Bollettino della Società Paleontologica Italiana	39 (2), 2000	ISSN 0375-7633	157-164	–	Modena, Giugno 2000

The Ostracods of the Plio-Pleistocene Monte San Nicola section (Gela, Sicily): an attempt of palaeoecological interpretation

Gioacchino BONADUCE   Diana BARRA   Giuseppe AIELLO
Dipartimento di Scienze della Terra
Università di Napoli Federico II

KEY WORDS – Ostracoda, Palaeoecology, Plio-Pleistocene, Sicily.

ABSTRACT – The ostracod assemblages of the Plio-Pleistocene section of Monte S. Nicola (Gela, Sicily) are studied quantitatively. The fluctuations in both the diversity and number of specimens are correlated with a climatic fluctuations as identified by Channell et al. *(1992) using planktonic foraminifers.*

The common occurrence of Agrenocythere pliocenica *up to the second half of MPl5 and its spasmodic and rare occurrence at the base of MPl6, demonstrate the gradual disappearance of the psychrosphere in the area and the beginning of the thermospheric environment.*

In our opinion, the evident species turnover in the same interval supports the hypothesis of a change in Mediterranean circulation from estuarine to antiestuarine.

RIASSUNTO – [Gli ostracodi della sezione Plio-Pleistocenica di Monte San Nicola (Gela, Sicilia): un'interpretazione paleoecologica] – *Vengono studiate quantitativamente le associazioni ad ostracodi della sezione Plio-Pleistocenica di Monte San Nicola (Gela, Sicilia).*

Le fluttuazioni sia della diversità che del numero di individui vengono indirettamente correlate con le fluttuazioni climatiche definite tramite i foraminiferi planctonici da Channell et al. *(1992).*

La comune presenza di Agrenocythere pliocenica *fino alla seconda parte della Biozona MPl5 e il suo sporadico rinvenimento alla base della Biozona MPl6 dimostra la graduale scomparsa della psicrosfera nell'area e l'inizio di un ambiente termosferico. Un evidente* turnover *di specie nello stesso intervallo viene interpretato come l'effetto del cambiamento della circolazione mediterranea da estuarina ad antiestuarina.*

INTRODUCTION

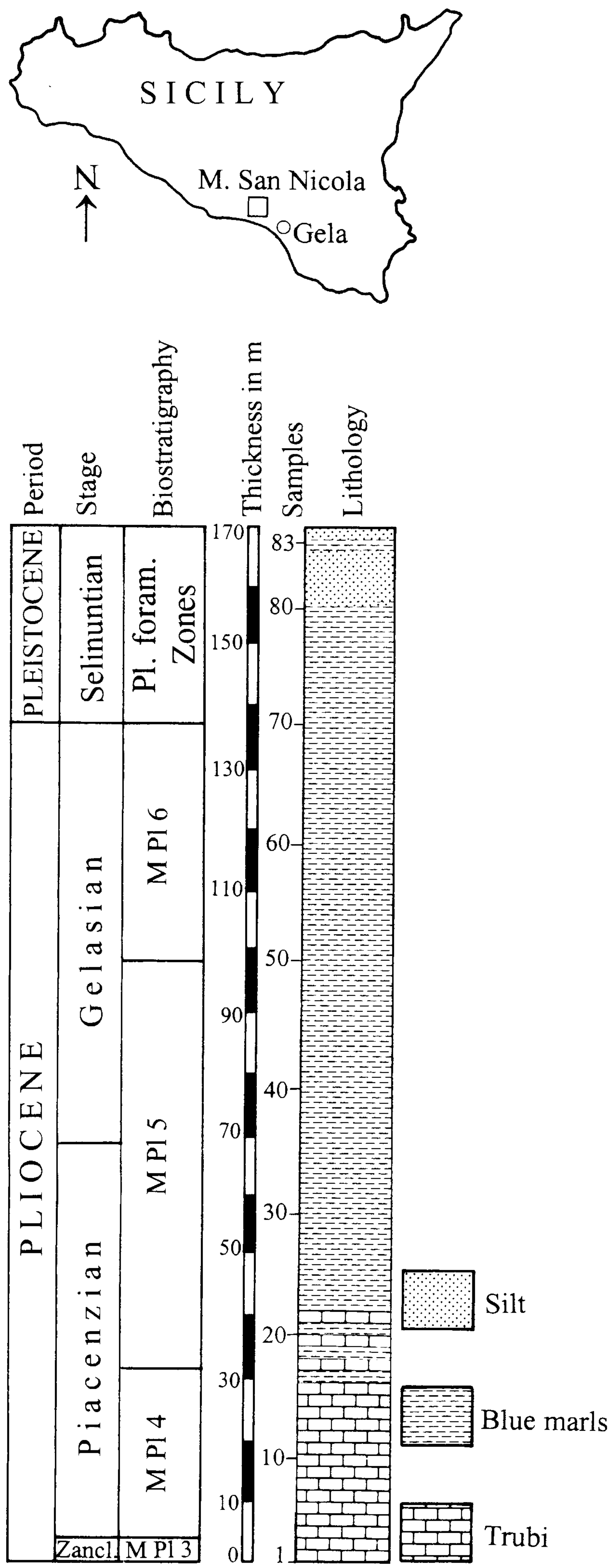
The biostratigraphy of the Monte San Nicola section (Gela, Sicily) has been defined by Sprovieri (Bonaduce & Sprovieri, 1985) by means of planktonic foraminifers. The section ranges from the upper part of the MPl3 Biozone (Pliocene) to the early Pleistocene (Text-fig. 1).

The ostracod biostratigraphy of the same section is studied by Aiello *et al.* (2000) who also undertake the quantitative analysis of the species as shown in their table 1.

These quantitative data are utilized in the present paper in an attempt to interpret bottom palaeoecological conditions and their evolution through time compared with that of the overlying water mass as deduced from the planktonic foraminifers.

Channell *et al.* (1992), from the standpoint of the calcareous plankton biostratigraphy and magnetostratigraphy of the present section, interprete the climatic changes which influenced the surface water temperatures. A short synthesis of their results is summarized below.

- From the base of the section up to the middle part of the MPl4 Biozone (interval from the base to about 24 m), corresponding to 3.70 to 3.38 Ma: climatic instability with repetitive intercalations of temperate and warm intervals.
- From the middle part of MPl4 up to the MPl4/MPl5 biozonal boundary (from about 24 to 33 m), corresponding to 3.38 to 3.16 Ma: rather sudden climatic warming with persistent warm conditions.
- From the MPl4/MPl5 biozonal boundary up to the lower part of the MPl5 Biozone (from about 33 to 48 m), and from 3.16 to 2.81 Ma: cool interval; this event is correlated with the world-wide cooling at 3.1 – 3.2 Ma.
- MPl5 Biozone *partim* (between about 48 and 62 m), and from 2.81 and 2.48 Ma: high climatic instability with several, rapid intercalations of cold and warm interval (glacial-interglacial regime). The sequence of the cold events recorded in this interval confirms that the final build-up of the Pliocene glacial ice cap in the Northern Hemisphere represents the culminating stage of a long interval of general climatic deterioration.
- From the second part of the MPl5 Biozone up to the MPl5/MPl6 biozonal boundary (from about 70 to 100 m): very warm interglacial conditions.
- From the base of MPl6 up to the Plio/Pleistocene boundary (from about 100 to 140 m): 4 climatic intervals are defined.
  100-106 m: climatic cooling;
  107-113 m: warm and more stable climatic conditions;
  127 m: beginning of gradual cooling in the topmost part of the Pliocene;



Text-fig. 1 - Biostratigraphy, lithostratigraphy and samples location of the Monte San Nicola section. Planktonic foraminiferal zones after Sprovieri (*in* Bonaduce & Sprovieri, 1985).The lower boundary of the Gelasian stage is from Sprovieri (pers. comm.).

140 m: further cooling at the beginning of the Pleistocene;

- Early Pleistocene (from about 150 m to the top of the section): progressive cooling.

The deep-water Pliocene ostracods have been previously studied quantitatively (Barra *et al.*, 1998) in the drilling at Punta di Maiata in the Capo Rossello area (Agrigento, Sicily), from the Miocene/Pliocene boundary up to the first part of MPl3 with the interpretation of the evolution of the bottom water conditions.

MATERIAL AND METHODS

The section at outcrop is some 170 m thick. The quantitative dataset is based on 83 samples (collected at 2 m intervals) as reported in Aiello *et al.* (2000) for the same section, from which 113 species of Ostracoda pertaining to 46 genera were recovered. All ostracods were picked out from samples of about 400 gr, washed through 120 meshes sieves. For each species the total number of adult specimens is calculated on the basis of the sum of the number of complete carapaces plus the greatest number between the left or right valves counted in the sample (see Tab. 1 *in* Aiello *et al.*, 2000).

Fluctuations in Simple Species Diversity, and in the abundance of adult specimens as a total number, expressed as percentages for each sample, have been taken into consideration.

GENERAL RESULTS

1 – *Diversity and abundance*

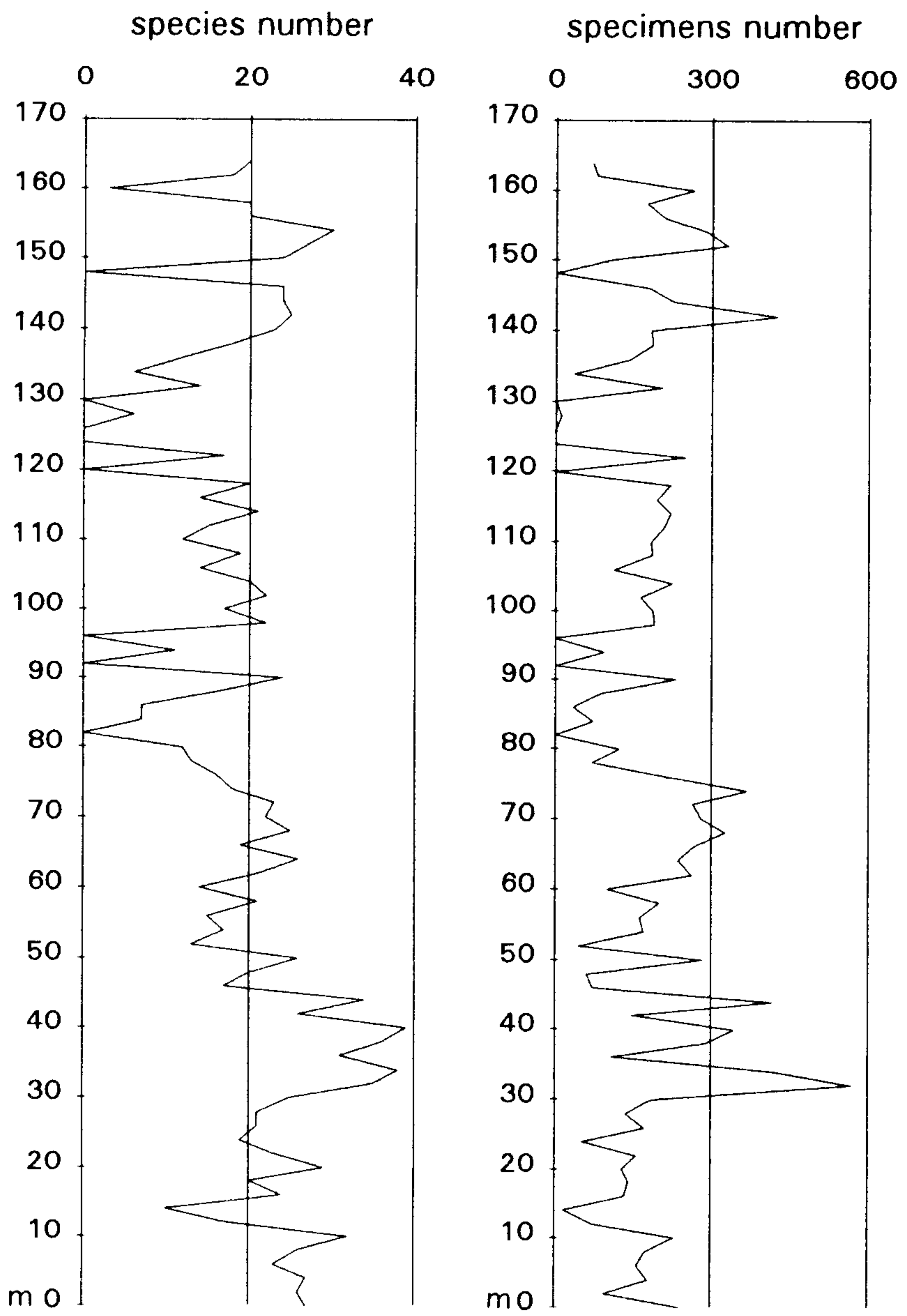
Fluctuations in Simple Species Diversity and abundance (total number of adult specimens) throughout the section show similar trends (Text-fig. 2).

There are 4 intervals which show high percentages in both number of specimens and species. The first, from 30 to 50 m shows an average of 264 specimens and 30 species per sample; the second, from 62 to 80 m has an average of 241 specimens and 20 species; the third, from 98 to 118 m, and the fourth, from 136 m to the top of the section, both show an average of 191 specimens and 18 species.

Two other intervals, however, from 82 to 96 m and from 120 to 130 m respectively, show relatively low values with some samples barren of ostracods. There are, nevertheless, two anomalous peaks for sample 46 at 90 m with 232 specimens and 24 species and sample 62 at 122 m with 249 specimens and 17 species, respectively.

2 – *The assemblages*

The most diverse and abundant assemblages are characterized by species of the genera *Agrenocythere, Argilloecia, Bythocypris, Cytherella, Henryhowella,*

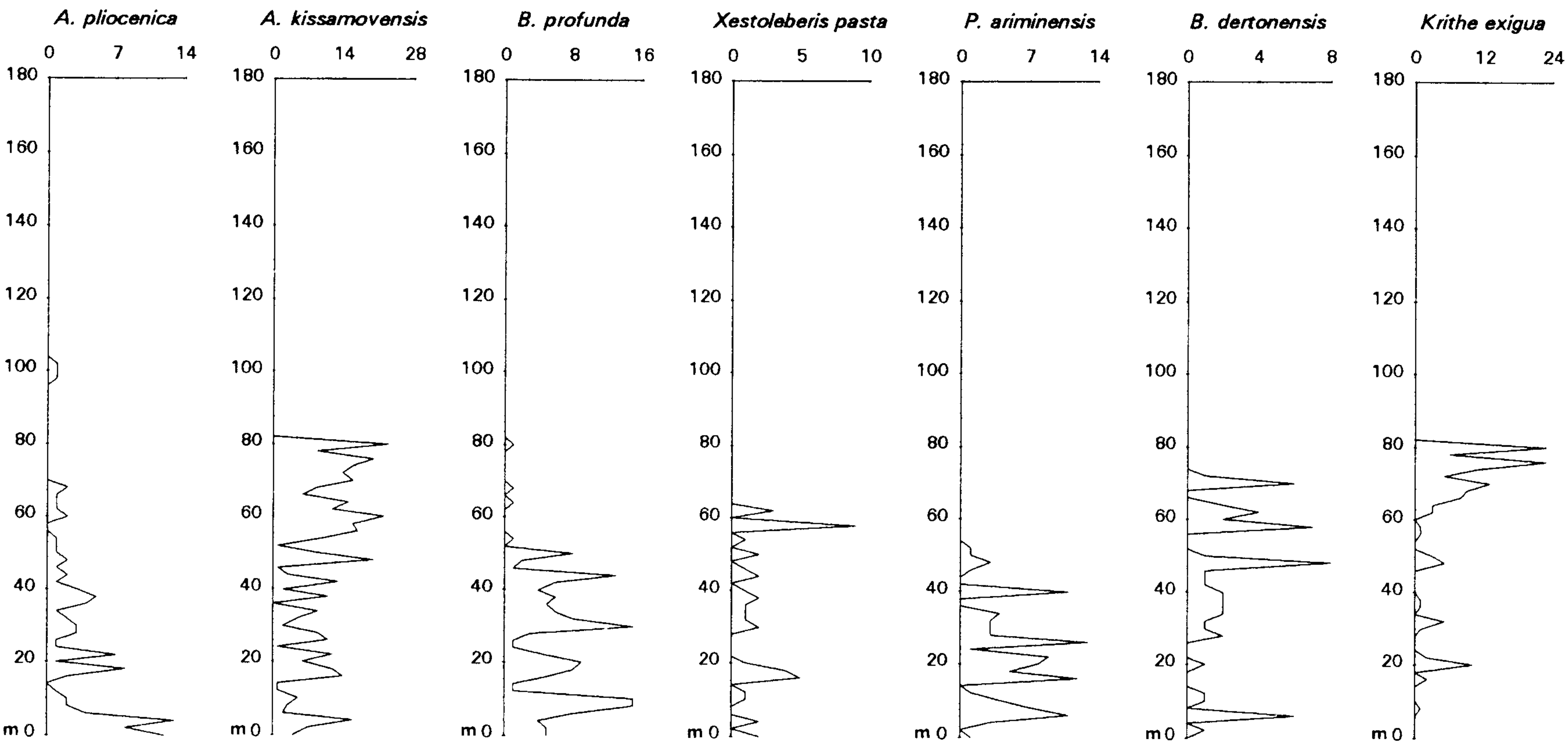


Text-fig. 2 - Distribution of the number of ostracod species and specimens through the section.

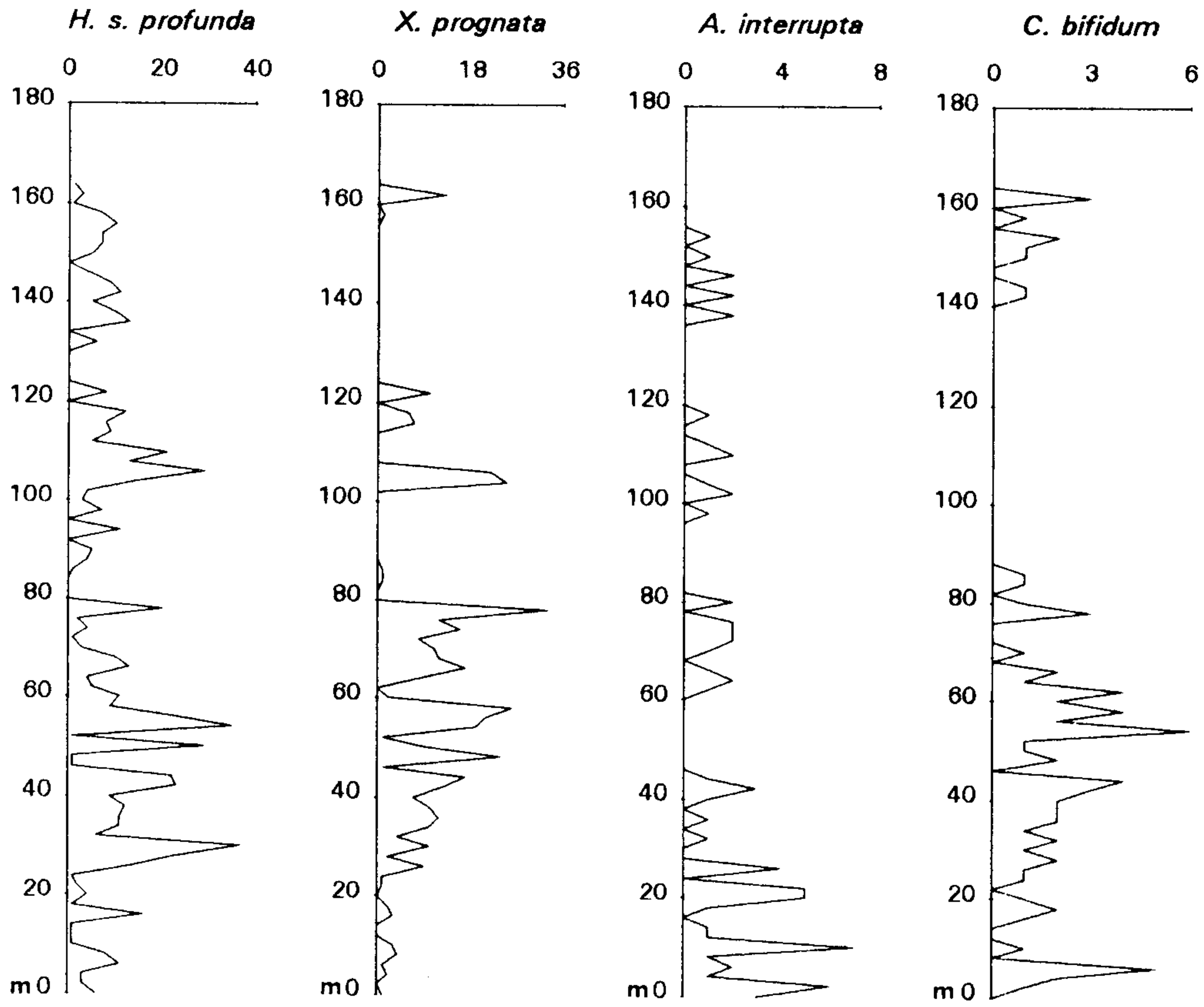
Krithe and *Xestoleberis* which confirm the palaeobathymetry of the section, previously evaluated of about 1000 m (Bonaduce & Sprovieri, 1985). *Xestoleberis* is generally a shallow water genus but few species are typical of upper bathyal environment (Abate *et al.*, 1994).

The topmost Pleistocene part of the section (corresponding to the final 10 m) is considerably contaminated by the shelf fauna. The common occurrence of shallow-water genera is recorded but not taken into consideration for palaeoenvironmental interpretation in the present paper. The shallow-water allochthonous ostracods comprise species of the following genera: *Loxoconcha, Sagmatocythere, Semicytherura, Paracytheridea, Aurila, Callistocythere, Costa, Carinocythereis, Pontocythere, Leptocythere* and *Cytheretta,* together with rare specimens of *Cyprideis.* That the palaeodepth during the early Pleistocene was Upper Bathyal is demonstrated by the occurrence of such deep-water species as *Anchistrocheles interrupta* Aiello, Barra & Bonaduce, 1996, *Cytheropteron testudo* Sars, 1869 (bathyal in the Mediterranean Sea), *Quasibuntonia radiatopora radiatopora* (Seguenza, 1880), *Retibythere (Bathybythere) scaberrima mediterranea* (Colalongo & Pasini, 1980) and by the high diversity of the genus *Krithe* which is indicative of Upper Bathyal and also deeper environment even in the Atlantic (Coles *et al.*, 1994). The contamination is possibly due to the erosion during the first Pleistocene glacial regressive phase or to tectonic activity or a combination of the two.

In the diagrams (Text-figs. 3-8) the percentage distribution throughout the section of some taxa considered to be of palaeoecological significance (see previous literature) is given.

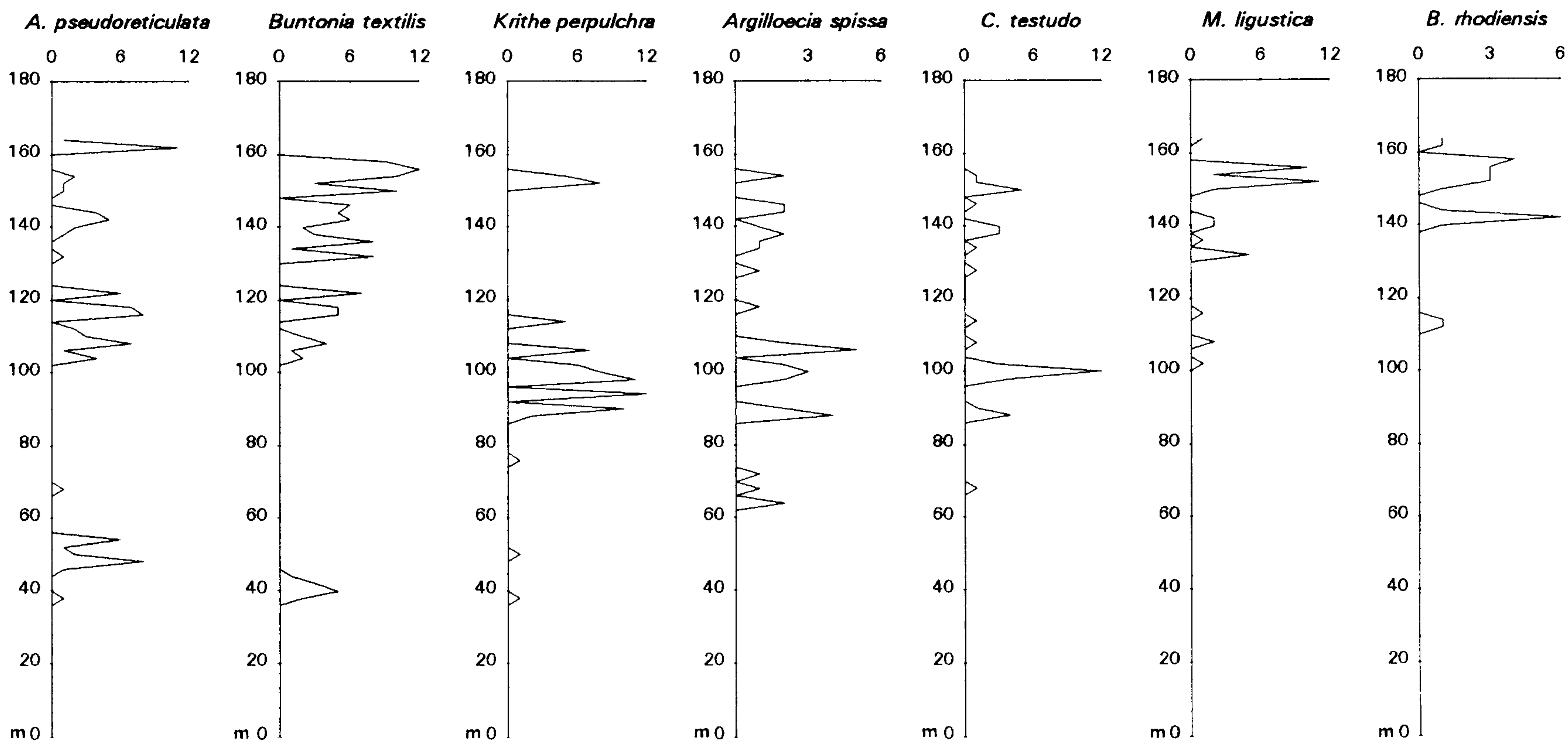


Text-fig. 3 - Abundance fluctuations of the most frequently occurring ostracod species in the section.

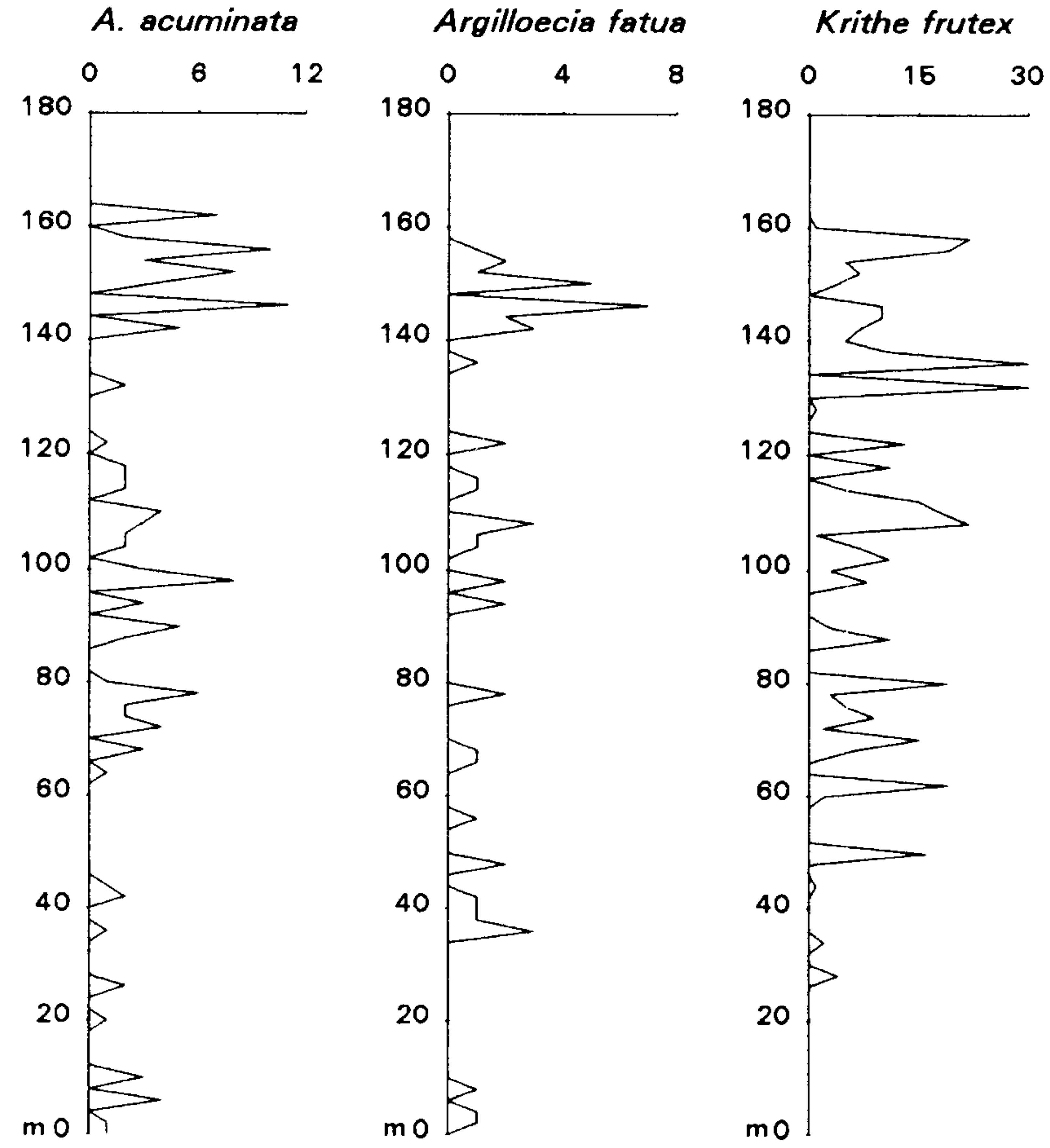


Text-fig. 4 - Abundance fluctuations of the most frequently occurring ostracod species in the section.

Agrenocythere pliocenica (Seguenza, 1880), *Argilloecia kissamovensis* Sissingh, 1972, *A. trapezium* Barra, Aiello & Bonaduce, 1997, *Bairdoppilata profunda* Aiello, Barra & Bonaduce, 2000, *Buntonia dertonensis* Ruggieri, 1954, *B. obesa* Ciampo, 1985, *Bythocypris bosquetiana* (Brady, 1866), *Cytheropteron omega* Aiello, Barra & Bonaduce, 1996, *Krithe exigua* Abate, Barra, Aiello & Bonaduce, 1993, *Paijenborchella iocosa* Kingma, 1948, *Parakrithe ariminensis* (Ruggieri, 1967) and *Xestoleberis pasta* Abate, Barra & Bonaduce, 1994, occur exclusively in the lower part of the section up to about 80 m (Text-fig. 3). In this part of the section *Anchistrocheles interrupta, Cytheropteron bifidum* Colalongo & Pasini, 1980, *Henryhowella sarsii profunda* Bonaduce, Barra & Aiello, 1999, *Parakrithe rotundata* Aiello, Barra, Abate & Bonaduce, 1993, and *Xestoleberis prognata* Bonaduce & Danielopol, 1988 are also well represented (Text-fig. 4).



Text-fig. 5 - Abundance fluctuations of the most frequently occurring ostracod species in the section.



Text-fig. 6 - Abundance fluctuations of the most frequently occurring ostracod species in the section.

Conversely, the occurrence of *Argilloecia acuminata* G.W. Müller, 1894, *A. fatua* Barra, Aiello & Bonaduce, 1996, *A. pseudoreticulata* Barra, Aiello & Bonaduce, 1996, *A. spissa* Barra, Aiello & Bonaduce, 1996, *Bosquetina rhodiensis* Sissingh, 1972, *Buntonia textilis* Bonaduce, Ciampo & Masoli, 1976, *Cytheropteron testudo, Krithe frutex* Abate, Barra, Aiello & Bonaduce, 1993, *K. perpulchra* Barra, Aiello & Bonaduce, 1993 and *Macromckenziea ligustica* (Bonaduce, Ciampo & Masoli, 1976) (Text-figs. 5-6), characterize the upper part of the section from 90 m up to the top.

DISCUSSION

The palaeoclimatic interpretation of Channell *et al.* (1992) is compared with our data. Some of the intervals defined by them correspond well to the fluctuations registered in the ostracod assemblages, while others show that the parameters responsible for the fluctuations of planktonic foraminifers do not always correspond exactly to the fluctuations of the benthic ostracods in either simple diversity or abundance.

The cool interval between 3.16 and 2.81 Ma correlates well with the first interval (from 30 to 50 m), corresponding to the range from the uppermost part of MPl4 up to the lower part of MPl5, in which the assemblages show high values in both number of species and specimens. This event corresponds to the global cooling at 3.1-3.2 Ma, well established in previous literature (Ciaranfi & Cita, 1973; Shackleton & Opdyke, 1973; Thunnell, 1979; Zachariasse & Spaak, 1983; Prell, 1984; Keigwin, 1987; *inter alios*).

The second interval, which also corresponds to an abundant and diverse ostracod fauna, between 62 and 80 m (second part of MPl5 Biozone), is correlatable with the cold events identified by Channell *et al.* (1992) and regarded as being related to the climatic changes brought about by the final build-up of the Arctic ice cap at 2.4 Ma (Zagwin, 1974; Cravatte & Suc, 1981; Shackleton *et al.*, 1984; Keigwin, 1987).

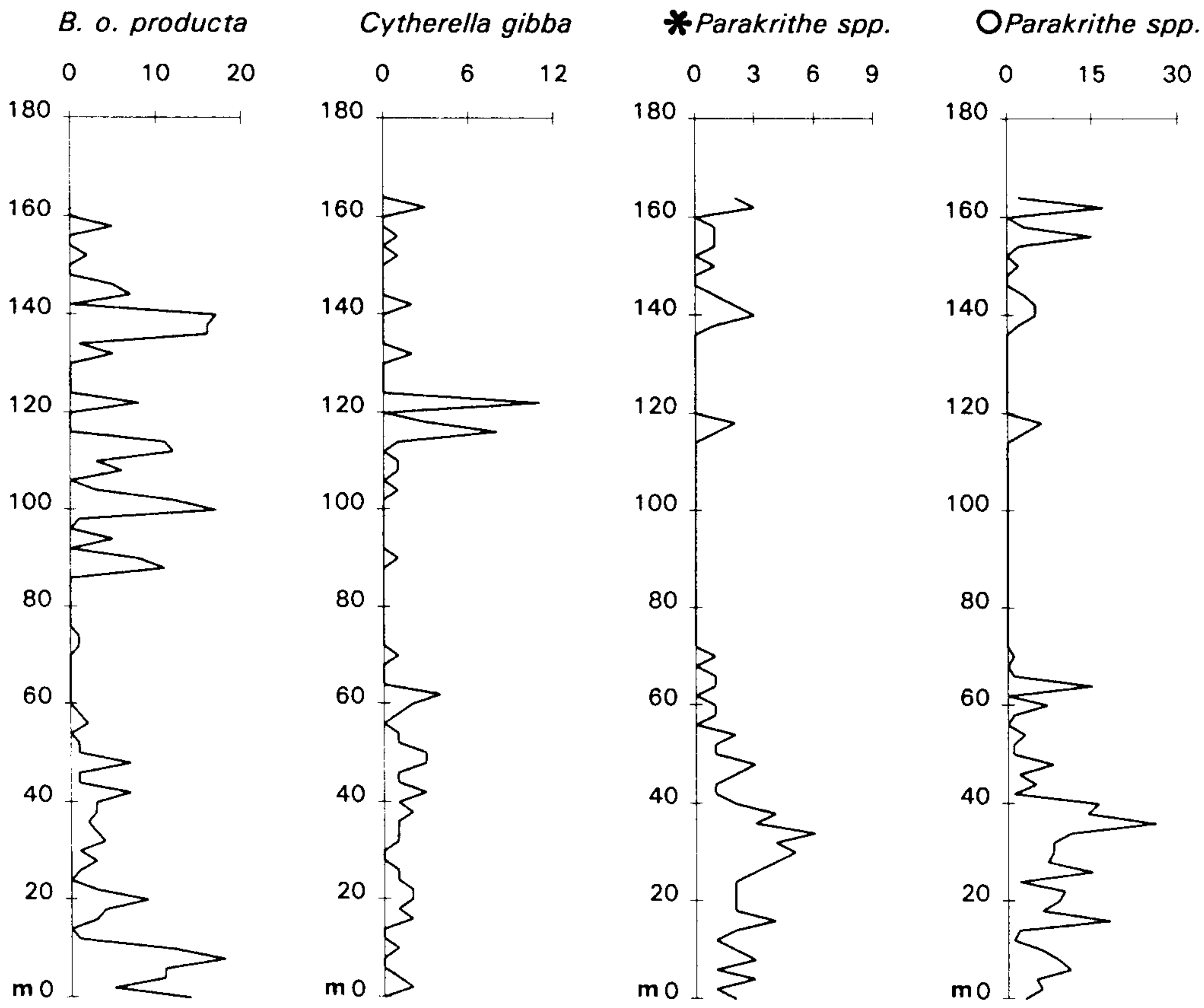
During most of the Pliocene, the deeper parts of the basin (about 1000 m deep in the studied area) were occupied by the psychrosphere, as defined by Benson (1973), fed by the Atlantic Deep Waters as demonstrated by the common occurrence of the typically psychrospheric species *Agrenocythere pliocenica* (Benson & Sylvester-Bradley, 1971; Benson, 1972; Aiello *et al.*, 2000).

The disappearance from the section of *A. pliocenica*, which occurs from the base of MPl2 (Barra *et al.*, 1998) up to the middle part of the MPl5, with random occurrences at the base of MPl6, is thought to correspond to the end of the psychrospheric environment in the area and to its gradual replacement by the thermosphere, due to the gradual change of the Mediterranean-Atlantic circulation from estuarine to antiestuarine around 2.4 Ma, in about the middle part of MPl5 (van Harten, 1984; Loubère, 1987; Rio *et al.*, 1990).

In the same interval a number of events are registered by the ostracod fauna:

- The more or less contemporaneous disappearance of *Argilloecia kissamovensis, Bairdoppilata profunda, Buntonia dertonensis, Krithe exigua, Parakrithe ariminensis* and *Xestoleberis pasta* (Text-fig. 3).
- The genus *Parakrithe, Bythocypris obtusata producta* (Seguenza, 1880) and *Cytherella gibba* Aiello, Barra, Bonaduce & Russo, 1996 are absent in the interval around 60-90 m (Text-fig. 7).
- *Anchistrocheles interrupta, Krithe compressa, K. iniqua, Paijenborchella malaiensis cymbula* Ruggieri, 1950, *Platyleberis profunda* (Breman, 1975) and *X. prognata* show more or less marked abundance peaks in the same interval (Text-figs. 4, 8).
- *Argilloecia acuminata, A. fatua, A. pseudoreticulata, A. spissa, Buntonia textilis, Cytheropteron testudo, Krithe frutex, K. perpulchra* are well represented only above about 90 m (Text-figs. 5-6), while *Bosquetina rhodiensis* and *Macromckenziea ligustica* each have their first occurrence (FO) above 100 m.

Moreover, Ciampo (1998) in his study of the Calvello basin (Basilicata, Italy), observed the last occurrence (LO) of *Parakrithe ariminensis* and *Buntonia dertonensis* between 2.6 and 2.3 Ma, which both disappear in the same interval in the present section (Text-fig. 3). This coincides with the first occurrence of many shallow-water species in the same interval, although in the Calvello Basin this may be the consequence of a local regressive phase.

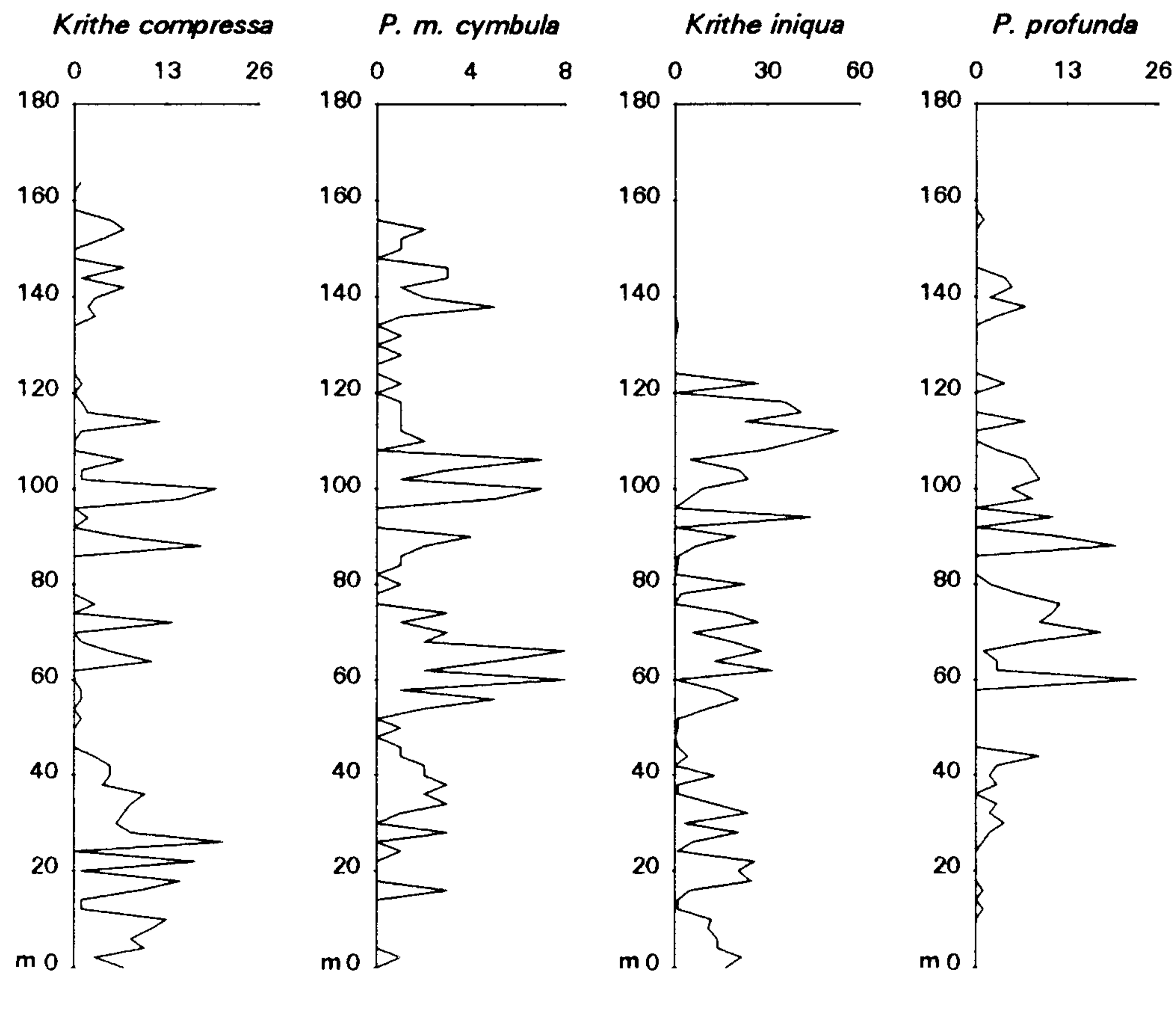


Text-fig. 7 - Abundance fluctuations of the most frequently occurring ostracod taxa in the section; * = number of species and ° = number of specimens of the genus *Parakrithe*.

From the previous data, it is evident that a turnover of ostracod species took place, beginning around 2.4 Ma, in mid MPl5 Biozone (Text-fig. 9), slightly above the base of the Gelasian stage, recently proposed by Rio *et al.* (1994).

Other authors also register the same biotic turnover in different groups of organisms (Thunell, 1981; Bonaduce & Sprovieri, 1985; Sprovieri, 1986; Sprovieri & Hasegawa, 1990).

The change in the assemblage of the deep Mediterranean at around 2.4 Ma and later seems to be the consequence of the beginning of changes in its circulation, which gradually started to modify the character of the water masses and also brought about the extinction of numerous species and the appearance of others. Consequently, the gradual disappearance of the psychrosphere is considered due to the inception of the antiestuarine circulation with the outflow of the dense Mediterranean bottom waters (Mediterranean Outflow Water) into the Atlantic and the ingress of the Atlantic surface waters into the Mediterranean (van Harten, 1984).



Text-fig. 8 - Abundance fluctuations of the most frequently occurring ostracod species in the section.

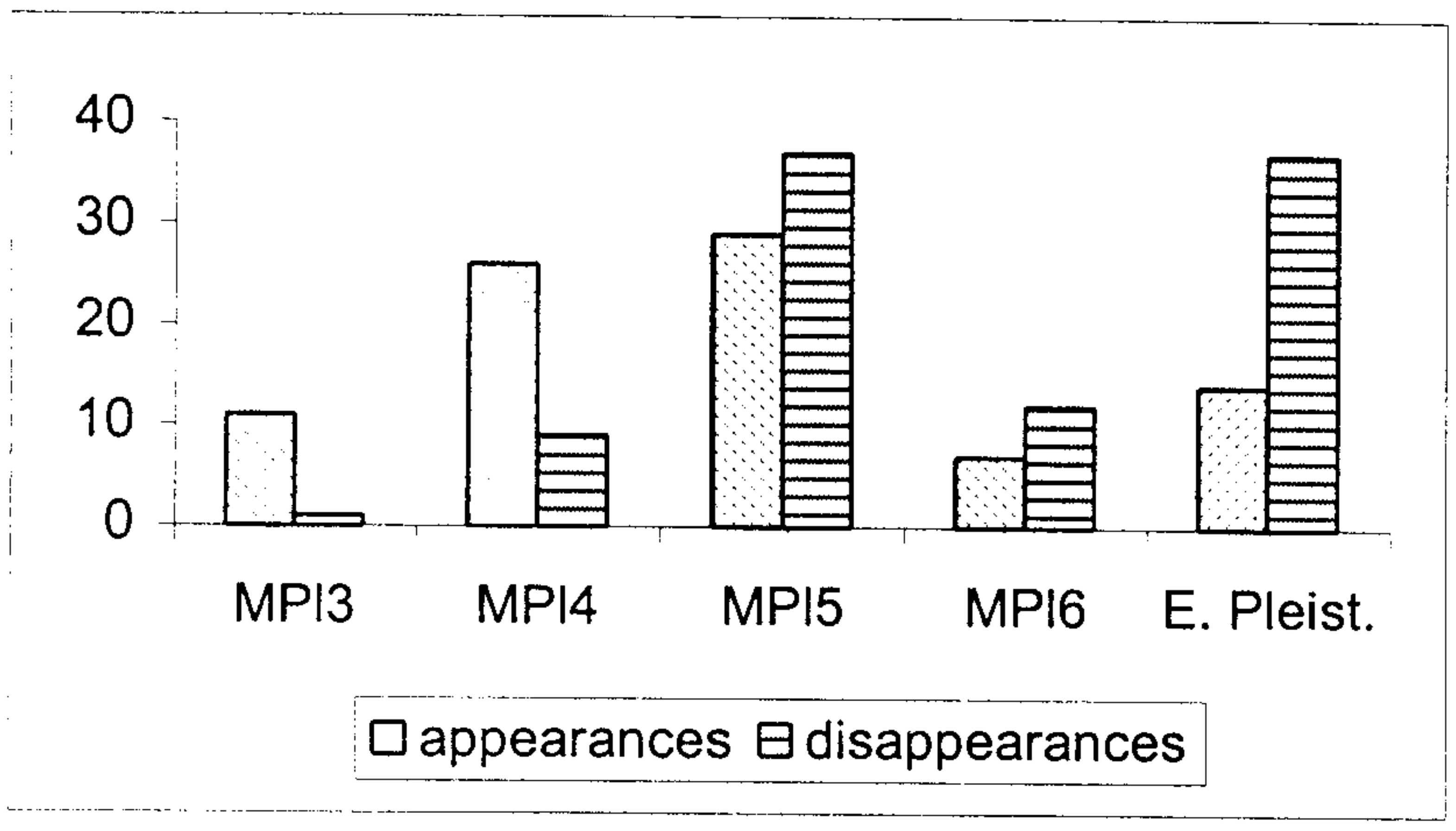
The occurrence of *A. pliocenica* in other sections up to the beginning of the Pleistocene (Greco *et al.*, 1974; Colalongo & Pasini, 1988), seems to demonstrate that up to this time the psychrosphere survived in some areas of the Mediterranean despite a reduced and disappearing influence of the cold deep-water Atlantic water masses.

The climatic instability defined by Channell *et al.* (1992) at the base of the section could be reflected in the relatively low and fluctuating values for both diversity and abundance in the ostracod fauna from the high points of MPl3 and the lower part of MPl4.

During the very warm interglacial conditions identified by Channell *et al.* (*op. cit.*) in the upper part of MPl5, between 82 and 96 m, the ostracods are less abundant in both number of specimens and species, which can be a delayed response by the benthic ostracods to the warm and more stable climatic conditions reported by the previous authors, from about 70 to 100 m.

Conversely, the beginning of the cooling intermittent phases stressed by Channell *et al.* (1992) which prelude the climatic deterioration registered at the end of the Pliocene, and the gradual progressive cooling of the surface waters in the basal part of the Pleistocene, correspond to two intervals (the first between 98 and 118 m and the second from 136 m up to the top of the section) in which the ostracod fauna is rich and abundant.

In our opinion, the relatively well established correlation between plankton and benthos in the section is not directly related to surface water temperature but is indirect and consequent to the change in the surface to bottom circulation with improving bottom ventilation and the related improvement in bottom food supply, leading to the development of a more diversified and abundant ostracod fauna. Generally during warm intervals, the water masse stratification reduces the surface to bottom circulation with consequent reduction of both food supply and oxygen at the bottom, resulting in a less diversified and less abundant ostracod fauna. This interpretation is supported by the results of Bertholon *et al.* (1998) for the Southern Adriatic trough during the last 18000 years B.P. A possibility which cannot be excluded is that the surface productivity may have been quantitatively more abundant during cold intervals and reduced during warm ones.



Text-fig. 9 - Histogram of the number of appearances and disappearances of ostracod species in the section.

With the end of the psychrosphere, the Mediterranean becomes thermospheric with bottom water temperatures influenced only by the Quaternary glacial-interglacial phases. In this interval, during the glacial phases, the deep-water ostracod assemblages are characterized by "cold" species migrating into the Mediterranean from the Atlantic (e.g. *Cytheropteron testudo, Bathycythere vanstraateni* Sissingh, 1971, *Echinocythereis echinata* (Sars, 1866), *Macropyxis adriatica* (Breman, 1975) and *Pedicythere mirabilis* Sissingh, 1975; Bonaduce & Mascellaro, 1985), while during "warm" phases the previous species disappear completely from the Mediterranean with a contemporaneous reduction in both simple species diversity and abundance.

CONCLUSIONS

From the present study of the Monte San Nicola section we are able to put forward the following conclusions:

1. The psychrosphere occurred from MPl2 to the first part of MPl6.
2. The disappearance of the psychrosphere occurs gradually at the beginning of MPl6 in the area, while in other Mediterranean section it seems to survive up to the early Pleistocene (Ruggieri, 1953; Colalongo & Pasini, 1980; 1988).
3. The turnover of ostracod species supports the hypothesis of a change in Mediterranean circulation from estuarine to antiestauarine from around 2.4 Ma onward.
4. The temperature of the bottom waters during most of the Pliocene was not influenced by the temperature of the surface waters and, consequently, the fluctuations of ostracod populations seem to correlate well with dissolved oxygen and food supply.
5. From the generally well diversified and relatively abundant ostracod fauna in the studied section we suggest that the deep bottom waters were well ventilated and sufficiently rich in food supply. This supports our contention that bottom water circulation in the Mediterranean fed by the Atlantic inflow and by its own surface-bottom circulation, although subject to fluctuations, was quite adequate to support a rich and diverse fauna.

ACKNOWLEDGEMENTS

We are deeply indebted to Prof. Franca Sgarrella, University of Naples, for the discussions on palaeoceanography and for the detailed comments and criticism on the first draft of this manuscript.

Research supported by MURST 60% (resp. G. Bonaduce).

REFERENCES

AIELLO, G., BARRA, D. & BONADUCE, G., 2000, Systematics and biostratigraphy of the ostracoda of the Plio-Pleistocene Monte S. Nicola section (Gela, Sicily): Boll. Soc. Paleont. Ital., 39 (1): 83-112.

BARRA, D., BONADUCE, G. & SGARRELLA, F., 1998, Paleoenvironmental bottom water conditions in the early Zanclean of the Capo Rossello area (Agrigento, Sicily): Boll. Soc. Paleont. Ital., 37 (1): 61-88.

BENSON, R. H., 1972, The *Bradleya* Problem with descriptions of two new psychrospheric ostracode genera, *Agrenocythere* and *Poseidonamicus* (Ostracoda: Crustacea): Smiths. Contr. Paleobiol., 12: 1-138.

—, 1973, Psychrosphaeric and continental ostracoda from ancient sediments in the floor of the Mediterranean. *In* Ryan, W. B. F., Hsü, K. J. *et al.* (eds.), Init. Repts. DSDP, Washington (U.S. Govt. Printing Office), 13 (2): 1002-1008.

— & SYLVESTER-BRADLEY, P. C., 1971, Deep-sea ostracodes and the transformation of ocean to sea in the Tethys: Bull. Centre Rech. Pau, SNPA, 5: 63-91.

BERTHOLON, L., ABATE, S., PEYPOUQUET, J. P., BONADUCE, G. & JORISSEN, F., 1998, Ostracods as indicators of the variable intensity of downwellings in Adriatic, during 18000 y. B.P. *In* Crasquin-Soleau, S., Braccini, E. & Lethiers, F., (eds.) Proc. 3rd Europ. Ostracod. Meeting, Paris 1996: Bull. Centre Rech. Elf Explor. Prod., Mém. 20: 402.

BONADUCE, G. & MASCELLARO, P., 1985, Ostracoda. *In* Moncharmont-Zei, M., Russo, B., Sgarrella, F., Bonaduce, G. & Mascellaro, P., Paleoclimatic record from 4 cores (Gulf of Taranto, Ionian Sea), evidence from Foraminifera and Ostracoda: Boll. Soc. Paleont. Ital., 23 (1): 21-51.

— & SPROVIERI, R., 1985, The appearance of *Cytheropteron testudo* Sars (Crustacea, Ostracoda) is a Pliocene event. Evidences from a sicilian sequence (Italy): Boll. Soc. Paleont. Ital., 23 (1): 131-136, 2 pls.

CHANNELL, J. E. T., DI STEFANO, E. & SPROVIERI, R., 1992, Calcareous Plankton Biostratigraphy, Magnetostratigraphy and Paleoclimatic History of the Plio-Pleistocene Monte San Nicola Section (Southern Sicily): Boll. Soc. Paleont. Ital., 31 (3): 351-382.

CIAMPO, G., 1998, Ostracoda from the Lower Pliocene – Lower Pleistocene of the Calvello Basin. *In* Crasquin-Soleau, S., Braccini, E. & Lethiers, F., (eds): Bull. Centre Rech. Elf Explor. Prod., Mém. 1, 20: 305-315.

CIARANFI, N. & CITA, M. B., 1973, Paleontological evidence of changes in the Pliocene Climates. *In* Ryan, W.B.F., Hsü, K.J. *et al.*, Init. Repts. DSDP, (U.S. Govt. Printing Office), 13: 1387-1399.

COLALONGO, M. L. & PASINI, G., 1980, La ostracofauna plio-pleistocenica della Sezione Vrica in Calabria (con considerazioni sul limite Neogene/Quaternario): Boll. Soc. Paleont. Ital., 19 (1): 44-126.

— & —, 1988, Ostracofauna plio-pleistocenica batiale rinvenuta nel Pozzo 654A dell'ODP Leg 107 (Mare Tirreno occidentale): Boll. Soc. Paleont. Ital., 27 (3): 277-289, pl. 1.

COLES, G. P., WHATLEY, R. C. & MOGUILEVSKY, A., 1994, The ostracod genus *Krithe* from the Tertiary and Quaternary of the North Atlantic: Paleontology, 37 (1): 71-120, 7 pls.

CRAVATTE, J. & SUC, J. P., 1981, Climatic evolution of north western Mediterranean area during Pliocene and early Pleistocene by pollen analysis and foraminifera of drill AUTAN 1. Chronostratigraphic correlation: Pollen and Spores, 23: 247-258.

GRECO, A., RUGGIERI, G. & SPROVIERI, R., 1974, La sezione Calabriana di Monasterace (Calabria): Boll. Soc. Geol. It., 93: 151-179.

KEIGWIN, L., 1987, Pliocene stable isotope record of Deep Sea Drilling Project Site 606: sequential events of ^{18}O enrichment beginning at 3.1 MA. *In* Ruddiman, W., Kidd *et al.*, Init. Repts. DSDP, 94: 911-920.

LOUBERE, P., 1987, Changes in mid-depth North Atlantic and Mediterranean circulation during the Late Pliocene. Isotopic and sedimentological evidence: Mar. Geol., 77: 15-38.

PRELL, W., 1984, Covariance patterns of foraminiferal $\delta^{18}O$:An evaluation of Pliocene ice volume changes near 3.2 milion years ago: Science, 226: 692-693.

RIO, D., SPROVIERI, R. & DI STEFANO, E., 1994, The Gelasian Stage: a proposal of a new chronostratigraphic unit of the Pliocene series: Riv. It. Paleont. Strat., 100 (1): 103-124.

—, —, THUNELL, R., VERGNAUD GRAZZINI, C. & GLAÇON G., 1990, Pliocene – Pleistocene paleoenvironmental history of the Western Mediterranean: A synthesis of ODP site 653 results. *In* Kastens, K.A., Mascle, J. *et al.* (eds.), Proc. ODP, Sci. Results, 107: 695-704.

RUGGIERI, G., 1953b, Età e faune di un terrazzo marino sulle coste ioniche della Calabria: Giorn. Geol., 23: 20-168.

SHACKLETON, N. J. & OPDYKE, N. D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 105 year and 106 year scale: Quat. Res., 3: 39-55.

—, BACKMAN, J., ZIMMERMAN, H. B., KENT, D. V., HALL, M. A., ROBERTS, D. G., SCHNITKER, D., BALDAUF, J. G., DESPRAIRES, A., HOMRIGHAUSEN, R., HUDDLESTUN, P., KEENE, J. B., KALTENBACK, A. J., KRUMSIEK., K. A. O., MORTON, A. C., MURRAY, J. W. & WESTBERG-SMITH, J., 1984, Oxygen isotope calibration of the onset of ice-rafting and the history of glaciation in the North Atlantic region: Nature, 307: 620-623.

SPROVIERI, R., 1986, Paleotemperature changes and speciation among benthic Foraminifera in the Mediterranean Pliocene: Boll. Soc. Paleont. Ital., 24 (1): 13-21.

— & HASEGAWA, S., 1990, Plio-Pleistocene benthic foraminifer stratigraphic distribution in the deep-sea record of the Tyrrhenian Sea (ODP Leg 107). *In* Kastens, K.A., Mascle, J. *et al.* (eds.), Proc. ODP, Sci. Results, 107: 429-459.

THUNELL, R., 1979, Climatic evolution of the Mediterranean Sea during the last 5.0 milion years: Sediment. Geol., 23: 67-79.

—, 1981, Cenozoic paleotemperature changes and planktonic foraminiferal speciation: Nature, 289: 670-672.

VAN HARTEN, D., 1984, A model of estuarine circulation in the Pliocene Mediterranean based on new ostracode evidence: Nature, 312: 359-361.

ZACHARIASSE, W. J. & SPAAK, P., 1983, Middle Miocene to Pliocene paleoenvironmental reconstruction of the Mediterranean and adjacent Atlantic Ocean: planktonic foraminiferal record of southern Italy: Utrecht Micropaleont. Bull., 30: 91-110.

ZAGWIJN, W. H., 1974, The Pliocene – Pleistocene boundary in western and southern Europe: Boreas, 3: 75-97.

(manuscript received June 30, 1999
accepted April 5, 2000)

Gioacchino BONADUCE
Diana BARRA
Giuseppe AIELLO

Dipartimento di Scienze della Terra
Università di Napoli "Federico II"
Largo S. Marcellino 10, 80138 Napoli, Italia