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OSTRACODA, DEPOSITIONAL ENVIRONMENTS AND LATE QUATERNARY EVOLUTION OF THE EASTERN NILE DELTA, EGYPT

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ABSTRACT - Ostracoda, *depositional environments and late Quaternary evolution of eastern Nile Delta, Egypt* - Il Quaternario, **4**(2), 1991, p. 275-302 - Ostracode assemblages serve to refine the interpretation of the depositional environments during the late Quaternary in the northeastern Nile delta of Egypt. Nine radiocarbon-dated cores, specifically selected along a land-to-sea SW to NE transect across the northeastern delta plain, provide a representative and near complete sequence of alluvial to open marine lithofacies of late Pleistocene to Recent age. Holocene sections in six of these nine cores comprise 33 ostracode species. 30 of these live in various modern Mediterranean environments; three forms (*Cytherella* sp. 1, *Loxoconcha* sp. 1, and *Sylvestra* sp. 1) have not been recorded previously in this sea and are now in open nomenclature. We clustered selected species in six groups, plus a miscellaneous stock of species represented by allochthonous juveniles only. Together, these characterize different depositional environments, from lagoonal to open marine prodelta settings.

Evaluation of the temporal and spatial distributions of ostracode faunae, in conjunction with petrological analysis of core sections, provides a basis to interpret the nature of Holocene deltaic facies which accumulated from about 7500 years B.P. The configuration of this region, including changes in position of the coastline, River Nile distributaries and delta lobes, is mapped for four time periods, from about 7500 years B.P. to 1500 years B.P., *i.e.* during the active progradation of the modern delta. Environmental markers, such as *Basslerites berchoni*, help recording progressive changes from marine to lagoonal settings. Other species appear responsive to climatic oscillations, such as *Sylvestra* sp. 1 whose distribution correlates well with a major change from wet to drier conditions at about 4000-3500 years B.P.

RIASSUNTO - Ostracoda, *ambienti deposizionali ed evoluzione olocenica del settore orientale del Delta del Nilo, Egitto* - Il Quaternario, **4**(2), 1991, p. 275-302 - Le faune ad ostracodi sono utilizzate per definire con maggior dettaglio gli ambienti deposizionali nel settore nord-orientale del delta del Nilo (Egitto) durante l'Olocene. Nove sondaggi, per i quali sono disponibili datazioni con ^{14}C, sono stati opportunamente scelti nella piana deltizia lungo un transetto SW-NE, da terra verso mare, in quanto testimoniano una sequenza quasi completa di litofacies da piana alluvionale al marino costiero dal tardo Pleistocene all'Attuale. Nelle sezioni oloceniche di sei dei nove sondaggi sono state rinvenute 33 specie di ostracodi, delle quali 30 sono attualmente viventi nel Mediterraneo. Tre specie (*Cytherella* sp. 1, *Loxoconcha* sp. 1 e *Sylvestra* sp. 1) non sono state mai segnalate nel Mediterraneo e sono qui considerate in nomenclatura aperta. Specie selezionate sono state riunite in 6 gruppi, dai quali sono state escluse le specie rappresentate esclusivamente da forme giovanili alloctone (*"miscellaneous stock"*). La combinazione di specie appartenenti ai gruppi suddetti caratterizzano differenti ambienti deposizionali dal lagunare ad ambienti marini di prodelta.

La definizione delle distribuzioni temporali e spaziali delle ostracofaune, integrata da dati di analisi petrologiche dei sondaggi, costituisce una base per interpretare la natura delle facies deltizie oloceniche a partire da circa 7500 anni B.P. Le distribuzioni delle ostracofaune sono utilizzate anche per meglio definire l'evoluzione paleogeografica del settore nord-orientale del delta. La configurazione di questa regione (cambiamenti della posizione della linea di costa, dei canali distributari e dei lobi del delta) è mappata in quattro intervalli cronologici, da circa 7500 anni B.P. a 1500 anni B.P., corrispondenti alla progradazione dell'attuale delta. Questo studio mette in luce alcuni indicatori ambientali, quali *Basslerites berchoni*, che potrebbero registrare progressivi cambiamenti da ambienti marini a lagunari. Altre specie sembrano rispondere ad oscillazioni climatiche, quali *Sylvestra* sp. 1, la cui distribuzione sembra correlabile a cambiamenti, avvenuti circa 4000-3500 anni B.P., da condizioni climatiche umide a più secche.

Key-words: *Ostracoda*, depositional environments, Nile delta, Holocene
Parole chiave: *Ostracoda*, ambienti deposizionali, delta del Nilo, Olocene

1. INTRODUCTION

This investigation examines the ostracode assemblages in a suite of radiocarbon-dated cores in the eastern Nile delta (Egypt). It was initiated in order to refine the interpretations of late Quaternary depositional environments of this major Mediterranean depocenter. The study integrates data on ostracodes and other fauna and flora with lithology and, in more general terms, with petrology, the latter already detailed in the logs of these borings.

The core sites were selected along a SW to NE transect about 47 km in length, extending from land to sea across the eastern Manzala lagoon region (Fig. 1). Manzala is the largest of the four major lagoons in the northern delta and it extends eastward from the Damietta branch of the Nile to the northwestern Sinai. The cores used in this study were collected by the Smithsonian Institution as part of the Mediterranean Basin (MEDIBA) Program in the Spring of 1987 (Stanley, 1988) using a trailer-mounted combination of rotary percussion machines. Nine cores were specifically chosen, from a suite of nearly 100 recovered across the northern Nile delta plain (Stanley, 1990), because they provided a representative and near-complete sequence of fluvial to open marine lithofacies. It was believed that a study of the ostracodes in these deposits could serve as a base reference for on-going and future studies of the late Pleistocene to the Recent evolution of the northern Nile delta.

2. PREVIOUS WORKS

For a general background on the Nile delta, the reader is directed to Said (1958), Butzer (1976) and Sestini (I976), for morphological studies, and to Zaghloul (1976), Rizzini *et al.*(1978), and Said (1981), for stratigraphic (mainly Miocene-Pleistocene) and tectonic investigations. In recent years, increased attention has been paid to the Holocene evolutionary history of the northern Nile delta, with a focus on sedimentary petrology combined with faunal and floral studies (Sneh *et al.*, 1986; Coutellier & Stanley, 1987; Kulyk, 1987; Frihy & Stanley, 1988; Pimmel & Stanley, 1989; Abu-Zeid & Stanley, 1990; Arbouille & Stanley,1991; Bernasconi *et al.*,1991).

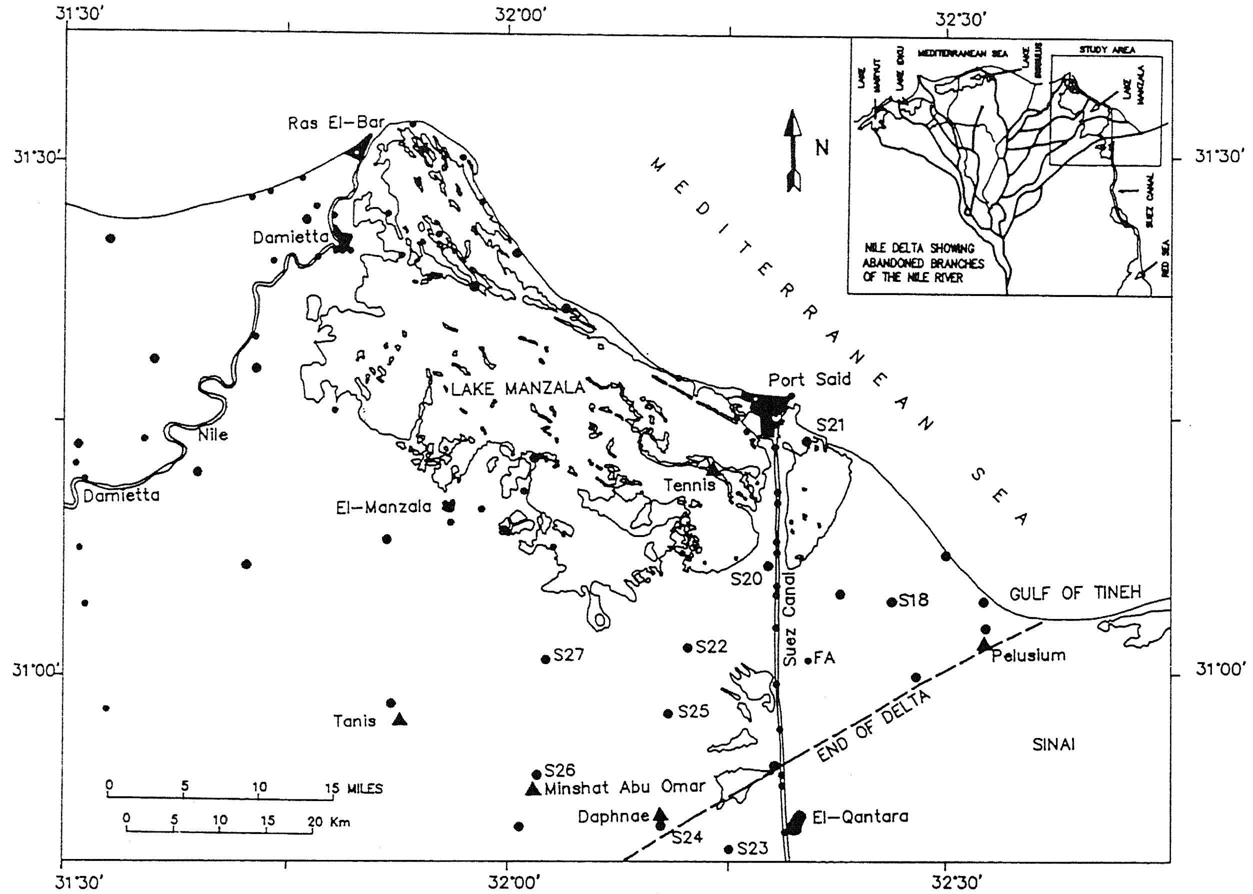

Fig. 1 - Map of the study area in the northeastern Nile delta, Egypt, showing Lake Manzala and other physiographic features discussed in text, and also selected archaeological sites (triangles). Large dots denote the positions of 9 studied Smithsonian borings detailed in this investigation; small dots indicate other sediment borings examined in this region (see Coutellier & Stanley, 1987) and core Fadda 1 (Sneh *et al.*, 1984), denoted here by FA. Former River Nile distributaries are shown in the inset.

Ubicazione dell'area studiata nel settore nord-orientale del delta del Nilo. Sono riportati la laguna di Manzala, alcune strutture fisiografiche discusse nel testo ed anche alcuni siti archeologici (triangoli). I punti più grossi indicano le ubicazioni dei 9 sondaggi Smithsonian esaminati in questa ricerca; i punti più piccoli riportano la posizione degli altri sondaggi esaminati in questa regione (cf. Coutellier & Stanley, 1987) e il sondaggio Fadda 1 (Sneh et al., *1984), qui indicato con la sigla FA. Gli antichi canali distributari del Nilo sono osservabili nel riquadro in alto a destra.*

3. SCOPE OF THIS WORK

The specific aims of this research, which is part of a long-term multidisciplinary study of the Nile delta, are: (1) to identify the fossil ostracode faunae in a near-complete sequence of terrestrial to open marine lithofacies; (2) to compare these fossil faunae with modern Mediterranean ostracode assemblages; (3) to show how their distribution in time and space occurs with respect to different specific deltaic environments; (4) to better interpret the ostracode faunae in the light of the specific lithofacies with which they are associated; and (5) to use them to more precisely determine Holocene changes in coastline positions, the influence of former distributary branches of the Nile, and the effects of paleoclimatic oscillations on the marine environments seaward of the delta.

4. METHODS

A total of 240 samples were examined in nine radiocarbon-dated Smithsonian cores (data in MEDIBA, 1990) along a series of boreholes from sea to land (from NE to SW): S-21, S-18, S-20, S-22, S-25, S-27, S-26, S-24 and S-23 (Fig. 1). The samples were washed through a 63 µm mesh. Of these samples, 211 were of confirmed Holocene age and 29 were of late Pleistocene to earliest Holocene. Ostracode species were identified in samples of six of the nine cores (no ostracodes were found in the samples of borings S-26, S-24, and S-23).

The proportions of mineralogical, faunal (excepted for ostracodes) and floral components of each sample were calculated on the basis of counts of 300 grains. Ostracodes were counted for the entire sample. These data are recorded in the data-base listings available at the Smithsonian (MEDIBA, 1990). The core sample numbers used in this study, recorded in Figures 2 to 7, correspond to those listed in the MEDIBA(1990) core records. For comparison purposes, we also examined the ostracodes of the top of two offshore cores (GC-2, GC-3) positioned seaward of the Rosetta Promontory; a map showing the location of these two sites is presented by Summerhayes *et al.* (1978, their Fig. 13).

5. OSTRACODES - GENERAL BACKGROUND

During its life cycle, each ostracode progressively sheds a series of carapaces, each representing the juvenile stages of growth (instars), before the adult stage. Most instars can be identified at the specific level. For the purpose of environmental interpretations here, the species represented by carapaces of adults together with instars are considered to be autochthonous; the implication is that most of the life cycle stages have been preserved *in situ*, without displacement of the smaller and generally lighter instars. Some samples contain only juveniles; in this case, they are considered allochthonous and probably displaced by currents.

In most cases, the adult valves commonly occur without their juveniles; these valves are interpreted as being essentially autochthonous. This latter interpretation is supported by (1) good carapace preservation, (2) findings of complete carapaces, and (3) the preservation of valves of both sexes. This, of course, does not preclude that adult-only samples have been subject to some minor displacement within the same environment after death.

6. IDENTIFICATION

Almost all ostracode species observed in the cores live at the present time in the Mediterranean. Information on the distribution and frequency of ostracode faunae in modern brackish to marine environments in other sectors of the Mediterranean Sea is thus of great use to interpret the fossil ostracode faunae examined in the six boreholes along the Manzala transect. An extensive and growing ostracode literature pertinent to the Mediterranean provided a reference to identify those species which can serve as diagnostic markers of specific depositional environments. This bibliography serves as our basic source for the present study. In particular, reference is made to monographic investigations of the Gulf of Naples (Müller, 1894) and the Adriatic Sea (Bonaduce *et al.*, 1975). Also used as a source are publications focusing on the African margin, *i.e.* Saint George Bay, Lebanon (Bonaduce *et al.*, 1970), Tunisian shelf (Bonaduce & Masoli, 1968; Bonaduce *et al.*, 1988), Lake of Tunis (Carbonel & Pujos, 1982) and other Tunisian lagoons (Mansouri & Carbonel, 1981; Mansouri *et al.*, 1985), a beach near Tripoli, Libya (Bonaduce & Pugliese, 1975), and the Bay of Bou-Ismail, Algiers (Yassini, 1979).

Some specific papers were particularly useful for the interpretation of shallow water and deltaic ostracode faunae. These include studies on marine and brackish-water environments in the northern Adriatic Sea, such as the Grado-Marano lagoon (Bonaduce *et al.*, 1973-74), the offshore part of the Tagliamento River delta (Ciliberto & Pugliese, 1980), and the Limski Kanal, Yugoslavia (Uffenorde, 1972). Reference is made to the Lago di Patria, near Naples (McKenzie, 1963) and the San Teodoro lagoon, Sardinia, in the Tyrrhenian Sea (Vismara Schilling & Ferretti, 1987). Also useful are unpublished data from ongoing research on ostracode assemblages in the gulfs of Naples, Salerno and Policastro (Tyrrhenian Sea) and brackish-water environments in the northern Adriatic Sea, such as Grado-Marano lagoon and tidal flats near Trieste (R. Marocco, N. Pugliese, and P. Ziveri, in preparation).

7. OBSERVATIONS

A total of thirty-three benthic ostracode species have been identified (Table 1). Twenty-four of these species have been assembled in 6 groups (A to F) which are defined in the following section of this article. Each group is constituted by species which live under distinct environmental conditions: fresh-water (Group A), brackish-water (Group B), and marine (progressively seaward, groups C to F). The brackish and marine species are listed alphabetically within each group. Information for each sample from each of the six cores where ostra-

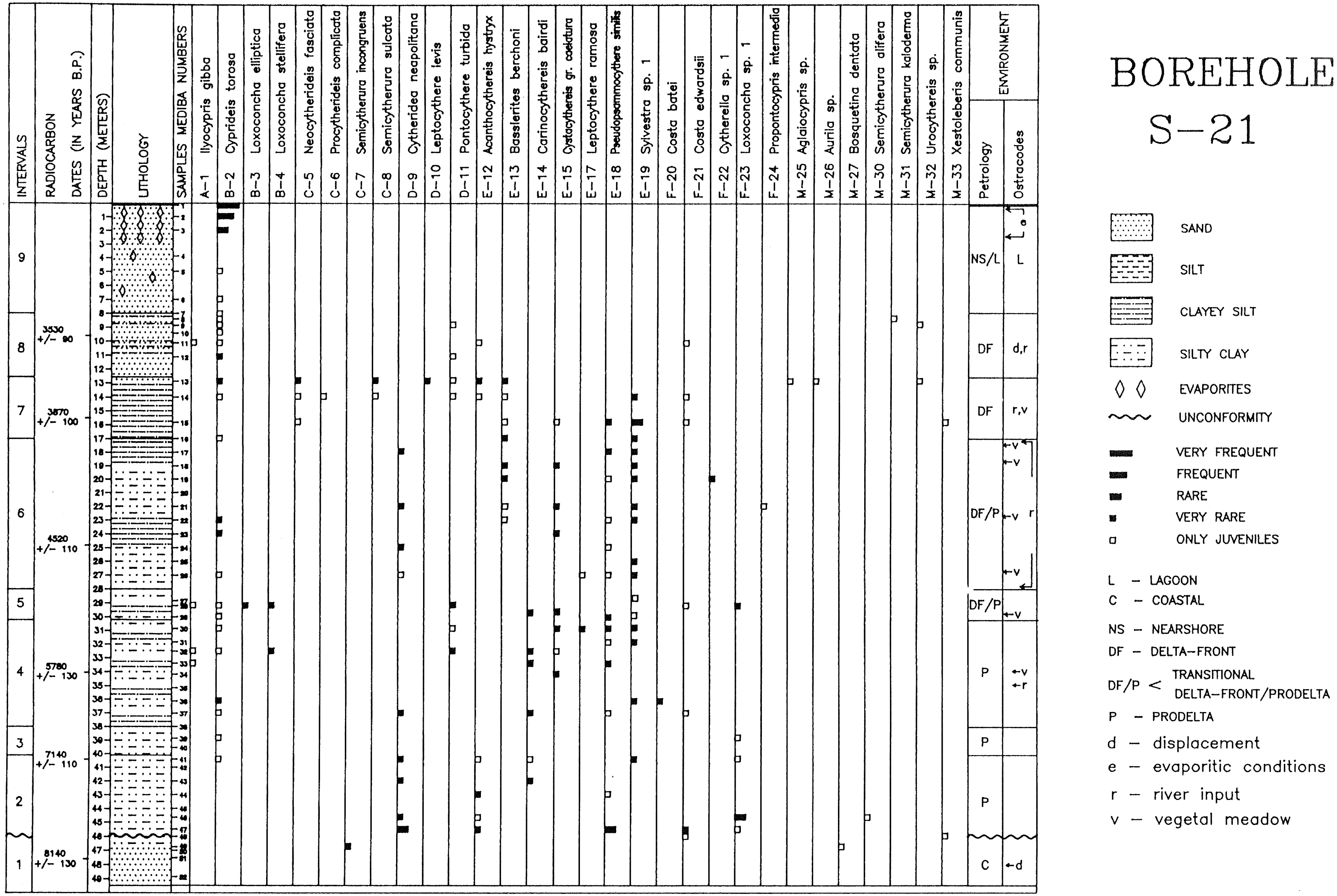
BOREHOLE
S–21
INTERVALS
RADIOCARBON DATES (IN YEARS B.P.)
DEPTH (METERS)
LITHOLOGY
SAMPLES MEDIBA NUMBERS
A–1 Ilyocypris gibba
B–2 Cyprideis torosa
B–3 Loxoconcha elliptica
B–4 Loxoconcha stellifera
C–5 Neocytherideis fasciata
C–6 Procytherideis complicata
C–7 Semicytherura incongruens
C–8 Semicytherura sulcata
D–9 Cytheridea neapolitana
D–10 Leptocythere levis
D–11 Pontocythere turbida
E–12 Acanthocythereis hystryx
E–13 Bassleriites berchoni
E–14 Carinocythereis bairdi
E–15 Cystacythereis gr. caelatura
E–17 Leptocythere ramosa
E–18 Pseudopsammocythere similis
E–19 Sylvestra sp. 1
F–20 Costa batei
F–21 Costa edwardsii
F–22 Cytherella sp. 1
F–23 Loxoconcha sp. 1
F–24 Propontocypris intermedia
M–25 Aglaiocypris sp.
M–26 Aurila sp.
M–27 Bosquetina dentata
M–30 Semicytherura alifera
M–31 Semicytherura kaloderma
M–32 Urocythereis sp.
M–33 Xestoleberis communis
ENVIRONMENT
Petrology
Ostracodes
3530 +/– 90
3870 +/– 100
4520 +/– 110
5780 +/– 130
7140 +/– 110
8140 +/– 130
NS/L
DF
DF/P
P
C
L
d,r
r,v
SAND
SILT
CLAYEY SILT
SILTY CLAY
EVAPORITES
UNCONFORMITY
VERY FREQUENT
FREQUENT
RARE
VERY RARE
ONLY JUVENILES
L – LAGOON
C – COASTAL
NS – NEARSHORE
DF – DELTA–FRONT
DF/P < TRANSITIONAL DELTA–FRONT/PRODELTA
P – PRODELTA
d – displacement
e – evaporitic conditions
r – river input
v – vegetal meadow

Table 1 - List of the thirty-three ostracode species recorded in northeastern Nile delta core sections of Holocene age. They are enumerated and listed by group, as defined in text. The species with (*) presently live in the gulfs of Policastro and Salerno in the Tyrrhenian Sea. SEM photographs of most of these forms are presented in Figures 8 and 9.

Elenco delle 33 specie di ostracodi ritrovate nelle sezioni oloceniche dei sondaggi provenienti dal settore nord-orientale del delta del Nilo. Le specie sono riunite nei gruppi definiti nel testo e sono provviste di un numero di codice. Le specie con (*) sono attualmente viventi nei golfi di Policastro e Salerno (Mar Tirreno). Molte di queste specie sono rappresentate in fotografie eseguite al microscopio elettronico a scansione (SEM) nelle Figure 8 e 9.

Fresh-water (Group A)
1 *Ilyocypris gibba* (Ramdhor, 1808)

Brackish-water (Group B)
2 *Cyprideis torosa* (Jones, 1857) - Fig. 8a
3 *Loxoconcha elliptica* Brady, 1868 - Fig. 8b
4 *Loxoconcha stellifera* G.W. Müller, 1894 - Fig. 8c

Marine Nearshore Normally with Vegetal Meadow (Group C)
5 *Neocytherideis fasciata* * (Brady & Robertson, 1874) - Fig. 8d
6 *Procytherideis complicata* - (Ruggieri, 1953)* - Fig. 8e
7 *Semicytherura incongruens* -(G.W. Müller, 1894)* - Fig. 8f
8 *Semicytherura sulcata* - (G.W. Müller, 1894)* - Fig. 8g

Marine Nearshore Normally without Vegetal Meadow (Group D)
9 *Cytheridea neapolitana* Kollmann, 1960* - Fig. 8h
10 *Leptocythere levis* (G.W. Müller, 1894)* - Fig. 8i
11 *Pontocythere turbida* (G.W. Müller, 1894)* - Fig. 8j

Marine Nearshore with Vegetal Meadow/Open Marine with or without Vegetal Meadow (Group E)
12 *Acanthocythereis hystrix* (Reuss, 1850) - Fig. 8k
13 *Basslerites berchoni* (Brady, 1870)* - Fig. 8l
14 *Carinocythereis bairdi* Uliczny, 1969* - Fig. 9a
15 *Cystacythereis* gr. *caelatura* Uliczny, 1969 - Fig. 9b
16 *Cytheroma variabilis* G.W. Müller, 1894* - Fig. 9c
17 *Leptocythere ramosa* (Rome, 1942)* - Fig. 9d
18 *Pseudopsammocythere similis* (G.W. Müller, 1894)* - Fig. 9e
19 *Sylvestra* sp. 1 - Fig. 9f

Open Marine (Group F)
20 *Costa batei* (Brady, 1868) - Fig. 9g·
21 *Costa edwardsii* (Roemer, 1838)* - Fig. 9h
22 *Cytherella* sp. 1 - Fig. 9i
23 *Loxoconcha* sp. 1 - Fig. 9j
24 *Propontocypris intermedia* (G.W. Müller, 1894)* - Fig. 9k

Miscellanea
25 *Aglaiocypris* sp.
26 *Aurila* sp.
27 *Bosquetina dentata* (G.W. Müller, 1894)
28 *Kroemmelbeinia* sp.
29 *Leptocythere* sp.
30 *Semicythererura alifera* Ruggieri, 1959
31 *Semicytherura kaloderma* Bonaduce & Pugliese, 1975
32 *Urocythereis* sp.
33 *Xestoleberis communis* G.W. Müller, 1894

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Fig. 2 - Facies log of borehole S-21 showing the lithology of each interval (1-9) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group (A to F), plus a Miscellanea (= M) stock; each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-21. Sono riportati dati della litologia di ogni intervallo (1-9) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita in gruppi (A-F) e in un Miscellanea (= M) stock; *ogni specie è contrassegnata da un codic(lettera + numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).*

codes occur is presented in six diagrams (Figs. 2-7).

Three of the above autochthonous species, *Sylvestra* sp. 1 (SEM photograph in Fig. 9f), *Cytherella* sp. 1 (SEM photograph in Fig. 9i), and *Loxoconcha* sp. 1 (SEM photograph in Fig. 9j), are considered here in open nomenclature, *i.e.* they have not been identified with certainty. The first is probably a new species; the others occur too rarely to give them a more precise taxonomic attribution.

Those juveniles of species forming groups A to F that are found without their adult stage counterpart are herein considered as displaced/reworked forms. Another group of juveniles, listed in a Miscellanea category (Table 1) and denoted in Figures 2 to 7, are also inter-

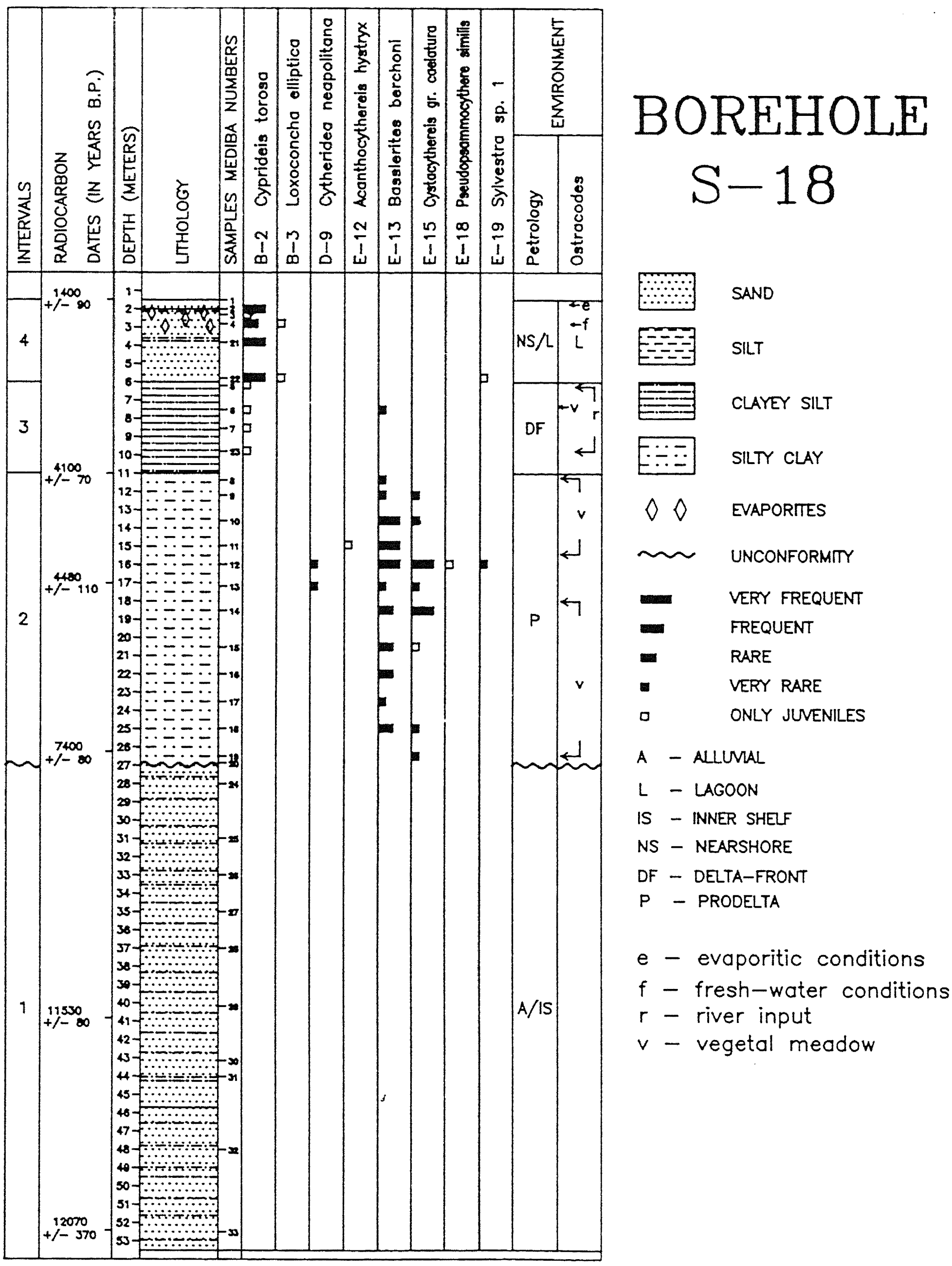


Fig. 3 - Facies log of borehole S-18 showing lithology of each interval (1-4) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group (B, D, and E); each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-18. Sono riportati dati della litologia di ogni intervallo (1-4) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita in gruppi (B, D ed E); ogni specie è contrassegnata da un codice (lettera+numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).

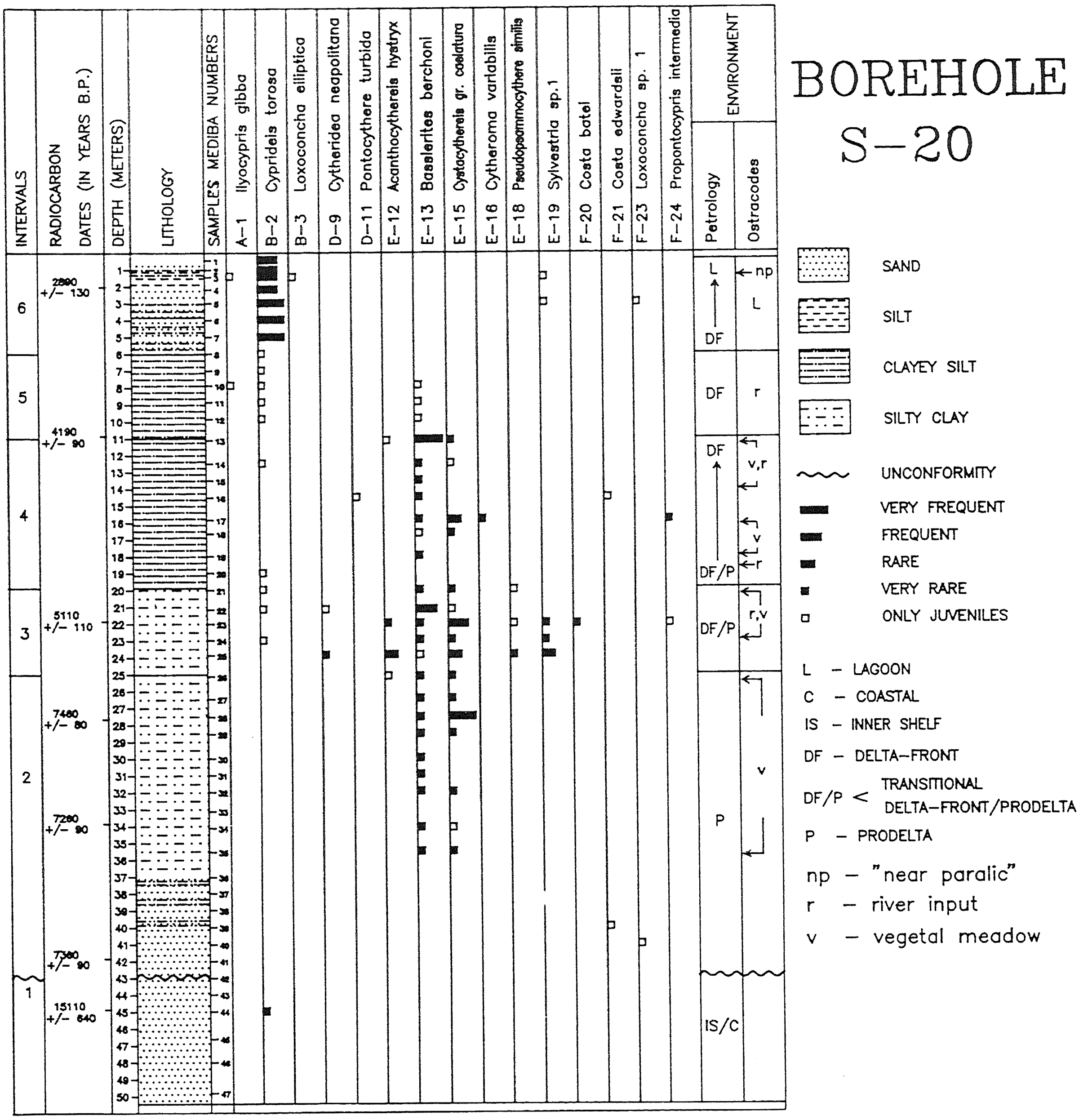


Fig. 4 - Facies log of borehole S-20 showing lithology of each interval (1-6) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group (A, B, D, E, and F); each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-20. Sono riportati dati della litologia di ogni intervallo (1-6) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita in gruppi (A, B, D, E e F); ogni specie è contrassegnata da un codice (lettera+numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).

preted as displaced/reworked forms.

The frequency of each species in each sample in the six diagrams is denoted in a semi-quantitative fashion: very rare (1-2 specimens), rare (3-5 specimens), frequent (6-10 specimens), and very frequent (>10 specimens). The presence of juvenile specimens of species is shown in Figures 2 to 7.

In Appendix A following the text we highlight the major ostracode components found in the six cores (S-2l, S-18, S-20, S-22, S-25, S-27) where they are present. The lithology of the other three borings without ostracode fauna (S-23, S-24, S-26) are also briefly described. Each boring is subdivided into intervals which are sequentially numbered from the base to the core top; these number-coded intervals constitute units defined primarily by their ostracode faunae, where present. All the cores examined here have been radiocarbon-dated (data in MEDIBA, 1990) to establish a chronostratigraphic

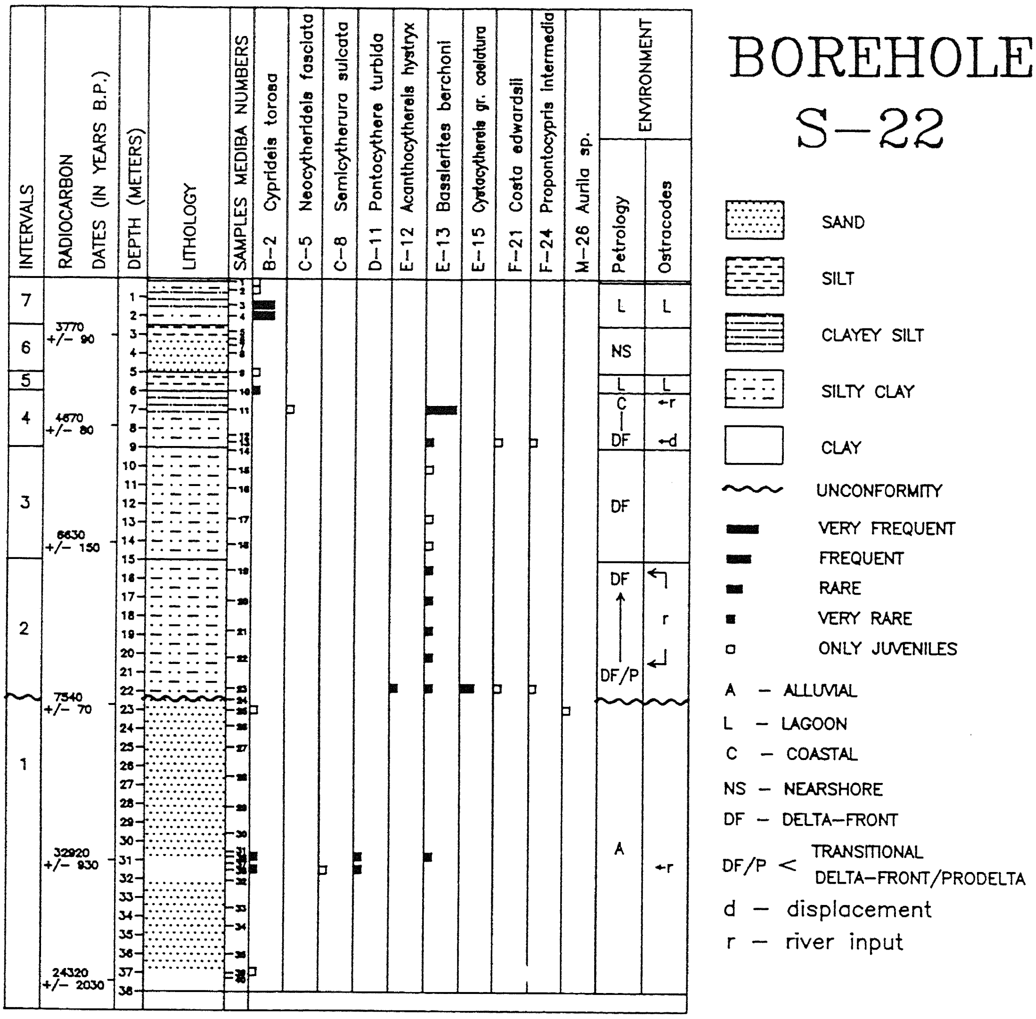


Fig. 5 - Facies log of borehole S-22 showing lithology of each interval (1-7) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group (B, C, D, E, and F), plus a Miscellanea (= M) stock; each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-22. Sono riportati dati della litologia di ogni intervallo (1-7) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita in gruppi (B, C, D, E e F) e in un Miscellanea (= M) stock; *ogni specie è contrassegnata da un codice (lettera+numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).*

base.

In Appendix A we call attention to dominant petrologic attributes of each interval, including sedimentary structures, texture, mineralogy and general faunal and floral components in the sand-sized fraction. Simplified core logs are depicted on each of the six diagrams that list the ostracode species (Figs. 2-7). The foraminiferal species cited for each of the intervals are from observations made during the course of this study. For further details on the petrology of these cores, see the MEDIBA (1990) data-base.

For each core interval described in Appendix A, interpretations of the environment of deposition are made independently on the basis of (1) ostracodes (either a single group or assemblage of multiple groups) and, subordinately, other taxa, and (2) petrology. The terminology used here to denote the different open marine to terrestrial lithofacies (prodelta, delta-front, coastal, lagoonal/ marsh, fluvial) is defined in Coutellier & Stanley (1987), Frihy & Stanley (1988) and Arbouille & Stanley (1991). The term transitional prodelta/delta-front used in this study refers to environments that are indetermediate between the prodelta and delta-front.

The first step in this study was the identification of depositional environments on the basis of petrology. Interpretation of each of these was then refined by consideration of the ostracode faunae. It is this latter aspect which is emphasized in the present article.

8. OSTRACODES AS USED TO INTERPRET NILE DELTA ENVIRONMENTS

8.1 Generalities

Most of the ostracode species identified in Nile delta cores (Table 1) are presently living in various paralic environments (such as fluvially-influenced delta, lagoon, near-shore to open marine) in different sectors of the Mediterranean Sea. Many of these forms are able to tolerate highly variable physical and chemical attributes of sea water, including large oscillations of salinity, temperature, pH and others. Deltaic environments are typically characterized by marked variations of these parameters. A species living under such variable conditions is called eurybiont. Organisms, including ostracodes, living in paralic environments where the salinity range is usually quite broad, are called euryhaline.

Thirty out of the thirty-three species identified in the present Nile delta study area (Table 1) live in the modern

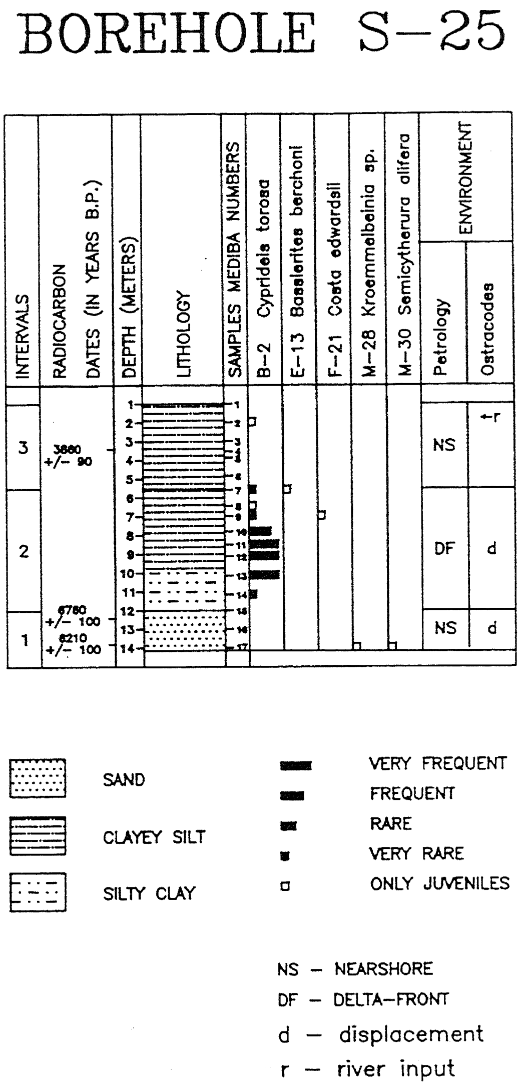


Fig. 6 - Facies log of borehole S-25 showing lithology of each interval (1-3) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group (B, E, and F), plus a Miscellanea (= M) stock; each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-25. Sono riportati dati della litologia di ogni intervallo (1-3) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita in gruppi (B, E e F) e in un Miscellanea (=M) stock; *ogni specie è contrassegnata da un codice (lettera+numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).*

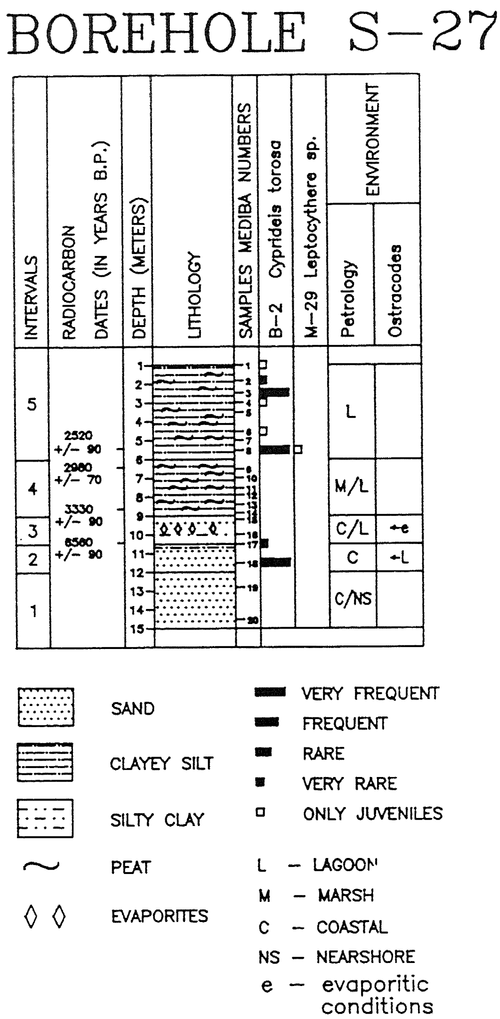
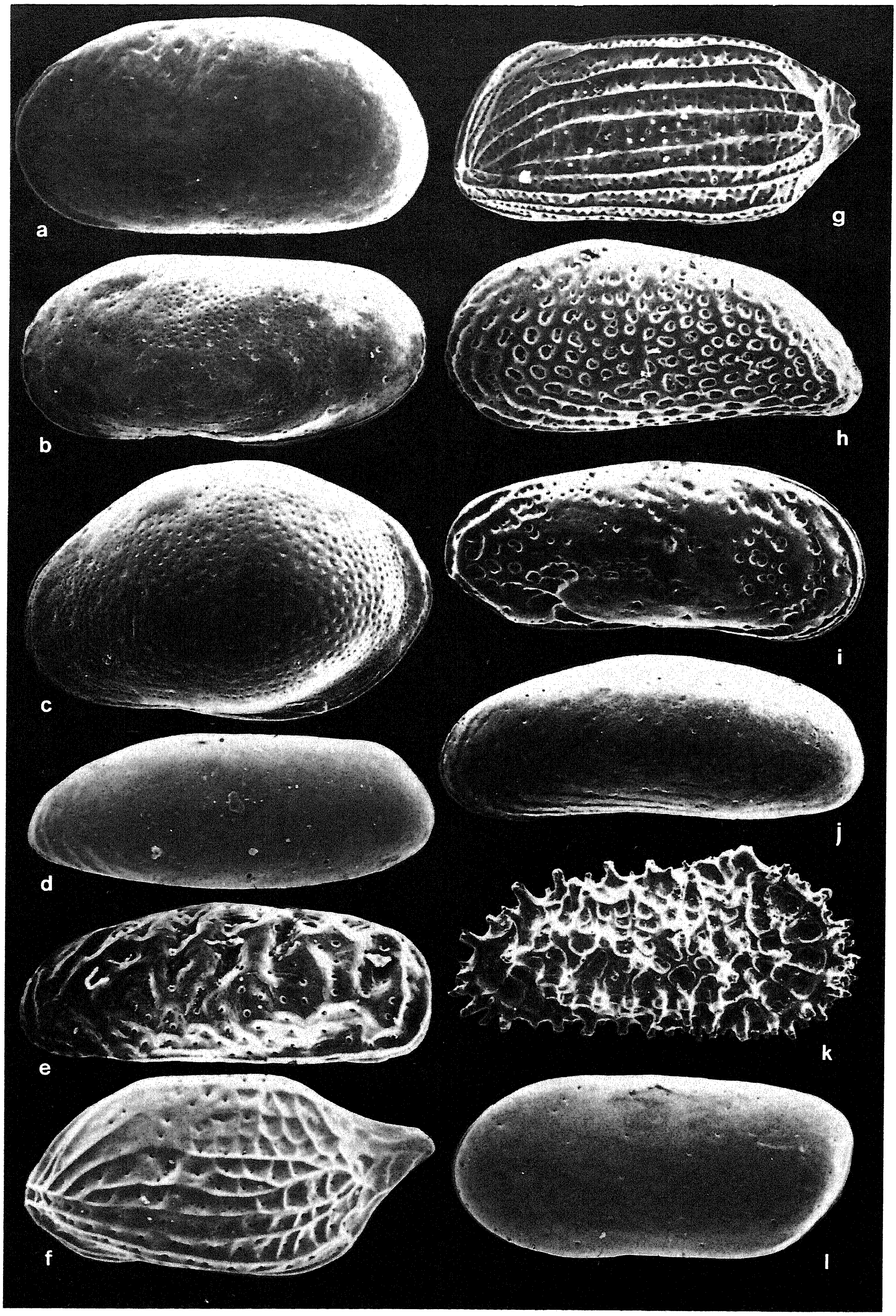


Fig. 7 - Facies log of borehole S-27 showing lithology of each interval (1-5) and, where available, radiocarbon dates and ostracodes. The ostracode fauna is clustered by group B, plus a Miscellanea (=M) stock; each form has a group letter-species number code as listed in Table 1. Interpretations of depositional environments are made on the basis of petrology and ostracode distribution (explanation in text and in Appendix A).

Facies del sondaggio S-27. Sono riportati dati della litologia di ogni intervallo (1-5) e, quando disponibili, dati radiometrici e sugli ostracodi. L'ostracofauna è riunita nel gruppo B e in un Miscellanea (=M) stock; *ogni specie è contrassegnata da un codice (lettera+numero), come riportato in Tabella 1. Le interpretazioni degli ambienti deposizionali sono basate sulla petrologia e sulla presenza degli ostracodi (spiegazione nel testo e in Appendice A).*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Mediterranean. SEM photographs of many of these are shown in Figures 8 and 9. Twenty-four of these species are subdivided into 6 groups (A-F) based on their living habitats. In addition, nine species that in Nile delta sections cannot be attributed to a specific habitat are listed under Miscellanea (Table 1). Only one species (*Ilyocypris gibba* forming Group A) is distinctly continental (lake, fresh-water pool, etc.); it is widely diffused in the circum-Mediterranean region. The environmental conditions of most of the other thirty-two species are not always proscribed and are by no means precise.

Salinity has been emphasized as one of the most important factors which determines the nature of ostracode assemblages in most environments, including paralic ones (Neale, 1965; Kilenyi, 1969). A case in point is a previous survey of ostracodes in one boring of the eastern Nile delta located just east of the Suez Canal (near our core S-18) where Sneh *et al.* (1986) interpret changes in salinity with time specifically on the basis of ostracode faunae. Studies of modern Mediterranean settings, however, indicate that this approach is not necessarily reliable, and other factors, in addition to salinity, need to be considered to correctly interpret environments.

For example, in paralic environments of the Nile delta, where salinity is usually highly variable, most of the ostracode species are euryhaline. It would be difficult, for this reason, to determine a specific hierarchy of species which tolerate a specific range of salinity. Rather, we tend to agree with Guelorget & Perthuisot (1983) who show that in paralic environments, such as Mediterranean lagoons, the distribution of organisms is independent of salinity. These authors emphasize that organisms living in paralic environments should not be considered simply as transitional forms between continental and marine settings. Rather, numerous environments are recognized within the paralic realm, and some ostracode assemblages tend to be diagnostic of each. It has been suggested that the distribution of paralic species is controlled by a parameter called ' confinement' which is defined as the time of renewal of marine originated elements (organic and inorganic) at each given point relative to the open sea (Guelorget & Perthuisot, 1983, their Fig. 19). Under this respect some Mediterranean lagoons can be subdivided into 6 zones (coded I to VI) which are located progressively landward, away from the sea. These zones are progressively more 'confined' as one proceeds inland from the open sea: those close to open sea are termed 'near paralic', and those located inland are termed 'far paralic'. With respect to the latter, these authors recognize two extreme conditions: fresh-water (strongly influenced by river input) and hypersaline (evaporitic).

In Nile delta cores we have definednot only the lagoonal ostracode faunae but also the coastal and more open marine ones. An extensive literature focuses on the ostracode faunae associated with these environments, but usually in a general way without ascribing specific species to very specific environmental conditions. The distributions of these species are in environments normally subject to continental run-off and, thus, are likely related in some manner to the distance from this less saline water input. This factor, in turn, would affect parameters such as salinity, temperature, pH, nature of the seafloor, turbidity and others. In this respect, on-going studies of living species in the gulfs of Policastro and Salerno are significant: they record the distributions of thirteen species which occur in Nile delta borings (see Table 1) and can be aggregated into four groups (C-F). These four Nile delta groups (Table 1) also include seven other species, which are assigned to the appropriate group (Table 1) based on the Mediterranean ostracode literature.

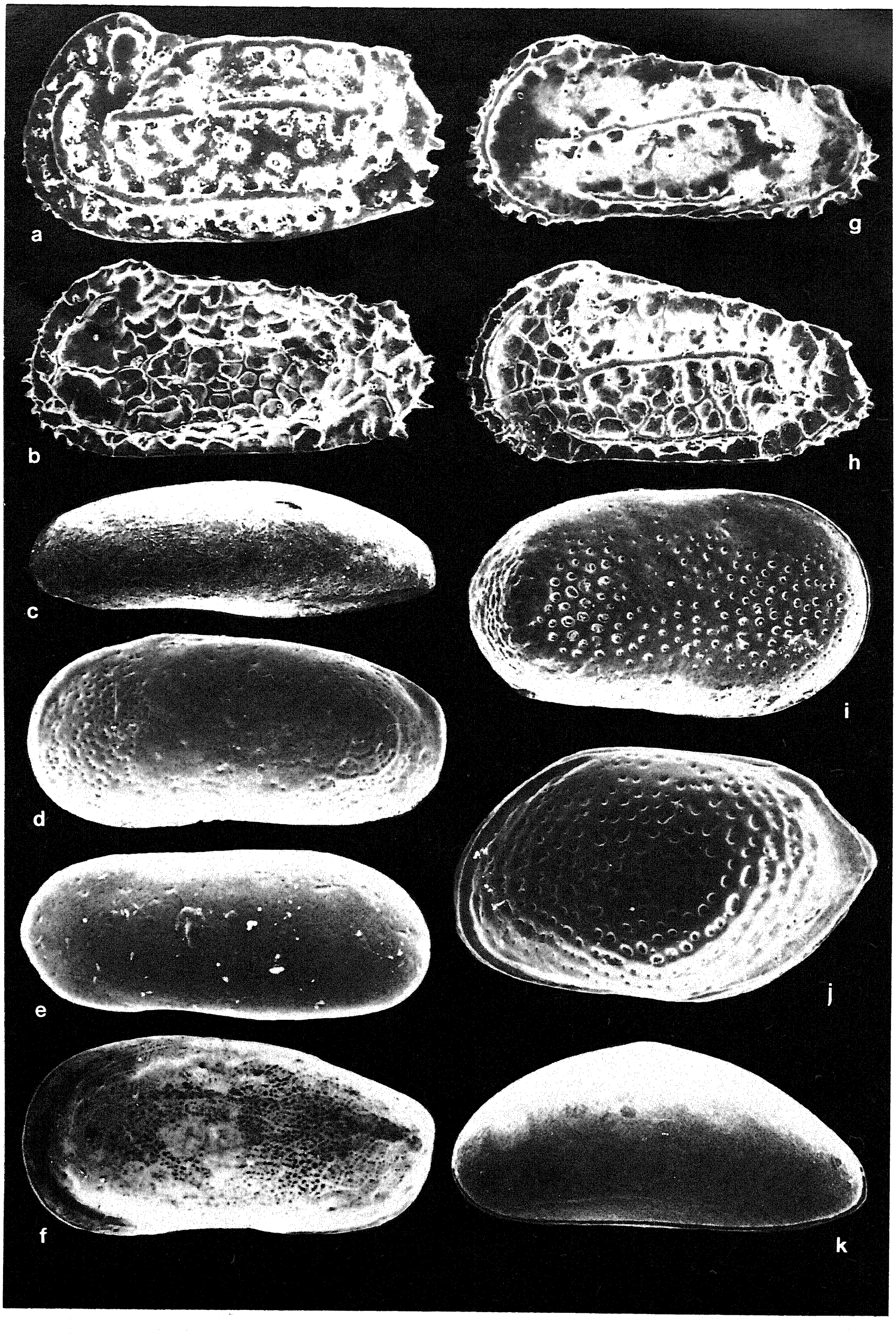
8.2 Selected diagnostic environmental markers

A brief summary of the twenty-four ostracode species forming groups A to F follows.

Group A - This group comprises only one fresh-water

Fig. 8 - SEM photomicrographs of autochthonous ostracode species forming groups B, C, D, and E *(pro parte)* as listed in Table 1: a) left valve of *Cyprideis torosa* in lateral exterior view (80x); b) left valve of *Loxoconcha elliptica* in lateral exterior view (140x); c) left valve of *Loxoconcha stellifera* in lateral exterior view (110x); d) left valve of *Neocytherideis fasciata* in lateral exterior view (105x); e) left valve of *Procytherideis complicata* in lateral exterior view (135x); f) left valve of *Semicytherura incongruens* in lateral exterior view (140x); g) left valve of *Semicytherura sulcata* in lateral exterior view (135x); h) left valve of *Cytheridea neapolitana* in lateral exterior view (90x); i) right valve of *Leptocythere levis* in lateral exterior view (175x); j) left valve of *Pontocythere turbida* in lateral exterior view (93x); k) right valve of *Acanthocythereis hystrix* in lateral exterior view (85x); l) left valve of *Basslerites berchoni* in lateral exterior view (173x).

Fotografie eseguite al microscopio elettronico a scansione (SEM) di specie di ostracodi ritenuti autoctoni appartenenti ai gruppi B, C, D ed E (pro parte), *come riportato in Tabella 1: a) valva sinistra di* Cyprideis torosa *in norma laterale esterna (80x); b) valva sinistra di* Loxoconcha elliptica *in norma laterale esterna (140x); c) valva sinistra di* Loxoconcha stellifera *in norma laterale esterna (110x); d) valva sinistra di* Neocytherideis fasciata *in norma laterale esterna (105x); e) valva sinistra di* Procytherideis complicata *in norma laterale esterna (135x); f) valva sinistra di* Semicytherura incongruens *in norma laterale esterna (140x); g) valva sinistra di* Semicytherura sulcata *in norma laterale esterna (135x); h) valva sinistra di* Cytheridea neapolitana *in norma laterale esterna (90x); i) valva destra di* Leptocythere levis *in norma laterale esterna (175x); j) valva sinistra di* Pontocythere turbida *in norma laterale esterna (93x); k) valva destra di* Acanthocythereis hystrix *in norma laterale esterna (85x); l) valva sinistra di* Basslerites berchoni *in norma laterale esterna (173x).*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species (*Ilyocypris gibba*). This form, in the cores examined, is represented by juveniles which are interpreted as having been displaced from essentially continental to various brackish-water, nearshore and/or open marine settings.

Group B - The three species which constitute this group are associated with core sections of lagoonal facies in Nile delta borings. These species are *Cyprideis torosa*, *Loxoconcha elliptica*, and *L. stellifera*. Of these species, *C. torosa* and *L. elliptica* are widely diffused in modern Mediterranean lagoons. Of the two, Vismara Schilling & Ferretti (1987) found that *C. torosa* was living near what could be termed a fresh-water environmental pole in the San Teodoro lagoon of Sardinia. The same two species also have been found in a tidal flat setting near Trieste, but there *L. elliptica* was found nearer to fresh-water input than *C. torosa*. Thus, these two ostracode species in Group B in Nile delta core sections appear to indicate a 'far paralic' shallow water setting, *i.e.* usually near a source of fresh-water input. In some cases, *C. torosa* occurs in a facies containing gypsum and halite indicating hypersaline 'far paralic' conditions, *i.e.* probably very shallow lagoons that undergo seasonal dessication and development of sebkha conditions (cf. Dov Por & Dimentman, 1985). It is also noted that *L. elliptica* is a periphytal species and a likely indicator of shallow lagoon to marsh conditions.

Fig. 9 - SEM photomicrographs of autochthonous ostracode species forming groups E *(pro parte)*, and F as listed in Table 1: a) left valve of *Carinocythereis bairdi* in lateral exterior view (90x); b) left valve of *Cystacythereis* gr. *caelatura* in lateral exterior view (115x); c) left valve of *Cytheroma variabilis* in lateral exterior view (200x); d) left valve of *Leptocythere ramosa* in lateral exterior view (150x); e) left valve of *Pseudopsammocythere similis* in lateral exterior view (160x); f) left valve of *Sylvestra* sp. 1 in lateral exterior view (205x); g) left valve of *Costa batei* in lateral exterior view (115x); h) left valve of *Costa edwardsii* in lateral exterior view (90x); i) right valve of *Cytherella* sp. 1 in lateral exterior view (115x); j) left valve of *Loxoconcha* sp. 1 in lateral exterior view (150x); k) complete carapace of *Propontocypris intermedia* in lateral left exterior view (102x).

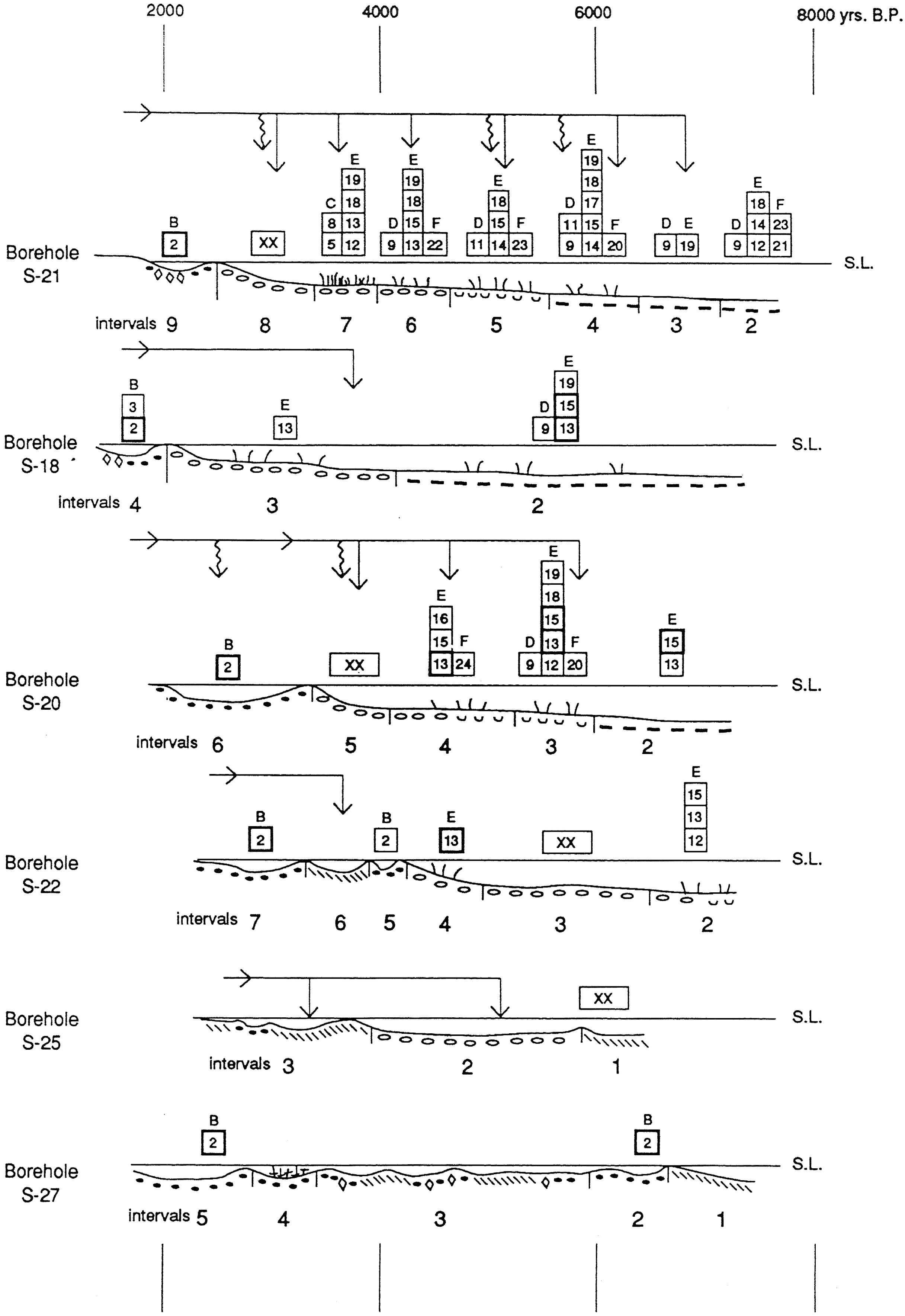
Fotografie eseguite al microscopio elettronico a scansione (SEM) di specie di ostracodi ritenuti autoctoni appartenenti ai gruppi E (pro parte) *e F, come riportato in Tabella 1: a) valva sinistra di* Carinocythereis bairdi *in norma laterale esterna (90x); b) valva sinistra di* Cystacythereis *gr.* caelatura *in norma laterale esterna (115x); c) valva sinistra di* Cytheroma variabilis *in norma laterale esterna (200x); d) valva sinistra di* Leptocythere ramosa *in norma laterale esterna (150x); e) valva sinistra di* Pseudopsammocythere similis *in norma laterale esterna (160x); f) valva sinistra di* Sylvestra *sp. 1 in norma laterale esterna (205x); g) valva sinistra di* Costa batei *in norma laterale esterna (115x); h) valva sinistra di* Costa edwardsii *in norma laterale esterna (90x); i) valva destra di* Cytherella *sp. 1 in norma laterale esterna (115x); j) valva sinistra di* Loxoconcha *sp. 1 in norma laterale esterna (150x); k) carapace completo di* Propontocypris intermedia *in norma laterale esterna sinistra (102x).*

Group C - This fauna comprises four species which we attribute to nearshore marine environments, normally with vegetal meadows, and located close to a fluvial input. The group includes: *Neocytherideis fasciata*, *Procytherideis complicata*, *Semicytherura incongruens*, and *S. sulcata*. The outer depth limit of the four species forming this group, where they are found with other species, can range to about 50 m in the Gulf of Salerno. However, in this gulf, an assemblage of only *N. fasciata* and *S. sulcata* lives on nearshore coastal sand substrata, with or without vegetation, at depths as shallow as 4 m. *S. incongruens* is associated with the two above species with an increased distance from fluvial input and increased depth (minimal 6 m to perhaps 20 m); they live on a seafloor of finer-grained size sediment (muddy sand and sandy mud).

Group D - This group comprises three species that live in sandy marine nearshore environments normally without vegetation. These are: *Cytheridea neapolitana*, *Leptocythere levis*, and *Pontocythere turbida*. On the basis of findings in the Gulf of Salerno these forms live at depths of approximately 6 to 20 m; at greater depths, these species live on muddy sand.

Group E - Eight species form this group which characterizes nearshore sandy mud with vegetal meadows and/or more open marine settings with or without vegetal meadows: *Acanthocythereis hystrix*, *Carinocythereis bairdi*, *Cytheroma variabilis*, *Leptocythere ramosa*, *Pseudopsammocythere similis*, *Basslerites berchoni*, *Cystacythereis* gr. *caelatura*, and *Sylvestra* sp.1. The first five forms listed above occur in the Gulf of Salerno, and their minimal depth is about 15 m (although each of them in other associations can live at greater depths, up to 50÷60 m). We found *C.* gr. *caelatura* at the top (0 to 4 cm) of core CG-3 located further seaward, *i.e.* on the inner shelf seaward of the Rosetta Promontory (cf. Summerhayes *et al.*, 1978, their Fig. 13). Moreover, *B. berchoni* and *C.* gr. *caelatura* live, sometimes together, along the modern North African margin in more proximal nearshore sectors influenced by fresh-water input. Since these two species occur together in Nile delta cores, along with the other species cited above, we attribute them to Group E. *Sylvestra* sp.l is probably a new species (Fig. 9f). All species of this genus at present live in a tropical environment (Red Sea, Gulf of Aden, Persian Gulf; Bonaduce *et al.*, 1990). In the Mediterranean basin some species of *Sylvestra* are found in older geological sections, *i.e.* from the Tortonian to the Tyrrhenian. A finding of a species of *Sylvestra*, together with some nearshore to open marine species, in shales of Tyrrhenian age (Sarno area of Italy) indicates that it is reasonable to include this form in Group E.

Group F - This group comprises five species which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S.L.
intervals 9 8 7 6 5 4 3 2
Borehole S-18
intervals 4 3 2
Borehole S-20
intervals 6 5 4 3 2
Borehole S-22
intervals 7 6 5 4 3 2
Borehole S-25
intervals 3 2 1
Borehole S-27
intervals 5 4 3 2 1
B
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D
E
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characterize an open marine sandy mud environment, without vegetation. These include: *Costa batei*, *C. edwardsii*, *Cytherella* sp. 1, and *Propontocypris intermedia* and *Loxoconcha* sp.1. *C. batei*, *C. edwardsii*, and *P. intermedia* occur in the gulfs of Policastro and Salerno at depths of less than 20 m. *Cytherella* sp. 1 and *Loxoconcha* sp. 1 (or *Lindisfarnia* sp. 1, according to Carbonel & Hamoudi, 1990) are tentatively placed in this group. The former could pertain to the group of *Cytherella alvearium*, which lives together with the above three species in the same seafloors of the Policastro and Salerno gulfs; the latter is very similar to *L. guttata* which at present lives together with *C. edwardsii* on the Moroccan continental margin (Carbonel & Hamoudi, 1990).

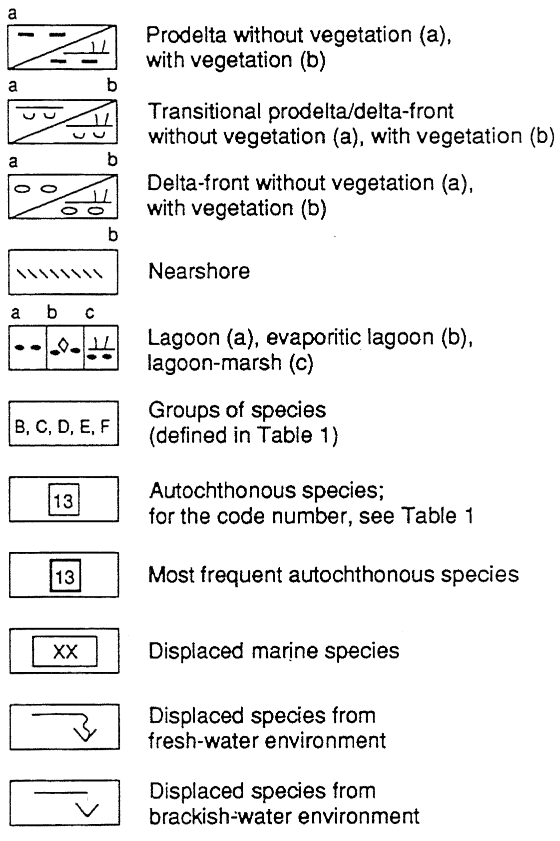

Fig. 10 - Schematic diagram showing relation among ostracodes, environments and time. The distribution of autochthonous ostracode species (code number in Table 1) is clustered by group (B to F) for each core interval. Displaced species from fresh, brackish and marine environments are also shown. Further explanation for interpretations on depositional environments is given in text and in Appendices A and B. Dates in years before present.

Diagramma schematico sulle relazioni tra ostracodi, ambienti e datazioni. La distribuzione delle specie autoctone (numero di codice in Tabella 1) è riunita in gruppi (B-F) per ogni intervallo. E' indicata la presenza di forme alloctone, provenienti da ambienti d'acqua dolce, salmastri e marini. Ulteriori spiegazioni sugli ambienti deposizionali sono riportate nel testo e nelle Appendici A e B. Le datazioni sono in anni B.P.

8.3 Problems of displacement

Deltas are settings where sediment is commonly reworked and displaced from one environment to another, and the Nile delta is no exception (cf. El Askary & Frihy, 1986; Frihy & Stanley, 1987). The discussion in the previous section focuses on ostracode species which are attributed to well defined environments, and which can be considered autochthonous. To better interpret the faunae in Nile cores, it is important to recognize that ostracodes, like terrigenous particles, can be displaced after death (allochthonous forms), and thus we need to take into consideration the role of their reworking.

In some Nile cores fresh-water juvenile forms (Group A) can be found with what appear to be lagoonal 'far paralic' ostracode assemblages. In other sections, fresh and brackish-water species of groups A and B are observed with marine ostracode assemblages. This calls to mind the results of other studies such as those of Kilenyi (1969) who noted that in the Thames estuary, fresh and brackish species were almost never found in the thanatacoenosis of their life habitat. Rather, these forms were commonly found in marine thanatacoenoses distant from their original life habitats. Comparable observations are made in the gulfs of Salerno and Policastro where fresh-water and brackish ostracodes were found on seafloors of open marine and outer shelf environments. In these gulfs, vegetal meadows in shallow marine settings near river mouths are able to trap such allochthonous specimens.

In addition to the above examples, various studies have considered lagoon settings which include the presence of nearshore and open marine forms. In the case of some Nile delta cores, this situation is usually recognized by the presence of marine juvenile species mixed with authochthonous brackish-water faunae, particularly in lagoonal 'near paralic' settings.

Among the thirty-three species identified in Nile delta cores, we note nine species which are always represented by juvenile specimens without their adult forms (Figs. 2-7). We interpret these as reworked and/or displaced forms, and consider them here an allochthonous stock. These species (listed under Miscellanea in Table 1) are found scattered with species of groups B to F described above. These nine species, which are not associated with any of the specific groups, are for the most part of marine nearshore and/or periphytal origin. An exception is *Bosquetina dentata*, a form which can be considered a deep water species, yet one which can also live in vegetal meadows in very shallow environments, such as in the Gulf of Policastro.

9. INTERPRETATION

9.1 Generalities

The presence of ostracode species and their frequency in each of the core intervals are shown in Figures 2 to 7. The occurrences of each authochthonous species (groups B to F) and, where present, those of allochthonous fresh and brackish-water forms (groups A, B) in each core interval are shown in a summary diagram (Fig. 10). Their occurrence in this figure is related to depositional environment and time, in years B.P.

Additional information pertinent to all core intervals is available in Appendix A. Predominant species (those that are frequent and very frequent), which characterize some of the intervals, are denoted graphically in Figure 10. Some core intervals are characterized by only one ostracode group as defined in the previous section. However, it is apparent from observations in Figures 2-7, and from the information in Appendix A, that core intervals commonly comprise autochthonous ostracodes pertaining to more than one group.

Figure 10 reveals that the species of group E are commonly associated with those of groups C, D and F. We recall that, at present, most species in these four groups live within a broad depth range in various continental shelf environments. Ostracodes of groups E (typically occurring nearshore on a vegetated floor and/or in a more open marine setting with or without vegetation) are associated with those of C (nearshore seafloor with or without vegetation): we interpret such an assemblage as characteristic of a nearshore vegetated floor with vegetation. In cases where species of Group E are associated with those of groups D (nearshore seafloor without vegetation) and F (open marine seafloor without vegetation), the assemblages are interpreted as open marine and living on a seafloor without vegetation.

Interpretations of depositional environments are derived by a coupling of data from ostracode faunae and from petrology (information in MEDIBA, 1990 and simplified in Appendix A). A summary of core interval interpretations is presented in Appendix B and also highlighted in Figure 10. This latter diagram emphasizes time in years B.P. rather than core interval thickness (shown in Figs. 2-7). and listed in Appendix A). The dates were determined by the radiocarbon method (MEDIBA, 1990). For purposes of simplification, time intervals of about 8,000÷6,000 years before present (B.P.), 6,000÷4,000 years B.P., 4,000÷2,000 years B.P., and <2,000 years B.P. are denoted in Figure 10.

Interval 1 in cores S-21, S-18, S-20, and S-22 comprises uppermost Pleistocene to early Holocene transgressive sand. This basal sand unit underlies, and is separated unconformably from, the Holocene progradational sequence (<7,500 years B.P.) which is of primary concern in the present study. This transgressive sand interval, older than 8,000 years B.P., is not depicted in Figure 10.

In the sections below, we attempt to refine interpretations of Nile delta depositional environments by emphasizing the nature and evolution of ostracode assemblages in each of the six cores containing these faunae along the northeast-to-southwest study transect. One aspect of interest is faunal change with time, *i.e.* from the bottom (lower to mid-Holocene, at about 7,500 years B.P.) to the core top (near-present to modern time). See Appendix A for further information on the petrology, faunal content and age of each interval.

Of the six cores comprising ostracodes in the sea-to-land transect, boring S-21 displays the most diversified fauna (*i.e.* from marine to lagoonal). It is for this reason that we consider this core as a reference boring to which the others can be compared.

9.2 Borehole S-21: a reference sequence

With regards to both lithofacies and ostracodes, core S-21 includes the most varied facies among the nine cores examined along the northeastern Nile delta transect. It comprises a sequence of nine intervals corresponding to the following facies, from the core base to the core top (Figs. 2 and 10): coastal ridge and/or offshore deposits (interval 1), prodelta (intervals 2, 3, and 4), transitional prodelta/delta-front (interval 5), delta-front (intervals 6, 7, and 8), and marine nearshore, including lagoonal proximal to evaporitic settings such as sebkha (interval 9). The age of these intervals ranges from lowermost Holocene (interval 1) to upper Holocene (interval 9). An unconformity exists between intervals 1 and 2 (cf. Bernasconi *et al.*, 1991): a stratigraphic break resulted from progradation of marine (interval 2) to coastal series above the underlying basal transgressive sands of interval 1.

Autochthonous ostracodes are present in most intervals (2 to 7, and 9), and these normally include assemblages characterized by species of Group E (the most common) together with species of groups C, D and F. Lagoonal ostracode species of Group B are present in interval 9.

Species of Group E, together with species of groups D and F, are identified in what are defined, on the basis of lithofacies, as prodelta, transitional prodelta/delta-front and distal delta-front facies. In some samples of the above facies where there is an exclusive presence of Group E species (Fig. 2), ostracodes may indicate a seafloor with local development of vegetal meadows (intervals 4 to 6). Proximal delta-front facies include species of groups C and E indicating a seafloor with vegetal meadows. Delta-front facies close to a river mouth do not include any autochthonous ostracodes, but only displaced specimens; this may be a response to high flood energy due to river input and/or reworking by strong coastal currents (cf. Inman & Jenkins, 1984). Lagoon facies which accumulated behind nearshore settings (interval 9) comprise a monospecific ostracode fauna (group B), including very frequent specimens of *C. torosa*. The presence of gypsum and halite in the latter interval indicates evaporitic conditions.

In open marine deposits, the autochthonous species are always represented by few specimens. Moreover, we note:

- Group C: specimens of *N. fasciata* and *S. sulcata* are present only in the proximal delta-front facies;
- Group D: *C. neapolitana* is present from distal delta-front to prodelta; *P. turbida* is distributed from transitional delta-front/prodelta to proximal prodelta;
- Group E: some species are present from proximal delta-front to distal prodelta (*P. similis* and *S.* sp. 1); *C. bairdi* is present from transitional delta-front/prodelta to distal prodelta; *B. berchoni* is present only in delta-front facies.

Other species of groups E and F are very rare and irregularly distributed in delta-front and prodelta deposits; for this reason we do not recognize any specific relation between these ostracodes and lithofacies.

All intervals, except interval 2, show a near-constant and often important influence of fresh and/or brackish-water input, as indicated by displaced specimens of groups A and B. Reworking is a normal phenomenon and expected in deltaic environments. Displaced forms may have been transported seaward in suspension to more distal prodelta environments; in shallower environments (such as proximal delta-front), these forms may have been trapped by algal meadows. It is of note that this period of seaward flooding occurred from about 7,000 to about 3,500 years B.P., a time-span which initally included wetter climatic conditions (cf. Adamson *et al.*, 1980; Foucault & Stanley, 1989; and Paulissen & Vermeersch, 1989).

It is remarkable that *Sylvestra* sp. 1 was distributed in this boring also from about 7,000 years B.P. to about 3,500 years B.P. The last occurrence of *S.* sp. 1 could well be related to a major climatic change, from wet to dry, which occurred about 4,000 years ago.

Facies in borehole S-21 show a regressive trend on the basis of both petrology and ostracode faunae. This is in good agreement with data on malacofaunae in this core (Bernasconi *et al.*, 1991, their Figs. 2 and 3) as well as foraminifera (F. Jorissen, personal communication, 1990). Molluscs, which can be used as water depth-indicators, record the greatest depths (about 25 m) in a part of this core which corresponds to our intervals 2 to 6 (*pro parte*). Upcore, molluscs indicate a marked decrease in depth (less than 10 m), in correspondance with our intervals 7 and 8 (*pro parte*). Foraminifera in this core record the greatest water depths (about 30 m) at the base of prodelta deposits (our interval 2); foraminiferal assemblages indicate progressively decreasing depths upward in borings S-21 (in correspondence with our intervals 4 to 6, less than 10 m). Depths then decreased notably upcore.

Ostracodes, in contrast to molluscs and foraminifera, do not provide such precise depth interpretations, at least in the case of the six Nile delta core sections. However, as demonstrated in boring S-21, ostracode faunae tend to support the information gathered independently from foraminifera and molluscs which indicate that the deepest depositional environments were those of prodelta deposits near the base to mid-portion of the core. It is of note that there is also a reasonable correlation between ostracodes and molluscs at about 20 m from the core top: here, the first occurrence of *B. berchoni* corresponds to the finding of a molluscan fauna which indicates a marked depth decrease. These two observations correspond to a change from transitional prodelta/delta-front to a delta-front setting.

9.3 Marine autochthonous ostracode faunae

Progradational marine sequences preserved in four of the cores (S-18, S-20, S-22, and S-25) positioned landward along the study transect relative to core S-21 comprise less diversified autochthonous ostracode faunae (Fig. 10).

Borehole S-18 (Fig. 3) includes only one species of Group E in delta-front facies. Few species of Group E and one of Group D occur in the prodelta sections.

Borehole S-20 (Fig. 4) includes a somewhat more diversified ostracode fauna than S-18 and S-22. Marine autochthonous species are limited to delta-front transitional delta-front/prodelta, and prodelta deposits. They pertain mainly to Group E and, subordinately, to groups D and F. These two latter groups occur only in delta-front and transitional delta-front/prodelta facies.

Borehole S-22 (Fig. 5) comprises a poor ostracode fauna (few species of Group E) which is present in proximal delta-front and transitional delta-front/prodelta deposits.

No autochthonous marine fauna is present in delta-front facies in cores S-20 (interval 5) and S-22 (interval 3), and nearshore marine facies in S-25.

All ostracode faunae in the above-cited facies, in cores S-18, S-20, and S-22, indicate a seafloor with local development of vegetal meadows (Fig. 10).

9.4 Lagoonal autochthonous ostracode faunae

Lagoonal facies, at about 3,000 years B.P., form much of the upper sequences in cores S-18, S-20, and S-22. In contrast, lagoonal deposits in core S-27 occur almost continuously from about 7,000 to about 2,000 years B.P. Autochthonous species of Group B (mainly *C. torosa*, sometimes very frequent) characterize these environments. Another species of Group B (*L. elliptica*) is very rare and occurs in core S-18 with *C. torosa*. We recall that this assemblage may indicate more extreme fresh-water ('far paralic') conditions in a lagoonal setting. The presence of gypsum and halite together with *C. torosa* in core S-18 records extreme evaporitic conditions (as in core S-21).

In core S-27 there are brackish-water environments with ostracodes (intervals 2 and 5). Intervals 3 and 4 are devoid of ostracodes: in these cases petrology is used to identify settings such as sebkha (interval 3) and marsh (interval 4).

9.5 Allochthonous ostracode faunae

We recall that in core S-21 ostracodes of groups A and B were almost continuously displaced seaward and thus preserved in most of the marine settings. In four of the other five cores where ostracodes are present (S-18, S-20, S-22, and S-25), the evidence for displacement is less obvious. Reworked specimens are present in various marine environments (excluding prodelta) and in lagoonal settings. Displaced fauna in such environments may derive from fresh-water environments (core S-20, interval 6) and/or from nearby near paralic settings (see Appendix A, core S-20).

In core S-20, allochthonous specimens of Group A and/or B have been transported seaward in suspension to transitional delta-front/prodelta settings. Evidence for displacement is less clear-cut in cores S-18, S-22, and S-25. In these three cores, we observe only reworked brackish-water specimens which have been transported to marine nearshore and/or delta-front environments. Displacement of marine species also occurs locally in marine settings, where autochthonous faunae are not usually present. Examples are noted in delta-front deposits of cores S-20 (interval 5) and S-22 (interval 3), and in nearshore facies of core S-25 (interval 1). This reworking may have resulted from high-energy bottom currents sweeping the seafloor, perhaps at times of floods and/or by storm waves.

9.6 Cores without ostracodes

Three cores (S-26, S-24, and S-23) positioned more landward along the study transect comprise mainly sand sections, with some minor interbedded strata of finer-grained sediments near core tops. Core samples usually contain a poor to negligible biogenic fraction. The sands, barren of ostracodes, in a few cases include fragments of molluscs. On the basis of petrology, these deposits are interpreted as alluvial (see Appendix A and MEDIBA, 1990). Radiocarbon dates reveal that, near the core top, the age of cores S-26 and S-23 is about 2,500 years B.P., and that of core S-24 is about 4,000 years B.P. In this latter core, the older dated sediments are silty clays which perhaps accumulated in small interchannel pools; the older age may be an artifact (*i.e.* older sediment reworked into younger sequences). One other radiocarbon date in the mid-core section of S-26 indicates an age of about 4,000 years B.P. for this alluvial sequence. Thus, study of Holocene units at sites S-26, S-24, and S-23 shows that the northeastern Nile delta was an alluvial plain during the time-span from about 4,000 to 2,000 years B.P.

With regards to the late Pleistocene, it is noted that the basal part of core S-24 is dated at about 24,000 years B.P. Thus, in agreement with Coutellier & Stanley (1987), it would appear that these three sites have been occupied by alluvial, not lagoonal, environments since the late Pleistocene. These observations do not exclude that some scattered fresh-water pools and marshes may have formed locally on the alluvial plain during the Holocene as postulated by Coutellier & Stanley (1987).

10. OSTRACODES AND DEPOSITIONAL ENVIRONMENTS: FINAL CONSIDERATIONS

In this investigation we have identified the fossil ostracode faunae in a near-complete sequence of terrestrial to open marine lithofacies. Where possible, these faunae have been interpreted by comparison with modern Mediterranean ostracode assemblages. It has been shown how the distribution of these fossil ostracodes in time and space occurs with respect to different specific deltaic environments. Interpretation of ostracode faunae, made in the light of specific lithofacies with which they are associated, sheds some new information on the Recent evolution of the northeastern Nile delta.

We recall that the Holocene facies, which lie above the basal transgressive sands (uppermost Pleistocene to lower Holocene), comprise 33 species of ostracodes clustered in six groups of selected species, plus a miscellaneous stock. The spatial and temporal distributions of these six groups is particularly useful to interpret the nature of the progradation of the deltaic sequences in this eastern part of the depocenter. Information provided by the ostracodes enables us to determine the changes in Holocene coastline positions, the influence of former distributary branches of the Nile and the effects of some paleoclimatic oscillations on the marine environments seaward of the delta.

Specific ostracode distributions and their changes with time help refine a series of paleogeographic maps (Fig. 11) that have been compiled earlier primarily on the

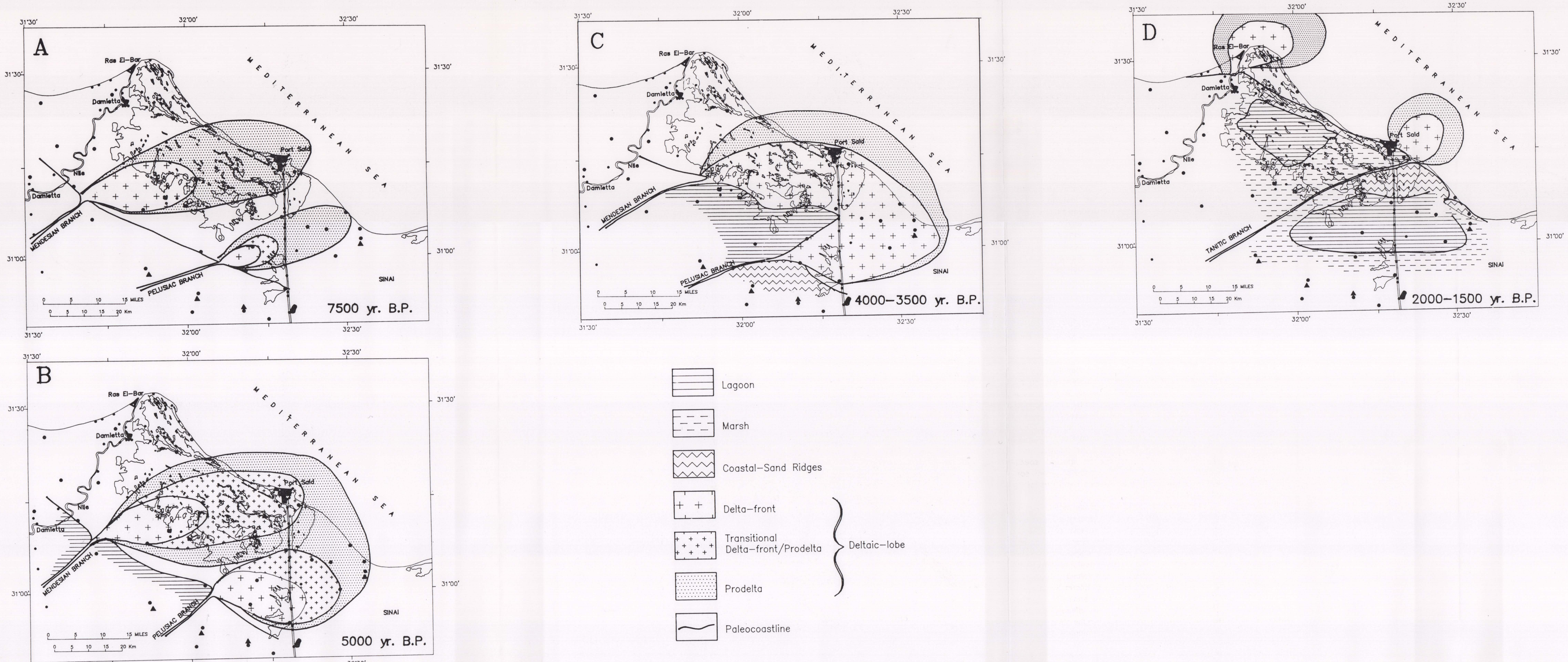

Fig. 11 - Paleogeographic maps (A to D) showing changes with time in the positions of the coastline, of former major River Nile distributary traces, and deltaic plain environments. The present geographic configuration, core positions, Suez Canal and some archaeological sites (Fig. 1) serve as points of reference. Interpretations are explained in text. Dates in years before present.

Mappe paleogeografiche (A-D) con l'indicazione dei cambiamenti nel tempo delle posizioni della linea di costa, dei persorsi degli antichi canali distributori del Nilo e degli ambienti della piana deltizia. L'attuale configurazione geografica, l'ubicazione dei sondaggi e di alcuni siti archeologici (Fig. 1) servono come punti di riferimento. Le interpretazioni sono riportate nel testo. Le datazioni sono in anni B.P.

basis of lithofacies analysis (Coutellier & Stanley, 1987, their Fig. 7). Herein, we consider the evolution of the eastern Nile delta region through a series of four time slices, from about 7,500 to 1,500 years B.P. We recall that the sea level rise had begun to decelerate by about 8,000 years B.P. and that the history of the modern Nile delta is closely associated with this event (Stanley, 1990). Moreover, we assume that strong easterly-directed coastal currents, such as those mapped at present (Inman & Jenkins, 1984), modified the configuration of the delta margin and offshore delta lobes; these currents, along with seasonal flooding of the Nile distributaries, resulted in the reworking and transport of allochthonous ostracode specimens. In the following paragraphs we introduce our findings in the nine cores examined in the present study in the context of earlier paleogeographic studies of this region by Sneh *et al.* (1986) and Coutellier & Stanley (1987).

The Mendesian branch of the Nile developed in the eastern Nile delta somewhat prior to about 7500 years B.P. There is evidence that, after this time, two deltaic lobes formed in this region and both extended northeastward: these are progradational sequences of the Mendesian and Pelusiac branches of the Nile (Fig. 11A). Of the two, the Mendesian lobe was the larger in terms of areal extension. Its presence is recorded at site S-21 (positioned near Port Said) by prodelta deposits containing a poor ostracode fauna. The Pelusiac system comprises several facies: marine nearshore (sites S-27 and S-25); delta-front to transitional delta-front/prodelta (site S-22); and prodelta (sites S-20 and S-18). The ostracode fauna in prodelta deposits of the Pelusiac, as in the Mendesian, is also poor. Only in transitional delta-front/prodelta deposits at site S-22 are the faunae relatively well diversified. The shallower marine facies of the Pelusiac may be characterized either by a few species, or by the absence of autochthonous fauna. At this time, allochthonous fresh and brackish-water specimens in marine settings are found only in Mendesian prodelta facies, but none occur in the Pelusiac deposits. It would thus appear that at about 7,500 years B.P., the influence of the Mendesian system on the setting seaward of the coast was considerably stronger than that of Pelusiac, and reached more open marine settings. The coastline was subparallel to the present shore and lay about 35 km landward of it (*i.e.* about 10÷15 km north of the archaeological site of Tanis). The NW-SE trending shoreline was backed by lagoonal settings (Coutellier & Stanley, 1987).

At about 5,000 years B.P. (Fig. 11B) the Mendesian and Pelusiac lobes had prograded eastward and were partially superposed. At that time, site S-21 (the only core locality within the Mendesian system examined in this study) was characterized primarily by transitional delta-front/prodelta deposits. A more complete series of marine deposits were recovered in the Pelusiac lobe as a function of more cores collected in this system: delta-front (site S-22 and S-25), transitional delta-front/prodelta (site S-20), and prodelta (site S-18). Autochthonous ostracode faunae are better represented in transitional delta-front/prodelta deposits than in the other marine facies of both Mendesian and Pelusiac systems. We found that at this time, allochthonous fresh and brackish-water forms are present as far seaward as transitional delta-front/prodelta environments. We recall that these allochthonous specimens, during the earlier time slice (about 7,500 years B.P.) were transported further seaward to prodelta environments. This could indicate that seaward flooding became weaker at about 5000 years B.P. The coastline appears to have receded landward by a few kilometers (but perhaps somewhat less than indicated by Coutellier & Stanley, l987, their Fig. 7B), and it was backed by coastal-lagoonal settings (including sebkhas at site S-27).

At about 4,000 to 3,500 years B.P. (Fig. 11C) the Mendesian lobe had overlapped more extensively with that of the Pelusiac system. Site S-21, still part of the Mendesian system, comprised delta-front facies with an autochthonous ostracode fauna which denotes the proximity of strong river influence. In contrast, the Pelusiac lobe included delta-front facies (in S-18, S-20 and S-25) with a more poorly developed autochthonous ostracode fauna. For example, site S-18 comprises only one species *(B. berchoni)*. Seaward flooding and strong nearshore currents, as in earlier times, strongly affected delta-front environments as indicated by the presence of allochthonous fresh and brackish-water forms. This flooding, and the strong easterly directed coast-parallel current flow resulted in further overlap and northeasternly trend of the two delta lobes; the stressed conditions which characterize such an environment help to explain the diminished ostracode populations and their distribution. During this period, the shoreline migrated northeastwardly (to about 20 km south of the present coast). It was backed by coastal-lagoonal (sites S-20, S-22, and S-25), marsh and sebkha (site S-27) settings. These lagoons extended southward as far as Tanis (Coutellier & Stanley, l987, their Fig. 7C).

By about 2,000 to 1,500 years B.P. (Fig. 11D), the coastline had migrated further to the northeast, *i.e.* close to the present shore. At this time the Tanitic branch had replaced the Mendesian branch, while the Pelusiac branch atrophied and disappeared (Coutellier & Stanley, 1987). Lagoonal settings had extended over a large part of the delta plain study area, and these comprised a typical 'far paralic' ostracode fauna. These forms and associated deposits indicate both evaporitic (sites S-21 and S-18) and fresh-water (site S-21, S-20 and S-27) extreme conditions to as far south as Tanis.

Attention should be called to the species *B. berchoni* in context of this paleogeographic evolution. This species, during the time-span from about 7,500 to 5,000 years B.P., is recorded only in the delta-front to prodelta settings of the Pelusiac system. By 4,000-3,000 years B.P., *B. berchoni* was distributed in the delta-front of both Mendesian and Pelusiac lobes. Since then, it began colonizing primarily shallower seafloors of both systems. In time, *B. berchoni* became the only species to colonize the delta-front seafloor, as recorded in core S-18. Thus, it would appear that this species became a progressively shallower water form primarily from >7,500 to about 3,000 years B.P. We recall that in the modern Mediterranean *B. berchoni* is also found living in lagoonal settings. Thus, it is proposed that *B. berchoni*, when it occurs as the only species in a Holocene Nile delta section, be considered a 'biological indicator' of environmental changes from marine to lagoonal settings during the development of this depocenter.

We can envision that the influence of less saline water flowing seaward (especially at times of flood), combined with the overlap and merging of two delta lobes (Pelusiac and Mendesian) at about 4000÷3500 years B.P., may have resulted in increased bottom currents and/or increased turbidity in nearshore settings. Such high stress environmental conditions in shallow marine environments, likely would have resulted in less diversified ostracode faunae. Thus a diminution of species may denote a marked environmental event, *i.e.* one resulting in a decreased number of species able to colonize the shallow seafloor in the delta-front and nearshore. It is of special note that at about 4000 years B.P. many paleoclimatological studies in East Africa (cfr. Adamson *et al.*, 1980; Foucault & Stanley, 1989; Paulissen & Vermeersh, 1989) have called attention to a major climatic change from wet to dry conditions. In this respect, we call attention to the temporal distribution of *Sylvestra* sp. 1, probably a new species which, until now, has not been recorded in the modern Mediterranean Sea. This species is widely diffused in marine deposits of Nile delta core sections, but it disappeared at about 4000÷3500 years B.P. Thus, it would appear that this species could also be a useful biological indicator in that its disappearance may denote a change from wet to dry climate.

The present investigation shows the extent to which it would be beneficial to initiate a study of ostracodes in modern "paralic" settings in the Nile delta area, and then to compare these faunae with those in comparable environments elsewhere in the Mediterranean. More precise information on species living in this depocenter would further refine our understanding of the evolution, during the late Quaternary, of the diverse depositional sequences preserved in the delta plain. Such research of both the modern and Holocene ostracodes, in conjunction with petrological analyses, is viewed as valuable barometer to measure changes of both paleoenvironments and paleoclimates affecting this, the major depocenter in the Mediterranean.

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APPENDIX A

The following is a compilation of the general petrology and of dominant faunal and floral components in the nine cores examined in the present investigation (Fig. 1). Much of this information is summarized in Figure 2 to 7. Interpretations as to depositional environment for each core interval are made separately on the basis of petrology and of faunal and floral assemblages. The basis for interpreting ostracodes (listing in Table 1) is discussed in text. The intervals are numerically coded, with interval 1 at the base of the cores.

Borehole S-21

Borehole S-21 (Fig. 2), 49.5 m in length, is located 5 km ESE of Port Said, and actually positioned near the coast at the mouth of the NE Suez Canal By-pass. It is characterized, from the core base to core top, by the following nine intervals:

1 - (49.5÷46 m; samples 52-48): dark grey sand with mollusc fragments, echinoid spines, and siliceous sponge-spicules. Forams are present only near the top, and consist of shallow-water miliolids, specimens pertaining to genera *Ammonia* and *Elphidium*, and scattered reworked *Globigerinidae*. Ostracode fauna consists mainly of very rare specimens of a species of Group C, *i.e. Semicytherura incongruens* (sample 49) together with scattered valves of juveniles of *Bosquetina dentata*, *Loxoconcha* sp. 1, *Xestoleberis communis*, and *Costa edwardsii* (sample 48).
Age: lower Holocene. ^{14}C dates: sample at 48 m = 8,140 ± 110 years B.P.; sample at 46 m = 8,190 ± 110 years B.P.
Environment:
A) Ostracodes: marine nearshore environment with vegetation, as indicated by *S. incongruens*, and by juveniles of *X.*

communis (periphytal species), *C. edwardsii* and *B. dentata*. The presence of juveniles could be related to displacement from a nearby shallow marine comparable environment.

B) Petrology: nearshore bar to coastal ridge, and identified as the basal transgressive sand lying stratigraphically below the Holocene progradational deltaic sequence.

2 - (46÷40.5 m; samples 47-42): dark olive silty, finely laminated clay with a very abundant biofacies (mollusc fragments, siliceous sponge-spicules, echinoid spines). Microfossils include abundant forams and ostracodes. The former are represented by various species of *Ammonia*, *Elphidium*, *Bulimina*, *Uvigerina*, *Nonionella*, and *Lagena*. Ostracodes consist of a few species, *i.e. Cytheridea neapolitana* (Group D), *Acanthocythereis hystrix*, *Pseudopsammocythere similis* (Group E), *C. edwardsii*, *Loxoconcha* sp. 1 (Group F), and at the bottom of the interval. Proceeding upward in this unit, the ostracode faunae are characterized by one species (monospecificity), *i.e. A. hystryx* (in sample 44), or a few species (oligospecificity), *i.e. C. neapolitana*. Ostracodes are sometimes completely absent (samples 45, 42). Moreover, in the upper part of the interval the most frequent species *(C. neapolitana*) is associated with a species of Group E, *i.e. Carinocythereis bairdi* (sample 43).

Age: lower-mid Holocene. ^{14}C date: sample at 40.5 m = 7,140 ± 110 years B.P.).

Environment:

A) Ostracodes: open marine environment as indicated by species of groups D, E, and F. The lack of ostracodes in some samples may have resulted from episodes of increased energy, such as strong currents sweeping the seafloor. We also note the presence of several juveniles of marine species, probably indicating some lateral displacement.

B) Petrology: prodelta.

3 - (40.5÷38 m; samples 41-38): dark olive silty clay, horizontally laminated, with mollusc fragments, echinoid spines and pyrite. Forams comprise mainly miliolids, *Ammonia*, and *Elphidium* which, in the upper part of the interval, are associated with specimens of *Lagena* and *Bulimina*. Ostracodes are represented by very rare specimens of *C. neapolitana* (Group D), *Sylvestra* sp. 1 (Group E), and *L.* sp. 1 (Group F); rare allochthonous valves of the juveniles of *Cyprideis torosa* (Group B) are present only in sample 39.

Age: lower to mid-Holocene (derived from stratigraphic position).

Environment:

A) Ostracodes: open marine as indicated by the species of groups D, E, and F, at times with input from brackish-water environments (presence of *C. torosa* .

B) Petrology: prodelta, with a somewhat less distal open marine aspect than the underlying interval.

4 - (38÷30 m; samples 37-30): dark olive silty clay and clayey silt, horizontally laminated, with mollusc fragments and echinoid spines, and pyrite. Forams are represented mainly by shallow marine forams (miliolids, *Ammonia*, *Elphidium*, etc.). The ostracode fauna is oligospecific, but somewhat more diversified than in the underlying interval. Noted are species of Group D *(C. neapolitana* and *Pontocythere turbida*), Group E *(C. bairdi*, *Cystacythereis* gr. *caelatura*, *Leptocythere ramosa*, *P. similis*, and *S.* sp. 1), and Group F (*Costa batei*); some brackish-water (*C.torosa* and *Loxoconcha stellifera*) and fresh-water *(Ilyocypris gibba*) species are also present.

Age: mid-Holocene. ^{14}C date: sample at 34.5 m = 5,780 ± 130 years B.P.

Environment:

A) Ostracodes: open marine environment, with development locally of vegetal meadows as indicated by different combinations of species of groups D, E, and F. The finding, almost throughout the interval, of fresh and brackish-water species indicates an almost continuous displacement from a brackish to fresh-water domain.

B) Petrology: prodelta.

5 - (30÷28 m; samples 29-27): horizontally laminated silty clay and clayey silt, with a small sand fraction, comprises increased proportions of sea-urchin plates and, subordinately, mollusc fragments, some glauconite/verdine (cf. Pimmel & Stanley, 1989) and plant debris. The foraminiferal assemblage consists of shallow-water forms *(Ammonia beccarii*, *Elphidium*, and, subordinately, miliolids and *Melonis*). Ostracodes are mainly represented by species of Group E, such as *C. bairdi*, *C.* gr. *caelatura*, *P. similis* (sample 29), and, subordinately, of groups D (*P. turbida*) and F (*L.* sp. 1; sample 28). Very rare juveniles of *S.* sp. 1 and *L.* sp. 1 occur, respectively, in samples 27 and 28. Brackish-water species *C. torosa* occurs in all samples; scattered valves of fresh and brackish-water *(Loxoconcha elliptica*) specimens occur in sample 28.

Age: mid-Holocene (derived from stratigraphic position).

Environment:

A) Ostracodes: open marine environment as indicated by the species of groups D, E, and F, perhaps with local vegetal meadows (in those samples where there is an exclusive presence of species of Group E); episodes of higher bottom-energy are indicated by abundant echinoid plates and mollusc fragments. There are indications of input from fresh *(Ilyocypris gibba*) and brackish *(C. torosa* and *L. elliptica*) water domains.

B) Petrology: intermediate or transitional between prodelta and delta-front.

6 - (28÷17 m; samples 26-16): horizontally laminated silty clay, clayey silt and minor sandy layers (somewhat coarser grained) are present (sample 20); very abundant vegetal frustules and mollusc fragments, and increased amounts of mica and glauconite/verdine. The forams are represented by shallow marine species including miliolids, *Ammonia*, and *Melonis*; *Bolivina* and *Uvigerina* specimens are also present. Proceeding upward in this interval to sample 24, the ostracode fauna becomes characterized mainly by *S.* sp. 1 (Group E), and scattered specimens of *C. neapolitana* (Group D). Sample 20, which is barren of ostracodes, is an exception; the other samples show a relatively more diversified fauna and include species of groups D *(C. neapolitana*), E *(Basslerites berchoni*, *C.* gr. *caelatura*, *P. similis*, and *S.* sp. 1), and F *(Cytherella* sp. 1). Brackish-water specimens *(C. torosa*) become more frequent upward, from sample 23 to the top of the interval.

Age: mid-Holocene. ^{14}C date: sample at 25 m = 4,520 ± 110 years B.P.

Environment:

A) Ostracodes: open marine environment as recorded by findings of species of groups D, E, and F, sometimes with vegetal meadows (in those samples where there is an exclusive presence of Group E); a brackish-water influence (presence of *C. torosa*) is more pronounced in the middle part of the interval. The barren sandy level (sample 20) may record a temporary episode of intensified sea-bottom currents.

B) Petrology: delta-front.

7 - (17÷13 m; samples 15-13): horizontally and cross-laminated layers of dark olive grey clayey silt, silt and muddy sand, with vegetal frustules and mollusc fragments and important proportions of glauconite/verdine and mica. Forams are very rare and consist mainly of *Ammonia* and *Bolivina* specimens. The ostracode fauna comprises species of Group C

(Neocytherideis fasciata and *Semicytherura sulcata*) and Group E *(A. hystrix, B. berchoni, P. similis* and *S.* sp. 1). Allochthonous specimens of brackish-water *C. torosa* are irregularly diffused. One specimen of *Leptocythere levis* (Group D) is also present, but it is displaced.
Age: upper Holocene. ^{14}C date: sample at 16 m = 3,870 ± 100 years B.P.
Environment:
A) Ostracodes: marine nearshore environment characterized by vegetal meadow indicated by the species of groups C and E; Group C forms may indicate the proximity to a river mouth.
B) Petrology: proximal delta-front.

8 - (13÷8 m; samples 12-7): interbedded laminated and cross-stratified dark olive sandy mud and muddy sand layers and silt with scattered vegetal frustules, mollusc fragments and siliceous sponge-spicules, and increased proportions of heavy minerals. The forams are rare and consist of specimens of *Ammonia* and *Melonis*. Ostracodes are very rare and include mainly scattered juveniles of nearshore marine species *(A. hystrix, C. edwardsii, P. turbida,* and *Urocythereis* sp.), and brackish-water *(C. torosa)* and fresh-water *(I. gibba)* species.
Age: upper Holocene. ^{14}C date: sample at 10 m = 3,520±90 years B.P.
Environment:
A) Ostracodes: nearshore marine environment influenced by fresh and brackish-water input (presence of *I. gibba*, and *C. torosa*); marine species are represented only by a mixed fauna of juveniles displaced from a nearby similar marine environment.
B) Petrology: delta-front, close to a river mouth.

9 - (8 m to core top; samples 6-1): sand with mollusc fragments, and important proportions of heavy minerals and gypsum; also present are plant debris, mica and glauconite/verdine. Forams are very rare in the lowermost part of the interval (finding of *Ammonia*). Ostracodes are represented only by *C. torosa* which becomes more frequent toward the core top.
Age: upper Holocene: about 3000 years B.P. (cf. Coutellier & Stanley, 1987).
Environment:
A) Ostracodes: littoral, becoming lagoonal toward the core top. This latter indicates extreme evaporitic conditions as recorded by *C. torosa.*
B) Petrology: a near-shore sand setting, comprisizing bar and/or coastal ridge deposits.

Borehole S-18

Borehole S-18 (Fig. 3), 53.5 m in length, is located about 10 km east of the Suez Canal and 25 km southeast of Port Said. It is characterized, from bottom to top, by the following four intervals:

1 - (53.5÷27 m; samples 33-20): brownish grey sand, with traces of silt; noted are mollusc fragments, heavy minerals and minor amounts of glauconite/verdine and pyrite. This interval is barren of forams and ostracodes.
Age: Uppermost Pleistocene. ^{14}C dates: sample at 52.5 m = 12,070 ± 370 years B.P.; sample at 41 m = 11,530 ± 80 years B.P.
Environment: petrologically this interval is interpreted as a coastal or inner shelf environment.

2 - (27÷11 m; samples 19-8): horizontal and some cross-laminated dark olive silty clay (silt fraction increases upward); the paleontological content is varied and consists of mollusc fragments and, subordinately, vegetal frustules, echinoid spines, and pyrite. The abundant benthic foraminiferal assemblage consists mainly of *A. tepida*, miliolids, and *Bolivina.* The ostracode fauna is oligospecific and comprises mainly the species of Group E *(B. berchoni* and, subordinately, of *C.* gr. *caelatura*). Both species are distributed irregularly at the base of this interval, and become more frequent upward at depths of 18.5 to 9 m. In addition to these forms, the middle part of this interval (19÷17 m) also includes very rare specimens of *C. neapolitana* (Group D) and *S.* sp. 1 (Group E).
Age: lower to mid-Holocene. ^{14}C dates: sample at 26.50 m = 7,400 ± 70 years B.P., and sample at 11 m = 4,100 ± 70 years B.P.
Environment:
A) Ostracodes: from nearshore with vegetal meadows to open marine with or without vegetal meadows (presence of species of groups D and E).
B) Petrology: prodelta, with possibly a somewhat more turbulent phase between 19 and 18 m, as indicated by cross-laminated structures.

3 - (11÷6 m; samples 23-5): horizontal and increased cross-laminated dark olive grey clayey silt, with vegetal frustules, mollusc fragments and much increased proportion of mica and glauconite/verdine. Forams are mainly represented by *A. tepida.* Ostracodes consist mainly of juveniles of *C. torosa*, and only one specimen of *B. berchoni* (Group E).
Age: upper Holocene (derived from stratigraphic position).
Environment:
A) Ostracodes: nearshore open marine environment with scattered vegetal meadows and strongly influenced by brackish-water input (presence of displaced juveniles of Group B). The presence of *B. berchoni* (Group E) would indicate an evolutionary trend from nearshore to a lagoon. This latter species can live in brackish-water environments; it has been identified in present some modern Mediterranean lagoons.
B) Petrology: delta-front.

4 - (6.0 - core top m; samples 22-1): grey sand and, in the uppermost 2 m, muddy sand and sandy mud (topward), with mollusc fragments and decreased amounts of mica and glauconite/verdine; also present are plant matter and echinoid spines. Of note is the much increased proportions of gypsum and halite from 3 m to the core top. Monospecific faunae occur in the case of both forams *(A. tepida)* and ostracodes *(C. torosa)*; the latter in sample 4 includes one autochthonous specimen of *L. elliptica.*
Age: upper Holocene. ^{14}C date: sample at 1.5 m = 1,400 ± 90 years B.P.
Environment:
A) Ostracodes: lagoon. At the top of the interval, the lagoon shows the effects of two extreme conditions· evaporitic (by the presence of *C. torosa*) and fresh-water (by the presence of *C. torosa/L. elliptica* assemblage).
B) Petrology: nearshore sand bar and/or coastal ridge which is backed by a lagoon evolving to a salt flat.

Borehole S-20

Borehole S-20 (Fig. 4), 50.5 m in length, is located on the western bank of Suez Canal, near the juncture of the NE Canal By-pass, about 17 km south of Port Said. It is characterized, from the bottom to top, by the following six intervals:

1 - (50.5÷42.5 m; samples 46-42): greyish sand with sponge spicules and rare mollusc fragments, and only one brackish-water ostracode specimen *(C. torosa)*.
Age: upper Pleistocene to lower Holocene. ^{14}C dates: sample at 45 m = 15,110±640 years B.P.
Environment:
A) Ostracodes: nearshore/coastal setting, with input from a nearby brackish-water environment.
B) Petrology: coastal-inner shelf sand, interpreted as basal transgressive unit below the Holocene progradational deltaic sequence.

2 - (42.5÷25 m; samples 41-26): finely laminated dark olive grey sandy mud and muddy sand in the lower part, becoming horizontally laminated dark olive silty clay, with vegetal frustules, mollusc fragments, and echinoid spines, heavy minerals, and pyrite. The forams are characterized mostly by oxidized (reddish) tests of *Ammonia* (mainly *A. tepida*), miliolids *Bolivina*, *Uvigerina* and *Cancris*. Ostracode fauna is represented in the lower part by very rare juveniles of the marine forms *C. edwardsii* and *L.* sp. 1. In the mid to upper part of the interval, species of Group E, such as *B. berchoni* and *C.* gr. *caelatura* are present. Very rare juveniles of *A. hystrix* also occur at the top of this interval.
Age: lower to mid-Holocene. ^{14}C dates: sample at 42 m = 7,360 ± 90 years B.P.; sample at 34 m = 7260 ± 90 years B.P.; sample at 27.5 m = 7,460 ± 80 years B.P.
Environment:
A) Ostracodes: nearshore open marine environment with vegetal meadows, as documented by the finding of species of Group E.
B) Petrology: prodelta.

3 - (25÷20 m; samples 25-21): horizontally laminated (cross-bedded at 24 m) dark olive grey silty clay with abundant vegetal frustules and, subordinately, mollusc fragments, echinoid spines and pyrite. The forams, also reddish, consist of mostly oxidized tests of *Ammonia* spp., miliolids and *Buliminidae*. Ostracode fauna is characterized mainly by species of Group E, *i.e. C.* gr. *caelatura* (the most common species) and *B. berchoni*. Other species of groups E *(A. hystrix, P. similis,* and *S.* sp. 1), D *(C. neapolitana)*, and F *(C. batei)* are irregurarly distributed throughout the interval. Juveniles of *C. torosa* are also present.
Age: mid-Holocene. ^{14}C date: sample at 22 m = 5,110 ± 110 years B.P.
Environment:
A) Ostracodes: mainly open marine environment (presence of species of groups D, E, and F), sometimes with vegetation (exclusive presence of Group E) and brackish-water influence. The occurrence of this ostracode assemblage could record a more marine, and probably deeper, episode in the evolution of the muddy offshore sector seaward of the delta. This could correspond to an ingression of the sea which occurred at about 5000 years B.P. (cf. Summerhayes *et al.*, 1978; Coutellier & Stanley, 1987). The reddish forams are probable indicators of reworking.
B) Petrology: transitional from prodelta to delta-front.

4 - (20÷11 m; samples 20-13): horizontal and some cross-laminated dark olive grey clayey silt, with vegetal frustules, and subordinate mollusc fragments and, in the uppermost part of the interval, siliceous sponge-spicules; mica and glauconite/verdine are present, while pyrite decreases somewhat. Forams are represented mainly by reddish specimens of *Ammonia*, miliolids, and *Buliminidae*. The lowermost part of the interval (sample 20) shows only reddish forams. *A. tepida* is the only species at the top of the interval. Ostracodes consist of the *B. berchoni/C.* gr. *caelatura* assemblage (Group E), although the latter species is sometimes absent. A few specimens of *Cytheroma variabilis* (Group E) and of *P. intermedia* (Group F) are present in sample 17. Very rare displaced juveniles of marine species are irregularly distributed in the middle part of this interval. The uppermost part (sample 13) comprises dominant *B. berchoni*, while *C.* gr. *caelatura* is represented by only one specimen. Two diatom findings occur in the upper part of the interval (samples 16 and 13).
Age: mid-Holocene ^{14}C date: sample at 11 m = 4,190 ± 90 years B.P.
Environment:
A) Ostracodes: nearshore open marine environment, with or without vegetation. The dominance of *B. berchoni*, and the decreased occurrence of *C.* gr. *caelatura* could indicate the beginning of an environmental change, *i.e.* from a shallow marine to nearshore setting very strongly influenced by fresh-water input. In addition, the diatom occurrences may perhaps record some eutrophication episodes and, consequently, environmental stress (anoxic phases).
B) Petrology: transitional prodelta/delta-front represented by the lower part of this interval, and delta-front from about 18 m to the top of the interval.

5 - (11÷6 m; samples 12-8): clayey silt, with increased proportions of sand, commonly cross-laminated; presence of vegetal frustules and mollusc fragments, with important proportions of glauconite/verdine and mica. Microfossils comprise only the foraminiferal species *A. tepida* and ostracode juveniles of the brackish-water *C. torosa* and *B. berchoni*.
Age: mid to upper Holocene (derived from stratigraphic position).
Environment:
A) Ostracodes: shallow marine with pronounced brackish-water input as indicated by a displacement phenomenon (presence of juveniles of brackish-water species and a lack of an autochthonous fauna).
B) Petrology: delta-front.

6 - (6 m to core top; samples 7-1): sandy silt, clay and muddy sand, some bioturbated, with vegetal frustules, mollusc fragments and increased proportions of heavy minerals and somewhat decreased amounts of mica and glauconite/verdine. Monospecific microfossil faunae occur with respect to both forams (*A. tepida*) and ostracodes (*C. torosa*). Scattered isolated valves of juveniles of brackish-water *L. elliptica* and of marine *L.* sp. 1, and *S.* sp. 1 are present.
Age: upper Holocene. ^{14}C date: sample at 2 m = 2,890 ± 130 years B.P.
Environment:
A) Ostracodes: lagoon, primarily on the basis of the finding of *C. torosa*. The presence of displaced marine juveniles may indicate the proximity to a lagoonal 'near paralic' setting.
B) Petrology: this interval appears to include delta-front facies at the base, to coast and then to lagoonal deposits at the top.

Borehole S-22

Borehole S-22 (Fig. 5), 38 m in length, is located about 10 km west of the Suez Canal, near Bahr el Baqar Drain, and 27 km southwest of Port Said. It is characterized from bottom to top by the following seven intervals:

1 - (38÷22.5 m; samples 40-24): two hard brown clay layers, between 38 and 37 m and 32 and 31 m, interbedded with medium to coarse greyish brownish sand with mollusc fragments and heavy minerals. Vegetal frustules occur in the middle-upper part, and echinoid spines in the upper part. Forams are represented by very rare specimens of *Ammonia* and miliolids in the uppermost sand interval. Ostracodes, found only in samples 38 and 36 next to the boundary of both stiff clay layers, consist of very rare specimens of *C. torosa*, *B. berchoni*, *S. sulcata*, and *P. turbida*.
Age: from upper Pleistocene to lower Holocene. ^{14}C dates: sample at 37.5 m = 24,320 ± 2,030 years B.P.; sample at 31.5 m = (?) 32,920 ± 930 years B.P.; and sample at 22.5 m = 7,540 ± 70 years B.P.
Environment:
A) Ostracodes: ostracode-deficient sands may be coastal environments, while the interval at 32-31 m records a nearshore setting with brackish-water input.
B) Petrology: alluvial overbank deposits (two stiff mud layers; cf. Arbouille & Stanley, 1991), with possible alluvial sand deposits between these two; this is covered by a basal transgressive sand below Holocene progradational deltaic sequence.

2 - (22.5÷15 m; samples 23-19): horizontally laminated (to about 15 m) and cross-bedded (at 16 m) dark olive silty clay, with mollusc fragments, vegetal frustules and pyrite, glauconite/verdine and mica; very rare echinoid spines in the lowermost part of the interval. Forams consist of specimens of *Ammonia* (mainly *A.tepida*), miliolids and *Buliminidae*. Ostracode fauna is represented mainly by *B. berchoni*. This species is found together with *C.* gr. *caelatura* and *A. hystrix* (Group E) and very rare juveniles of *C. edwardsii* and *P. intermedia*, in the lowermost part of the interval. *B. berchoni* is the only species present in the upper part.
Age: lower-mid Holocene (derived from stratigraphic position).
Environment:
A) Ostracodes: nearshore open marine with local vegetal meadows as indicated by the species of Group E. The presence of *B. berchoni* upward may record the beginning of an environmental change from shallow marine to one nearshore which was more influenced by continental input.
B) Petrology: the lower part of this interval is interpreted as transitional between prodelta and delta-front; most of the interval is delta-front.

3 - (15÷9 m; samples 18-14): cross-laminated dark olive silty layers and silty clay, with mollusc fragments, pyrite, mica, and glauconite/verdine and, subordinately, vegetal frustules. Forams are represented by *Ammonia* spp. specimens (mainly *A. tepida*) and very rare miliolids. Ostracodes consist only of displaced juveniles of *B. berchoni*, likely derived from nearby environments.
Age: mid-Holocene. ^{14}C date: sample at 14 m = 6,630 ± 150 years B.P.
Environment:
A) Ostracodes: shallow marine setting seaward strongly affected by displacement from nearby continental environments.
B) Petrology: delta-front.

4 - (9÷6 m; samples 13-11): horizontally laminated and cross-stratified dark olive clayey silt, silt and muddy sand, with mollusc fragments and, subordinately, vegetal frustules; also noted are a decrease in mica and glauconite/verdine and increase in heavy minerals. The few forams include *Ammonia* spp. and *Buliminidae*. Ostracode fauna is represented by *B. berchoni* which, in the uppermost part, becomes very frequent, and by scattered juveniles of nearshore marine species.
Age: mid-Holocene. ^{14}C date: sample at 8.5 m = 4,670 ± 80 years B.P.
Environment:
A) Ostracodes: shallow marine with evidence of displacement from nearby marine environments.
B) Petrology: delta-front to coastal.

5 - (6÷5 m; samples 10-9): cross-laminated grey silt and sand, with vegetal frustules and pyrite, mollusc fragments and heavy minerals. Forams are rare. Ostracodes are represented only by very rare specimens of *C. torosa* (Group B).
Age: mid-to upper Holocene (derived from stratigraphic position)
Environment:
A) Ostracodes: coastal and lagoonal.
B) Petrology: possible lagoon.

6 - (5÷2.5 m; samples 8-5): grey sand topped by dark clayey silt with mollusc fragments and vegetal debris. Benthic forams and ostracodes are absent.
Age: upper Holocene. ^{14}C date: sample at 3.5 m = 3,770 ± 90 years B.P.
Environment: Petrologically this interval is interpreted as nearshore to coastal.

7 - (2.5 m - top; samples 4-1): dark olive grey clayey silt and silty clay, poorly stratified with burrow and/or root structures, with abundant vegetal frustules, mollusc fragments, pyrite and heavy minerals. The microfossils are represented by monospecific assemblages of forams (*A. tepida*) and of ostracodes (*C. torosa*).
Age: upper Holocene (derived from stratigraphic position).
Environment:
A) Ostracodes: lagoon.
B) Petrology: lagoon.

Borehole S-25

Borehole S-25 (Fig. 6), 14 m in length, is located 12.5 km west of the Suez Canal and 35 km southwest of Port Said. It is characterized, from bottom to top, by the following three intervals:

1 - (14÷12 m; samples 17-15): grey sand with mollusc fragments, pyrite and heavy minerals and, subordinately, echinoid spines. The microfossils consist of very rare forams (mainly *A. tepida*) and juveniles of ostracode species of *Kroemmelbeinia* and *Semicytherura*.
Age: lower to mid-Holocene. ^{14}C dates: sample at 14 m = 6,210 ± 100 years B.P., and sample at 12.5 m = 6760 ± 100 years B.P.
Environment:
A) Ostracodes: marine nearshore, close to beach.
B) Petrology: shallow marine/coastal with possible proximity to offshore bar.

2 - (12÷5.5 m; samples 14-7): horizontally laminated dark grey silty clay (at base of interval) and horizontal and cross-lami-

nated clayey silt (in upper part), with vegetal frustules, mollusc fragments, echinoid spines and increased proportions of mica, heavy minerals and glauconite/verdine. Forams consist of *Ammonia* spp. Ostracode faunae include mainly *C. torosa*. Both foram test and ostracode valves display a poor state of preservation (oxidized, pyritized, fragmented) and are considered allochthonous.
Age: mid-Holocene (derived from stratigraphic position).
Environment:
A) Ostracodes: all the ostracode fauna is lagoonal, but specimens can be considered displaced from lagoon to nearshore marine environment.
B) Petrology: delta-front.

3 - (5.5 m - core top; samples 6-1): dark grey clayey silt, bioturbated at the top, and muddy sand (4÷2.5 m), locally with pyrite, mica, much increased plant debris and mollusc fragments. Forams are absent, and there are scattered juveniles of *C. torosa* in the upper part.
Age: upper Holocene. ^{14}C date: sample at 3.50 m = 3,860 ± 90 years B.P.
Environment:
A) Ostracodes: marine nearshore, with weak episodic brackish influence.
B) Petrology: nearshore marine, indicating coastal to lagoon.

Borehole S-27

Borehole S-27 (Fig. 7), 15 m in length, is located 27 km west of the Suez Canal and 37 km southwest of Port Said. It is characterized, from bottom to top, by the following five intervals:

1 - (15÷12 m; samples 20-19): grey sand, with trace of mud, heavy minerals and pyrite, and some mollusc fragments. Microfossils are absent.
Age: lower Holocene (derived from stratigraphic position; this interval is perhaps underlain by uppermost Pleistocene sequences).
Environment: Petrologically, this interval is interpreted as a coastal (offshore bar or beach) deposit.

2 - (12÷10.5 m; samples 18-17): grey sand with trace of mud, with mollusc fragments, pyrite and heavy minerals. Forams are absent, and ostracodes are represented by very frequent specimens of *C.torosa*.
Age: lower-mid Holocene. ^{14}C date: sample at 10.5 m = 6,560 ± 90 years B.P.
Environment:
A) Ostracodes: lagoon.
B) Petrology: coastal (offshore bar to beach) deposit.

3 - (10.5÷9 m; samples 16-15): laminated grey sandy mud (lower part) and sand (upper part), with rare mollusc fragments; gypsum and heavy minerals are present. Microfossils are absent.
Age: mid-Holocene (derived from stratigraphic position).
Environment: Petrologically, this interval is interpreted as coastal to lagoonal.

4 - (9÷6 m; samples 14-9): grey muddy sand and sandy mud with at least six peat layers (to 30 cm thick); vegetal frustules are very abundant, pyrite is present, and diatoms are found in samples 13 and 12. No other microfossils occur.
Age: upper Holocene. ^{14}C dates: sample at 9 m = 3,330 ± 90 years B.P.; sample at 6 m = 2,980 ± 70 years B.P.
Environment: Petrologically, this interval is interpreted as marsh to lagoonal.

5 - (6 m - core top; samples 8-1): horizontally laminated and locally bioturbated grey sandy silty mud, with two sandy mud horizons (at 5 and 3 m) and, locally (at about 3 m), several thin peat layers; present are mollusc fragments, and a decreased amount of vegetal debris, including fresh-water characean oogons in the lowermost part of the interval. Pyrite, heavy minerals, mica and glauconite/verdine occur in the mid to upper part. Monospecific microfossil assemblages, locally present, include the foram *A. tepida* and the ostracode *C. torosa*.
Age: upper Holocene. ^{14}C dates: sample at 5.5 m = 2,520 ± 90 years B.P.; sample at 2.50 m = 3,160 ± 90 years B.P.
Environment:
A) Ostracodes: lagoon.
B) Petrology: lagoon, affected by possible inflow from fresh-water and, less likely, sea-water.

Borehole S-26

This borehole, 13.5 m in length, is located about 28 km west of Suez Canal and 47 km southwest of Port Said. It is characterized, from bottom to top, by the following three intervals:

1 - (13.5÷7 m; samples 45-39): yellowish grey sand, with heavy minerals, pyrite, and lithic fragments. No fossil are noted.
Age: lower-mid Holocene (derived from stratigraphic position).
Environment: Petrologically, this interval is interpreted as alluvial sand.

2 - (7÷5.5 m; samples 32-38): grey sandy mud with plant debris and diatoms; some pyrite and pebbles are present, but no other fossils occur.
Age: mid-Holocene. ^{14}C date: sample at 6 m = 4,210 ± years 90 B.P.
Environment: Petrologically, this interval is interpreted as alluvial overbank depression fill.

3 - (5.5 m - core top; samples 37-30): yellowish sand, with two muddy horizons (at about 3 m, and 1.5 to core top). These latter include plant debris, some pyrite and aggregates. Mollusc fragments are found in the uppermost core. No microfossils occur.
Age: mid-to upper Holocene. ^{14}C dates: sample at 5 m = 4370 ± 170 years B.P.; sample at 2.5 m = 2,820 ± 120 years B.P.; sample at 1.5 m = 2,500±170 years B.P.
Environment: petrologically, this interval is interpreted as alluvial, with some overbank deposits; a connection with a shallow interfluvial pool or lagoon is not ruled out.

Borehole S-24

This borehole, 10.5 m in length, is located 15 km west of the Suez Canal and about 47 km southwest of Port Said. It is characterized, from bottom to top, by the following two intervals:

1 - (10.5÷8 m; samples 13-11): very stiff brown clay-rich mud with minor silt and sand content, laminated, with few mollusc

fragments and vegetal debris and pyrite; no microfossils are present.
Age: upper Pleistocene to lower Holocene. ^{14}C date: sample at 10 m = 24,240 ± 1,510 years B.P.
Environment: Petrologically, this interval is interpreted as alluvial, probably including overbank and interchannel deposits.

2 - (8 m - core top; samples 48-9): yellowish sand and yellowish brown mud near core top, with heavy minerals and an increase of mollusc fragments near the top of the core. No microfossils occur.
Age: mid to upper Holocene. ^{14}C date: sample at 1 m = 4,130 ± 180 years B.P.
Environment: petrologically, this interval is interpreted as alluvial deposits, with episodic sediment accumulation in small interfluvial pools (in upper core).

Borehole S-23

This borehole, 13.5 m in length, is located 24 km west of the Suez Canal and almost 47 km SSW of Port Said. It is characterized, for the most part, by a yellowish brown sand with traces of silt; muddy sand occurs at the core top. Of the biogenic components, mollusc fragments are found only at two intervals: 7.5÷5 m and 1.5 m from the core top. No microfossils occur.

Age: lower Holocene (at core base, from stratigraphic position) to upper Holocene. ^{14}C date: sample at 1.5 m = 2,490 ± 80 years B.P.

Environment: petrologically, this core is interpreted as of largely alluvial origin, with possible connections to ephemeral interchannel shallow pools.

APPENDIX B

The following is a summary synthesis of interpretations pertaining to of the stratigraphic intervals in the six of the nine cores that comprise ostracodes (see Appendix A). The paleoenvironmental significance of ostracode faunae is considered in light of information presented in the discussion sections of the text. This information is depicted in Figure 10. Intervals in the case of each boring are considered from the base to the top.

Borehole S-21

1 - (49.5÷46 m, lowermost Holocene): basal transgressive sand, perhaps a coastal ridge and/or off-shore deposit; ostracodes show some local displacement from shallow marine sea-grass meadows and also from proximal fluvial input.

2 - (46÷40.5 m, lower-mid Holocene): prodelta; ostracode-barren samples and allochthonous specimens suggest episodic high energy conditions.

3 - (40.5÷38 m, lower-mid Holocene): prodelta; ostracodes indicate an input from brackish-water environment.

4 - (38÷30 m, mid-Holocene): prodelta; ostracode faunae may indicate local sea-grass meadows and influence from fresh and brackish-water environments.

5 - (30÷28 m, mid-Holocene): transitional prodelta to delta-front; ostracodes may indicate local sea-grass meadows and input from fresh and brackish-water environments.

6 (28÷17 m, mid-Holocene): delta-front; ostracodes may indicate local vegetal sea-grass meadows, and a brackish-water influence is evident. Barren sandy levels in this interval may indicate episodes of increased bottom currents.

7 - (17÷13 m, upper Holocene): proximal delta-front; ostracodes indicate proximality to a river mouth and the presence of sea-grass meadows.

8 - (13÷8 m, upper Holocene): delta-front, close to a river mouth; ostracodes comprise only displaced faunae of juveniles mixed from fresh-water to marine settings.

9 - (8 m to core top, upper Holocene): nearshore sand deposits, including offshore bars and coastal ridges; ostracodes indicate a "far paralic" lagoonal setting, probably with extreme (evaporitic) conditions.

Borehole S-18

1 - (53.5÷27 m, uppermost Pleistocene): alluvial to inner shelf/coastal; absence of ostracodes records very high energy-turbulent conditions.

2 - (27÷11 m, lower-mid Holocene): prodelta; ostracode fauna may indicate the development of local vegetal meadows.

3 - (11÷6 m, upper Holocene): delta-front; ostracodes, mostly juveniles, derived mainly from brackish-water, indicate seafloor with scattered vegetal meadows.

4 - (6.0 m to core top, upper Holocene): nearshore bar and/or coastal ridge, backed by a lagoon evolving to a salt flat; ostracodes record lagoonal "far paralic" settings, with both evaporitic and fresh-water extreme conditions.

Borehole S-20

1 - (50.5÷42.5 m, upper Pleistocene to lower Holocene): basal transgressive sand (inner shelf to coastal), covered by marine prodelta facies.

2 - (42.5÷25 m, lower-mid Holocene): prodelta; ostracode fauna may indicate the presence of vegetal meadows.

3 - (25÷20 m, mid-Holocene): transitional prodelta/delta-front; ostracode fauna may indicate local vegetal meadows and, at times, influence of fluvial input.

4 - (20÷11 m, mid-Holocene): transitional prodelta/delta-front (in lower part of interval), becoming delta-front (in upper part); ostracode faunae may indicate vegetal meadows and an increased fluvial input with time.

5 - (11÷6 m, upper-mid Holocene): delta-front; ostracodes are represented by juveniles displaced from fresh, brackish, and marine nearshore environments.

6 - (6 m to core top, upper Holocene): delta-front (at base of interval) to coastal, and then to lagoon (at top); ostracodes may indicate the proximity of "near paralic" lagoonal or nearshore settings.

Borehole S-22

1 - (38÷22.5 m, upper Pleistocene to lower Holocene): two stiff clay layers probably indicate alluvial overbank-interchannel deposits, and upward sands constitute a basal transgressive unit; ostracodes in sand record nearshore conditions with brackish-water input.

2 - (22.5÷15 m, lower-mid Holocene): transitional prodelta/delta-front in lower part, and delta-front in most of interval; ostracode fauna may indicate local vegetal meadows. Ostracodes found upward in the interval may also record the beginning of environmental change from a shallow marine to nearshore setting more clearly influenced by continental input.

3 - (15÷9 m, mid-Holocene): delta-front; ostracodes include juveniles displaced from a nearby marine environment.

4 - (9÷6 m, mid-Holocene): delta-front to coastal; ostracodes indicate evident river input, and also displacement from a nearby marine environment.

5 - (6÷5 m, mid-upper Holocene): possible lagoon; ostracodes tend to support this.

6 - (5÷2.5 m, upper Holocene): nearshore.

7 - (2.5 m - core top, upper Holocene): lagoon, as confirmed by ostracodes.

Borehole S-25

1 - (14÷12 m, lower-mid Holocene): nearshore (possible offshore bar) deposits; ostracodes comprise only marine nearshore displaced forms.

2 - (12÷5.5 m, mid-Holocene): delta-front; ostracodes include only displaced forms displaced from a lagoon.

3 - (5.5 m - core top, upper Holocene): nearshore, with coastal to lagoonal influence; ostracodes include very rare juveniles which are displaced from a lagoon.

Borehole S-27

1 - (15÷12 m, lower Holocene, perhaps underlain by uppermost Pleistocene): coastal (offshore bar or beach) deposits.

2 - (12÷10.5 m, lower-mid Holocene): coastal deposits; ostracodes indicate a lagoonal setting.

3 - (10.5÷9 m, mid-Holocene): coast to lagoon.

4 - (9÷6 m, upper Holocene): marsh to lagoon.

5 - (6m to core top, upper Holocene): lagoon, with possible fresh-water inflow; ostracodes confirm a lagoonal origin.

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