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# The flora of an estuarine channel margin in the Early Cretaceous of Jordan

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with 3 figures and 2 plates

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Content:


## Abstract

Estuarine channels and wet places near the sea were the living environment of *Weichselia reticulata* found in the Aarda Formation, Talal Member of the Kurnub Sandstone of early Cretaceous age in Jordan. A channel is described and with it the general environment in which the Kurnub Sandstone formed. A lithostatigraphical characterization of the Kurnub Sandstone in Central Jordan is presented. Plants found within the lignitic channel fill consist mainly of fronds of *Weichselia*, a tree fern that was characteristic of an environment in which during the late Cretaceous and early Tertiary the mangrove forest developed. *Weichselia* is a characteristic plant of estuarine tropical or near tropical conditions found world-wide and represents early Cretaceous mangrove. Some other plant remains like another fern and leaves, and a cone of a cycadeen species are described as well.

## Zusammenfassung

Ein ästuarer Flußkanal in der Kurnub Sandsteinserie, Aarda Formation, Talal Member wurde zum Altwasser, dessen Ufer vom Sumpf-Baumfarn *Weichselia reticulata* dicht besiedelt war. Der Kanal und seine Füllung werden beschrieben, und das generelle Ablagerungsmilieu sowie der Sedimentationsraum gekennzeichnet. Pflanzenfossilien bestehen im wesentlichen aus Resten des Baumfarns *Weichselia*, daneben kommen aber auch einige Blätter und Zapfen von cycadeenartigen Pflanzen vor. Besonders *Weichselia* wird aus den reichhaltigen Literaturdaten diskutiert und interpretiert. Dieser Baumfarn nahm während der frühen Kreide bis mindestens in das Cenoman hinein die Stelle am Meeresufer ein, die später vom Mangrovewald besiedelt wird, der sich aber erst während der späten Kreide und dann im Alttertiär ausformt. Der Kurnub Sandstein Mitteljordaniens wird lithostratigraphisch untergliedert.

## 1 Introduction

Mangrove forests are the characteristic feature seen on modern tropical estuarine areas all over the world. This kind of vegetation has not begun to appeare before Cenomanian time, and the estuarine facies before was dominated by the fern *Weichselia* found in tropical and semitropical climates on both coasts of the Tethys Ocean and its marginal seas. *Weichselia* represents one of the most common plant fossil found in the Early Cretaceous, and its occurrence in Germany was discussed by MÄGDEFRAU (1968) from Neocomian near Quedlinburg. Its presence in a similar stratigraphic position was described by EDWARDS (1929) from the Kurnub Formation in Jordan. As was indicated by BENDER (1968), *Weichselia reticulata* was found near the old bridge over Zerka river which is now destroyed due to the construction of the King Talal Reservoir and subsequent flooding of the bridge and its road. Remains of this fern were also found by MÄDLER (according to BENDER 1968) downriver from that position, perhaps close to the occurrence that we had a chance to study in detail 1995 and described here. Fluviatile channels in part filled with coal in the lower portion of the Kurnub Sandstone have been briefly described by ABED (1978, 1982) and BANDEL & VÀVRA (1981) had taken note of the presence of silty sandstone beds with numerous trace fossils and mass occurrences of small marine or brackish water caenogastropods indicating influence of the sea near these.

## 2 The Kurnub Sandstone

The Kurnub Formation (QUENNELL 1951) of Jordan in the area of the valley of Zerqa River is about 300 m (BENDER 1968) or 330 m thick (PARKER 1971) and can be differentiated into four members (BANDEL & VÀVRA 1981). The name Kurnub Sandstone was first assigned in 1933, in an unpublished account of DAMESIN (according to PARKER 1971) to sandstones exposed at Kurnub, near Beersheba in the Negev Desert. BLAKE (1936) gives the thickness of the Kurnub Sandstone Group in the Negev near Kurnub as 415 m between the top of the Jurassic and the base of the Cenomanian. At Wadi Hathira in the northern Negev SHAW (1947) measured about 400 m of sandstones, in their central part he found the ammonite *Knemiceras compressum* HYATT. This horizon situated 120 to 150 m above the top of the Upper Jurassic (BENTOR & VROMAN 1951) consists of sandy and limonitic limestone with a small fauna of ammonites, bivalves and some foraminifera, described by AVNIMELECH et al. (1954). It points to an early Albian age. PARKER (1971) created the subdivisions, a lower one called Aarda Formation and an upper one called Subeihi Formation. To the lower about 30 m thick member of Aarda Formation we here apply the new name "King Talal Member". In the canyon of the Zerqa River the Kurnub it is represented by sandstone with channel-deposits which in part consist of coal bearing silty layers (ABED 1978). The King Talal Member is overlain by the about 100 m thick upper member of the Aarda Formation of PARKER (1971) that consists of varicoloured and quite pure quartz sandstone of fluviatile derival here newly named Ruman Member. ABED (1982) found a major direction of crossbeds towards the NE within this sequence with the sand derived from the SE and, thus, the Nubian Continent.

When marine influence increased again the third about 35 m thick member of the Kurnub Group and the basal one of the Subeihi Formation was laid down. Here sand filled channels and silty to clay-rich interlayer of the Amber Member were deposited (BANDEL & HADDADIN 1979). It is overlain by about 130 m of the Jerash Member which consists of channel sands intercalated with thin silty beds and clay fills of channels both of which hold plant remains and trace fossils (BANDEL & HADDADIN 1979, BANDEL & VÁVRA 1981). According to PARKER (1971) the Subeihi Formation measures 132 m in thickness near its type locality 3 km west of Subeihi. A bed within the Amber Member or the basal Jerash Member has been dated further to the west of the Zerqa River near the road from Es Salt to Deir Alla by the occurrence of the ammonite *Knemiceras* as of Albian Age (WETZEL & MORTON 1959) and this age has been confirmed by AL-SAID & MUSTAFA (1994) with the help of pollen and spores that they extracted from beds within the Amber Member.

Thus, the Kurnub Sandstone Group consisting of Aarda and Subeihi Formation and its four members King Talal, Ruman, Amber and Jerash overly Mid-Jurassic limestones of Callovian age (BANDEL & ZEISS 1987) of the Tahuna Member of Muadddi Formation (BANDEL 1981) with a slightly angular unconformity, and they end in the glauconitic marls of the Cenomanian Rumeimin Formation (BANDEL & GEYS 1985). BLANKENHORN (1914) had first noted that the Nubian Sandstone in its upper portion is of early Cretaceous age, and WETZEL & MORTON (1959) found the early Cretaceous sandstones of Jordan overly the Jurassic bed with a clear erosional unconformity, which was supported by BANDEL (1981).

In the southeast of Jordan BENDER & MäDLER (1969) found the Kurnub Formation to measure between 200 to 10 m in thickness. Here it begins with a finegrained root horizon. According to sedimentological characters the sandstones above this soil appear to be deposited under arid-terrestrial and fluviatile conditions. When the plant remains are consulted, the upper portion of this formation was found to have been formed under more humid tropical climate since it contains a flora that consists solely of leaves of angiosperms, and was, thus, interpreted to have formed during Cenomanian time. Further to the north Cenomanian deposits are of marine nature, usually holding much glauconite and a predominance of marls and limestones over quartz sand as is also the case in the central Jordanian position discussed in this paper.

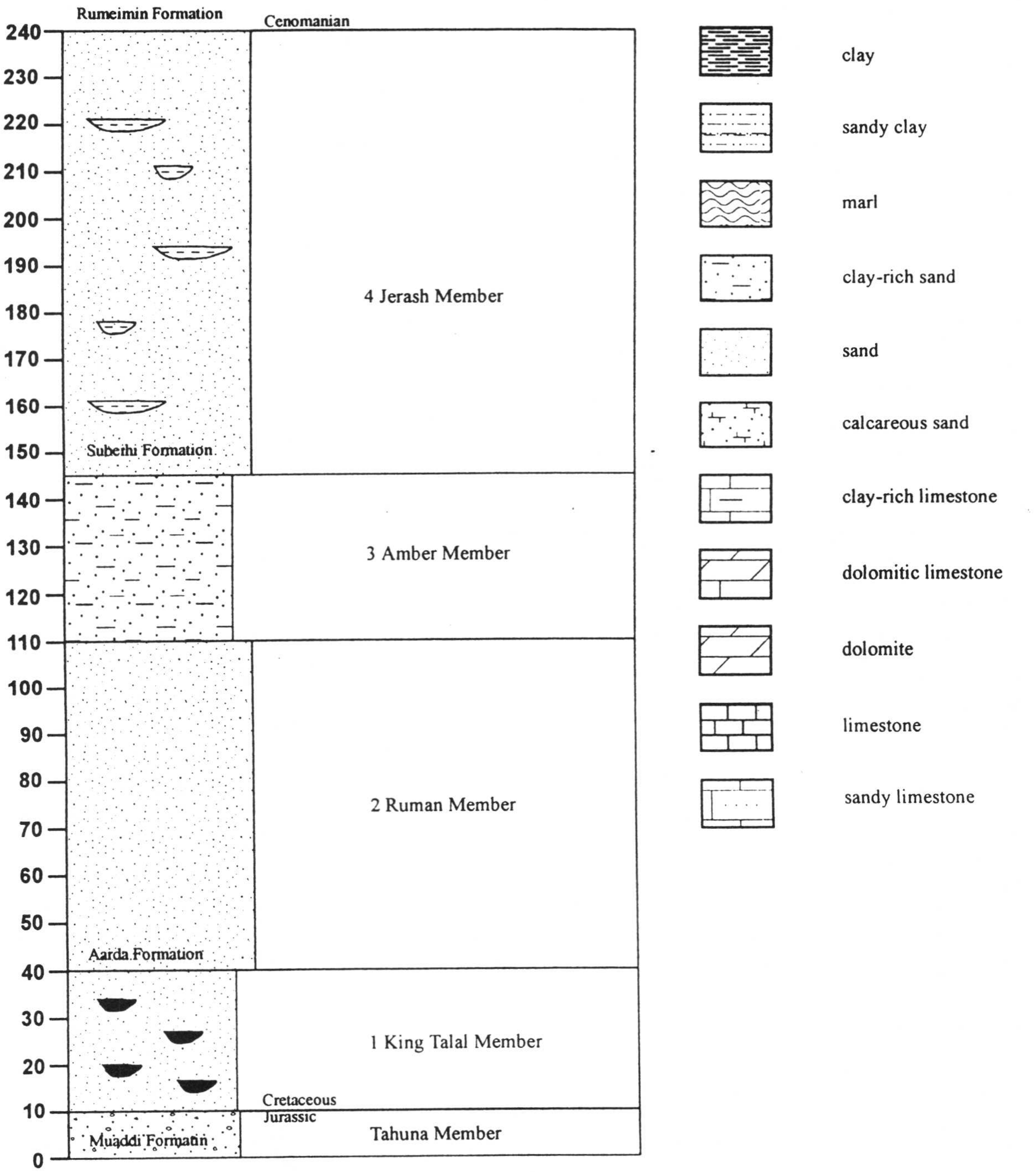


Fig. 1: The simplified section of the Kurnub Sandstone as it is exposed along the valley of the Zerqa River from the King Talal Dam to the highway Amman-Jerash, with the two formations Aarda and Subeihi and the four members King Talal, Ruman, Amber and Jerash indicated.

## 3 Comparison with subsurface data

From eight sections derived from logs of drill sites in northern Jordan we can include the general lithology into our discussion and use them for the interpretation of the depositional history of the Kurnub Sandstone in Jordan. Four of these are distributed in the north of Jordan, namely Northern Highland (NH-2) just north of Irbid, Ramtha 1 (ER-1 A) just east of Irbid, Northern Highland (NH-1) in the desert to the east of Irbid near Mafraq, and Ajlun (AJ-1) to the southwest of Irbid near Ajlun. Another three drill sites lie to the east in the Risha Area of Jordan (see location map). These three desert localities are RH-1, RH-2 and RH-11. A single further source of information come from a drill site near the Azraq Oasis to the east of Amman, which is Wadi Ghadaf (WG-2). The three sections in the Risha area indicate that the Kurnub Sandstone here is much thinner (44-54 m). Here sand beds are intercalated with dolomitic and shaly beds in such a way that two times of strong marine influence can be recognized. The differentiation of the four members can not be carried out with much confidence, but it is quite likely that the Aarda Formation includes the lower marine deposits of dolomitic beds and the Subeihi the upper of these. They clearly indicate that the sea lay in the north of Jordan as well as outcrop document that it lay in the west as well and fluviatile sands were transported from the Nubian Continent mainly toward the west and deposited here and only subordinately to the north. Probably the lower of the marine phases coincided with the channels of the top of King Talal member and the upper marine phase is evidence of the Amber member transgression.

The section from the desert near Azraq (Wadi Ghadaf) indicated little or no marine influence except that sandstones near the shaly and somewhat calcareous middle of the section hold glauconitic grains and deposition began with shales. The more southerly position of this section is also responsible for its base, that here lies on Triassic sandstones, while in the Risha sections it is formed by Jurassic limestones. Going towards the northwest on the Northern Highland 1 drill site, the lithological sequence changes little, but thickness increases from almost 70 m near Azraq to about 210 m near Mafraq. The intercalations in the sandstone here consist of dolomitic beds which in the lower one are quite prominent. This indicates that marine ingressions onto the sandy fluviatile plains of the Kurnub landscape locally went quite far inland. The countryside must have been rather flat so that advances of the sea could proceed far inland. But it did not consist of a total plain as is indicated by the section in the west, in Ajlun (AJ-1) where there is no thick deposit of dolomitic sediment intercalated, but several thin beds indicate more, but shorter excursions of the sea onto the flood plains here. Similar features can be noted in exposed sections of the Kurnub Sandstone, for example near Naur where into the fluviatile sandstone layers of dolomitic beds and shaly beds are intercalated which show bioturbation indicative of marine or near marine life. The section drilled near Irbid (ER-A1) demonstrates a similar profile as seen in Ajlun, but here the Kurnub sandstones are somewhat thicker (183 and 225 m). In the basal portion the sand holds some lignitic beds and also dolomitic layers. In the central part there are some plant bearing shales as well as glauconitic grains within the sand that also have been noted in the upper part. The drill hole near the Yarmouk River (NH-2) is similar to that of Mafraq in composition and thickness.

In conclusion it can be stated that the Kurnub Sandstones form deposits on a rather flat plain near sea level. Before it has been eroded down after it had been faulted into a hilly landscape during latest Jurassic or/and earliest Cretaceous time (BANDEL 1981). With begin of Kurnub deposition most of Jordan and certainly central and northern Jordan as far east as the Risha area and the Azraq area began subsiding sufficiently so that fluviatile deposits were placed here permanently. The time of unrest before Kurnub deposition may be related to the larger tectonic unrest connected to the splitting up of the Gondwana continent such as the disintegration of Africa from South America and Africa from Antarctica. The begin of deposition also coincides with the world-wide rise of sea level at Aptian-Albian time.

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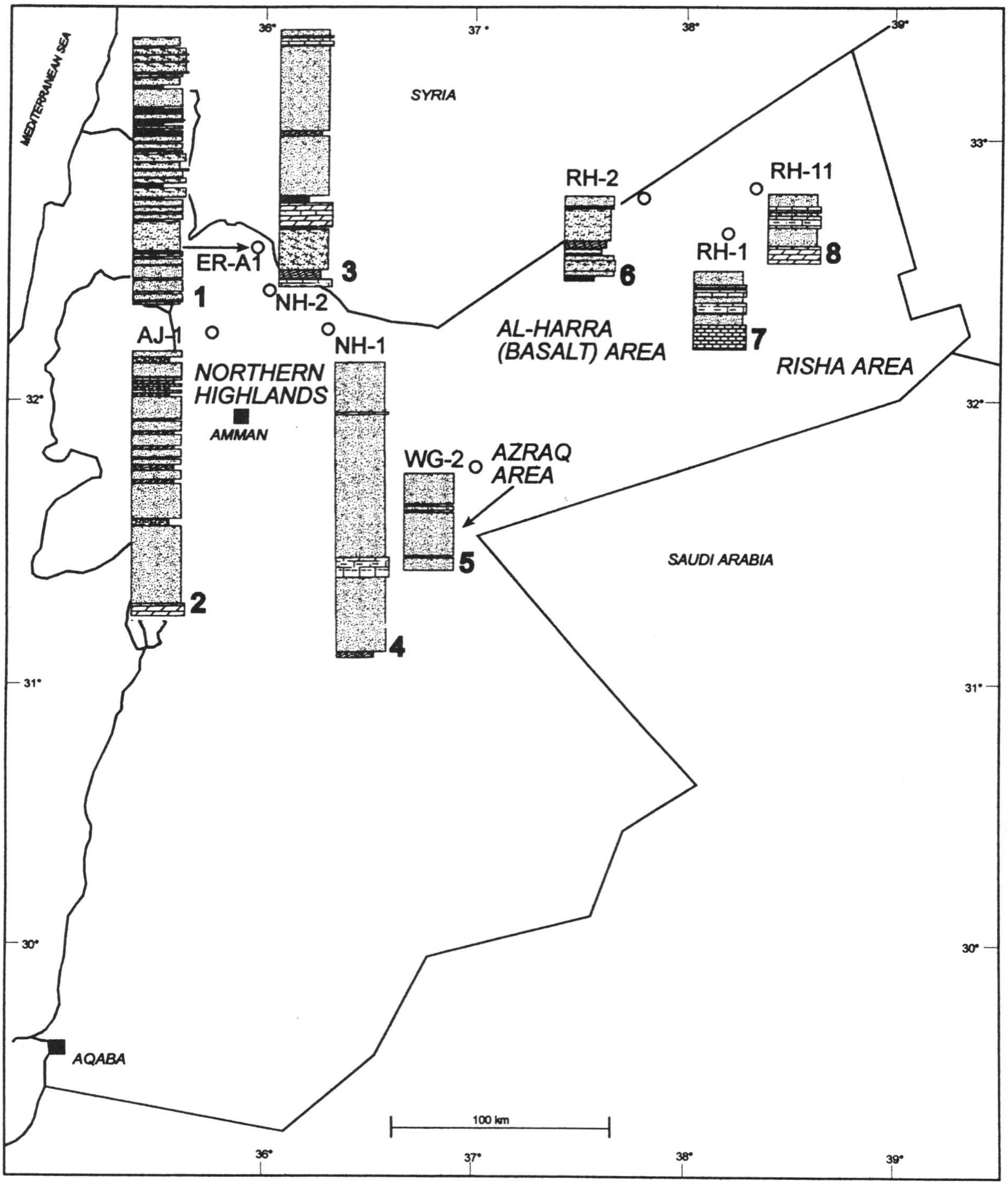
Fig. 2: Kurnub Sandstone in Jordan as can be gathered from several drill holes and differentiated acccording to fig.1. Section 1 is from Ramtha 1 with the top of the formation at 869 m depth and thickness of the Kurnub of 245 m, section 2 is from Ajlun with 547 m depth and thickness of the Kurnub of 182 m, section 3 is from the Northern Highland NH-2 with the top of the Kurnub 1575 m below surface and the formation 225 m thick, section 4 is from Northern Highland NH-1 with the top of the Kurnub 347 m deep and the formation 209 m thick, section 5 was drilled in Wadi Ghadaf in the Azraq area and reached the Kurnub in 1797 m depth and penetrated it after 87 m thickness, section 6 is from the Risha area with 615 m depth reaching the Kurnub of 68 m thickness, section 7 is from Risha with top of the Kurnub 704 m below surface and 44 m thick, and section 8 is from Risha area with 488 m below surface reaching the Kurnub that is 42 m thick.




The drilled sections compared with the outcropping Kurnub sandstones near the Arda Road, the wadis east of Deir Alla indicate that northwestern Jordan had a position near the margin of the southern Tethys Ocean and the northern shores of the Nubian Continent. Sandstone was deposited by channels in a fluviadeltaic system than thinned out and forked to the northwest, thus, forming a classic bird foot delta. Its pattern was reconstructed by

COHEN (1986) based on drill data in Israel to the southeast of Tel Aviv. This delta that is present in the subsurface of northern Israel can be connected to the same river system that also deposited the Kurnub Sandstones of northern Jordan. The Jordan Rift resulted in a 110 km sinistral fault that has since moved Israel and the Sinai relative to Jordan and the bulk of Arabia displacing the delta fan. The Arabian Plate has since rotated somewhat in regard to the African Plate due to the opening of the Red Sea, but otherwise the delta of the Kurnub river system is known in its position on the margin of the Gondwana Continent.

## 4 Description of the channel

Well sorted fine quartz sand overlies the Jurassic limestone for about 20 m deposited in large unindirectional cross beds of fluviatile character. Individual sets are graded from bottom to the top as is found in fluviatile environments of an estuarine river up to the estuary entrance. The succeeding channel pattern fluctuated across these sandy flats forming an about 10 m thick unit of about 200 m width. The channel studied in detail is part of this larger unit and about 4 m deep and 50 m wide, situated in its upper portion. Above it fluviatile sands in large cross beds like those present below, which just to the east grade into channel deposits again which are overprinted by marine benthic life. Thus, periodical increased riverflow transformed parts of the area in sandy braidplains with alluvial fans into which the channel was eroded. Marine influence is documented by numerous trace fossils. The bioturbation consists basically of a network of crab burrows of the thallassinoid type. But besides crabs also bivalves were present and left the characteristic resting marks and motion trails of the *Pelecypodichnus* type. The alluvial plains supported a rich growth of herbaceous and bush-like pteridophytes, mainly consisting of *Weichselia*. Remains of this fern-like plant are very common in the lignitic mudstone that filled the channel.

The channel is flat bottomed with lag-pellet breccia scoured from the removed sediment. Weakening flow induced the crossed bedded basal fills with debris of trees at its base. The drift wood remains, among them some fruit-cones of cycadeen plants, are partly incoaled or have been transformed into pyrite. Here stems of *Weichselia* appear to be the most common logs. The layers above filling the channel consist of 2.7 m of fine lignitic mudstone which in part is a coal. Originally this material must have been an organic ooze. During early diagenesis numerous pyritic nodules grew as concretions in this organic mud. Plant remains, predominantly *Weichselia* fronds are common locally. To the margins of the channel the more silt is added, and finally sand and *Weichselia* remains are here more commonly preserved. Outside of *Weichselia* macroscopic fossils are rare. The finegrained lignitic beds of the channel fill break parallel to bedding when dry and appear massive when moist. The organic ooze was mixed with more clay in the upper layers of the channel fill and with more silt near channel margins. The increase in silt and sand content cause the channel fill to grade into the sand near the channel margins.

The lignitic mudstone is overlain by a sand bed with irregular base demonstrating scour and fills and a rippled top. This bed measures a few centimeters to about 70 cm in thickness. In the central channel portion it is overlain by clay that is bioturbated in its basal portion and well bedded above. Near channel margins these beds are more silty and more organic and contain numerous *Weichselia* remains. In its basal portion many stems with up to 15 cm width are found and further up more remains of more or less well preserved leaves and fronds are present. The primary pinnae still retain their original convex concave shape, but stems are always compacted and strongly incoaled. In the bioturbation process of the basal clay layer in the centre of the channel growth of the fern *Weichselia* had no part, since its remains do not enter the sand below, and there are no indications of larger roots that may have entered the sediment here.

The top of the channel is formed by an about 50 cm thick, well bedded sand bed with bioturbations of crab burrows of the same type as in lateral position to the coal filled channel. Muddy sediment has been transported into these sand beds from below by the crabs when they excavated their burrows. Aside from numerous well preserved burrow systems of different crabs also the trails of bivalves are common along with a number of other trace fossils indicating a rather diverse assemblage of marine animals have lived here and left their traces in the silty sand. After a period of fluctuating marine and fluviatile influence river flow increased, and the sand deposited on top of the channel consist of such river deposits without influence of bioturbations.

*Weichselia* stems and leaves are well preserved and bear no traces of long transport. They must therefore have grown very close to the margins of the channel. But there is no indication that the plant actually lived directly on the banks and within the shallow portions of the channel since there are no traces of larger roots to be found in its deposits. A similar channel as that described in detail had been observed at the King Talal reservoir near the dam, in about 12 m above the Jurassic limestones. ABED (1978, 1982) described channels filled with low-quality lignite from the Ain Khunaizir at the Ardaa road but with little detail.

## 5 Description of the flora: *Weichselia*

The most common plant remains consist of leaves and stems of *Weichselia* which is a tree fern. The genus *Weichselia* STIELER, 1857 is based on *Weichselia reticulata* that has been originally named for sterile fronds found in the English Wealden originally called *Pecopteris reticulata* STOKES & WEBB, 1824. The genus *Weichselia* has been created to hold fossils of this species found at Quedlinburg on the northern margin of Harz Mountain in Germany. On this plant from Quedlinburg several authors have commented, among these STIELER (1857), LIPP (1932), GOTHAN (1923), MÄGDEFRAU (1968), DABER (1968). The family Weichseliaceae ZIMMERMANN, 1959 with the genus *Weichselia reticulata* according to ALVIN (1971) represents a leptosporangiate fern in which stem and petiole of the adult plant have a complex polycyclic dictyostele and secretory ducts. The frond has primary divisions in a predate manner on the petiole, and the fertile frond differs from the sterile one (DABER 1968, LIPP 1932, ALVIN 1971). *Stiehleria simildae* (STIEHLER, 1857) representing badly preserved stems found in Quedlinburg may represent the stems of *Weichselia reticulata* (ALVIN, 1971).

*Weichselia* lived during late Jurassic (?) and early Cretaceous time. According to MÄGDEFRAU (1968) it had leaves of 1 to 2 m length arising directly from the rootstock (rhizome). But reconstructions of the plant differ according to the author, perhaps indicating that *Weichselia* actually represents a number of similar species. In the reconstruction presented by MÄGDEFRAU (1968, fig. 286) the leaves are forked near their base while leaves are unforked in the plant as drawn by (BOMMER 1910). It may have been unforked and sometimes forked as in the reconstruction of ALVIN (1971), which with minor changes is illustrated here again (Fig. 3).

ALVIN (1971) compared the arrangement of the leaves with the end of the petiole in the living fern *Matonia pectinata* where leaves divide up into a palmate arrangement. The leaf is the flat, green and expanded part of the fern that reaches about 1 m in length and 15 to 30 cm in width in case of *Weichselia* and have broadly lanceolate shape and bipennate composition. Leaves are of different size when they are sterile or fertile. They are not unlike those found among modern *Osmunda* and have, thus, been placed with that genus which did not prove to be correct (ALVIN 1971).

ALVIN (1971) observed no wing-like aphlebial structures like those reported by LIPPS (1932), GOTHAN & WEYLAND (1954), MÄGDEFRAU (1968) and DABER (1968) between the bifurcation of the stem from German material. We have also not seen aphlebial structures in the many leaves found in Jordan. Where they branch they do so without connection, and this may also indicate that there is actually more than one species involved in *Weichselia reticulata*.

According to ALVIN (1971) the massive erect or suberect stem was 5-8 cm in diameter. We have found stems of at least 15 cm width and of quite some length. This agrees with results of NICOL-LEJAL & DOMINIK (1990) who found similarly large stem size from the Cenomanian of Egypt and discussed earlier description of such stems from the Baharia Oasis in Egypt that had been called *Paradoxopteris* and connected with *Weichselia*.

The stem has an irregular contour due to the spirally arranged former leaf bases and root attachments which are quite unlike the roots of any known fern (ALVIN 1971). Such roots are not found in the channel proper in Jordan. The cylindrical roots were about 2 cm wide and oriented obliquely downwards branching from the stem at an angle of about 30°. ALVIN (1971) suggested that there was one rooting organ associated with each petiole. This appears not to be a likely arrangement in fully grown specimen from Jordan according to our observations and from Egypt according to NICOL-LEJAL & DOMINIK (1990). Here *Weichselia* developed a long thick stem without branching and connection between roots and leaves, perhaps with the exception of the earliest petiole of leaves formed before the fern grew in height.

The axis of the sterile leaf had a maximum diameter of 2 cm and to it 10 or more pairs of leaflets of oblong shape with a length of about 15 cm up to 25 cm and arranged in alternating rows are attached (Pl. I, figs. 1-5, 8-10, Pl. II, figs.1, 2). The leaflets are attached to the axis along their whole width (GOTHAN & WEYLAND 1954), they are 6-15 mm apart and consists of subleaflets attached to an axis of about 2 mm width. Leaflets are inserted along the upper side of the leaf axis and form a so called "butterfly position" (DABER 1968). The subleaflets are narrow oblong with blunt tipped ends and rounded bases. Terminal subleaflets are larger and often semi-arched when the next lower ones are continuous with them. Subleaflets are of slightly sigmoidal shape, parallel-sided except for the rounded end and length of 3 to 6 mm and breadth of 1.3-2.5 mm (ALVIN 1971, 1974). NICOL-LEJAL & DOMINIK (1990) found larger ones with to 9 mm in length in the Cenomanian of Egypt, and this is also the case of *Weichselia* from Jordan. Veining of the subleaflets is net-like with the midrip grading into a net veining before reaching the apex (Pl. I, Figs. 5, 9, 10). This netted pattern lies in the thick and leathery leaf and veining is more pronounced on the lower surface. FLORIN (1919) noted that stomata lie in grooves, which represents a xeromorph feature as is found in modern *Niphobolus*. According to ALVIN (1971) the leaf is, thus, protected against desiccation by thickened stomata which are bulging and large in the interstices of the veins on the lower side of the leaflets. Here the epidermis is densely stomatic.

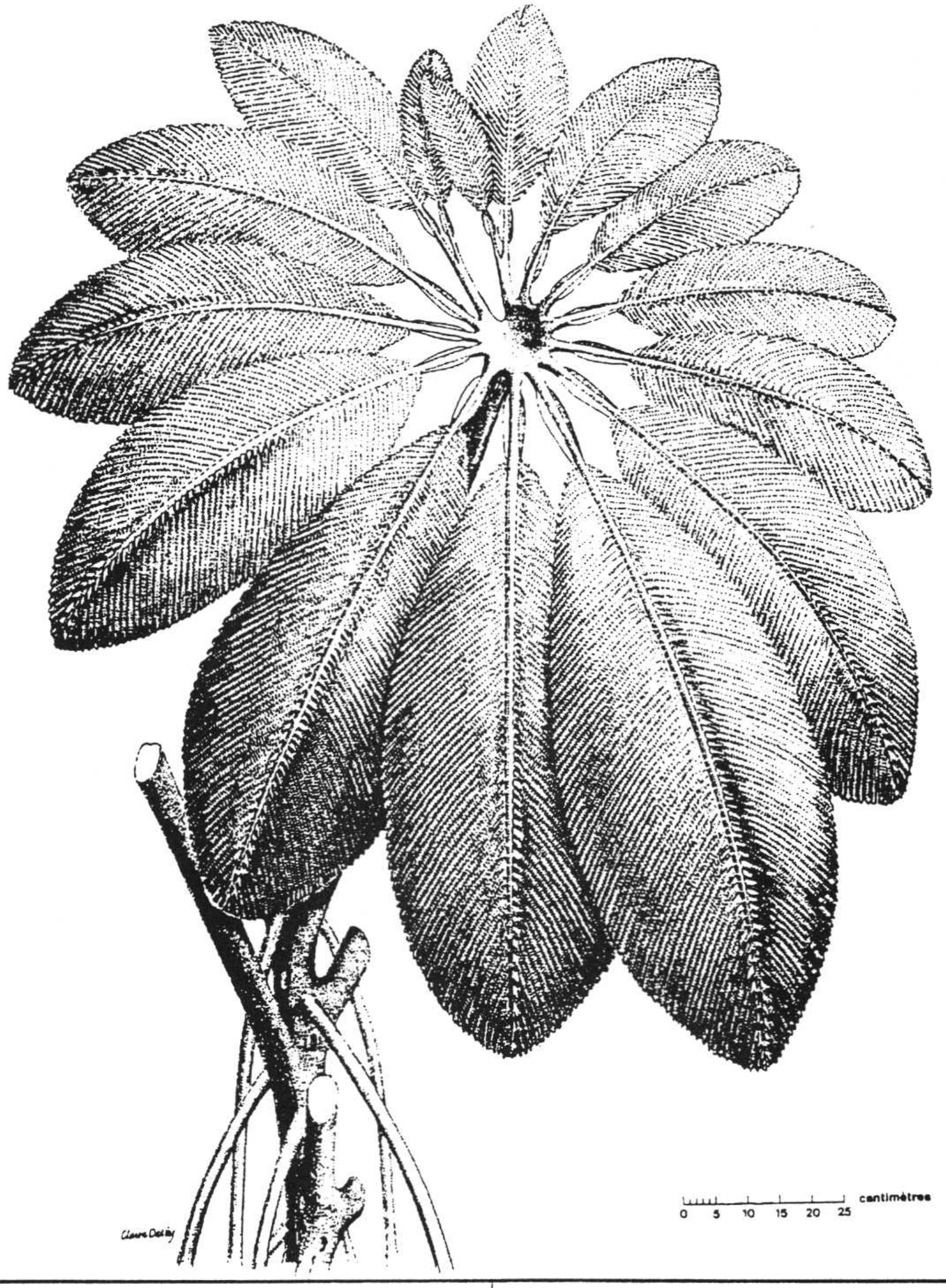
The foliation is very variable, especially when young and fully grown leafs are compared. GOTHAN (1923) reconstructed the fern as rather rigid with spread out leaves. A nearly complete individual shows the end of a stem or branch with a circle of fronds attached to it umbrella-like with the single leaves (fronds) up to 1 m long. GOTHAN noted that the plant was bend down due to its being covered by sand, but still in contact with the root horizon. The plant was, thus, short and appeared to have a non branching stem. In the light of what we know by now it appeared to have been a juvenile plant or another less tree fern-like species of *Weichselia* than the ones that grew on the northern shores of Gondwana.

The fertile leaves differ in shape from those of the sterile leaves and have instead of the small subleaflets (pinnulae) spherical fructifications on both sides of the rhachis as has been known since NATHORST (1891) described it from the Holma sandstone in Sweden comparing it with modern *Onoclea* a fern of the Polypodiaceae. The ultimate divisions of the fertile frond is non-laminate and bears two rows of soral clusters that consist of a receptacle bearing the tightly packed sori. A sorus is simple and consists of a ring of large sporangia covered by a peltate indusium (BOMMER 1910, SCHUSTER 1930, ALVIN 1971). The fertile leaves were not found in contact with vegetative leaves in the European material described by BOMMER (1910, ALVIN (1968, 1971), LIPPS (1932) and EDWARDS (1933). According to LIPPS (1932) they consist of scale-like leaves each of which holds six 0.8 mm high and 0.3 mm wide ovoid sporangia and about twelve form the fructification (sorus) arranged around the rhachis. The trilate tetrahedral isospores were extracted from them by LIPPS (1932), and ALVIN (1971) figured them.

The spore is ejected, when matures and grows into a prothallium on moist soil. In ferns (Filices) to which *Weichselia* belongs, the haploid gametophyte changes with the diploide sporophyte. On the lower side of the prothallium the antheridia form which release spermatozoides and archegonia that represent female egg containers. Spermatozoids and eggs are haploid and fuse to a diploid egg from which a new fern arises. Spores of *Weichselia* have a well developed trilete ridge (LIPPS 1932, ALVIN 1971) and AL-SAID & MUSTAFA (1994) described similar spores as *Cyathidites* occuring very commonly in the lignite of the channels in the King Talal Member of Aarda Formation in Jordan.

A fertile leaf was present in our material from Jordan (Pl. 1, figs. 6, 7). Here we can present some new data. ALVIN (1971, Pl. 5, fig. 11-22) suggested that there is no mixed fertile-vegetative condition in *Weichselia* , but the Jordanian fossils shows a steril leaf that continues in a fertile leaf. Thus, the exact nature of this fertile frond, which according to EDWARDS (1933) and also to ALVIN (1971) was still uncertain, in the *Weichselia* from the lower Kurnub Sandstone near King Talal Dam is demonstated to lie at the tip of leaflets since the transition from a sterile to a fertile leaflet is preserved (Pl. I, figs. 6, 7).

Fig. 3: Reconstruction of the fern *Weichselia reticulata* as presented by ALVIN (1971, Fig. 3) with the stem bearing rooting organs and the circle of leaves (petioles). Only young individuals of *Weichselia* in Jordan had this shape, later they developed a tree like shape with a long stem between the roots and the circle of leaves.

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The stem anatomy resembles that of *Paradoxopteris* HIRMER, 1927 (SCHUSTER 1930, EDWARDS 1933, NICOL-LEJAL & DOMINIK 1990) and according to ALVIN (1971) consists of a peripheral fibrous zone of 1.5 mm thickness surrounding a parenchymatous zone that contains a polycyclic system of meristeles. The peripheral zone contains a ring of cavities or canals of up to 1 mm in diameter. ALVIN (1971) considers them to represent secretory canals. The peripheral tissue consists of smaller cells on the ouside. The meristeles lie in concentric rings and are concentrically constructed. The xylem mass is thinnest in the middle and thickest near the ends of the "C". It consists of tracheids. LEJAL-NICOL & DOMINIK (1990) analysed the stem from the Baharya Oasis in western Egypt with the aid of the scanning electronic microscope and found very large water transport cells in the wood similar to such plants that live near to water.

## 6 Description of the flora: Other plants

Leaves and cones of a member of the Cycadales (Pl. II, figs. 5, 6, 8-10).

The family Cycadacea is composed of palm-like plants with leaves arranged in spirals around the stem. The plants are either male or female and have fructifications consisting of cones which resemble cones found in other gymnosperms, but differ from them by having cone scales that do not separate widely at maturity as they do in conifers. Male cones are smaller, but produce extremely many pollen grains. The female cone has two or more seeds on each of the cone leaves and several hundred seeds united in each cone. The cone of Cycadeaceae may be rather large and have a central axis and numerous spreading structures, the scales (Pl. II, fig. 5). These sporophylls are modified leaves arranged in columns that are distributed on the axis in a low spiral (Pl. II, fig. 10). Each female sporophyll has the seeds attached directly to the stalk of the sporophyll. The outer surface of the cone has a rhomboid scale pattern (Pl. II, figs. 5, 9) similar to the modern *Microcycas* cone (JONES 1993), where it is of more hexagonal scale shape.

Cycad leaves are carried in a crown which terminates the trunk. The leaves of almost all modern cycads are once divided or pinnate. The pinnae or single leaves of a *Zamites* like frond with nearly parallel veins are encountered more rarely than *Weichselia* and are illustrated in Pl. II, figs. 6, 8. EDWARDS (1929) reported the occurrence of *Weichselia* associated with *Zamites* and *Brachyphyllum* in the Early Cretaceous of the Lebanon. The leaves of different plants that grew at early Cretaceous times but belonged to Benettitales, Nilssoniaceae, Caytoniaceae etc., common similar to each other and resemble the leaves found in ancient and modern cycadeens, but the shape of their stomata with the epidermis of the leaves differ. The shapes of the individual leaves of genera like *Zamites*, *Ptilophyllum*, *Anomozamites*, *Otozamite*, *Pterophyllum*, and *Taeniopteris* have been quite similar to each other from the late Carboniferous to the Early Cretaceous Wealden facies and into the Neocomian (Zimmermann 1959, Jones 1993). Modern cycads still have similar foliation.

Also another fern closely resembling modern Polypodiaceae has been encountered with few fragments of fertile fronds still bearing their spore capsules (Pl. II, figs. 3, 4). A thick leathery leave of some unknown plant (Pl. II, fig. 7) completes the floral remains that were encountered together with the numerous *Weichselia* fronds. The cycad, the fern and the other probably tree-like plant lived at some distance from the channel and the *Weichselia* thickets and their remains are, thus, much rarer.

The climate of Tethyan coast of Gondwana during the late Jurassic and the early Cretaceous was considered to have been tropical and semiarid with the ferns *Weichselia* and *Piazopteris* common along with members of the Bennettitales, Araucariaceae and Cheirolepidiaceae growing together with them. Only in the second half of the Cretaceous the climate turned to become more humid (VAKHRAMEEV 1988).

## 7 Paleoecology of the *Weichselia* swamp

MÄGDEFRAU (1968) reconstructed the living environment of *Weichselia* based on the outcrops in the vicinity of Quedlinburg as sand dunes near the shore of the sea. In the German Wealden swamps that existed in the transition from the Jurassic to the Cretaceous and during early Cretaceous *Weichselia* was not present, but in the English Wealden it is described by HUGHES (1975) and from such beds it has originally been named. In these deltaic environments of the lowermost Cretaceous in southeast England sandy environments were present as well. A similar sandy setting was reconstructed for *Weichselia* from the Holma-Sandstone of Sweden by SCHUSTER (1930), and it has also been accepted by GOTHAN & WEYLAND (1954).

According to ALVIN (1971) *Weichselia* represented a massive fern with rather unusual rooting organs similar to the modern tropical *Pandanus*. *Weichselia* represented the dominant species of the community in which it generally grew. Its special root compared to aerial prop roots resemble such plants that nowadays grow in the tropical mangrove forest. NICOL-LEJAL & DOMINIK (1990) found that the structure of the wood of the stem of *Weichselia* reflects growth from wet environment while the xerophytic structure of the leaves reflects adaptation to dry climate. *Weichselia* was, thus, growing from wet ground into dry air in a tropical climate probably with alternating dry and rainy seasons. *Weichselia* grew along the northern shore of Gondwana from the late Jurassic to the late Cenomanian (NICOL-LEJAL & DOMINIK 1990). It accompanied embayments reaching the Niger on the Atlantic side of the African plate as well as the Indian Ocean reaching Kenia and is found in Tunesia, Egypt, and the Sudan, as well as in Syria and Jordan. It represents a coastal shore plant especially of estuarine facies and is found mainly in this environment on both shores of the Tethys Ocean, and its side branches onto Africa and Europe prior to the appearance of the mangrove.

Modern mangrove is an area taken by bushes and trees found especially within the mouth of rivers in tropical areas. Like the seagrass environment this forest is a result of the evolution of the angiosperms. Mangrove evolution is indicated with the first appearance of the mangove palm *Nypa* (Arecaceae) in the Coniacian of Gondwana (KRUTSCH 1970) along the tropical west African and Southamerican coast of the Atlantic Ocean. Traces of this mangrove palm appeared during the Cretaceous in Egypt, India and Indonesia (SCHRANK 1984, MULLER 1968). During the Eocene *Nypa* also grew along the shores of Europe, tracing the occurrence of mangrove forests in southern England, in the Paris Basin, Germany, Poland, and Hungary (MAI 1995). Today the mangrove palm grows in estuarine coastal swamps in southeast Asia. During the Tertiary the fern *Acrostichum* grew within the mangroves of Europe (CHANDLER 1960), as it does in southeast Asian mangroves today. Trees and bushes belonging to the Rhizophoraceae are known since Eocene, and they dominate the modern mangrove with 4 genera and 12 species, but having more genera and species within the tropical rainforest. Their characteristic fruiting organs and their pollen grains are known since Eocene of Europe Africa and America (MAI 1995) with first similar pollen from the Paleocene (KRUTZSCH 1970, 1989). *Rhizophora* grows side roots from the Mainstem, and *Bruguiera* has angular roots which come out of the ground (prop roots), and here form air breathing portions. *Avicennia marina* of the Avicenniaceae grows in American mangroves and has typical roots with vertical branches which issue from the mud near the bush or tree. It is known from the Miocene of Europe (NAGY 1990, NAGY & KOKAY 1991, BESSEDIK 1981). Sonneratiaceae with the six species of *Sonneratia* have breathing roots issuing from the mud of the mangrove forest like in *Avicennia* and lives along the coast of the Indian Ocean.

All these plants with exception of the mangrove fern *Acrostichium* which is not similar to *Weichselia* have evolved long after the Kurnub canal formed during Preaptian time within the estuarine region of a river and filled. In the Kurnub Sandstone Group the onset of angiosperm settlement in the area is well documented in the Amber Member of Albian age (BANDEL & VÁVRA 1981, AL-SAID & MUSTAFA 1994). Even during Cenomanian time angiosperms did not enter the estuarine area of changing salinities as was noted by NICOL-LEJAL & DOMINIK (1990) where Vitaceae, Lauraceae, Mangoliaceae, Cornaceae and Proteaceae had species of trees and bushes growing nearby on land, and Nymphaeaceae uand Typhaceae grew in the fresh water, but the area occupied later by mangrove was that in which *Weichselia* grew in the area of the southern shore of Africa which is now the Baharia Oasis in Egypt. In Jordan *Weichselia* was not noted in the Amber Member, probably because it was not an estuarine region, but a coastal area where sea and land were next to each other without brackish water and estuarine conditions between them (BANDEL & HADDADIN 1979).

## 8 Paleogeography of the Kurnub Sandstone

EDWARD (1933) considered all species described in the genus *Weichselia* to be undistinguishable from *Weichselia reticulata,* and thus, noted the geographically extremely widespread occurence ranging from South America to Africa, Europe and India. According to VAKHRAMEEV (1988) *Weichselia reticulata* is a plant of the arid zone, found very widespread from near Moscow to Mongolia and Eastern China to Tibet, western (England), central (Germany), southern (Montsec) (BARALE 1979) and eastern Europe (Russia, Romania), Japan as well as the South American Cordillera, Africa in Tunesia, Egypt, and Nigeria. The later dates were confirmed by NICOL-LEJAL & DOMINIK (1990) who noted *Weichselia* in Northern Africa from the late Jurassic to the late Cenomanian, and from Niger to Egypt, and Sudan to Kenya, as well as in Syria and Jordan. Its absence from former boreal regions was noted by ALVIN (1971). *Weichselia* posessed xerophilic characters and characterizes the arid and semiarid zone of the early Cretaceous on both sides of the Tethyian Ocean.

During the Lower Cretaceous the Tethian Sea separated the Euamerican region and the Asian Block on one side from the African-Arabian Plate and the South American Plate on the other side. Thus, floral regions were separated from each other by the circumequatorial Tethyan Ocean.

Jordan lies on the northwestern edge of the Arabo-Nubian shield which formed the relatively stable southern flank of the Tethys Ocean. Following a marine regression in the Late Jurassic the sea returned during the Early Cretaceous, to oscilate and started with an intensive marine invasion only during the early Late Cretaceous (Cenomanian, when most of Jordan was covered by sea well until the early Tertiary (until Mid Eocene time). The Neocomian-Maastrichtian sequence exposed in Jordan clearly exhibits an increase in marine influence with the Cenomanian transgression representing a major advance onto the African plate.

In southern Israel, Jordan, and Egypt it is possible to trace the landward extent of marine calcareous or fossiliferous clastic beds and reconstruct the approximate position of various shorelines (LEWY 1990). In Wadi Hathira in the northern Negev there are about 450 m of mostly continental sandstones with three marine horizons about 120-160 m obove the top of the Jurassic beds (AVNIMELECH et al. 1954). Within this about 50 m thick marin intermission they found the bivalves *Exogyra*, *Neithea*, *Trigonia* and the ammonite *Knemiceras* together with marine foraminifera in limonitic limestone (REISS 1961). GRADER et al. (1960) reported that from Kurnub in the Negev Desert to the northwest the early Cretaceous becomes more shaly and calcareous, indicating a change from continental depositional regime to a marginal marine sedimentation. GRADER et al. (1960) divided the subsurface rock column in Israel a lower uniform shale unit of Barremian to Tithonian age which is 280 m thick. It is overlain by a sandy-shaly-limy oolitic complex of Valanginian, Hauterivian and Barremian with 375 m thickness. A third unit of 370 m thickness consists of similar rocks as the unit below, but also including some dolomitic portions. It reaches Aptian age. The upper unit is dolomitic-limy, chalky-shaly, holding detritic layers of 320 m thickness and Albian age. This uppermost unit is time equivalent to about the Jerash Member in northern Jordan, perhaps also the Amber member. The three lower marine early Cretaceous units of Israel can not be related to the Subeihi Formation directly, but should at least in part their time equivalent.

This displacement that occurred in connection with the formation of the Jordan Rift system during the Neogene is reflected in the displacement of Triassic and Jurassic coastlines (BANDEL 1981). The fluvio-deltaic sand bodies have inclusions of lignite marking a coastline which migrated through time southeastward. The Kurnub Sandstone was deposited simultaneously with the shallow marine and coastal Helez, and the Telamim Formation as was described by COHEN (1986) to the west of Jordan Rift and the Gevaram and Talme Yafe Formations which accumulated in deeper water west of the shelf platform (BEIN & WEILER 1976). During deposition of the Kurnub Sandstone the sea also lay toward the north where it covered the Palmyride Basin (BEST et al. 1993). In that basin dolomitic limestone was deposited. The sea ended near the drill sections in the Risha area, and these deposits also indicate the margin of the Nubian Continent. The sea from the east was linked with the open Tethys Ocean that washed the coastal line almost parallel to modern Levantine shore.

Spores extracted from the Kurnub series near the Talal Dam site by AL-SAID & MUSTAFA (1994) indicate an age of deposition that was before angiosperms appeared, thus, older than Aptian/Albian times. The great hiatus present between Mid Jurassic rocks on one side and early Cretaceous on the other side indicates an extended period on non deposition in northern Jordan before the begin of Kurnub sedimentation. A similar time of erosion before the onset of early Cretaceous deposition was noted in the North, in the Palmyrite Basin in Syria (BEST et al. 1993). Even though the unconformity between beds of older age and early Cretaceous rocks is rarely observed in the outcrops in Jordan, and the contact is commonly quite indistinct, in an area reaching from Wadi Zerqa to Wadi Mujib within a distance of about 75 km from north to south about 1500 m of sediment had been eroded prior to the deposition of the sandy Kurnub-Group (BANDEL 1981, BANDEL & KHOURY 1981). The only exposure with clear erosional disconformity and inclined strata below the Kurnub base is exposed to the north of Naur in the northwest of Amman. Here inclined Mid Triassic rocks have been trunkated. The fault bound erosion of older strata in a southwards ascending staircase (step faulting) is developed in Jordan as well as west of the rift in the Negev. According to GRADER et al. (1960) the main transgression on the peneplained lands occurred again at Aptian time. It appeared that this was probably a bit earlier in Northern Jordan since there are no angiosperm pollen to be extracted from the King Talal Member.

From the oceanographic setting and the onlapping nature of the Cretaceous marin sediments it may be concluded that relative sea-level generally rose progessively ingressing further onto the Arabo-Nubian continent. The sandstones of the Kurnub Group belong to the so called Nubian Sandstones. The Cretaceous Nubian Sandstones of Egypt was deposited under tropical to subtropical climate (BACHMANN et al. 1996). Such Early Cretaceous Nubian Sandstone is known from North and Central Sudan, Lybia Egypt and Arabia. BARTOUX & FRITEL

(1925) described from East of Aswan in Egypt from such sandstones a flora containing *Weichselia* sp. Early Cretaceous sandstones are also known from southern margin of Gebel el Galala in Egypt. Here they compose the 80 to 100 m thick Dakhal Formation that hold massive trunks of tree ferns near its base possibly belonging to *Weichselia* (BANDEL & KUSS 1986). These sandstones also contain crab burrows, while further to the east in Wadi Qena they are devoid of trace fossils and of purely fluviatile character (BANDEL et al. 1987). *Weichselia* trunks, thus, would also occur together with sand that was deposited near and within the influence of the sea, as in Quendlinburg or near Jerash. They are still present in the Cenomanian as shown by NICOL-LEJAL & DOMINIK (1990).

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**Plate I**

All figures represent *Weichselia.*

Fig. 1 Pairs of leaflets of oblong shape are arranged in alternating rows and consist of subleaflets (width of illustrated frond about 5 cm).

Fig. 2 The axis of the sterile leave has a diameter of a little more than 1cm.

Fig. 3 Leaflets were inserted along the upper side of the almost 2 cm wide leaf axis (centre) and form a so called "butterfly position".

Fig. 4 The leaflets are attached to the axis along their whole width and are about 10 mm apart. Their subleaflets are attached to an axis of up to 2 mm in width.

Fig. 5 Veining of the up to 4 mm wide subleaflets is net-like with the midrip grading into a net veining before reaching the apex.

Fig. 6 The fertile leave differs in shape from the sterile leaves and have instead of the small subleaflets (pinnulae) spherical fructifications on both sides of the rhachis (same as fig. 7). The transition from a sterile to a fertile leaflet is seen in the lower to the upper portion of the figure.

Fig. 7 The steril leaflet continues in a fertile leaflet (about 10 mm width). Thus, it lies at the tip of leaflets.

Fig. 8 Terminal subleaflets are larger and often semi-arched when the next lower ones are continuous with them. (2 cm length).

Fig. 9 This netted pattern lies in the thick and leathery leaf and veining is more pronounced on the lower surface. A leaflet is about 13 mm wide.

Fig. 10 The subleaflets are narrow, oblong with blunt tipped ends, and rounded bases. (leaflet about 12 mm wide).

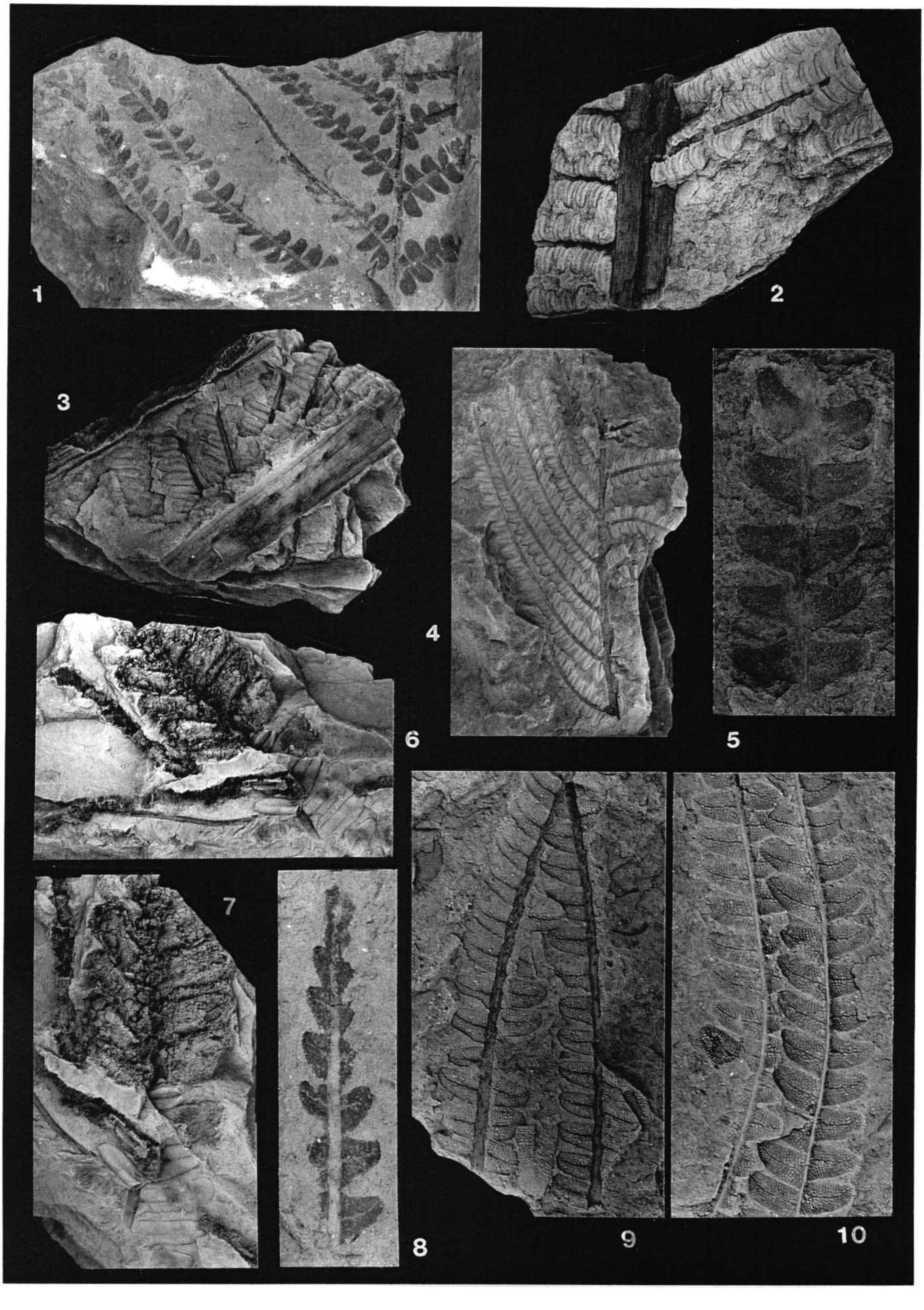
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**Plate II**

Fig. 1 Subleaflets of *Weichselia* are of slightly sigmoidal shape, parallel-sided except for the rounded end. The leaflets are about 18 mm wide and overlap.

Fig. 2 *Weichselia* had rather rigid fronds with spread out leaves and rigid leaflets, in this case of almost 2 cm width.

Fig. 3 A fern resembling modern *Polypodium* with round fruitdots on the base of its about 8 mm long subleaflets.

Fig. 4 A similar fern as in fig.3 demonstrating the broad attachment to the leaflets to the leave as is found among many Polypodiaceae. The leave is about 2 cm wide.

Fig. 5 The cone of a cycad preserved with sporophylls in the upper portion and imprints of the outer surface in the lower portion which is shown in detail in fig. 9.

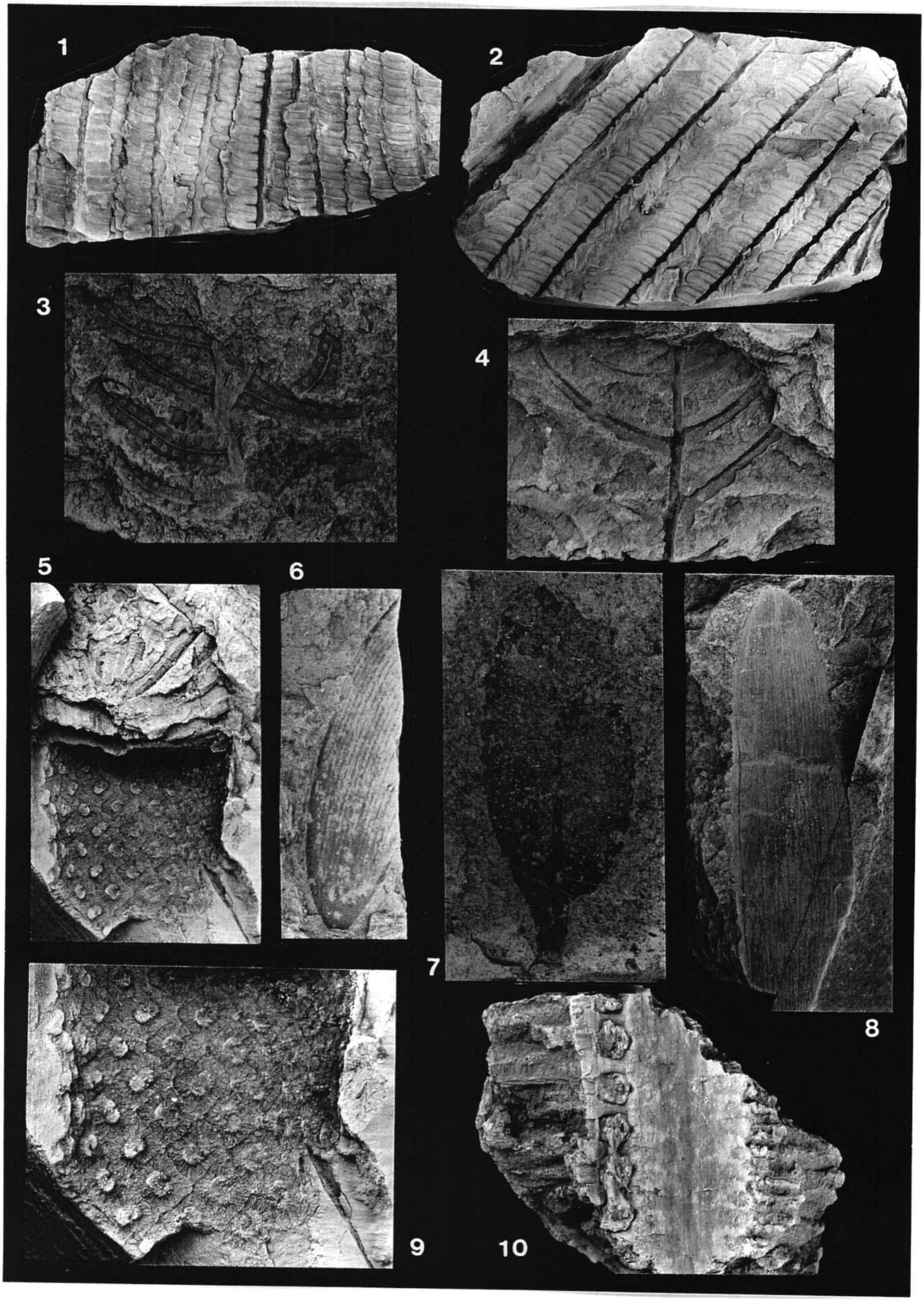
Fig. 6 The basal portion of a leaflet of a cycadean frond of the *Zamites* type with parallel veining. The leaflet is about 7 mm wide.

Fig. 7 A thick leathery leave of about 12 mm width belonging to an unknown plant.

Fig. 8 The anterior portion of a 10 mm wide leaflet of a cycadean frond of the *Zamites* type with parallel veining.

Fig. 9 The outer surface of the cone has a rhomboid scale pattern (detail to fig. 5).

Fig. 10 The fructification of a cycad that consists of cone with seeds (seen on left middle) on each of the cone leaves (seen on both sides) arranged around a central axis. The female sporophyll has the seeds attached directly to the stalk of the sporophyll.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## Paläontologie, Stratigraphie, Fazies

Freiberger Forschungshefte, Reihe C

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