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Lacustrine Paleoenvironments of the Area of Bir Tarfawi-Bir Sahara East Reconstructed from Fossil Ostracods and the Chemistry of their Shells

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INTRODUCTION

Several seasons of detailed geoarchaeological work by the Combined Prehistoric Expedition have shown that the climate in this now hyper-arid sector of the Eastern Sahara was considerably wetter on a number of occasions during the past two hundred thousand years (Wendorf and Schild 1980; Kowalski *et al.* 1989; Szabo *et al.* 1989). During these more humid intervals, the water-tables were often very close to the surface and shallow lakes occupied deflational hollows in the general vicinity of Bir Sahara East and Bir Tarfawi in the southwestern desert of Egypt. In both localities, at least five discrete lake events have been identified, although it is not certain that the Sahara East lakes were synchronous with those at Tarfawi. The two oldest lakes at Tarfawi, the Sand Pan and the Tarfawi White Lake, may date respectively to 175 and 160 ka; three younger Tarfawi lakes (Grey Phases 1-3 of the East Lake) all have Uranium-series ages closely bracketed within a period of 10 kyr about 135 ka, although preliminary thermoluminescence dates are consistently younger (Chs. 13 and 14, this volume). The youngest lake at Tarfawi, the Green Phase, may date to about 70 ka.

Associated with each of these lakes is a series of Middle Paleolithic artifact concentrations; some are also associated with a tropical savanna fauna, indicating prehistoric human occupation of what was then a very different Saharan landscape. During February 1987, one of us (M.A.J.W.) reexamined each of the exposed geological and archaeological trenches in both Tarfawi and Sahara East to familiarize himself with the details of the lithostratigraphic sequence associated with each of the lacustrine events. Sediment samples were collected at intervals of 5-10 cm for each lake sequence and were later analysed by P.D.D. for subfossil ostracods. Five sites contained a detectable ostracod fauna, but the others had too few to warrant further study.

Of the five sites, one, BS-13, falls within lithostratigraphic unit 14 (shelly grey marl) of the West Lake 2 at Sahara East. The remaining four sites are all at Tarfawi: Tr. 10/86 (300 m north of BT-14) belongs with the Tarfawi White Lake; E-86-2 is near the base of Grey Phase 3(?) with dark organic staining; E-87-2 (Tr. 14/87) samples the base of the Green Phase; and Tr. 7/86 is the type locality for the Green Phase.

Before commenting in greater detail about the paleolimnological characteristics of the lakes in question, we offer some introductory comments about the types of paleoenvironmental information that may be gleaned from stable-isotope and trace-element analyses of subfossil ostracod shells. For any lake, the properties of its water are a legacy of the interactions between the entire hydrological budget of the basin in which the lake occurs, the basin topography and geology, and the climatic conditions affecting the basin. If we assume that over short periods of the geological time scale (10-50 kyr) basin topography and geology change little, the lake's water-properties (chemical composition, water temperature, status as ephemeral or permanent, and amount of water) will be directly related to climatic conditions which control the basin's hydrology overall.

Conditions in lakes vary between locations. For example, temperature variations are greater and more frequent near the shore than in the deepest part of the lake. It is therefore necessary to identify the location where data are gathered in any lake (even a fossil lake) before extrapolation of the lake's water-properties can be equated with climatic conditions above the lake. This is particularly important when reconstructing the past histories of ancient lakes and the climatic conditions which affected them. A variety of sedimentological and biological facies can be used for this purpose (De Deckker 1988).

OSTRACODS

Microfossils can answer questions on site location fairly adequately, as well as on the physico-chemical properties of lake water. So far ostracods are probably the best available organisms for the reconstruction of lacustrine paleoenvironments.

Ostracods are microcrustaceans that can live in nearly all types of aquatic environments, including very saline waters. They secrete and periodically shed a bivalved shell (usually <1 mm long) of low-Mg calcite, which fossilizes readily. The chemical composition of the shells can give information on certain properties of the water in which the

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ostracods lived (temperature, salinity, the Mg/Ca and Sr/Ca ratios of the water). In addition, knowledge of the ecology of extant species can clarify the range of salinities and broad solute composition of the water, and whether or not the water was permanent (Carbonel *et al.* 1988; De Deckker and Forester 1988). Analysis of population structures (the study of juvenile and adult specimens found together within one sample) and the state of shell preservation can indicate whether specimens have been reworked, hence allowing inferences to be made on the type of lake facies in which the ostracods lived.

Research pioneered at the Australian National University and Monash University (Chivas *et al.* 1986a, 1986b; De Deckker *et al.* 1988a, 1988b) has made possible the reconstruction of various water properties in paleolakes on the basis of Mg and Sr analyses of fossil ostracod shells. Given a monospecific sample of ostracods from an individual stratigraphic horizon for which analyses of the Sr/Ca and Mg/Ca of *individual shells* are available, and knowing that the uptake of Sr in the shells is controlled by the Sr/Ca composition of the host water *only* (and hence, in some circumstances, indirectly by salinity), and that the uptake of Mg is controlled by *both* water temperature and the Mg/Ca of the water, the following deductions are possible.

(1) If all the Sr/Ca values form a tight cluster, the lake salinity did not normally fluctuate during the life of the ostracods. A change in Sr/Ca would result from the precipitation of carbonate (or sulphate) minerals from the water.

(2) If both the Sr/Ca and Mg/Ca values of ostracod valves form tight clusters, the lake's water composition and temperature (and, often, salinity) did not vary, indicating deep-water conditions.

(3) If the Sr/Ca and Mg/Ca values are scattered, we may infer broad fluctuations in water chemistry and, perhaps, salinity and temperature.

Similarly, analyses of individual ostracod shells from different horizons in a sediment profile can point to salinity and temperature variations through time. (For more details, see Chivas *et al.* 1985, 1986a, 1986; De Deckker *et al.* 1988a, 1988b; and the summary diagram of De Deckker and Forester 1988.)

In vitro experiments and field collections as part of the Australian work have permitted us to determine the relationships between some ions (Mg, Sr) in the water and ostracod shells formed in the same water. Thus, Chivas and others (1986b) have established the distribution coefficient (KD) for all the species in the euryhaline genus, *Cyprideis*. Data available so far indicate that:

the KD[Sr] in *Cyprideis* $= \frac{(\mathrm{Sr/Ca})\mathrm{shell}}{(\mathrm{Sr/Ca})\mathrm{water}} = 0.475 \pm 0.057$;

and

the KD[Mg] in *Cyprideis* (at 25°C) $= \frac{(\mathrm{Mg/Ca})\mathrm{shell}}{(\mathrm{Mg/Ca})\mathrm{water}} = 0.00458 \pm 0.00072$.

By analysis of the Sr/Ca and Mg/Ca of *Cyprideis* shells from the Tarfawi and Sahara East sites and use of the above coefficients, we have been able to reconstruct the Sr/Ca and Mg/Ca of the paleowaters.

BIR TARFAWI

TR. 10/86 (TARFAWI WHITE LAKE) (SAMPLES M 151-155)

General Comments (based on ostracod data only). A well developed lake with fresh to slightly saline water, shallow (at the studied site), permanent, with dominance of Na and Cl, presence of aquatic vegetation, and organic-rich substratum. For species composition, see Table 6.1. Analogies in the ostracod fauna suggest that this site resembles the shallow parts of modern Lake Kinnereth-Tiberias (Lemer-Seggev 1968).

Trace-Element Studies. The Mg/Ca of the water, calculated from the ostracod Mg/Ca composition, fell within the 1.5-4.5 range (Figs. 6.1 and 6.2), indicating that the water was probably close to fresh [commonly freshwater has a Mg/Ca <1 (De Deckker *et al.* 1988a, 1988b)]. This is confirmed by the presence of the freshwater species, *C. vidua*, in all samples. As a first approximation, if we assume that the Mg/Ca of the water did not change, temperature variation was no more than *ca.* 15°C (based on unpublished data of De Deckker who computed the thermodependence of Mg in *Cyprideis* shells by *in vitro* experiments).

In all samples, there is evidence of temperature fluctuations, implying that the water was shallow at this site. This is supported by the broad scatter of the Sr/Ca of the same ostracod shells (Figs. 6.3 and 6.4). A possible explanation for this range of values is that there must always have been some carbonate precipitating from the lake water to cause a change in its Sr/Ca and Mg/Ca. The broad changes recorded through the profile show parallel trends in Sr/Ca and Mg/Ca variation, which further supports the concept of carbonate precipitation at the time of ostracod shell formation.

TR. 7/86 (GREEN PHASE) (SAMPLES M 156-159)

General Comments. Ostracods are rare and mostly fragmentary. They all belong to *Cyprideis torosa* and therefore indicate that the lake was probably slightly saline

TABLE 6.1

Distribution of Ostracod Species 1, Charophyte Oogonia and Fish Remains from Five Stratigraphic Sections in Southwestern Egypt

SAMPLE [2]		Cyprideis torosa	Potamocypris producta	Darwinula stevensoni	Hemicypris intermedia	Heterocypris incongruens	Dolerocypris fasciata	Candona marchica	Cypridopsis vidua	Limnocythere aff. stationis	*charophytes*	*fish remains*
BS-13-1	75 cm from surface	X[3]										
2	65	X	X	O	O							
3	55	X		X	X		X					
4	45	X	X	X	X	X		X	X	O		
5	35	X	X	X	X			X				
6	25	X		X	X							
7	15	O										
M -151	0- 5 cm from surface	X		X	X			X	X		X	
152	5-10	X		X	X			X	X			
153	10-15	X		X				X	X			
154	15-20	X				X		X	X		X	
155	20-25	X		X	X			X	X		X	
M -156	25-30 cm from base	O										O
157	45-50	O										
158	70±2	O										
159	90±2	O										
M -164	0- 5 cm from surface	O										
165	5-10	O										
166	10-15											
167	15-20	O										
168	20-25											
169	25-30	O										
170	30-35											
171	35-40											
172	40-45											
173	45-50	O										
174	50-55											
175	55-60											
176	60-65	O										
177	65-70	O										
M-59	55 cm from surface	O										
60	40	O										
61	35											
62	30											
63	25											
64	20											

1. All ostracod species listed can tolerate slightly saline waters: *Cyprideis torosa* and *Darwinula stevensoni* require permanent water to reproduce; *Cypridopsis vidua* usually frequents eutrophic waters.
2. Samples BS-13 1-7 are from Sahara East; the remainder are from Tarfawi.
3. X=common; O=rare

to saline. No other information can be extrapolated from them.

E-87-2, TR. 14/87 (BASE OF GREEN PHASE) (SAMPLES M 164-177)

General Comments. Ostracods are rare or absent. Only *Cyprideis torosa* is present, meaning a slightly saline to saline lake. The material is reworked. Nothing else can be determined.

E-86-2 (DARK LAYER NEAR BASE OF GREY PHASE 3?) (SAMPLES M 59-64)

General Comments. The few ostracods are *Cyprideis torosa*, indicating a slightly saline to saline lake.

BIR SAHARA EAST

BS-13 (NORTHERN EDGE, WEST LAKE 2) (SAMPLES BS-13 1-7).

General Comments. A fairly well developed lake, fresh to slightly saline, with permanent water, deep at times, and less aquatic vegetation than in Tr. 10/86 at Tarfawi. The importance of Na and Cl in the water is based principally on the presence of *Cyprideis*. By analogy with

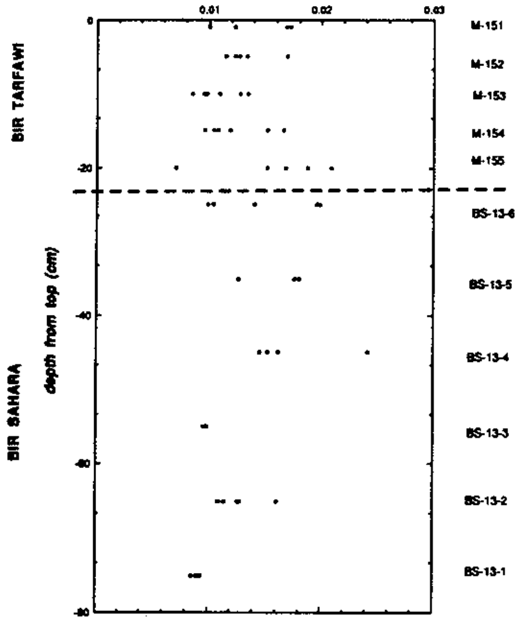

Figure 6.1. Mg/Ca molar ratios of individual ostracod shells (all of *Cyprideis torosa*) for selected stratigraphic horizons from the Tarfawi (BT) and Sahara East (BS) paleolake sites. Depths are in cm below the surface of each trench. The dashed horizontal line separates data from the two depressions.

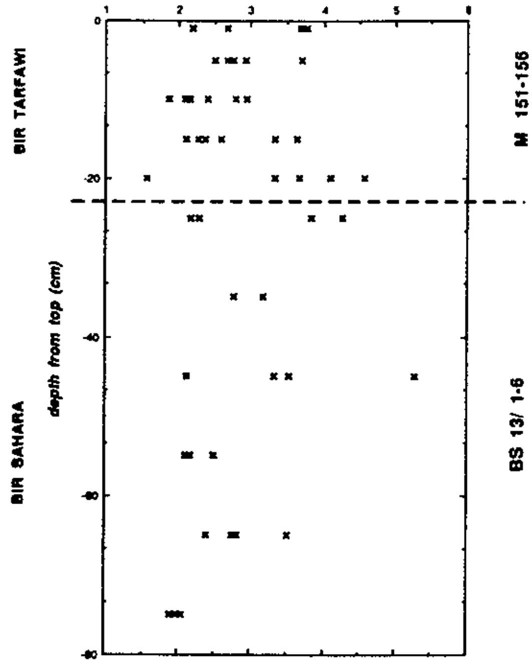

Figure 6.2. Mg/Ca molar ratios of the paleolake waters obtained by dividing the Mg/Ca value of each *C. torosa* shell by the distribution coefficient KD[Mg] for that species (0.00458 at 25°C). The dashed line separates data from the two depressions.

the modern biota (Lerner-Seggev 1968), this site resembles the shallow parts of Lake Kinnereth-Tiberias. Further details on species composition are given in Table 6.1.

Trace-Element Studies. The Mg/Ca values form tight clusters at 55 and 75 cm below the surface (Samples BS-13 1 and 3), indicating deposition under a substantial column of water. For those levels, the water must have been almost fresh (its Mg/Ca=2) and there was little temperature variation. The broad Sr/Ca range in the same levels indicates that aragonite was precipitating (when precipitating, aragonite forces a broad change in the Sr/Ca of the host water because its KD[Sr] is >1). For the other samples, the water must have been shallower, as indicated by the scattered Mg/Ca values, and temperature variations were of the order of 15°C. Overall, therefore, the lake level fluctuated frequently. Figs. 6.3 and 6.4 give further details on ostracod shell chemistry and postulated water ionic composition for this site.

COMMENTS ON THE LAKES WITH ABUNDANT OSTRACODS

Ostracods were abundant in the samples taken from the Tarfawi White Lake and from West Lake 2. The Mg/Ca composition of the *Cyprideis* shells indicates that the Mg/Ca ratios of the lake waters in which they lived was of the order of 1.5-4.5, or perhaps even less if we allow for the effect of temperature on this ratio. It is surprising for the Mg/Ca ratio of water to be close to unity in a semi-arid to arid environment. If the water had travelled far, it would have had much higher Mg/Ca ratios because of calcite precipitation, such as in travertine deposits, which is a common phenomenon in this environment. The waters of these lakes must therefore have come from nearby springs or short streams. The idea of spring-fed bodies of water is appealing because of the presence of fossil spring-mounds in the area (Wendorf and Schild 1980: Figs. 2.4, 2.7 and 2.19). This suggests that the lakes were groundwater-fed, and consequently, their behavior would relate directly to the regional hydrological budget.

In light of this, it would be interesting to determine the Mg/Ca composition of modern groundwater. If it is close to 1, then it would not be difficult to estimate how much precipitation would be necessary to form lakes again. On the other hand, if the Mg/Ca ratio of modern groundwater is considerably more than 1, our calculations would

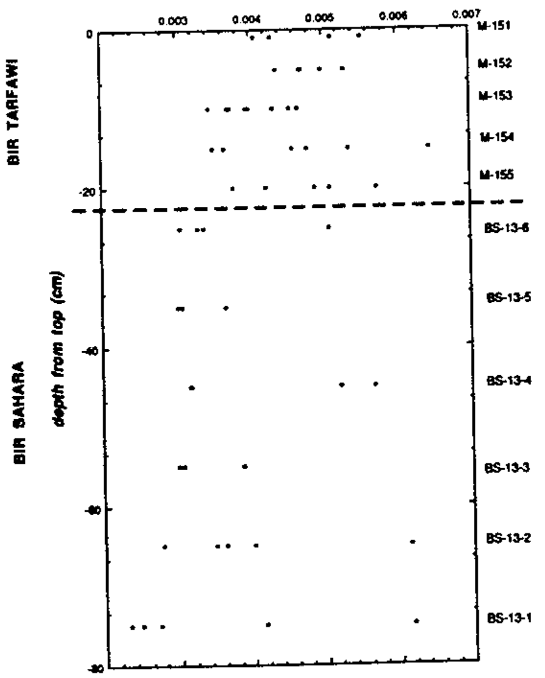

Figure 6.3. Sr/Ca molar ratios of individual *C. torosa* ostracod shells for selected stratigraphic units. Depths are in cm below the surface of each trench. The dashed line separates data from the two depressions.

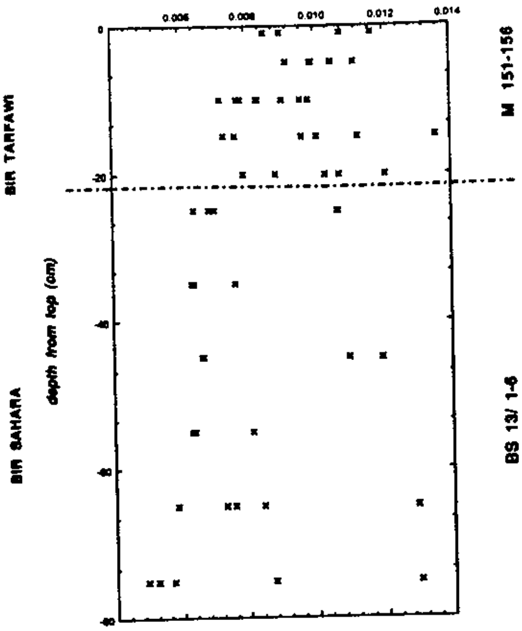

Figure 6.4. Sr/Ca molar ratios of the lake-water obtained by dividing the Sr/Ca value of each individual *C. torosa* shell by the distribution coefficient KD[Sr] for that species (0.475). The dashed line separates data from the two depressions.

imply very drastic hydrological changes since the existence of the paleolakes.

The presence of *Cyprideis torosa* in all the samples which yielded ostracods indicates water with ionic dominance of Na and Cl. *C. torosa* and *Darwinula stevensoni* require permanent water to reproduce, while *Cypridopsis vidua* usually frequents eutrophic waters.

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