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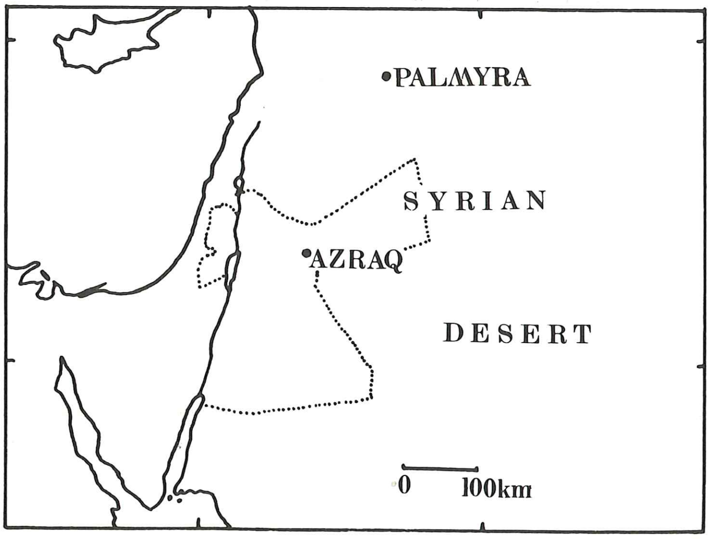
Micropalaeontological and Palaeoecological Studies of Recent Sediments from the Azraq Marshes in the Jordanian Desert

Introduction

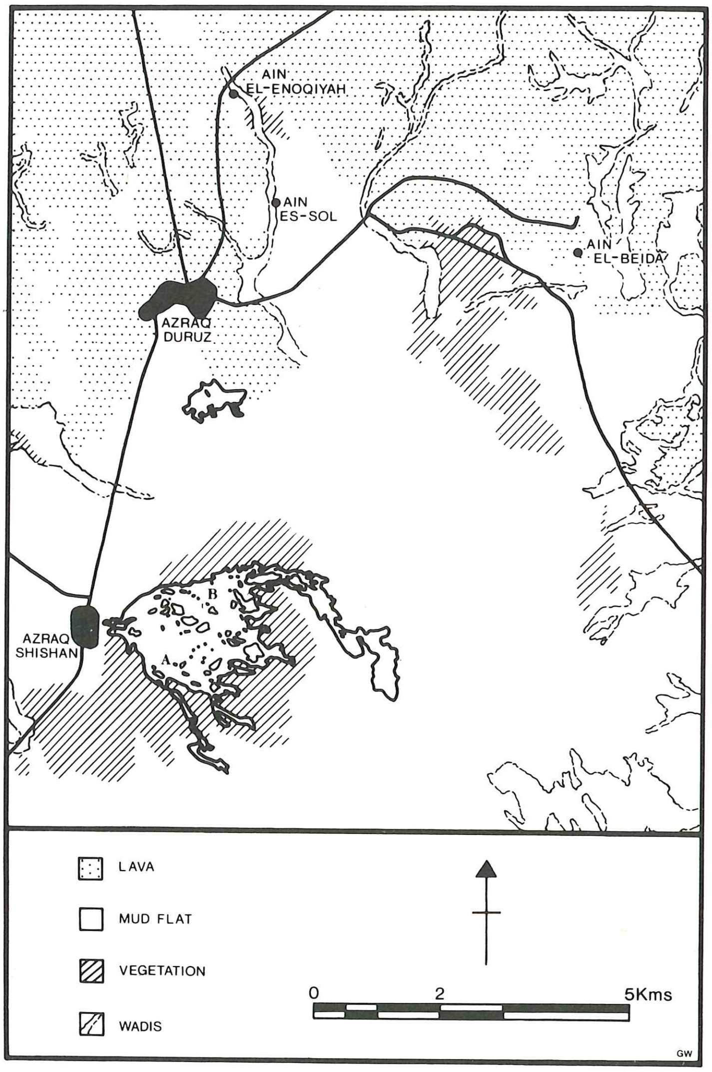
The oases at Azraq and Palmyra (FIG. 1) are the two major desert oases found in the Syrian desert between the Arabian Peninsula to the south and the mountains of Anatolia to the north. Azraq oasis lies in a broad depression in the north east desert of Jordan, some 85 km. ESE of Amman (FIG. 2). In the late Pleistocene the basin was occupied by a large lake—Lake Azraq, (Bender, 1974; Hemsley and George, 1966; Nelson, 1974). This is currently being investigated by Dr A. Garrard of the British Institute for Archaeology in Amman. As a result of relative desiccation in the Holocene, the basin floor now comprises a series of saline mudflats and silt dunes, freshwater pools and marshes. The latter are fed by groundwater, offering a permanent water supply in an area characterised by extreme heat and aridity.

The region possesses a 'Saharan Mediterranean climate of the warm variety' in the classification of Poore and Robertson (1964). Daily temperatures average 35°–37° C in summer. On average less than 100 mm. of precipitation is recorded each year. This scanty precipitation does not fall evenly throughout the year. The precipitation régime is characterised by very heavy falls in brief periods in the months from November to April. The effect is so extreme that the percentage of annual precipitation falling in a single day averages 50 per cent.

1. The location of Azraq Oasis, Jordan.



2. The Azraq marshes and coring sites near Azraq Shishan.



Potential evapo-transpiration is calculated as between 1,150 and 2,100 mm. per annum (Hemsley and George, 1966).

The area is nowadays a major wildlife reserve (Hemsley and George, 1966; Mountford 1965; Nelson, 1973). It is also subjected to continuous pumping to supply water by pipeline to a large area of Jordan. The availability of water in the past has resulted in fairly intense occupation of the region in historic and prehistoric time. Consequently the area has been the subject of a series of scientific expeditions, by geologists, biologists and archaeologists who have published substantial reports (Bender, 1974; Hemsley and George, 1966; Kennedy, 1982; Mountford, 1965; Nelson, 1973). In recent years fears have been expressed that water pumping may be having a deleterious effect on the marsh and its wildlife.

This concern prompted the expedition in July 1982, whose results are reported here. This palaeoecological study was intended to provide base-line data on the range of environmental conditions that have existed in the marsh in recent years.

The Azraq Basin

The most important details of the geology and biology of the area are described in Hemsley and George (1966) and may be interpreted from FIG. 2. The edge of a barren basalt or limestone plateau forms a natural scarp 5–20 m. high along the northern margins of the basin (FIG. 2). The plateau is breached by deep, narrow wadis prone to severe flash floods. Most of the basin is shown as Mud Flat on the Government maps. These flats are salt pans with essentially no vegetation. Heavy storms may cause the inundation of the entire basin. The lake resulting from heavy storms in April 1982 reached and often crossed the circuitous roads which bound the basin.

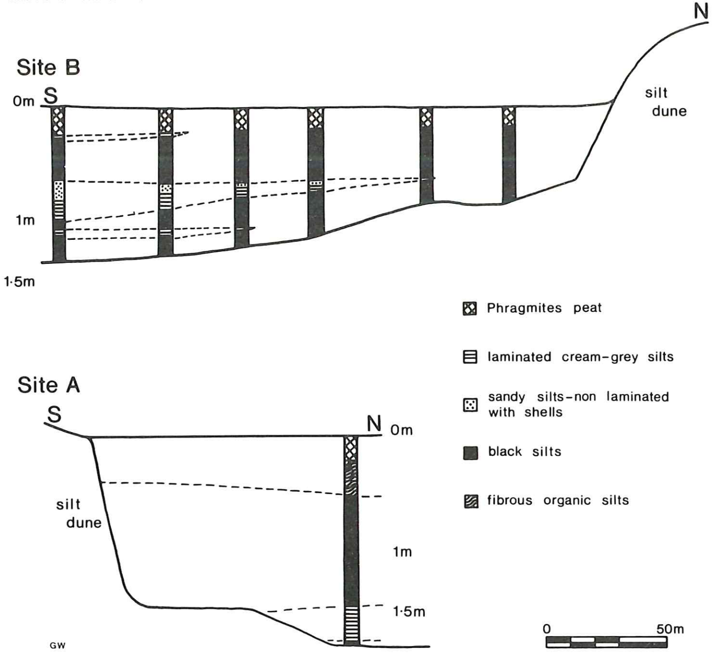
Marsh and open water occurs near the villages of Azraq Druz and Azraq Shishan. These essentially freshwater wetlands are contained within a rim of silt-dunes. These dunes also crop out above the marsh to produce many small islands (FIG. 2). The silt dune soils are saline with efflorescent salt crystals, halophytic vegetation, and tamarisk trees—the latter most abundant at the junction with the marsh. These trees and shrubs constitute the 'vegetation' unit reproduced on FIG. 2 from the Government maps. The marsh is dominated by grasses, sedges and reeds.

The more intensively developed lake/marsh at Azraq Druz failed to yield good coring sites. The Azraq Shishan marsh yielded good cores with a Russian peat corer at two locations (A and B—on FIG. 2). The presence of flood waters from the exceptional April storms made it quite impossible to reach the potentially deepest locations immediately opposite Azraq Shishan.

Stratigraphy and sedimentation in the Azraq Shishan marsh

The stratigraphy of the two sites is set out in FIG. 3 and TABLES 1 and 2. These transects were taken across the deepest sequences of alluvial deposits found after extensive probings with the corer.

3. Stratigraphy of recent sediments in the Azraq Shishan marsh at sites A and B.



A thin, loose detritus peat with remains of grasses, sedges and reeds, is widely developed across the surface except in local zones marked by salt scalds. The black detrital silts contain partially decomposed plant debris and black coloured minerals derived from the nearby basalts. The modern analogues for the creamy/white silts were noted at the margins of

Table 1 Stratigraphy at the north side of Azraq Shishan marsh. Site B; core B_{10}, FIGS 2 and 3. Sampled by Russian Peat Corer, July 25, 1982, in *Phragmites*/*Typha* swamp

Depth (cm.)	*Stratum*
0–25.5	Black, *Phragmites* and *Typha* peat; fibrous, silty, partially humified, open textured, and extensively bioturbated. Top 15 cm. too fluid to sample. Elsewhere, the surface is marked by salt scalds.
25.5–29	Gradual transition to:
29–65	Grey silt, laminated, stiff, no plant fibres, with sharp contact below with:
65–80	Grey/cream sandy silt with molluscan fragments of Hydrobiidae and Succiniidae.
80–98	Black/cream laminated silts, a few shells.
98–102	Black silts; abrupt transition below to:
102–110	Cream silts, laminated, stiff, no shells, gradual transition over 5 cm. to:
110–135	Dark grey/black silts, very stiff.
135+	Dark grey soil on silt dune: impenetrable.

Sample codes		
	GL4890#1	0–50 cm.
	GL4890#2	50–100 cm.
	GL4890#3	100–130 cm.

Table 2 Stratigraphy at the south side of Azraq Shishan Marsh. Site A; core A_8; sampled July 29, 1982, in *Phragmites/Typha* marsh.

Depth (cm.)	*Stratum*
0–22	Black, peaty silt—fluid.
22–37	Black, peaty, detritus silt, with monocot. roots, stems and leaves.
37–60	Black, detritus silt, some plant fibres.
60–140	Grey/black silt, stiff, occasional monocot. leaves and stems.
140–150	Cream silt with fine sand; poorly laminated; probably passing down into a fibrous peat which was noted on the tip of the corer.
150+	Silt dune? Impenetrable.

Sample codes		
	GL4890#4	0–50 cm.
	GL4890#5	50–100 cm.
	GL4890#6	95–145 cm.

the saline salt pans beyond the marsh. In the cores these creamy/white silts contain sub-fossil molluscs of the families Hydrobiidae and Succiniidae.

The stratigraphy indicates local environmental fluctuations had taken place in the lake; freshwater swamp conditions alternating with more saline, open mudflats.

Heavy metals

Sub samples (c 1 g) were oven dried (105° C) and organic matter was determined from weight loss after ignition at 430° C for 24 hours in silica crucibles. The ignited sample was boiled under reflux for five hours in 90 per cent HNO_3 : 10 per cent HCl (Sinex *et al.*, 1980; Sinex and Helz, 1981) and then evaporated to dryness. The metals were taken up into dilute nitric acid (25 ml.; 0.01 M.). Pb, Zn, Cu and Ni were determined by atomic absorption spectrophotometry (air/acetylene flame) using an EEL 240 instrument. Initial observations on core geochemistry are shown in FIG. 4.

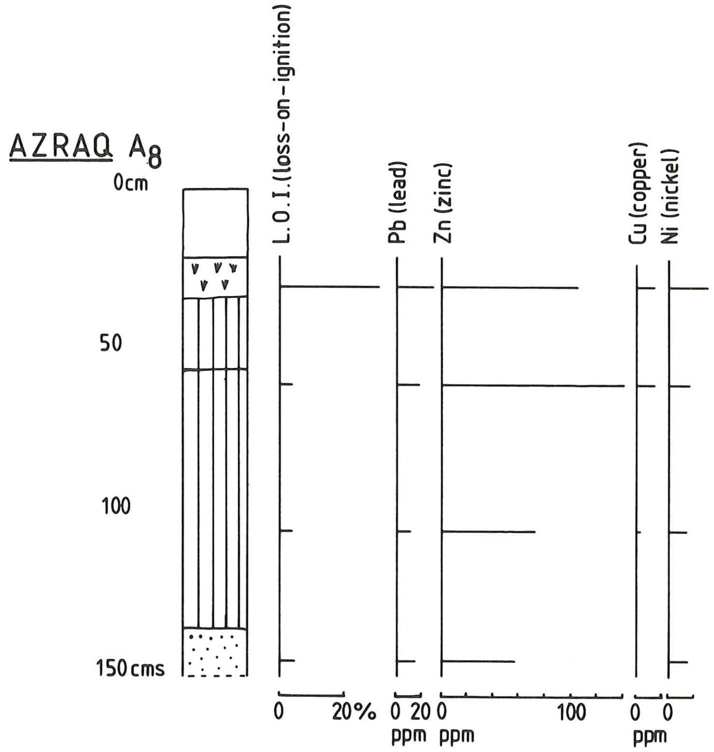
The LOI data indicate that below the near surface peats, the dark colouration of the lower silts is a function of the abundance of dark coloured minerals rather than organic matter.

It is the changes in the abundance of metals that merits attention. Values in the upper parts of the core are nearly double those found in the lower half of the core. The most probable source of these heavy metals is emissions from vehicles on the roads through Azraq Shishan. This village is at a junction of major international routes which converge from Iraq, Saudi Arabia and the Gulf States. Substantial vehicle traffic developed in the 1930s and 1940s to service an oil pipeline and roads to these other countries. The development and use of the Azraq military airfield, initially by the Royal Air Force and later by the Royal Jordanian Air Force, may also have been important in this context.

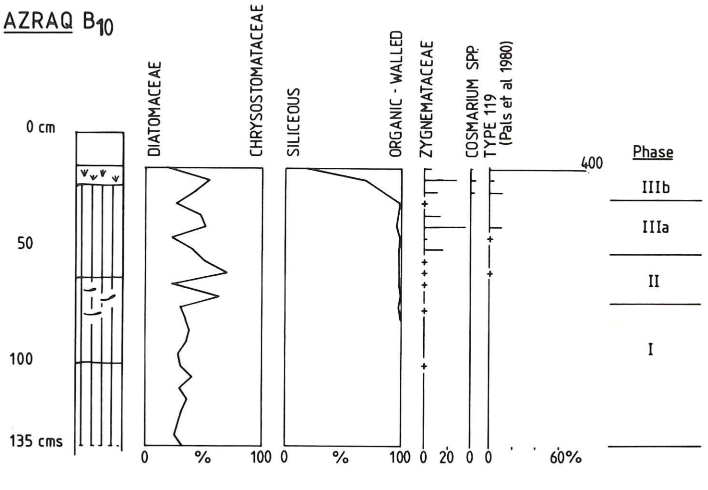
Micropalaeontology

Twenty five 1 ml. samples from Azraq B_{10} and seventeen from Azraq A_8 were boiled in 5% KOH, sieved on a 10 µm nylon mesh and swirled on a watch glass. The remaining residues were largely composed of siliceous microfossils, with varying amounts of pollen and organic-walled microfossils. Counts of 200 siliceous microfossils and where possible 200 pollen grains were made from each sample. The results are shown as FIGS 5, 6, 7, 8.

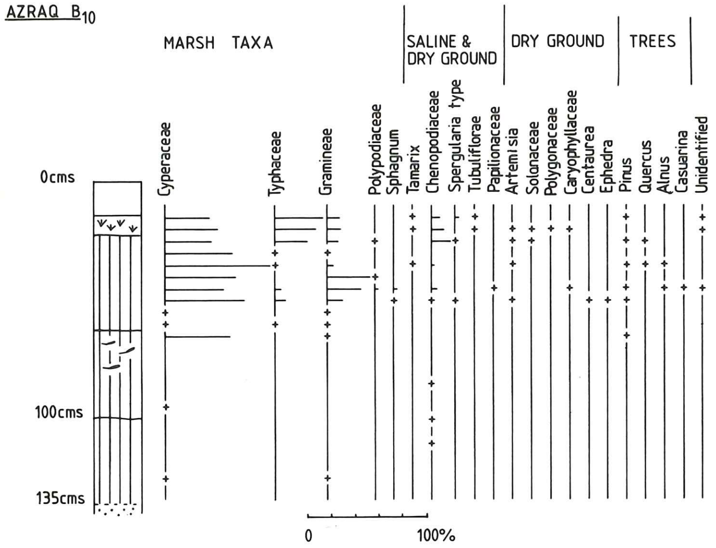
4. Preliminary geochemical data on recent marsh sediments at Azraq Shishan.



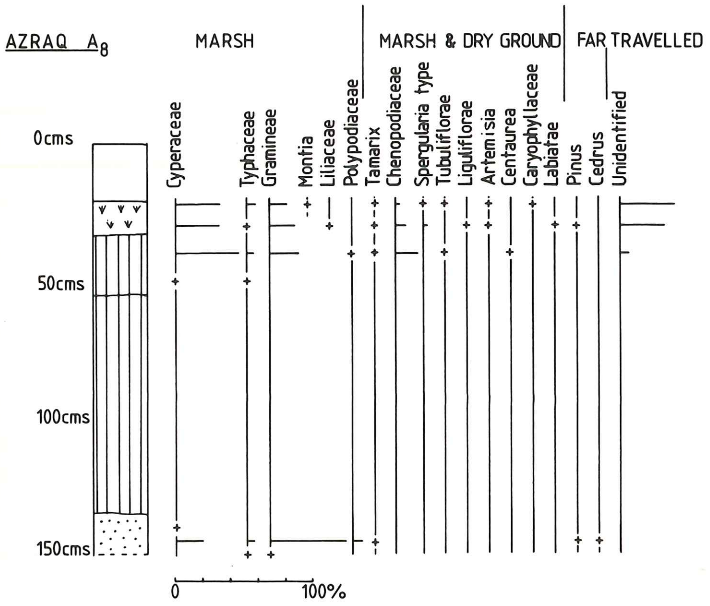
5. Siliceous and organic-walled microfossils from core B_{10}, Azraq Oasis.



6. Pollen and spores from core B_{10}, Azraq Oasis.



7. Pollen and spores from core A_8, Azraq Oasis.



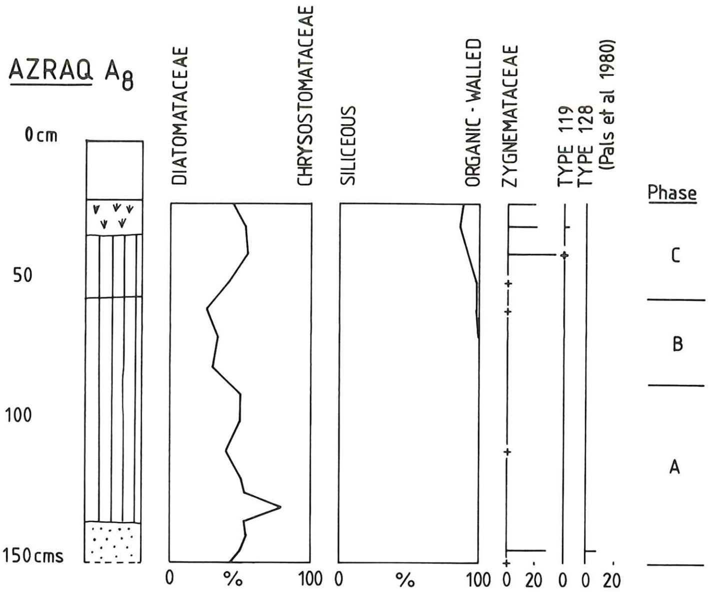
Siliceous microfossils

The siliceous microfossils included sponge spicules (which were comparatively rare) and the frustules of Diatomataceae and cysts of Chrysostomataceae. The sponge spicules were of two types:

i) hollow needle-like shafts of some 500 μm length, which could not be related to any particular species;

ii) short, cylindrical shafts, 60–100 μm long, terminating in a cluster of short processes, which radiated perpendicularly from the shaft at each end. This type of spicule is found in the gemmules of non-marine sponges, such as *Ephydatia*, as illustrated by Pals, Van Geel, and Delfos (1980, p. 411; plate IV, FIG. 138a–c). These gemmules are resting stages, capable of withstanding desiccation and extremes of salinity. Sponges of the genus *Ephydatia* are tolerant of both fresh and brackish water environments.

8. Siliceous and organic-walled microfossils from core A_8, Azraq Oasis.



These sponge spicules consequently are seen to have only limited environmental significance, and are not considered further.

The cysts of the Chrysostomataceae are hollow, spherical or vase-shaped bodies 5–20 μm in diameter, with a pore or neck sealed by an operculum. They may be psilate, or bear a reticulate or conate ornament. The taxonomy of cysts of the Chrysostomataceae is little known; but the Chrysostomataceae are established as freshwater algae which prefer slightly acid conditions (Ehrlich and Singer, 1976).

Present throughout the cores are diatom frustules referable to the genera *Nitzschia, Epitemia, Pinnularia, Stauroneis, Melosira, Cocconeis, Diploneis, Caloneis, Cymbella, Eunotia* and many as yet unidentified taxa. Since unidentified taxa comprise up to 75 per cent of the specimens examined at some levels, the diatom counts cannot be satisfactorily interpreted at the moment, and are not presented here. Most of the identified taxa are benthic rather than planktonic, suggesting that relatively shallow water conditions prevailed during the deposition of the sediments sampled. Several of the diatom genera (*Nitzschia, Melosira,* and *Diploneis*) include species which are either tolerant of, or are confined to brackish water. It is suspected that these species bloomed as the seasonal waters of the Azraq marshes became more saline as evaporation proceeded and the marsh and lake dried up each year.

Pollen and spores

Pollen and spores are present in twenty three samples, but abundant only in twelve. The samples are mostly dominated by pollen from taxa indicative of marshes—Cyperaceae, Typhaceae, Liliaceae, Gramineae, the aquatic *Montia*, with spores from the Cryptogams. In their summary of the vegetation of the Azraq region, Hemsley and George (1966) attribute all the Typhaceae to *Typha* spp., but many of the pollen grains found are referable to the *Sparganium* type, being monads rather than the tetrads characteristic of *Typha*. The Gramineae are grouped with the marsh taxa because both field observation and the opinion of Weinstein (1977) indicates that these are usually hydrophilous plants in this arid region. Included in the Gramineae are pollen of the *Phragmites* type (<16 µm.) which is abundant; unidentified grasses (20–45 µm.), which are also abundant; and rare cereal type grains (60–80 µm.). Cereal cultivation was not described by Hemsley and George (1966), but was observed being practised by sedentary Bedouin during the 1982 field season. The grains might also derive from wild cereals.

Pollen from other habitats is generally sparse in the cores. The Chenopodiaceae and *Spergularia* suggest saline mudflats, silt dunes, and salt springs around the marsh, although they are also a common component of the vegetation of open, dry land habitats. Shrubs of *Tamarix* spp., grow on saline soils on the silt dunes, and occasionally at the edges of the marsh. The Compositae (Liguliflorae, Tubuliflorae, *Centaurea* and *Artemisia*) are mostly taxa of open, dry habitats, as are *Ephedra*, the Caryophyllaceae, Labiatae, and Polygonaceae.

A relatively far-travelled component is present in small numbers. It comprises the trees *Alnus, Cedrus, Pinus* and *Quercus*, and the shrub *Casuarina*. Pines and evergreen oaks are known from the western part of the Azraq basin (Hemsley and George, 1966). The pollen of the other species probably derives from the mountains of Lebanon (Bottema and Barkoudah, 1979) or Israel (Weinstein, 1977).

Most of the unidentified pollen is similar to that of *Chrysosplenium*, very small (15 µm.), microreticulate, tricolpate, or tricolporate grains. *Chrysosplenium* and other saxifrages are not reported in Hemsley and George (1966), consequently some of these grains may represent other taxa. Other morphotypes represent less than 1 per cent of the assemblages.

Dating evidence is provided by the grains of *Casuarina*. This shrub was not introduced to the Middle East until the 1890s, and was not common until the 1920s (Mehringer *et al.*, 1979).

Organic-walled microfossils

The organic-walled microfossils are mostly of algal origin. Most of the microfossils recorded in FIGS 5 and 8 are *Spirogyra* spores, though types such as that figured by Van Geel (1978) as Type 58 are also present. The Zygnemataceae are characteristic of warm, shallow, oxygen-rich, fresh or brackish water. The desmids (*Cosmarium* spp.) are characteristic of freshwater, as are the *incertae sedis* types 119 and 128 of Pals, Van Geel and Delfos (1980).

Interpretation

Azraq B_{10}

Phase 1 is characterised by a relatively stable Diatomaceae/Chrysostomataceae ratio with about 24–30 per cent diatoms. Pollen and organic-walled microfossils are present intermittently, suggesting strongly oxidising conditions. Three samples, at 85, 100 and 110 cm. contain large numbers of grains of Chenopodiaceae, but no other pollen. This phase is thought to represent a saline mud-flat, occasionally colonised by chenopods, and subject to seasonal flooding.

Phase 2 is characterised by widely and rapidly oscillating Diatomaceae/Chrysostomataceae ratios, with about 22–70 per cent diatoms. The diatom assemblages are mostly dominated by a single species. Zygnemataceae are present, but characteristically freshwater, organic-walled micro-fossils are absent, except at 60 cm. The pollen is sparse, and dominated by marsh species. This phase is interpreted as representing the interface between marshes and saline mudflats, with rather saline water present for much of the year.

Phase 3 is characterised by lesser oscillations in the Diatomaceae/Chrysostomataceae ratios (18–55 per cent diatoms) and relatively abundant pollen which is dominated by marsh species. Phase 3b is differentiated from Phase 3a by the presence of the freshwater alga *Cosmarium* and the sudden increase in organic matter in the core (FIG. 4). Phase 3b is also characterised by relatively high incidences of Typhaceae and Chenopodiaceae. Both phases 3a and 3b represent a freshwater marsh. The increasing importance of organic-walled microfossils in phase 3b suggests a less dense marsh flora, since increased sunlight would allow algae to bloom. The increase in chenopod pollen from local salt flats also suggests a relative decrease in pollen production by the marsh flora. This change in the marsh flora might be the result of direct or indirect interference with the environment by man.

The presence of *Casuarina* grains indicates the base of 3a post-dates the 1890s, possibly the 1920s.

Azraq A_8

Phase A is characterised by relatively high and stable Diatomaceae/Chrysostomataceae ratios (40–55 per cent diatoms), with the exception of the sample from 130 cm. which contain 80 per cent diatoms. The three lowest samples contain sparse marsh pollen and organic-walled microfossils. Phase A is interpreted as a marsh-edge environment, gradually passing upwards into saline mudflats.

Phase B is characterised by a low incidence of diatoms (25–32 per cent). It probably represents similar conditions to those seen in Phase 1 of Azraq B_{10}, saline mudflat.

Phase C is characterised by a high incidence of diatoms (52–60 per cent) and high incidences of pollen and organic-walled microfossils. This is a marsh assemblage similar to Phase 3 of Azraq B_{10}.

Synthesis

The evidence presented here indicates that the nature of the environment at the sites has altered considerably in the recent past. The series of vegetation changes and changes in sediment type indicate fluctuations between freshwater marsh and saline mudflats. This must reflect changing hydrological conditions at the sites.

Near the base of Azraq A_8, marsh was developed at or near the site, but gradually retreated, allowing saline mudflats to develop. Both boreholes then show saline mudflats until 75 cm. at Azraq B_{10} and 60 cm. at Azraq A_8. There is a transition to freshwater marsh in Azraq B_{10} which is not present in Azraq A_8. At 50 cm. in both cores, freshwater marsh is established. This apparent synchroneity of change suggests a major environmental cause, rather than being the result of purely local events. The presence of *Casuarina* grains indicates this change post-dates the 1890s. The results of the heavy metal analyses, which show much higher levels of contamination at 30 and 60 cm. than at 105 and 145 cm. leads us to hypothesize that the most recent forcing hydrological change may have been initiated by the construction and use of the oil pipelines, airfield, water pipelines and highways during and after the 1930s. Alternatively, the hydrological changes might have been caused by the irrigation and water extraction schemes of the recent past, which Hemsley and George (1966) believe caused widespread disruption of habitats.

If the change from saline to freshwater marsh and the increase in heavy metals do date from the 1930s then the stratigraphic data indicates that the marsh has been accreting at a rate of $\leqslant 1$ cm. per year. This rate cannot be extrapolated to the sediments further down the cores because they are of different texture having accumulated in different depositional environments. There is insufficient evidence to explain satisfactorily the earlier environmental changes noted in the cores.

Conclusions

Stratigraphic and micropalaeontological investigations of two sequences in the Azraq marshes in north east Jordan have revealed that significant variations in habitat conditions have occurred in the recent past: freshwater swamp has given way to saline mudflats, with a final reversion to freshwater swamp. This last event is provisionally attributed to the 1930–1940 period, and might be associated with the construction and use of an airfield, pipelines and highways in the area. Unfortunately, the cores obtained have proved to cover too short a period of time to justify comparisons with longer sequences described from this region by Ehrlich and Singer (1976) and by Horowitz (1977).

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The micropalaeontological preparations described are deposited in the following laboratories—University of Sheffield, Department of Geology (Palynology Laboratory); The British Museum (Natural History); and the British Institute of Archaeology and History at Amman.

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