THE DEPOSITIONAL ENVIRONMENT OF AMBER – BEARING

ROCKS IN JORDAN

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ملخص

أنتج شجر اللزّاب اوراوكاريان اجاتيس العنبر المكتشف حديثا في طبقات العصر الطباشيري.ويمثل هذا العنبر كافورا متحجرا تشكّل في مناطق ساحلية وتجمّع في تربة غاباتها . أدى طغيان المياه المتكرر على المناطق الساحلية إلى إعادة ترسيب بعض هذا العنبر، وقد أمكن التعرف على بيئات قرب ساحلية مختلفة من آثار الحيوانات والنباتات القديمة.

ABSTRACT

The newly – discovered amber of Lower Cretaceous age was formed by an araucarian conifer. The amber which represents a fossil copal, was produced in abundance in the coastal forests and enriched in the forest soil. Repeated transgressions of the sea over the coastal swamps redeposited some of the amber. Different nearshore environments are recognized by their characteristic trace fossil fauna and by plant fossils.

INTRODUCTION

Amber is an unusual type of rock formed by the oxidation of resins produced by tree – like plants. The Roman historian, Tacitus, in his «Germania» has already described the unique nature of the mineral amber (Succinit or Elektrum) in saying:» One easily sees that amber is the resin of some trees since it contains all kinds of small animals that crawl around on the earth or even those that fly. They are now contained in a solid material that must have been liquid when it surrounded them.» Tacitus was writing about the Baltic amber which was well known since ancient times and which was held in high value by the Romans as well as by people before and after them.

Baltic amber is a fossil resin which was produced mainly by a now extinct species of the genus **Pinus**, a pine tree which flourished on the shores of a former sea in the Upper Eocene (Tertiary) times and in forests on Fennoscandian land. Much of it was redeposited in Tertiary and Quaternary times and is now present in secondary deposits in the marine beds of the Lower Oligocene in the glacial deposits of the Quaternary. From these, amber was washed out by the waters of the Baltic sea and washed up on the shores, where it was collected for trading and for local use, and where it is still collected today.

Since amber is only slightly heavier than water (spec. weight 1.050 – 1.096) it is easily transported by currents and, like driftwood, is washed up on beaches.

Besides the Baltic region, amber has been discovered in a number of other places around the world. Some years ago it was discovered in the Lower Cretaceous strata of Lebanon. Here it was found in connection with coal seams and deltaic deposits of the Neocomian and the Aptian (Lower Cretaceous). Dietrich (1976) collected and studied the Lebanese amber and expressed the opinion that Cretaceous amber was formed by araucarian trees and not by pine trees.

Some years ago (1960) Abbas Haddadin, one of the authors of this study, discovered pieces of amber on the road near the Amman – Jarash bridge over the Zarka river. He showed some of these samples to Klaus Bandel, the other author of this report, and this gave rise to a geological research of this occurrence, the report of which is represented in this paper.

The help rendered by Machmud el Kaisy in preparing the sections of the amber and wood, and of Adnan Sabbah and Mohm. Bustanji for drafting the figures is gratefully acknowledged. Our special thanks are due to Dr. Elias Salameh for his interest in this work and for critically reading the manuscript.

GEOLOGICAL SETTING

Between the Zerka bridge on the Amman – Jarash road and the upper reaches of the King Talal Reservoir Lower Cretaceous sand and siltones of the Kurnub – Group are exposed in the Wadi Zerka. The name Kurnub Sandstone was first assigned to sandstones exposed at Kurnub, near Beersheba in Southern Palestine. in an unpublished account by Damesin

(1933). Quennel (1951) also gave the name Kurnub sandstone to rocks exposed in the area of the Zerka river.

The Kurnub Group disconformably overlies Jurassic sediments. The boundary between both is well exposed at river level near the upperstream end of the king Talal Reservoir. According to Parker (1971) the Kurnub Group in the Wadi Zerka region measures about 330 m in total thickness. The upper border of this group is characterized by glauconitic sediments overlain by yellow brown dolomitic limestone and clays with a rich marine and lagoonal fauna. These are well exposed above the studied section in the road cuts on the Amman – Jarash road at the southern side of the Wadi Zerka. These marine lagoonal beds are of Cenomanian age (Bender, 1968).

The studied section, which has several beds containing amber, is situated a few kilometers downstream of the Zerka bridge on the Amman – Jarash road, near the small settlement, Khirbat es Suweirat (Fig. 1, Location 3). On the left side of the bridge siltbeds are exposed. They are overlain by massive sandstones and contain a rich flora and amber (Fig. 1, Location 2). Another outcrop, which has little amber but abundant plant remains, is found about 1 km upstream of the bridge in the northern cliffs of the Wadi Zerka (Fig. 1, Location 1).

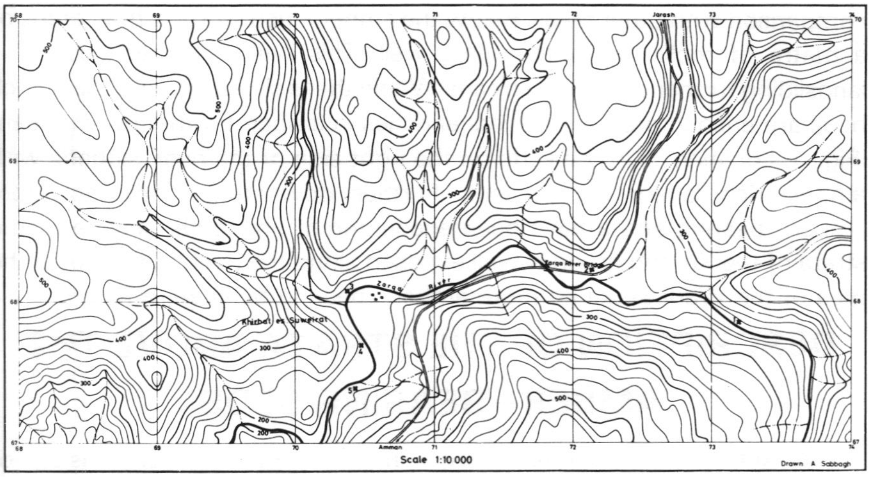

Figure 1: Map of the Zerka Valley with the locations 1 to 5 where amber and plant fossils were found.

Between the bridge and Khirabat es Suweirat, on both sides of the river, no amber was found in the exposed rocks. At the river crossing on the left side of the valley a section of the middle portion of the Kurnub Group is well exposed. Here the richest deposits of amber were encountered. A detailed section is presented below (Fig. 4). Above these amber – bearing beds about 140 m of rock is exposed without disturbance by faults. This

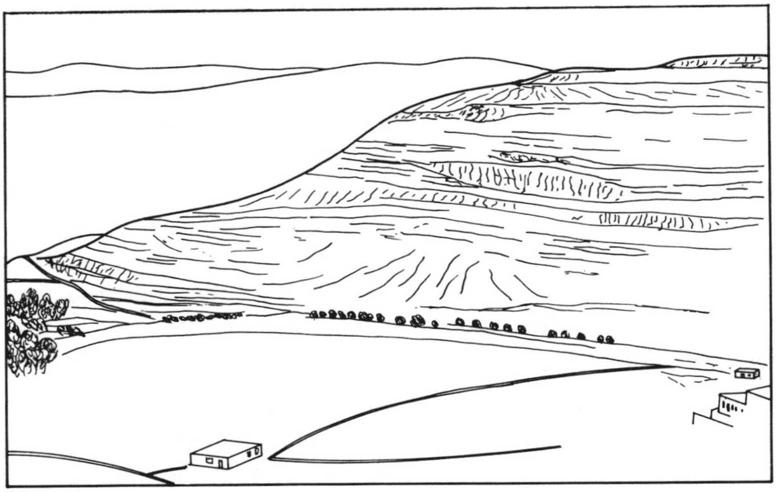

Figure 2: The mountain opposite the village Khirbat es Suweirat drawn from photographs shows the locality 3 and sequence above it. In this study the amber – bearing strata of locality 3 are described in detail and the overburden, up to the top of the mountain is discribed in a general way

sequence is described here without detail (Fig. 3) to enable better comparison with other areas. Below the amber – rich strata, a few tenths of a metre of rocks are outcropping well. This well – exposed section is landsliding further down the stream. Within these slides, silty and clay – rich beds are encountered with layers enriches in amber. Further downstream (Fig. 1, Location 5) in the cliffs on the right side of the river, siltbeds with amber – rich layers are present. Further downstream still, no more amber – bearing strata have been encountered. The lower section of the strata of the Kurnub group is well exposed along the river banks, but in the area of the Wadi Zerka no more amber – bearing beds were found.

DESCRIPTION OF THE STRATA ABOVE THE AMBER – BEARING BEDS

The top of the mountain shown in the sketch (Fig. 2) consists of calcareous rock (Unit 200). Limestone precipitated from rainwater and groundwater has encrusted layers of gravel and rock debris and formed massive limestone above these. Basaltic rocks (Unit 190) are underlying gravel and calcareous caliche. These volcanic rocks are highly weathered and original minerals have to a large degree been transformed into clay minerals. Weathering of the volcanic flow also has produced roundish, concentrically layered, ball – like features of the basalt.

Between the top of the basalt flow and the calcareous beds, gravel is exposed and fluviatile sediments fill channels cut into the basalt. The volcanic material itself overlies sandy and silty, unlithified sediments. These are poorly exposed at the surface (Unit 180). Beds of this unit consist of 2 m thick, well – bedded, calcareous sandstones with a crossbedding structure are poorly exposed at the surface (Unit 180). Beds of Unit 170consist of 2m thick, well – bedded, calcareous sandstones with a crossbedding structure on 7m thick coarse sandstones with large scale crossbedding. About 17m of siltstone with intercalted sandstone beds follow (Unit 160). The layers are only weakly lithified and often show the effects of strong bioturbation. Unit 150 comprises a sequence of silt – and sandstones. The well – lithified sandstone layers often show rippled surfaces and plant remains. Trace fossils are common. Crab and bivalve trails and resting tracks can be differentiated. Some layers contain an abundence of badly – preserved gastropod shells.

Below the fossil – rich Unit 150, a 3 m thick sand stone bed (Unit 140) forms a vertical ledge in the slope of the mountain. In its upper part it contains large trace fossils of marine origin (**Diplocraterion, Teichichnus** and others).Unit 130 consists of 6 m of varicolored sandstones with crossbedding. These sandstones contain a few silt – sandstone layers with trace fossils and some totally bioturbated calcareous sandstones. Unit 130 forms the top of a very massive, crossbedded, up to 15 m thick sandstone. Unit 120 can easily be recognized from the sketch of the mountain presented in Figure 2, because it forms a lenticular body that thins out on both sides.The lateral continuation of this sandstone bed consists of a series of sand and siltstones with trace fossils abundant.

Below Unit 120 yellowish and reddish silt – and sandstones of about 20 m thickness are exposed (Unit 110). Here trace fossils are abundant. Below, Units 100,90 and 80 comprise beds of about 35 m of siltstone, lenticular sandstone bodies, and calcareous sandstones. Some of the siltstones show root horizons and the massive calcareous sandstones are completely bioturbated. Sandstones with crossbedding usually form discontinuous bodies that grade into thinner sand – and siltstone layers.

DESCRIPTION OF THE AMBER – BEARING BEDS

The massive sandstones (Unit 80) grade at their base into badly lithified, crossbedded sandstones (Unit 70). These crossbedded layers grade rapidly into horizontally laminated sandy siltstones with abundant but badly preserved plant remains (Unit 60). In this bed the first small, reddish pieces of amber can be encountered both disseminated within the sandy – silty

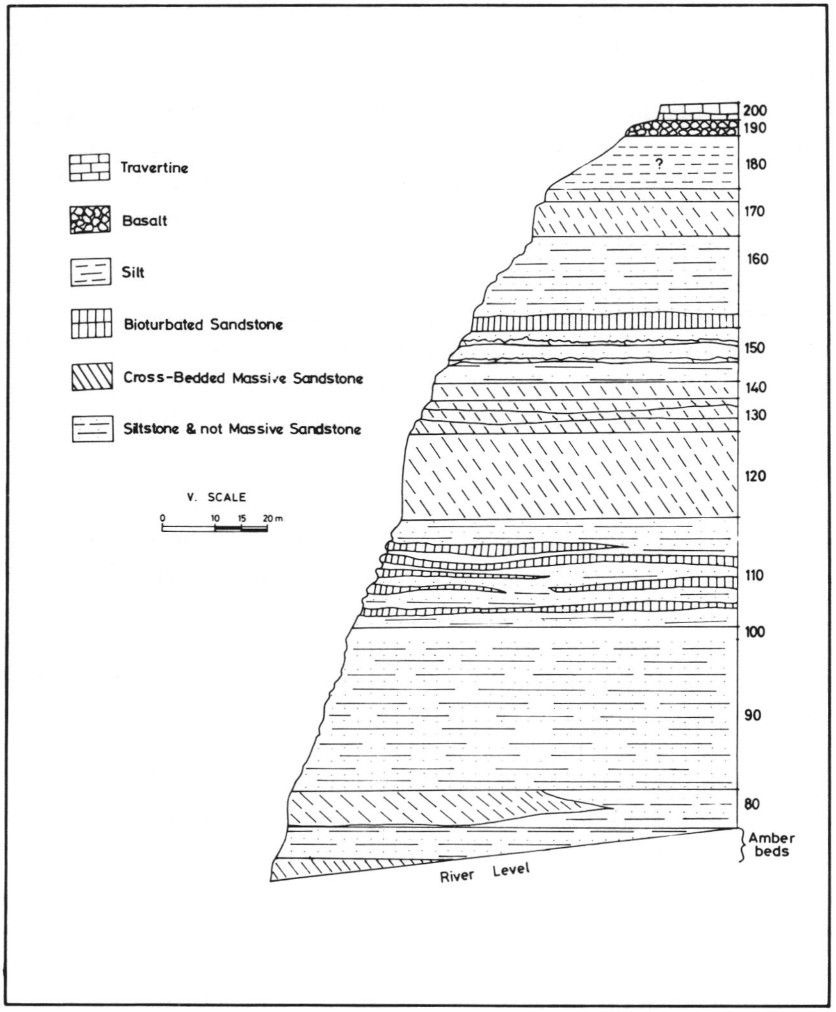

Figure 3: A general section of the stata overlying the amber – bearing beds as they are exposed on the mountain slope seen in Fig. 2

rock matrix and enriched on bedding planes with plant fossils. The laminated layers become finer in grain size below (Unit 50). Here the clay – rich silt beds contain well preserved plant remains, mainly leaves, and abundant amber, mostly of small, drop – like shape, rarely as larger pieces. The leaves often show such a good preservation that their original epidermis is conserved. The only type of bioturbation encountered in Units 60 and 50 consists of 6 – 8 mm wide burrows with straight to slightly bent tunnel directions cutting through the stratification at no definite angles. These burrows are filled mainly with plant fragments and pieces of small amber. The base of Unit 50 is formed by an enrichment of organic remains consisting of wood fragments and large pieces of amber. The latter is very brittle and of red color and disintegrates easily into small fragments.

A well solidified, sandy siltbed about 1 m thick, follows below Unit 50. In this Unit 40 stratification is completely absent due to intensive bioturbation. Its base (Unit 30) is formed by about a 10 cm thick layer rich in wood fragments and red, brittle, usually rounded, pieces of amber. The wood fragments are up to 10 cm long and the amber shows diameters of up to 5 cm. Outside the general bioturbation of Unit 40 the only trace fossils that can be recognized individually are **Ophiomorpha** – like burrow systems.

Unit 30 is underlain by a root horizon. Roots of up to 0.8 cm in width are common. They extend into the upper portion of the well – bedded Unit 20. The latter shows lamination of dark clay – rich layers with up to a few mm of thick, light, discontinuous silt and sand layers that are more dominant in the upper portion of the unit than in the lower part. Well – preserved leaves are uncommonly found in the clay – rich laminae. Here rarely lamellibranchs with their two valves still connected to each other may also be found. **Chondrites** – like burrow systems follow the bedding planes, mainly where light colored, silty or sandy layers are present. The single – filled burrows of these systems are 1 – 2 mm thick. Thin sand laminae may be completely transformed into the sediment fill of the **Chondrites** – like burrow systems. The bedding is crossed byasecondtrace fossil type which is commonly seen in this unit. **Planolites**– like burrow systems of about 6 mm width with well developed concave fill structures are more abundant in the upper part of the unit, but are also common in its lower portion. Grains of amber are rarely

encountered in these beds. Much pyrite is present either bound to wood fragments or disseminated in the clay rich layers.

The dividing line between Unit 20 and Unit 10 is distinct and well visible in the outcrops. The sandstone layer of Unit 10 at some places is present as hardground surface encrusted by iron – oxides and iron carbonates penetrated by numerous burrows of about 6 mm in width. They continue down to a depth of 40 cm but usually branch or curve sidewavs before reaching a depth of 25 cm. These burrows are filled with dark clay, like that found in the layer above the hard ground. The iron oxide and iron carbonate encrusts well – bedded sandstone, at places with little bioturbation showing a laminar bedding. The crusts are 2 – 4 cm thick. Iron carbonate layers are also present in flat nodular shape throughout the whole Unit 10. On the surface and the base of these ironstone layers in the central portion of Unit 10 **Rhizocoraliium** – like spreiten burrow systems are found. They are oriented in strict parallels to the bedding and cover as much as 50% of thebedding surface. The lower portion of Unit 10 displays burrow systems oftheTeichichnus–type and also **Ophiomorpha**– like filled tunnel systems with tube widths of 3 to 10 mm.

The iron oxide crusts of Unit 10 extend in numerous burrow systems into the underlying Unit 01. From the ferruginous hard ground surface the spreiten burrow system of **Diplocraterion** – **Rhizocorallium** extends into the gray, silty, sandy Unit 01. Just below the omission surface only vertically oriented Diplocraterion – type spreiten are present, while deeper within Unit 01 (about 15 – 20 cm) the spreiten system changes in orientation. A more horizontal position of the spreite places it within the definition of **Rhizocorallium**– like trace fossils. **Teichichnus**– like tunnels and feeding structures are present as well in unit 10 as below in Unit 01. While in Unit 10 these burrows are filled with ironoxide – rich material, in Unit 01 they are filled with the white and grey material from the surrounding matrix.

At the hardground contact between Units 10 and 01, borings penetrate into the lower bed at a distance of 1 – 2 cm from each other and extend to a depth of about 5 cm. These irregular burrow systems are filled with an ironoxide stained material. Only larger burrows and spreiten – systems carry this reddish – brown material deeper into the grey beds of Unit 01. The **Diplocraterion** – **Rhizocorallium** like burrows are situated at about 25 cm from each other. Some larger burrows similar to those nowadays made by different large crabs and crayfish are encountered. Some of these burrows pentrate the hardground at a low angle and are up to 13 cm wide and show an irregular oval diameter. Others with a width of up to 5cm branch and show typical scratch marks on the outside which are characteristic of **Ophiomorpha** – like burrow systems. All burrow systems have their entrance at the surface of the red – brown iron – oxide crust of 2 – 3 cm in thickness, before entering the grey silt – sandstone of Unit 01. The latter shows a mottled dark and light – grey appearance and is completely bioturbated. Some larger, usually rounded pieces of brown to honey – colored amber, are encountered here. Deeper down (Unit 02) only **Ophiomorpha**– like tunnel systems with about 3.5 cm tunnel diameter and **Teichichnus**– like fill structures can be picked out as recognizable trace fossil in the otherwise completely bioturbated, greenish grey to dark grey silt and sandstone bed. In the lower portion of Unit 02 very large filled burrows of somewhat diffuse outlines are present. They are either filled with material, that is very rich in plant remains. and amber or filled with light grey silt – sandstone. Many plant remains are encountered throughout the Unit but all of them have been effected by bioturbation. In the lower portion of Unit 01 many small drop – like or sphere – like, pieces of amber are dissiminated within the silty sandstone. Here also large, often spherical and usually rounded pieces of amber are found, some of which are as large as 9 cm in diameter. The amber here is brown to honey – colored and often not as brittle as observed above and below this unit. Often amber pieces have been bored into on the outside by marine fouling organisms. Wood fragments which are very commonly found in this layer, are frequently pyritized.

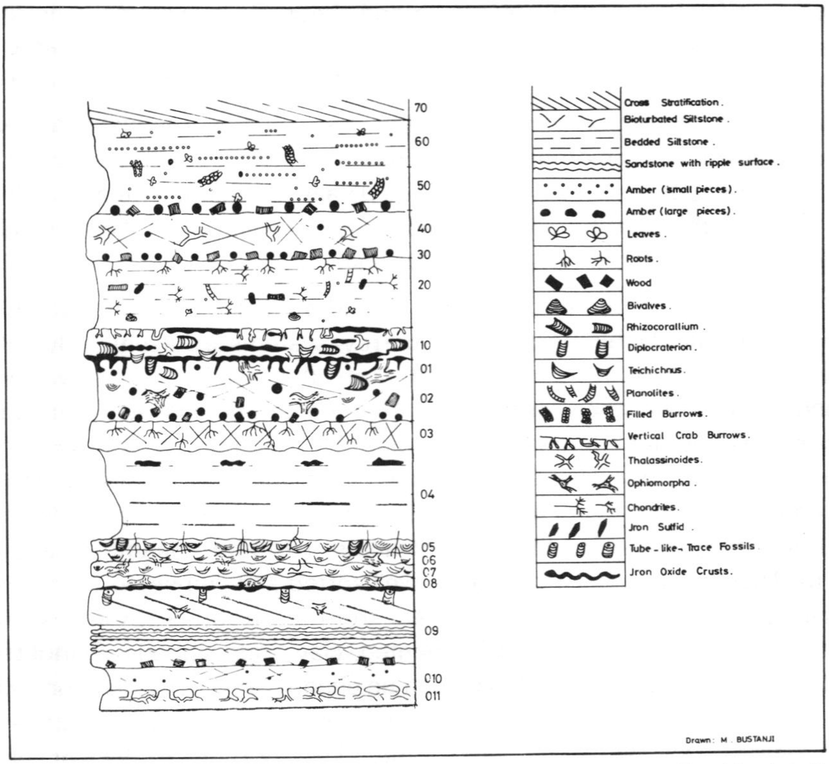

Figure 4: Sketch of the section at location 3 which was described in detail.

While the Units 01 and 02 are not strongly lithified and much clay and fine silt fractions are incorporated into these «dirty sandstones», the layer below is more coarsely grained and of purer sandstone composition. Unit 03 is also strongly lithified and the original stratification has been completey destroyed by bioturbation. No distinct types of trace fossils can be differentiated in this Unit. From the base of Unit 02, root systems penetrate into Unit 03 and are encountered over the whole width of the bed. These root systems are clearly visible as black coal coations in their original autochthonous arrangement. Large, usually rounded, and honey colored pieces of amber are disseminated within the whole of Unit 03, but they are more commonly found near the base. The latter is not even but undulating and forms a sharp contact with the underlying grey – green silt – clay beds. 20 cm below this contact, iron oxide and iron – carbonate concretions are observed within Unit 04, which is about 1.6m thick and consists of clay and silt beds which are very badly exposed. No amber was found here.

The base of the clay-rich Unit 04 consists of a hard, calcareous sandstone (Unit 05) which is completely bioturbated by well-defined burrow systems of **Teichichnus**-like structures. Only rarely is a spreiten system of **Diplocraterion** present among these. Root systems penetrate this layer descending from Unit 04. Another such hard calcareous sandstone layer (Unit 07) is separated from Unit 05 by a 15 to 20 cm thick grey-brownish siltbed (Unit 06). Here, besides the **Teichichnus**-like burrow systems, **Ophiomorpha**-like tunnel systems follow the bedding surface. The root systems noted in Units 05 and 06 do not extent into Unit 07. Only **Ophiomorpha** is observed together with the characteristic **Teichichnus** that bioturbated the latter unit.

Below Unit 07, a bed of completely bioturbated clay-siltsone (Unit 08) with some larger **Ophiomorpha**-like burrow systems is present. Only in its lower part, where it is in contact with the sandstone below, are **Teichichnus**-like trace fossils seen. They penetrate, shallowly, into the sandstones and are composed of sandstone-filled burrow systems. The top of this sandstone (Unit 09) is covered by a black iron oxide crust with a maximum thickness of 1 cm. Unit 09 is composed of lenticular sandstone bodies with a maximum thickness of about 1 m and a length of about 20 m. These beds consist of coarse, well sorted and cemented sand. The individual sand layers are separated from each other by intensively bioturbated, thin and much less cemented, clay-rich siltbeds. **Planolites** and **Teichichnus**-like trace fossils can be encountered here. The burrows are usually filled with sand and they only penetrate the uppermost few millimeters of the sandstone beds. In the thicker portions of the lenticular sand bodies, cross lamination is well visible. Thin sandstone beds usually show ripple marks with a crest distance of about 10 cm. A back and forth alteration of cross bedding is the usual pattern within the sandstones. Each set is up to 8 cm thick. Vertical burrows penetrate the sandstone beds to 20 cm depth. The cylindrical trace fossils are between 2 and 6 cm wide and show a concentric structure when cut in horizontal position and a radial annulation on their outside crusts which are composed of iron oxide stained sand. In the thicker beds burrow systems are also encountered which are oriented parallel to the bedding plane. They are found at a depth of about 25 cm. There **Ophiomorpha**-like, branching tunnel systems of 2-3 cm in width are filled with horizontally laminated greenish silt. Bioturbation is only a minor feature within the lenticular sand beds which does not destroy the original cross lamination.

On the very base of Unit 09 much pyritized drift wood and clay balls are seen. Unit 09 is underlain by a fine, gray silt-clay bed (Unit 010) which is completely bioturbated. In its lower part much organic material is present. Here also large wood fragments and scattered pieces of amber are found. The end of the continuously exposed section at the entry of a creek into the Zerka river is formed by about 40 cm of light gray sandstone. They are completely bioturbated. In Unit 011wellpreserved **Thalassinoides** burrow systems are present. These burrow systems show vertical shaft openings on the surface which form the border between Units 010 and 011. These rounded tunnel ends are about 6 mm wide and at distances of 2 – 3 cm from each other. The burrow systems turn into a more horizontal course shortly below the surface of Unit 011. They form a branching labyrinth within the layer to about a depth of 25 cm. They are filled with dark, clay – rich sediment from above.

THE FLORA

In the slopes exposed in the Wadi Zarka between the bridge of the Amman – Jarash road and the King Talal Reservoir the sediments of the Kurnub Group contain, at many places, the remains of the vegetation which flourished on river banks and in the swamps and the shore region of the ancient sea. This sea was always present in the West in Lower Cretaceous times. Plant remains are also very abundant in the studied sections which contain the amber beds. Plant fossils were also collected in localities 1 and 2 (Fig. 1) upstrean from the studied section and at locality 4 downstrean from it.

Well – preserved leaves were found in the well – bedded silty claystones and clay – rich siltstones but trace fossils were rare or totally absent. The only trace fossil present consisted of scattered vertical or inclined burrows filled with an enrichment of organic material and especially small pieces of amber.

Within the horizontally laminated sediment, leaves and amber are abundant on the bedding planes and have been enriched to such a degree that thin coal – like crusts are formed. When the plant remains are very abundant a lignitic mudstone or a muddy lignite is formed. Within these layers (which were encountered only in localities 1 and 2)fossils are usually not well preserved and the sediment shows no lamination but irregular structures. In the section near Khirbat esSuweiratwell preserved leaves are found in greater number only within Units 50 and 60. The plant remains are frequentlvwell preserved and cuticles and cutinized membranes could be separated from the leaves and spore capsules.

Especially well preserved cuticles were washed from Unit 02. Here, bioturbation has disrupted the larger plant fossils, but the fragments of leaves and other plant remains are better preserved than in the laminated silt and claybeds of Unit 50. Cuticle preparations reveal a suit of microscopic characters by which specimens may be more positively identified than from the external form alone.

Edwards (1929) determined at a location north of the old bridge across the Zerka (now flooded by the King Talal Reservoir) **Weichselia reticulata, Zamites** sp., **Otozamites** sp., and **Podozamites** sp. Bender (1968) also mentions **Weichselia reticulata** at a location 6 km south of the old Zerka bridge.

Cuticula analysis from disrupted leaves of the Unit 02 indicate that four distinctly different plants were present These cuticulas were compared with cuticulae which were not as well preserved but which were taken from well preserved leaves. Two of the plants have a fern – like foliage, the third is distinguished by oval leaves which have a distinct central broad vein and the fourth, most common one, shows slender long leaves (Fig. 5). The remains of leaves and other plants found in the central and upper Kurnub Group will be discussed in greater detail in another study that is now in preparation.

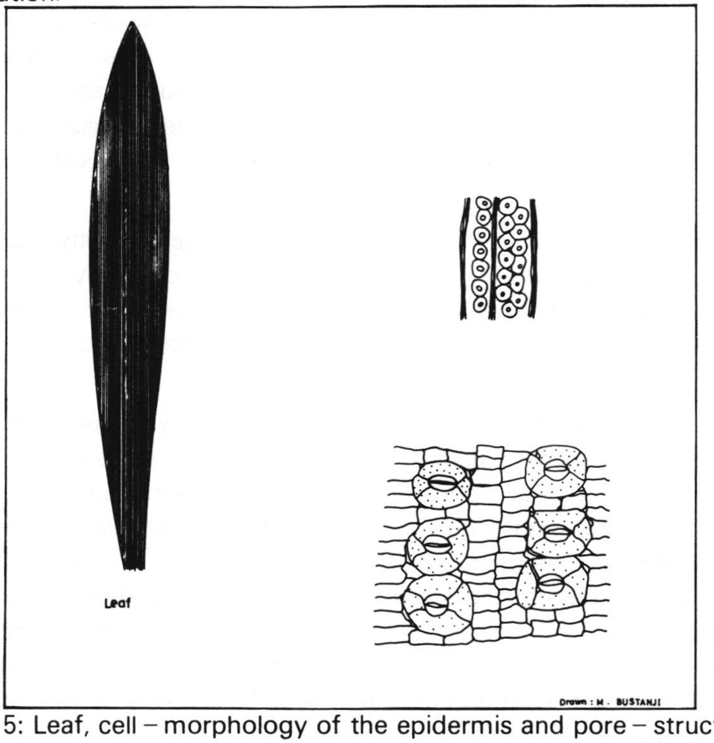

Figure 5: Leaf, cell – morphology of the epidermis and pore – structure of the wood of the amber – producing araucarian conifer from the Lower Cretaceous of Jordan.

One of the plants, which has fern – like foliage and pinnae with close set, thick leaflets with a strong median rib and a regular network of smaller veins, is like that described by Gothan and Weyland (1954) as **Weichselia reticulata.** This fern is a characteristic plant of the older Cretaceous floras in many parts of the world, and it indicates Neocomian age. It is believed to have belonged to the vegetation of sandy soils and dunes (Mägdefrau, 1968).

The other plant with which this study is mainly concerned is the one most commonly found in these rocks. In plant – rich layers mainly long, oval, ribbon – like leaves are seen on the bedding planes. The cuticula, which is usually still preserved, is very thick in the fossil and must have been leather – like in consistence. Wood – fragments and wood – roots in the layers dominated by leaves of this shape were studied in thin section. The wood is well preserved and shows the anatomical features to be in good condition. The annual growth rings are well developed and the texture of the wood shows definite features of the pores (Fig.5). A comparison with the wood of living and fossil gymnosperms indicates a close relation to araucarian gymnosperms (Gothan and Weyland, 1954). At the present time, two genera represent the family Araucariacea, both as large trees found in the Southern Hemisphere. Only the genus **Agathis** has leaves comparable to those encountered in the Lower Cretaceous of Jordan. These leaves make up a foliage that is rather non – characteristic for gymnosperms. Recent **Agathis** species are the producers of amber – like substances which are discussed below in more detail.

Some root horizons have been observed in the studied sections which penetrate the **Units** 05, 03 and 20. These autochthonous remains of plant growths suggest conditions of emergence or near emergence during their formation. Analysis of wood from these roots indicates that at least some of them belonged to an araucarian tree. These roots could have belonged to the **Agathis** – like conifer that flourished at the place where the leaves are preserved. The roots still penetrate the ancient soil, its wood is preserved in pieces, and its resin as amber. This conifer inhabited the coastline of the Lower Cretaceous sea and the riverbanks of the streams running into this sea coming from East and South.

The Lower Cretaceous period was the era of the gymnosperms, with conifers forming a prominent part of the vegetation. During the Lower Cretaceous, Jordan beloged to the realm of the Southern Hemisphere separated from the Northern Hemisphere by the barrier of the Tethys Sea. The river system that transported the sands of the Kurnub Group to its present position came from the Arabian – African Continent. This explains the great differences of the flora present in Jordan compared with that found in rocks of similar age in Europe and North – America. The absence of the northern gymnosperm familes **Taxodiacea, Cupressacea** and **Pinacea** can be thus explained.

THE FAUNA

Body fossils are extremely rare within the studied section of the amber – bearing beds, while the activities of animal life in the sediment is preserved in abundant trace fossils. The extreme paucity of body fossils is attributed to subsequent dissolution and not to their primary absence. The only body fossils found consist of bivalves with theirgaping Valves still connected to each other. Thebivalvesconsist of species with 1 – 2 cm long, ovoid shells. A shallow sulcus on the posterior portion of the bivalves separates a dorsal portion with about 10 ribs in a radial arrangement from the remainder of the shell that demonstrates only growth lines. The anterior margin is short while the posterior margin is moderately extended. Two muscle scars are visible but the pallial line is not preserved. The morphology of the bivalves suggests a burrowing or boring mode of life similar to recent representatives of the **Pholadacea.**

Trace fossils are present in all units that were studied in detail. Trace making organisms actively modified the sediment and substrate. They destroyed the pre – existing structures and created new structures and textures. Thus many of the sediments in the studied section have been intensively churned and the pre – existing inorganic sediment structures have been destroyed. This intensive bioturbation accounts for the massive, structureless aspect of the Units 40, 01, 02, and 010.

In the other Units of the section, burrows are seen at the background of primary sedimentary features. The trace fossils form valuable indicators of the ecological conditions which prevailed during their formation. Within the studied section very few trace fossils are preserved on the bedding planes (Unit 09) and none that have been produced on the free surface of the sediment have been preserved.We are onlyconcernedwith burrow systems of different kinds which are preserved within the different layers of the section. The type of burrows that are visible, and show good preservation, present a potential key to the bathymetry. In the supralittoral and littoral zones animals typically build deep verical burrows, whereas in the sublittoral zones they ordinarily construct shallow or horizontal burrows (Seilacher, 1964; Roads, 1966). This connection between bathymetry and burrow orientation can here be especially well studied with trace fossils that belong to the genera **Diplocraterion** and **Rhizocorallium** .The same animal must have produced both trace fossils even though they are classified in two different genera. In the section discussed they in this paper they often show a connection to each other. According to Osgood (1975) the behavior of the organisms involved in the costruction of these trace fossils is well known even though the identity of the trace makers remains a mystery. The U– shaped main tubes show arcs (spreiten) between the arms of theU.They are remnants of earlier formed bases of the U.The organisms, therefore, must have progrssively deepened the U tube by removing the sediment from the floor of the tunnel. At the same time they plastered sediment against the ceiling. This sediment, redeposited in the burrow system of **Rhizocorallium – Diplocraterion,** has been mainly derived from the former sea floor surface, and to a lesser extent from the sediment into which the burrow was excavated. Therefore, the red, ferruginous sediment of Unit 10 has been carried down into the burrow systems,penetrating the grey Unit 01. The inhabitants of these burrows may have been either suspension feeders or collectors of food from the sediment surface, while the bottom substrate itself served mainly as a home.

Rhizocorallium – like burrows follow the bedding planes or are slighlty inclined to them. Only the burrow openings are twisted into vertical position to end on the former surface of the sea bottom. These burrows are found in fine – grained, often laminated, beds and are indicators of quiet, continuously submerged environments. **Diplocraterion**– like burrows are arranged vertically and penetrate hard ground surfaces, as found in Unit 10. In the sandstones exposed just below the measured section, vertical U – shaped spreiten burrows of this type form a dense population in crossbedded beach or pointbar sands.

The trace fossils here called **Ophiomorpha** and **Thalassinoides** consist of tube systems of up to 4 cm in width. They are anastomosing and show a more horizontal than vertical orientation in the sediment. The generic name **Ophiomorpha** was applied to those types of burrows which show scratch marks on the outer face of the tunnel walls, or have a nodular appearence on the outside. The tunnels of their burrow systems usually show a greater width than those assigned to the genus **Thalassinoides**.The latter name has been assigned to tunnels which possess smooth walls and a lining of sediment which is different from the outside and also from the inside fill of the burrow system.

Thalassinoides and **Ophiomorpha** have been attributed to decapod crustaceans (Bromley and Frey, 1974). Several recent callianassid shrimps and other shrimps produce burrows which exhibit the branching patterns and wall structures of **Ophiomorpha** and **Thalassinoides**. These burrow systems are excavated in the process of feeding and the open tunnels are then maintained as dwelling burrows. The passages of the **Callianassa** burrows are lined with a sticky, coherent, fine – grained sediment (Shinn, 1968). Such a lining with the darker material derived from the layer above (Unit 010) is well represented in the **Thalassinoides** burrows of Unit 011.

However, as Seilacher (1967) stated, a lininig is present or absent depending on whether the sediment into which the burrow was corstructed was consolidated or non – consolidated.

Callianassids and other shrimps live in a wide range of habitats from the intertidal zone to deeper water, and frommainly marine environments to almost fresh water conditions. However, **Ophiomorpha** and **Thalassinoides** burrow systems are usually interpreted as evidence of very shallow water depths (Radwanski, Friis and Larson, 1975). Kennedy and McDougall (1969) stated that the **Ophiomorpha** structure in recent sediments is being produced mainly from the littoral zone onwards, between the mean sea level and low level on beaches that face the open ocean andin the shallow neritic zone.Burrowing structures of **Ophiomorpha** and **Thalassinoides** – like habitus are generally considered, following their recent occurrences, as indicators of marine conditions.

The trace fossils here assigned to the genus **Teichichnus** completely bioturbate the Units 05 – 08. **Teichichnus** structures were produced as a result of disturbance and redeposition of sediment by the displacement of the horizontal, cylindrical burrow system. In the layered trace fossil, the spreite is either a long vertical or nearly vertical wall — shaped body or a lenticular horizontal ovoid body made up of a pile of gutter – shaped laminae. According to Warme, Kennedy and Schneiderman (1973),McDougall (1969) and Chisholm (1970)some modern arthropods and other marine organisms backfill their burrows and leave structures which are, to some degree, like those found in the trace fossil **Teichichnus**. Warme. Kennedy and Schneiderman (1973) interprete **Teichichnus** – like trace fossils as indicators of a quiet water environment. The producer was a sediment – eating, marine organism, probably a member of the decapod crustaceans.

Trace fossils united under the generic term **Planolites** are burrows that penetrate the rock irregularly in varying directions.The filling of the burrow consists of concave laminae in conical shape. Seilacher (1963) considered **Planolites** of little value as a bathymetric indicator and also as a salinity indicator. Marine and non – marine stuffed burrows of the **Planolites** type are known. Bandel (1967) thought that the sand and silt filling of the **Planolites** burrow was probably brought in by the worm – like animal after being passed through its alimentary canal. The producer of **Planolites** was a sediment eating creature.

Very plant – like, and regularly ramifying tunnel structures which neither cross each other nor anastomose are called **Chondrites**. Only in Unit 20 are such trace fossils found. In the clay – siltstone these tunnel structures are arranged horizontally along sandy intercalations. **Chondrites** is of little value as a bathymetric indicator (Bandel, 1973). It is possible that some member of the polychaete worms, constituting the most abundant and diverse groups of burrowing organisms in the estuarine and intertidal sediments of our time, has constructed Chondrites burrow systems. Some of the feeding structures produced by them are similar, as Schäfer (1962) and Howard and Frey (1973) have found. Members of the polychates often maintain a connection with the sediment – water interface but burrow downward to a sediment layer favourable for feeding. Here the worm feeds extensively within the selected sediment unit, which consisted in the section here described of a thin, white, sand layer in the otherwise finer – grained laminated deposits. The burrows here consitute branched, vein – like systems that are bound stratigraphically to the parting laminae of sand.

Vertical or nearly vertical burrow systems with original entrances at the sediment surface are found preserved on the omission surfaces at the top of Units 01 and 10. These burrows branch and form irregular U – like ends. They were formed during a time of non – deposition of sediment. Crustaceans living at the shore or near it were the originators. The fiddler crabs **(Uca)**, for example, compose such closely spaced living burrows, which do not reach deeper than 30 cm. The Cretaceous burrows compare quite well in size and shape with the burrows made by the fiddler crabs in our time. According to Dörjes and Hertweck (1975) such burrow types can be interpreted as indicators of the shore face.

Cylindrical, annulated, tube – like burrows in vertical position are seen in the upper portion of the crossbedded sand layers (Unit 09) and have been produced by organisms dwelling in this sand perhaps by coelenterates like the recent **Cerianthus.** This anthozoan lives within the sand, extending its tentacles above it when feeding. If conditions are unfavourable the animal retracts into its dwelling burrow. Schäfer (1962) described the construction of this dwelling burrow of **Cerianthus** in detail. The walls of the burrow are arranged vertically to the sediment surface and are covered and impregnated with mucus substance. In Unit 09 the coelenterates must have penetrated the sediment from the surface. They have extended their burrows into the sediment for more less the same depth. Only those portions of the lenticular sand bodies with a greater thickness than about 30 cm were settled. They must have been exposed to a stronger current action than the surrounding lower bottom and therefore provided a more attractive place for the settlement of this suspension feeding organism. The modern **Cerianthus** prefers sandy bottoms below the low tide line as living place (Schäfer, 1962).

In the Units 50 and 60 the only trace fossil present consists of tubes filled with organic materials enriched from the surrounding sediment. These burrows could have been constructed in marine or fresh – water environments alike. Their occurrence as the only trace fossil in these well – laminated sediments makes it more likely that they were formed in fresh water with far less abundant sediment dwelling infauna than is seen in marine environments.

Many pieces of amber, especially those of larger size, found in the Units 01 and 02 have been bored by marine fouling organisms. The oval shape of most of these borings and their size range (between 1 mm and 10 mm) indicates that bivalves have been the originators. Rows of round, about 1 mm wide, spherical bore holes are more typically produced by boring sponges. Other marine fouling organisms could also have been resposible for some of the more irregular bore holes found in the outer crust of the amber. The bored amber must have been adrift or rolled free and unattached to the bottom substrate for quite some time, so that the marine borers could attack it. Since most of the amber has been derived from the forest soil, the borings give evidence for the reworking of the soil due to advances of the sea over coastal forests.

THE AMBER

The originator of the amber which was discovered in the Lower Cretaceous rocks of the Wadi Zerka is evidently an araucarian conifer related to the recent genus **Agathis**. Wood with araucarian characteristics (Fig.5) is found within the section discussed here, as well as at the plant rich localities on the bridge (Fig. 1,Loc.2). Some of this wood shows vescicles which are filled with amber, thus clearly demonstrationg that amber and wood were produced by the same tree. The characteristic leaves of the Cretaceous araucarian conifer are the most common plant fossils found along with the amber. Therfore, it seems quite logical to connect these leaves to the amber producing conifer. The **Agathis** – like conifer represents the principal plant encountered in the coastal swamps and forests that grew in the area of the measured section, since their roots are still to be found within the rock in their original place of growth.

The recent representatives of the genus **Agathis** are the producers of the copals. The kauri copal or kauri gum is obtained from the kauri pine **Agathis australis** which is New Zealand's largest and most important tree (Hill, 1952). The New Zealand copal is chiefly subfossil in nature and is dug up on ridges and in swamps and boggy groung from the forest soil. This copal measures up to 6 cm in diameter, is yellow, transparent and very hard.

The amber from Jordan is similar in so many details to these «subambers» of our time. Even the type of forest can be compared with the recent forest land in New Zealand. The shape and color also is quite like that of the fossil amber, where we encounter pieces of up to 10 cm in diameter. The most amazing fact is, that in thé forests of some areas in the recent Southern Hemisphere the same trees are still producing amber – like substances that had already formed copals in the Lower Cretaceous of Jordan.

Resins, like copal and its fossil counterpart – the amber, represent oxidation products of essential oils and are very complex in their chemical composition. Liquid bubbles, most probably filled with such oils, are still seen in the Cretaceous amber. The resin was secreted in definite cavities or passages. It normally oozes out through the bark and hardens on exposure to the air. During the drying process the resin is very sticky and therefore all kinds of wind and wing transported anorganic and organic materials can become glued to the resin and incorporated into it. Dietrich (1976) reported hundreds of inclusions of fossil insects, spiders, mites and the remains of bird feathers caught by the hardening resin of the Cretaceous amber of Lebanon. The amber of Jordan provided no insect fossils until now. Only spores and polles along with thread – like structures, which are tentatively interpreted as the remains of spider webs, have been found. Only ambers from the Units 01 and 02 were studied microscopically up to this stage and only 20 thin sections were prepared. The research has to be extended in the future and it is expected that more fossils will be found in this amber.

The color of the amber is redbrown and there are shades ranging from brown honey – colors to almost colorless yellow. The amber can be clear and transparent as glass or it can be opaque. Sometimes it is evenpitchblack, like asphalt. The opacity depends largely on the amount of bubbles present within the clear amber matrix. The bubbles are either filled with liquid or gas or both. The bubbles may have a rounded shape or oval outlines, or may be drawn out into ribbon – like structures due its formation. Plant remains within the amber, aside from pollen and spores, are usually strongly encoaled.

The amber described is usually not visibly affected by rockforming forces except in Unit 50 – 60 where the larger pieces of amber were clearly affected by compaction. In the localities 1 and 2 (Fig. 1) the amber is also affected by compaction as in the Unit 50 and 60. Here the amber was sometimes reactivated during diagenesis so that cracks and joint fissures of the rock may be filled with it. Ambers in localities 4 and 5 also show no influence of tectonic forces or of the diagenesis of the rocks surrounding them. The amber in all amber – bearing beds was found to be quite brittle and it usually disintegrates into angular pieces when taken from the surrounding sediment. It was only within Units 01 and 02 that larger pieces of amber, with a gem quality, could be extracted.

RECONSTRUCTION OF THE ENVIRONMENT OF AMBER FORMATION AND DEPOSITION

At the beginning of the Cretaceous period deltaic and coastal sediments were deposited from material carried to the sea shore by rivers coming from the Arabian – African Continent. The lowlands were periodically flooded by incursions of the sea and afterwards fell dry again. Their sediments are preserved and are described and discussed here in detail (Fig. 4).

A vegetation composed of ferns, cycadophytes and conifers covered the riverbanks, the coastal lowlands, and the swamp areas. A very dominant plant in this commonity was a large conifer belonging to the family **Araucariacea** which has a close affinity to the recent genus **Agathis.** Its foliage, quite uncharacteristic of most conifers, consisted of large ribbon – like, long – oval leaves which littered the forest floor, the pool bottoms, and the bottom and banks of the dead river arms near or within the forest. These conifers produced resins that came up to the surface of the stem or were held in the vesciles within the wood. These resins turned into hard copals due to the evaporation of the less viscouse solvents and the oxidation of the resins themselves. The copals resisted the decomposition of organic matter much better than the wood and leaves of the conifer and thus became enriched in the forest soils. Transgressions of the sea onto the coastal forest caused the trees to die and the soil to be reworked. The newly submerged bottom was then settled by marine organisms which completely reworked the sediment. Only deeper portions or consolidated portions were not attacked by the activity of this benthic infauna. Here the original root systems of the forest trees could be preserved. Such root horizons are seen in the Units 05,03 and at the top of Unit 20. Reworked soils are present in Units 010, 04, 02 – 01 and 30 – 40.

The activity of decapod crustaceans (shrimp and crabs) of different sizes and, most probably of a fair number of different species is still clearly visible in the reworked soils and neighbouring sediments. Usually a drift wood horizon indicates the presence of a former muddy beach in places above the root horizons. Wood and amber deposited along these beaches and on the bottom of shallow lagoons and estuaries had been drifting partly free floating in the water and partly transported along the bottom sediment. Here they served as substrate to wood and amber – boring bivalves and other marine fouling organisms. Redeposited forest soil and new plant material from the coastal vegetation, enriched with the drifted material, and cast ashore, make up the Units 010, 02 – 01, and 30 – 40. The material was intensively turned over and mixed by burrowing organisms, mainly shore living decapods.

The muddy, swampy shore and the shallow lagoonal water was protected from the open sea by sandy shoals.The sediments of such a shoal consist of lenticular sand bodies affected by tidal currents. In Unit 09 sandbeds with two – directional crossbedding are observed. These shifting sands could be settled in only by a few animals suited to this environment such as sand – tube forming anthozoans and decapod crustaceans.

In the offshore lagoonal areas a high density of infaunal creatures completely turned over the sediment which was sometimes rich in carbonate material. The beds formed under such conditions are represented by Units 05,08. Their lagoonal character is revealed by the infaunal traces which were produced in great numbers by only one or a few species. An open sea infauna should have been more varied.

Estuarine environments were responsible for the formation of Unit 10. This unit is characterized by a basal and a final omission surface. The discontinuity surface was formed during temporarybreaks in the deposition without apparent erosion. The sediment below the basal ommission surface (Unit 01) was formed just offshore, most probably within the shallow water of a coastal lagoon. The trace fossils of the omission are characterized by **Diplocraterion – Rhizocorallium** and crustacean burrows that penetrate these sediments. They come from the discontinuity surface which is encrusted with ferruginous material, and they date from the period of sediment omission. They were,therefore, filled with ferruginous material during their construction and maintenance by the benthonic animals. Crowding of burrows is observed at the hard ground where the burrows remained open to the sea floor (or beach surface) throughout the duration of the hiatus. Estuarine conditions during the deposition of Unite 10 are indicated by the presence of trace fossils consisting of both vertical and horizontal burrows and burrow systems (Howard and Frey, 1975). In Unit 10 between the upper and the lower omission surface muddy and sandy deposits formed. The sediments are impregnated with ferruginous material and are cemented by limonitic crusts and flat concretions of ironstone.The iron is derived from dissolved iron salts in the fresh water. The iron was precipitated in the estuarine area where fresh water mixed with the sea water.

The crustacean burrows of the upper omission surface constructed in a beach environment are filled with the postomission sedimentation of Unit 20. The environmental conditions during the deposition of Unit 20 allowed the return of sedimentation and the trace fossil fauna is characterized by

Chondrites and **Planolites.** Sedimentation has shifted away from the estuarine area into more quite coastal lagoonal environment. Here, the infaunal life was very limited so that the primary laminar sediment structures were not destroyed.

Fresh water or almost fresh water conditions in the swampy shore area or the mouth of a river are indicated in the Units 50 and 60. Here, the plant remains from the nearby coastal forests became preserved almost without interaction of infaunal sediment – dwelling organisms. Plant debris and amber transported by the river water became entrapped in the pools or dead river arms. These beds were subsequently covered by river sands.

CONCLUSION

Amber found in the central portion of the Kurnub Group (Lower Cretaceous) was produced by a close relative of the recent araucarian conifer **Agathis**. This large conifer constituted the main tree in coastal forests. Resins produced in abundance by the conifers of the forest transformed into copals that became enriched in the forest soil. During transgressions of the sea the forest soil was reworked and the amber deposited on the muddy shore and the bottom of the coastal lagoons which formed at the same spot. Some of this amber had, during its transport in the marine environment, been settled by boring bivalves and other fouling marine organisms before becoming redeposited not far from its origin. Several types of nearshore lagoonal, estuarine and freshwater environements could be recognized and characterized by the trace fossils produced by the different animals living within the sediment. The very shallow conditions of the formation of these deposits are indicated by autochthonous root horizons penetrating the upper portion of all recognized types. Thus five periods of emergence and advances of the coastal forests over the former and mainly marine sediments are matched by five submergences and subsequent advances of the sea over the area of the coastal forests. These are noted in the measured section.

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