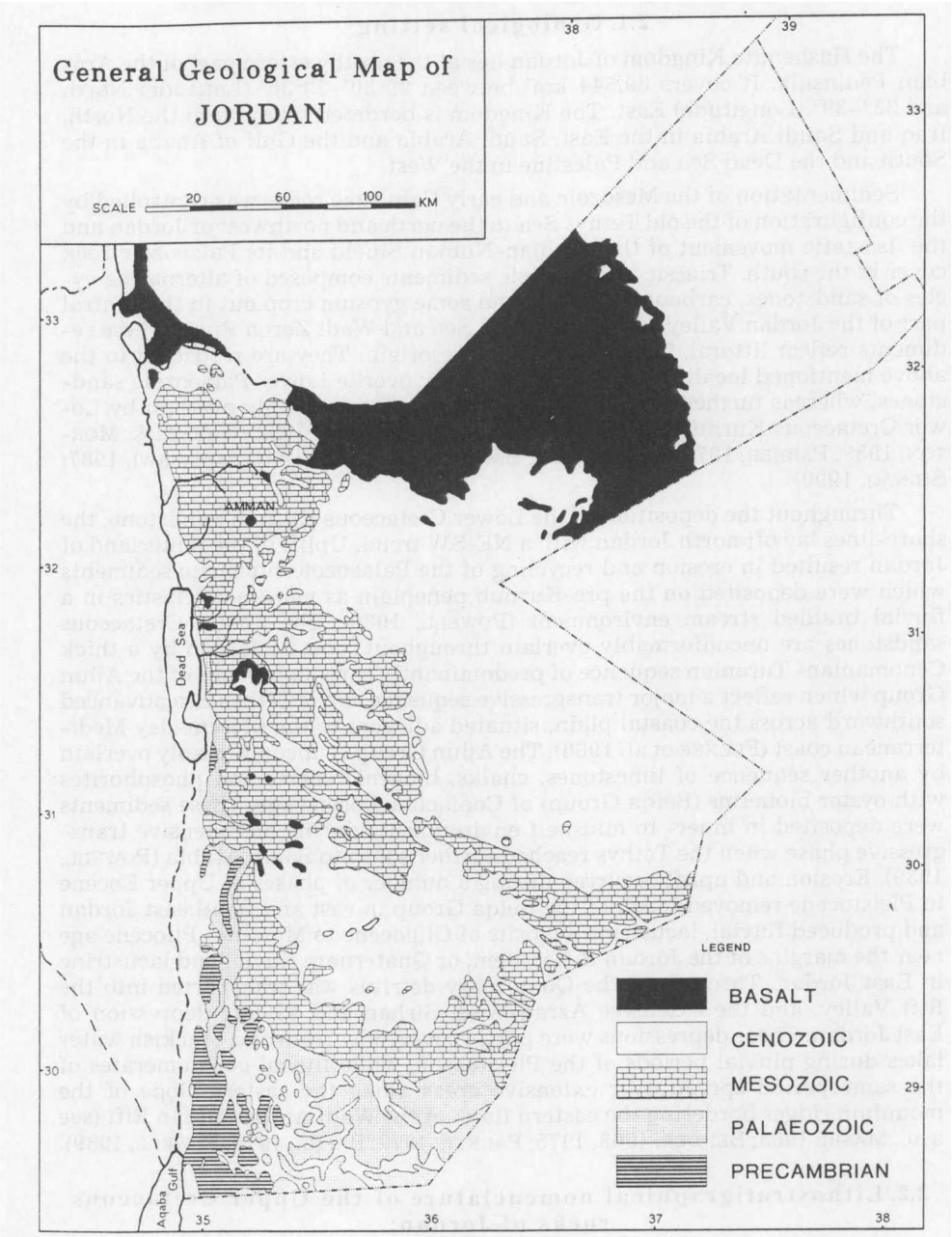

Fig. 2: Genéralised geological map of Jordan (after BENDER, 1968).

are shown in (fig. 4), herein, the subdivisions of POWELL (1989) are currently considered. Ajlun Group (Cenomanian-Turonian) and the lower part of Belqa Group (Coniacian-Maastrichtian) form the base of this study because of their abundant oyster fossil contents. For the purpose of this study, two compiled columnar sections, as reference sections for the Upper Cretaceous rocks of Jordan,

were measured: the first in Wadi Salihi area (fig. 5) north of Amman (location fig. 1), and the second in Wadi Mujib (fig. 6) in Central Jordan (location fig. 1). Oyster samples were collected along the two sections and samples collected elsewhere were compared with these reference sections.

2.2.1. Ajlun group

Strata of this group directly overlie the Lower Cretaceous Kurnub Sandstone Group and crop out in North Jordan and along the margins of the Rift to Ras-El-Naqab area in the South (fig. 3). This group ranges in thickness from 600 m at Irbid in the North and decreases gradually in the southern and southeastern directions (450 m in Wadi Mujib, 180 m in Ras-El-Naqab and zero in Batn-El-Ghul) (POWELL, 1989: 25, 27). According to POWELL (1989), the group is subdivided into six formations.

2.2.1.1. Naur Limestone Formation

This cliff-forming formation (?Albian-Lower Cenomanian) unconformably overlies the Kurnub Sandstone Group from northern to southern Jordan along the eastern margins of the Jordan Rift. It comprises a maximum thickness of 220 m and is subdivided into four members. The lower (Wadi Juhra Member) is mainly composed of sandy marls and dark grey shales with some shelly fauna and plant fossils mainly in the lower most part. It is followed by Member (B): a cliff-forming dolomite, dolomitic limestones and limestones with some chert nodules and abundant *Thalassinoides* burrows (filled with dolomite) which impart a distinctive nodular texture (ABED & SCHNEIDER, 1982). *Pycnodonte vesiculosum* (SOWERBY) (Wadi Salihi, North Jordan) and *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS) (Wadi Mujib, Central Jordan) associated with gastropod moulds which are very common especially in the middle part below the beds rich in the large foraminifera *Orbitulina concava* (LAMARCK). Member (C) consists of marls, dark grey shales and grey limestones with *Thalassinoides* burrows, gastropods, echinoids and bivalves with abundant *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS). Member (D) is composed of cliff-forming dolomites, dolomitic limestones with grey chert nodules. The upper part also contains *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS).

2.2.1.2. Fuheis Formation

This formation overlies the Naur Formation throughout most of North Jordan and has a maximum thickness of 80m. It is composed of fossiliferous marls and marly limestones with thin coquinal oyster packstone beds – *Rhynchostreon mermeti* (COQUAND) in Wadi Salihi section (North Jordan) and *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS) in Wadi Mujib section (Central Jordan). *Laevigyra luynesi* (LARTET) and *Laevigyra dhondtae* MALCHUS are present. In addition to the oysters, moulds of bivalves, gastropods and echinoids are present. The formation is assigned to ?Middle to Upper Cenomanian age (see WETZEL & MORTON, 1959; BASHA, 1979; DILLEY, 1985; BARTOV et al., 1972; BANDEL & GEYS, 1985).

2.2.1.3. Hummar Formation

This formation crops out in North Jordan and thins rapidly south of Wadi Mujib-Central Jordan (60–85 m in Amman area and 10 m in Wadi Mujib). It cannot be recognised in central and southern Jordan due to lateral passage to soft marl-siltstone beds (POWELL, 1989). The formation is cliff-forming and consists of grey limestones, dolomitic limestones and dolomites with a relatively poor macrofossil content such as *Exogyra (Costagyra) olisiponensis* (SHARPE),

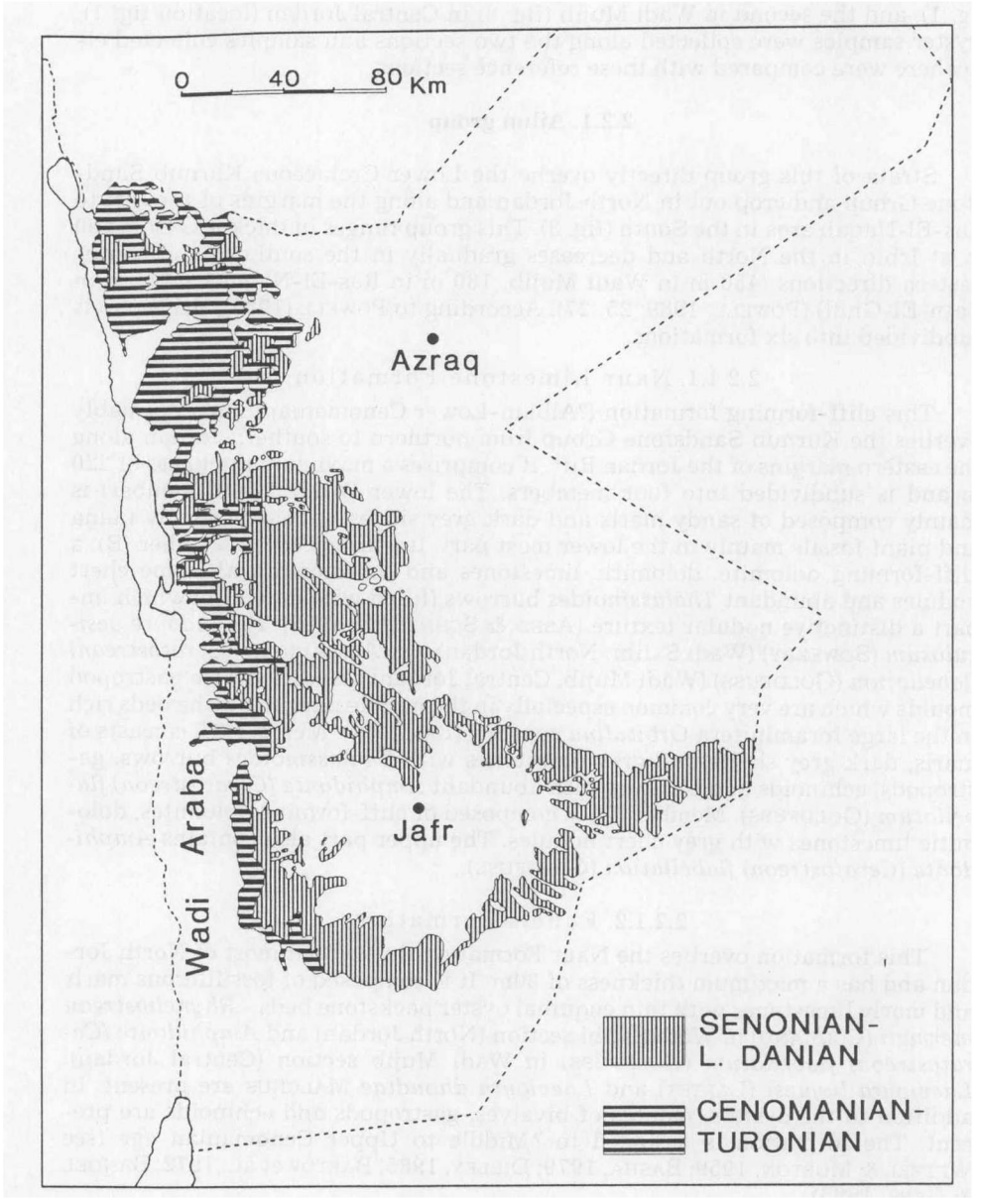

Fig. 3: Distribution of the outcropping Upper Cretaceous rocks in Jordan (data after BENDER, 1975). Cenomanian-Turonian represents the Ajlun Group, and Senonian-Danian represents the Upper Cretaceous part of Belqa Group.

Laevigyra luynesi (LARTET) and *Plicatula auressensis* (COQUAND). It is assigned to Upper Cenomanian age (see POWELL, 1989: 48).

2.2.1.4. Shuayb Formation

This formation consists of about 50 m of thinly bedded limestone, marly limestone and marl. It has a soft-weathering appearance and it is fossiliferous in

most parts. This formation overlies the Hummar Formation in north-central and northern Jordan. In central and southern Jordan, where the Hummar Formation is absent, the base of Shuayb Formation is not traceable, it is included in the undifferentiated Fuheis/Hummar/Shuayb unit. The formation is assigned to Lower Turonian age according to its micro- (mainly foraminifera) and macrofossils. The marly parts are rich in oysters such as *Amphidonte (Ceratostreon) flabellatum* (GOLDFUSS), *Rhynchostreon mermeti* (COQUAND), *Ilymatogyra (Afrogyra) africana* (LAMARCK) and *Laevigyra luynesi* (LARTET) (only in the upper most parts) in addition to other bivalves and gastropods, echinoids and ammonites (see WETZEL & MORTON, 1959; DILLEY, 1985 (sensu POWELL, 1989); POWELL, 1989).

2.2.1.5. Fuheis/Hummar/Shuayb (undifferentiated)

The thickness of Fuheis, Hummar and Shuayb Formations decreases gradually southwards, the boundaries between the three formations are not traceable in central and southern Jordan. Therefore, they are treated as an undivided unit equivalent to the three formations of North Jordan. This unit consist predominantly of marls, mudstones, thin-bedded nodular limestone and gypsum. These rocks are subject to landslip and debris-flow which obscure the outcrop in most areas. They comprise about 150 m in Wadi Mujib-Central Jordan and about 50 m in Ras-El-Naqab area-South Jordan. The marly base of this unit is fossiliferous, it comprises diverse micro- and macrofauna mainly foraminifera, ostracoda, echinodermata, gastropoda and bivalvia of Upper Cenomanian-Lower Turonian age. Oysters present are: *Curvostrea rouvillei* (COQUAND), *Exogyra (Exogyra) italica* (SEGUENZA), *Ilymatogyra (Afrogyra) africana* (LAMARCK), *Exogyra (Costagyra) olisiponensis* (SHARPE), *Laevigyra luynesi* (LARTET), *Laevigyra dhondte* MALCHUS, *Rhynchostreon mermeti* (COQUAND) and *Pycnodonte (Phygraea) vesiculosum* (SOWERBY).

2.2.1.6. Wadi As Sir Limestone Formation

Throughout most of Jordan, the Wadi As Sir Limestone Formation represents the topmost formation of Ajlun Group and is disconformably overlain by the white chalks of the Belqa Group. This formation is distributed along the Rift escarpment from north to south Jordan and is present to the east of Hamza-Azraq basin in Jabal Waqf As Suwwan and in Zakimat El Hasa. It wedges out southeastwards along the escarpment between Ras-El-Naqab and Batn-El-Ghul, where Turonian fluvial sandstones similar to the Lower Cretaceous Kurnub facies were deposited (POWELL, 1989: 60). The formation consists of well-bedded massive limestones, dolomitic limestones and dolomites with some chert nodules and local beds of gypsum. It comprises a thickness of 140 m in Wadi Mujib, about 100 m in Amman area, about 120 m in Karak area and 65 m in Jabal Waqf As Suwwan. According to its Foraminifera and Ammonite contents, the formation is assigned to Turonian-Coniacian age (WETZEL & MORTON, 1959; BASHA, 1978). The base of the section in Wadi Wala is predominated by *Oscillopha wala* n. sp. whilst *Exogyra (Costagyra) olisiponensis* (SHARPE) is frequently present in the Salihi section north of Amman.

2.2.1.7. Khureij Limestone Formation

This formation is composed of 100–120 m thick soft-weathering alternations of marls, limestones, dolomitic limestones and dolomites. It overlies the Wadi As Sir Formation in Jabal Khureij (central to southern Wadi Araba) and is only locally developed due to non-deposition or pre-Belqa Group erosion or a combination of these effects, during the Coniacian. POWELL (1989: 72) suggested a Coniacian to Santonian age for the sequence in Jabal Khureij; his suggestion

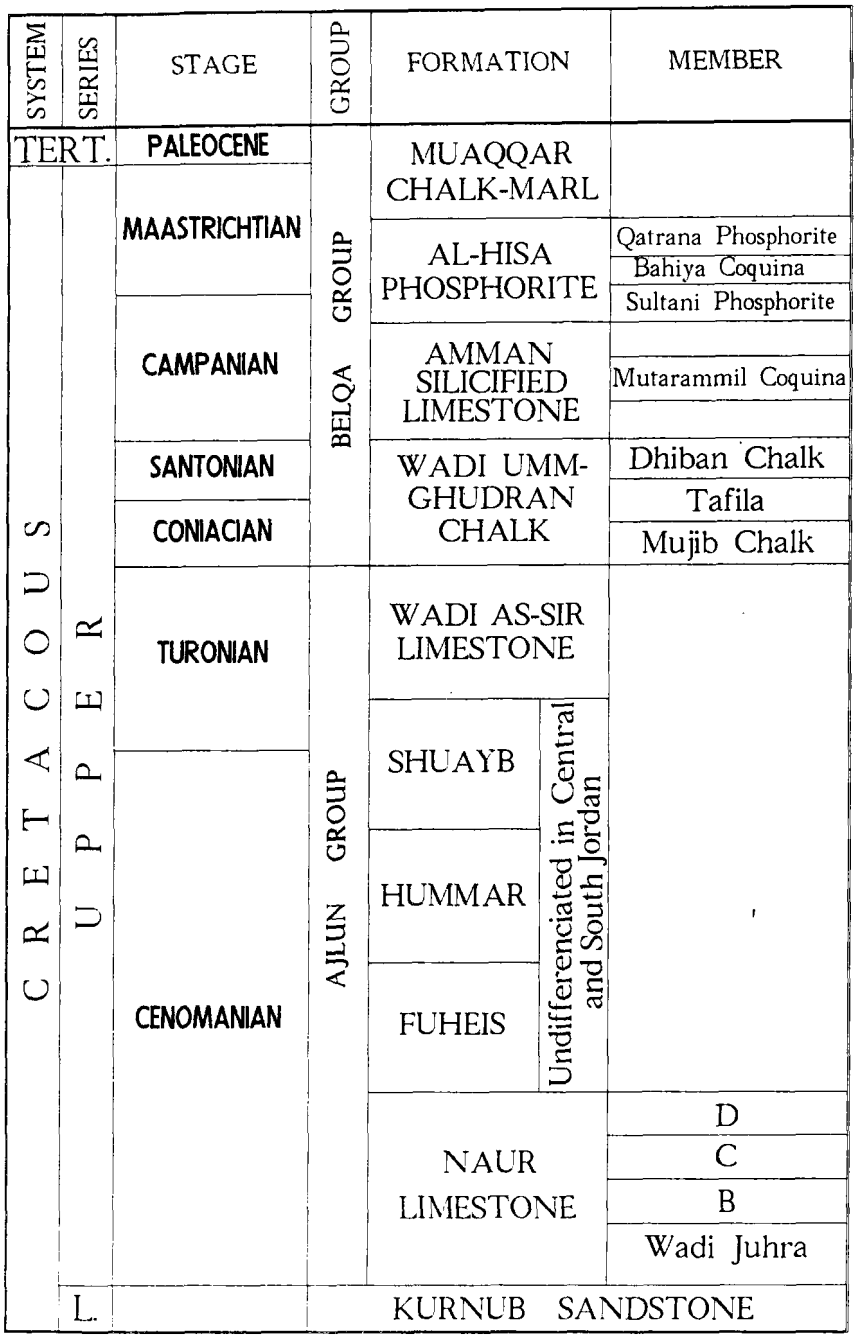

Fig. 4: Nomenclature for the Upper Cretaceous rocks of Jordan (after POWELL, 1989).

is based on preliminary age determinations of ostracods and bivalves (no oysters).

2.2.2. Belqa group

The predominantly pelagic sediments of Belqa Group (chalks, marls, cherts and phosphates) disconformably overlie the Ajlun Group throughout most of Jordan (fig. 3). The group is assigned to Upper Cretaceous (Coniacian) to Tertiary (Upper Eocene) age. It comprises an outcropping thickness of about 600 m in Irbid area and 400–450 m in Ehd Dhira area in the north, 550–600 m in Shawbak area and more than 320 m in Gharandal in the south. The group is subdivided into six formations, four of which are within the Cretaceous period and two are within the Tertiary (see POWELL, 1989)

2.2.2.1. Wadi Umm Ghudran Formation

This formation is mainly composed of soft chalk with some limestone and chert beds or nodules. It overlies the Wadi As Sir Formation and can be traced from north Jordan to central Jordan along the eastern Rift margins, but south of Wadi Tafila the chalks are absent or very thin and the unit is not readily distinguished from the overlying Amman Silicified Limestone Formation. In the area south of Amman, between Madaba and Tafila, the formation is subdivided into three members: the Mujib Chalk, Tafila and Dhiban Chalk, the lithology of the lower and the upper members is similar, consisting of white to grey-white massive chalk with fish fragments, shark teeth, phosphate granules and small bivalve fragments. The middle, Tafila Member, is composed of chalks and chalky marls intercalated with thin lime-stone and chert beds and nodules. The formation ranges, in exposed thickness, between 87 m in Wadi Mujib, central Jordan and 32 m in Waqf As Suwwan, south-eastern Jordan. It is assigned to Upper Coniacian to Santonian age according to the presence of some ammonites, planktonic foraminifera, ostracoda and calcareous nanoplanktons. The small oyster *Pycnodonte (Phygraea) vesiculare* (LAMARCK) forma *nikitini* (ARKHANGUELSKY) is found in the three members in many localities (see WETZEL & MORTON, 1959; BENDER, 1968; POWELL, 1989).

2.2.2.2. Amman Silicified Limestone Formation

This formation is composed of predominantly massive, dark-weathering cherts which exhibit a variety of textures ranging from homogenous to brecciated limestone (as beds or concretion), dolomitic chalky marls, oyster coquinal beds and minor amounts of phosphates (as granules or peloides). In Central Jordan, thin to thick oyster-coquinal beds are present. They consist of fragments or complete shells mainly composed of *Nicaisolopha nicaisei* (COQUAND). The cross-stratified beds indicate strong water currents that reworked and abraded the beds into dune-like banks. The thin beds without cross-bedding to the west and north suggest deeper water zones (POWELL, 1989: 95). The formation measures a maximum thickness of 100 m in Wadi Mujib, about 60 m in Amman-Zerqa area, about 50 m in Irbid area, 45 m in Ras-El-Naqab and only 13 m in Zakimat Al Hisa (POWELL, 1989:97). It is assigned to Campanian age according to its micro- and macrofaunal content. Oysters present are *Pycnodonte (Phygraea) vesiculare* (LAMARCK) forma *typica, Nicaisolopha nicaisei* (COQUAND) and *Gryphaeostrea canaliculata* (SOWERBY).

2.2.2.3. Al Hisa Phosphorite Formation

This formation is as well heterogenous in lithology as the underlying Amman Silicified Limestone Formation. It consists of predominantly phosphate beds with chert, limestones (as beds or nodules), marls, chalky marls and oyster-coquinal beds or oyster-bioherms. The latter form a very distinctive feature in the phosphate belt in Central Jordan, where they are separately mapped as Siwaqa Coquina and Bahiya Coquina by the Jordanian Geological Mapping Divi-