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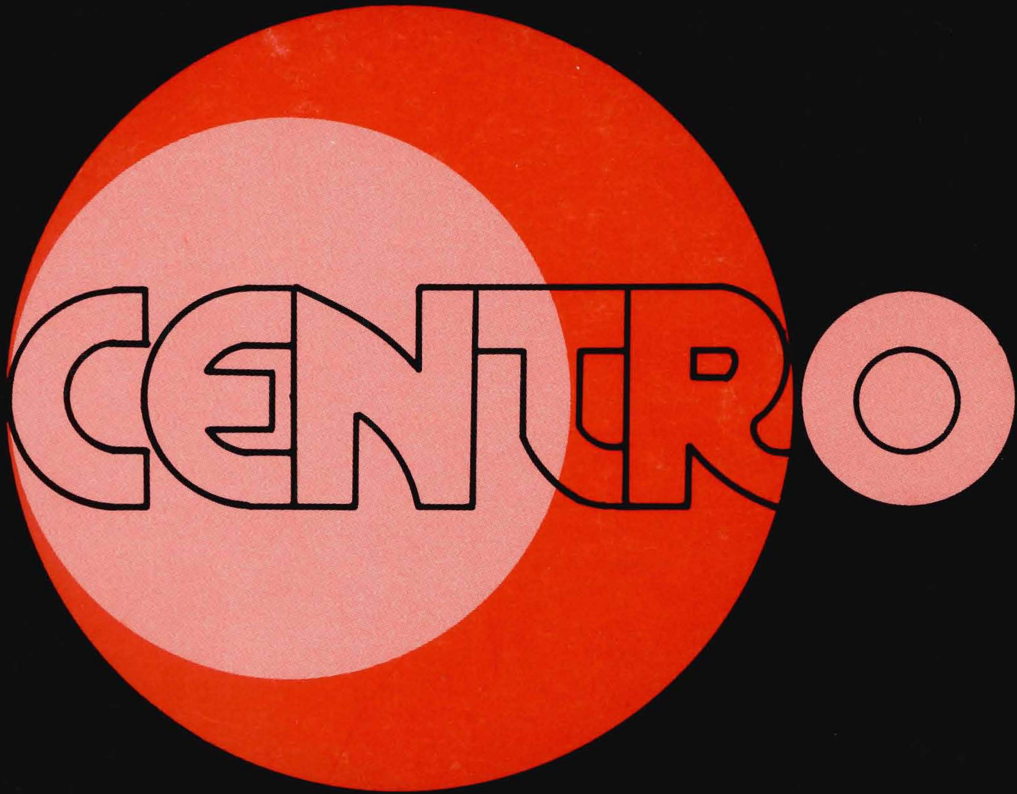

# CENTRO

AN INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
IN THE MEDITERRANEAN

UNIVERSITY OF MALTA

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On the same lines as previous editions, this third issue of CENTRO provides an opportunity for researchers on environmental issues in the Mediterranean, and especially the central Mediterranean region, for presenting their work to an international readership. Each of the papers presented here reflects the high quality of scientific work being carried out in the region within the bounds of traditional fields of science. Considering the role of this journal in disseminating this type of work, one would agree that CENTRO has obtained a measure of success. On the other hand, recalling that one of the major objectives of CENTRO is to promote an integrated approach towards the study of the region, this third issue indicates that there is still a long way to go before this objective can be achieved.

To reiterate our position, we share the belief that environmental issues are multi-disciplinary in nature and that as such any effort to analyze them should be equally multi-disciplinary in approach. The constraints imposed on our way of thinking by traditional educational systems which classify knowledge into rigid and compartmentalized subject areas must be overcome. However, the effort required to do so should not be underestimated. It is in this respect that one can say that CENTRO has not made any headway in providing a multi-disciplinary approach to environmental issues which are of concern to the region. This state of affairs indicates that a different strategy may be required; one that could guide us more effectively towards the achievement of our objectives.

Therefore as from next issue we hope to be able to treat some single topic of interest from various perspectives and still avoid being superficial in our treatment. This may be the way to ensure a useful service to our increasing list of subscribers.

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# The Għar Lapsi limestones: sedimentology of a Miocene intra-shelf graben

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## ABSTRACT

The Għar Lapsi succession of west Malta developed during a Late Tortonian – Early Messinian episode of tectonism associated with the Magħlaq Fault Zone. These syntectonic strata, *Porites* coral bioherms bioclastic packstones and wackestones, debris flow deposits and calciturbidites form a prism banked against the southwest-facing fault-line but are absent from the island of Filfla which lies about 4.5km to the west.

Faunal correlation is imprecise; however, the macrofaunas and general foraminiferal microfaunas of the *Porites* bioherm show it to be correlated with the Tal-Pitkal Member (Late Tortonian). The overlying calciturbidites and debris flow deposits are part of the Ġebel Imbark Member (Early Messinian).

These strata are part of a half-graben fill which cuts the Miocene shelf between Filfla and the present Magħlaq cliffs of Malta. The absence of planktonic Foraminifera from the graben fill sequence and low percentages recorded from strata on Filfla island confirm that this structure was intra-shelf in origin rather than a shelf edge feature.

Calciturbidite laminites and debris flow deposits, developed during the Lower Messinian, were deposited during a eustatic fall of Mediterranean sea-level concomitant with the Lower Evaporite Complex of Sicily.

## Introduction

The central Mediterranean island of Malta is composed of a sub-horizontal Oligocene and Miocene succession (Felix, 1963; Giannelli and Salvatorini, 1975) terminated by the Upper Coralline Limestone Formation (Pedley, 1978).

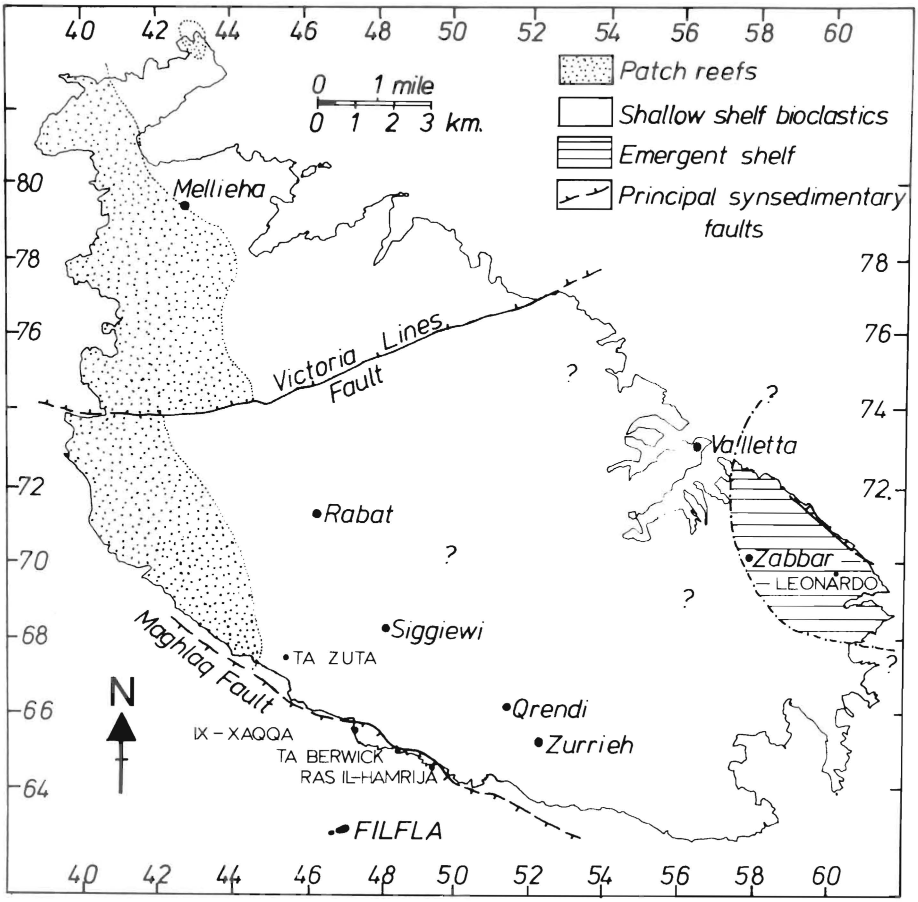

**Fig. 1.** Map of the island of Malta showing the location of the principal towns, outcrops and faults. The general lithofacies distributions and patch-reef associations are also indicated.

Syndepositional tectonism has exerted a fundamental control upon facies distributions within the islands, but nowhere more so than in the Upper Coralline Limestone Formation. The principal outcrops of Late Tortonian-Early Messinian Upper Coralline Limestone strata lie in the western and northern areas of the island (Pedley, 1983). Additionally, several small outliers of similar aged strata occur in south and central Malta and provide sufficient information to permit a reconstruction of deposits long since removed. These are:

*1. Għar Lapsi outlier (Fig. 1, Ix-Xaqqa ta' Ras il-Ħamrija sections)*

A 2.3km long coastal outlier, about 0.8km at its widest and bounded on its landward side by the Magħlaq Fault with a calculated throw of about 203m (Pedley *et al.*, 1976). Sediments consist of shallow marine carbonates, including a reefal and thick resediment sequence. Although dislocated by fractures, a full sequence is developed from Blue Clay Formation to top Upper Coralline Limestone Formation.

*2. Filfla Islet outlier (Fig. 1)*

An Upper Coralline Limestone stack lying 4.5km offshore to the southwest of Malta, consisting of shallow shelf wackestones and packstones succession lying over about 15m of Blue Clay Formation.

*3. San Leonardo outlier, east of Żabbar (Fig. 1)*

A peritidal sequence of uncertain Late Miocene age containing charophytes and hydrobid gastropods (Pedley and Waugh, 1976). It lies unconformably on *Globigerina* Limestone Formation (Lr. Miocene).

Past studies of these outliers are few. Trechmann (1938), gave some account of the Quaternary geology around Għar Lapsi and the lithostratigraphies of each were outlined in Pedley *et al.* (1976); Pedley (1978). Consideration was given to regional structural aspects including the Magħlaq Fault by Illies (1981); Reuther (1984a, 1984b).

The unique lithostratigraphy of the Għar Lapsi outlier is the subject of this paper. The outlier, though small, is the only part of an extensive Central Mediterranean Pantelleria rift system currently to be exposed. As such it provides an insight into syntectonic depositional processes associated with the rift development. Furthermore, the youngest parts of the deposit record a Late Miocene emergence better than that seen in any other Maltese locality.

## General Regional Lithostratigraphy

Before embarking on a consideration of local stratigraphies, it is important to make reference to the Upper Coralline Limestone shelf succession common to the Maltese Islands. This is provided in the Ta' Żuta cliffs, which lie about 3.4km west of Siġġiewi (Figs. 1 and 2), at the south end of the Rabat Plateau.

*1. Ta' Żuta, Rabat Plateau (Fig. 1 and 2)*

a) *Mtarfa Member:* The oldest Upper Coralline Limestone unit is the Mtarfa Member (16m) which contains, at its base, a thin laminar micrite bed unique to the locality (The Fawwara Fish Bed, Pedley, 1978). The glauconitic Greensand Formation lies at the base of the fish bed.

The main body of the member comprises a lower cream coloured wackestone and packstone shelf sequence with a full marine fauna including scattered planktonic foraminiferids (Ġebel Mtarfa Beds), and an overlying white wackestone and packstone sequence containing fewer fossils and no planktonics (Rdum il-Ħmar Beds of Pedley, 1978). Both beds are massive and, other than ubiquitous bioturbation, generally lack sedimentary structures. Ripple lamination occurs in the upper part of the Rdum il-Ħmar Beds.

b) *Tal-Pitkal Member:* The Tal-Pitkal Member conformably overlies the Mtarfa Member. This shallow shelf sequence developed progressively upwards into coarse grained bioclastic packstone with an abundant marine fauna and coralline algae content. At Ta' Żuta (a typical example of the eastern facies) reefs are absent, however, in more northwesterly outcrops *Porites* patch-reefs are common in the upper part of the Member.

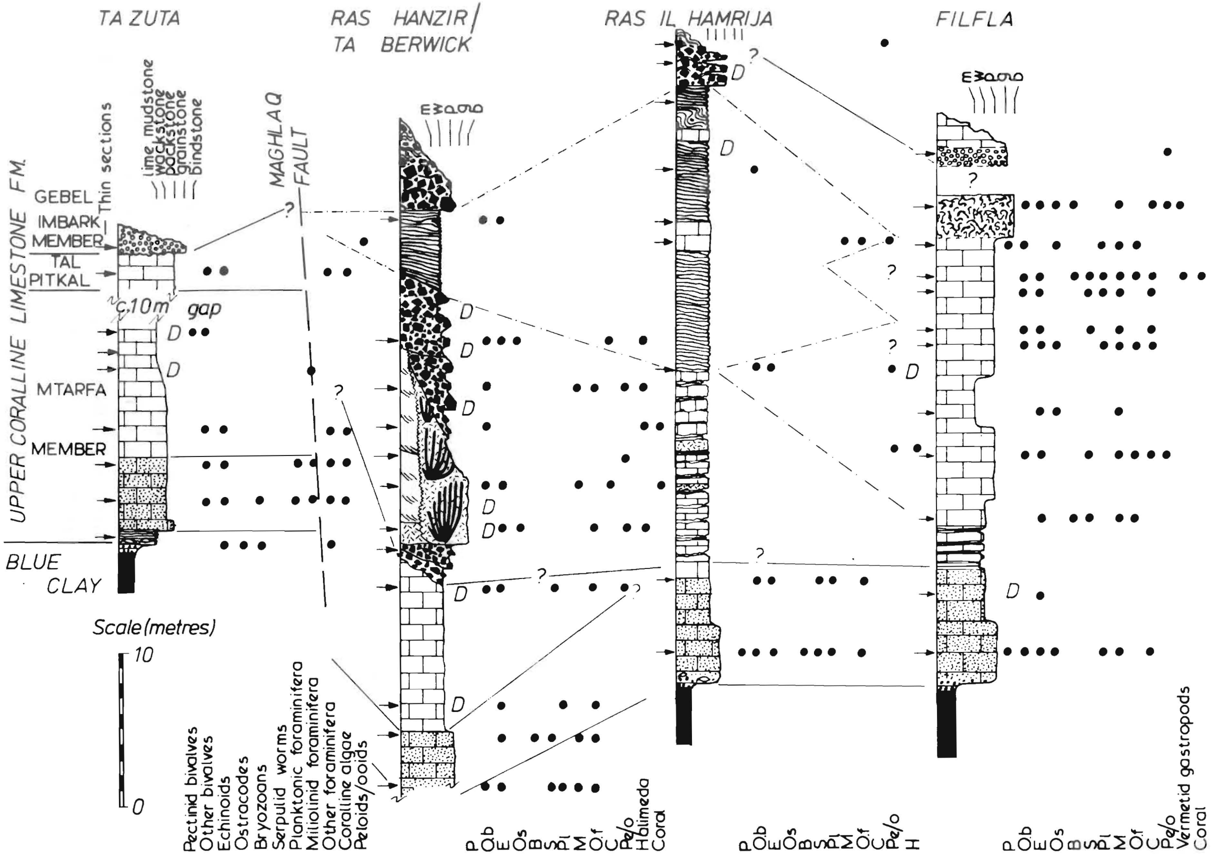

**Fig. 2.** Bar columns taken from each of the main outcrops of the Upper Coralline Limestone Formation (See Fig. 1 for localities). Solid lines indicate correlation of members listed on the left hand side of the figure. Heavy broken line is the principal fracture of the Magħlaq Fault. Chains of dots and dashes show internal correlation of the Għar Lapsi succession. D indicates dolomitization (usually microdolomite). Small arrows (left side of columns) are sample points with generalized thin-section data plotted opposite on the right side of the column. Note the presence of miliolinid Foraminifera throughout all columns and presence of planktonic forams, generally in the base of the Mtarfa Member only, except in the Filfla section.

c) *Ġebel Imbark Member:* The top of the Tal-Pitkal beds is truncated by an intraformational erosion surface, and ooidal grainstones of the Ġebel Imbark Member overlie the hiatus directly. About 3m of these are preserved locally. Slightly younger micritic strata of restricted shallow water aspect overlie the oolites in northern Malta but not in the Rabat Plateau area.

**Lithostratigraphy of Other Outliers**

The following two outliers show contemporaneous strata developed SW of the Magħlaq Fault.

*1. Filfla Islet (Fig. 1 and 2)*

The Ġebel Mtarfa Beds (about 7m thick and with a glauconitic base) are similar to those in the Ta' Żuta section and consist of massive bedded cream wackestones (stippled lower part to Mtarfa Member in Fig. 2). The overlying Rdum il-Ħmar Beds (about 11m thick) are massive bedded white non-ferroan wackestones and mudstones containing an abundant lucinid and cardiid bivalve fauna (moulds and casts).

The Tal-Pitkal Member conformably overlies the Mtarfa Member. It is represented by about 11m of pale grey packstones and is terminated by about 3m of serpulid biostrome. The latter probably correlates with patch-reefs in the Tal-Pitkal member of the Rabat Plateau (see Pedley, 1979, 1983).

The Ġebel Imbark Member (only seen in fallen blocks) appears to be represented by about 2m of typical, white ooidal grainstone lying with sharp contact close above the serpulid biostrome. Other elements of the member were not accessible for sampling. The similarity between the Filfla and Ta' Żuta successions, therefore, is strong.

*2. Għar Lapsi Outlier*

Carbonates in this outlier, in contrast, become highly variable above the recognisable Mtarfa Member. The beds are best considered by locality as many are hitherto undescribed and their relative ages are not always clear.

(a) *Ras il-Ħamrija* (Fig. 1): This most southeasterly outcrop gives the following succession: The Mtarfa Member (15m) is of standard type. The lowest beds (Ġebel Mtarfa Beds) consist of massive bedded, cream to yellow wackestones and packstones. At their base is a glauconitic streak and a transitional contact with the underlying Blue Clay Formation. The member contains pectinids, small bryozoan colonies and *Terebratula* at its base *(Terebratula-Aphelesia* Bed of Pedley, 1976) but macrofaunas become sparse higher in the member. The transitionally overlying Rdum il-Ħmar Beds are atypical. Their lowermost massive bedded nature gives way higher in the sequence to thinner beds of pale grey carbonate mudstones and wackestones, finally grading upwards into laminated mudstones. These have previously been described as the Għar Lapsi beds (Pedley, 1978) and to avoid confusion with previous discussions they will hereafter be addressed as 'mudstone laminites'. Although faunas are sparse, *Halimeda* plates abound at a few levels towards the top.

The Tal-Pitkal Member cannot specifically be identified here. In its place the mudstone laminites (about 20m thick) are developed above the Mtarfa Member. Individual laminae range from 30mm to 10mm in thickness and often comprise 1m thick laminaset units. Contorted beds occur on the north side of Ras il-Ħamrija and

Fig. 3. View looking SE from near Għar Lapsi, of the Ta' Berwick cliff section, with the Ras il-Ħamrija peninsula in the distance. See Fig. 4 for explanation of lithologies present.

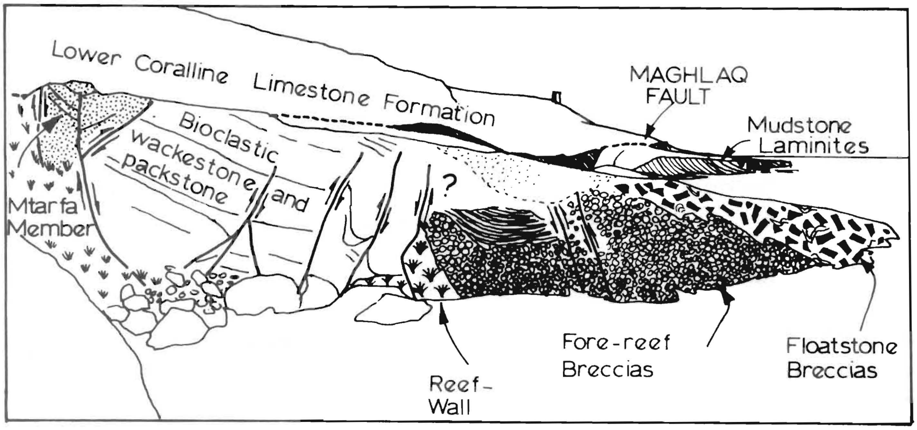

Fig. 4. Detail of the view in Fig. 3 illustrating the distribution of named units and local faulting within the succession. Note the dominance of fore-reef talus versus *in situ* reef and the rapid lateral facies changes in the section. Height of Ta' Berwick cliffs about 18m.

small ripples with northwest orientated crests occur on mudstone laminite bedding planes. Other bedding surfaces carry disarticulated lucinid bivalves with convex-up orientations. No other macrofaunas occur.

Lithoclast floatstone breccias (about 3m preserved) occur above a sharp truncation surface terminating the mudstones. The floating clasts are principally of dolomitized laminated mudstone supported in a bioclast-rich, undolomitized matrix. Other clasts show soft sediment deformation and deformed laminae are common. Thin micritic levels occur towards the preserved top of the breccias. Pedley (1978) records porcellanous micrites and birds-eye textures from this level.

(b) *Ta' Berwick, Ras Ħanżir and Għar Lapsi* (Fig. 1): Collectively, these centrally located localities, though tectonically disturbed, preserve a readily identifiable Mtarfa Member (about 15m thick). This consists of a lower, cream coloured wackestones and packstones sequence, ascribable to the Ġebel Mtarfa Beds, and overlying pale-grey, chalky but massive bedded Rdum il-Ħmar Beds. An arbitrary upper limit to the Mtarfa Member is provided by a step-faulted surface near Għar Lapsi above which occur *Halimeda* gravels and a reefal succession. At Għar Lapsi a considerable thickness of reef breccias appears to underlie an *in situ Porites* reef. The Ta' Berwick sequence is representative of this part of the outlier (see Figs. 2 and 3).

A *Porites* reef, developed directly on the Rdum il-Ħmar Beds (Mtarfa Member), is restricted in occurrence to these localities. It consists of *in situ* and part rotated blocks of pale-grey, tough wackestone, containing *Porites* coral growths (organ-pipe growth-form, cf. Grasso and Pedley, in press). The unit is up to 10m in thickness. The coral rods are 1.5-2m long and 30-50mm diameter. A maximum visible development of about 5m of standing reef wall is present, though smaller *in situ Porites* patch-reefs are developed higher in the reef breccias west of Għar Lapsi.

On the north side of this coral reef-wall occurs a well bedded to cross-stratified bioclastic and ooidal wackestone and packstone (rarely grainstone) sequence (here about 10m thick). This sequence abuts the north side of the reef wall, with vertical contact immediately east of Għar Lapsi (see Figs. 2 and 3). On the south side of the reef wall occur poorly bedded *Porites* reef breccias which dip crudely towards the south. The thickness of the breccias varies according to locality and at outcrop are distributed lateral to the observable reef-wall (Ta' Berwick), below and above it (Għar Lapsi) and at times only above it (Ras Ħanżir). A thin development of mudstone laminites (about 4m thick) is seen above the breccias at Ta' Berwick.

Lithoclast floatstone breccias cap the sequence with sharp underlying contact. Over 6m are preserved and are identical to those at Ras il-Ħamrija. A tough micritic capping level near Għar Lapsi contains both calcrete and rhizocretion fabrics (see later).

(c) *Ix-Xaqqa* (Fig. 1): At the extreme west end of the outlier occurs a thick (>25m) bioclastic development arranged in wedging sets of planar-bedded units, each 0.5-4m thick. The base of the sequence is not seen and the cliff line exposures are mainly inaccessible. Samples from the top of the outcrop suggest the entire succession to be composed of wackestones and packstones, sometimes *Halimeda*-rich or with abundant ooids and peloids. Offshore observation indicates that the wedging sets become more complex and total unit thickness becomes greater towards the Magħlaq fault-line.

## Petrogaphic Interpretation of the Għar Lapsi Outlier Lithologies

### 1. *Mtarfa Member*

The Ta' Berwick and Ras il-Ħamrija sequences are closely comparable to the Ta' Żuta succession with an abundance of bivalve moulds, echinoid plates, bryozoan debris and foraminiferids. Pectinid debris and planktonic Foraminifera are restricted to the basal cream coloured wackestones and packstones (Ġebel Mtarfa Beds) which, at Ras il-Ħamrija, carry detrital glauconite and *Terebratula* sp. immediately above their contact with the Blue Clay Formation. The pale-grey upper beds (equivalent to the

Rdum il-Ħmar beds at Ta' Żuta) are typically wackestones with fewer and smaller bioclasts. These are now moulds. The entire member is composed of non-ferroan calcite.

The Filfla developments are also similar but differ in that planktonic Foraminifera generally occur throughout the member, albeit rather sparsely.

### 2. *Porites reef*

The rock consists principally of micrite providing an interstitial fill, but scattered mollusc moulds and *Halimeda* plates are common. *Porites* colonies (now moulds) are the only observable framework. Around Għar Lapsi the reef grades laterally northwards into *Halimeda* packstones. Most of the reefoid strata is now non-ferroan dolomite. The fabric is very comparable to that of patch-reefs within the Tal-Pitkal Member of north Malta described by Pedley (1979).

### 3. *Porites reef breccias*

These are petrologically identical to the *Porites* wall strata. Clast sizes vary from sub-millimetre up to 0.3m. Interstitial matrix is minimal but bioclastic packstone may be present. Most of the reef material is now dolomicrospar.

### 4. *Bioclastic packstones and grainstones*

These strata comprise the majority of the poorly accessible Ix-Xaqqa sections and the cross-stratified strata north of the *Porites* reef-wall. Bioclastic debris is often well rounded and ooidal levels are common. *Halimeda* packstones are interspersed throughout the sequence. Non-ferroan carbonates appear to dominate.

### 5. *Mudstone laminites*

The laminated mudstones often show normal grading of micro debris set in a micrite matrix. Frequently, sub-centimetre thick individual laminae show sharp basal contacts especially from the Ras il-Ħamrija sections. Clasts are usually silt sized and indeterminate, however, occasional bivalve and benthonic Foraminifera occur and rare quartz is recorded. Typically, the rocks are non-ferroan carbonate mudstones and wackestones. Dolomicrospar and gypsum micro-veining are present at Ras il-Ħamrija.

### 6. *Lithoclast floatstone breccias*

The non-ferroan wackestone and packstone matrix of these rocks contains much indeterminate bioclastic debris and occasional benthonic Foraminifera. The randomly orientated clasts are principally angular to sub-rounded fragments of mudstone laminate. Clast sizes range from cobbles down to millimetre long fragments, many apparently having been dolomitized prior to incorporation.

The highest preserved stratum in this unit contains fewer and smaller lithoclasts, and is often dominated by micrite with peloidal or clotted texture. Both rhizocretion and vadoid fabrics are present in these micrites in the Għar Lapsi and Ras il-Ħamrija localities.

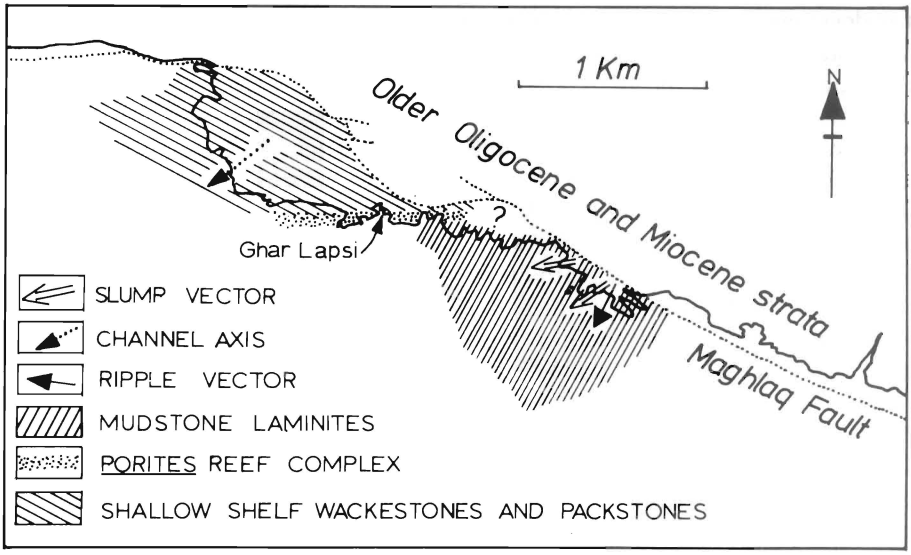

**Fig. 5.** Plan view of the Għar Lapsi area showing the distribution of the major lithological units. The reef-wall occurs immediately to the south of an E-W branch fault from the Magħlaq fracture. Various current vector data obtained from surface outcrops are also indicated.

## Discussion of Facies Trends

The Upper Coralline Limestone of the Għar Lapsi outlier is of greater thickness than the local standard succession. Above a recognisable Mtarfa Member, the sediments show few similarities with either the Ta' Żuta or Filfla sections. The facies interrelationships within the Għar Lapsi outlier are made more complex by faulting. Nevertheless, the descernible facies trends appear to be related to an early fault controlled topography.

Virtually all contemporaneous strata northeast of the Magħlaq Fault Zone (east Malta) has been lost by erosion; however, the preservation of the Għar Lapsi outlier facies argues for the existence of a shallow water depositional area in southern Malta during the Late Miocene from which much of the sediment was derived (see current vectors in Fig. 5). Peritidal sediments at San Leonardo near Żabbar (Fig. 1) confirm the former existence of more extensive carbonate deposits in this area. The Għar Lapsi carbonates can be grouped into two genetic associations:

### 1. *The reef wall complex*

The *Porites* reef wall provides the key for interpretation of the Għar Lapsi succession. This narrow E-W trending biohermal build-up extends from Ta' Berwick to Għar Lapsi and then out to sea. It is the only development within the islands of a typical Late Miocene 'Type B' reef (cf. Esteban, 1979) though other comparable reefs are common in W Sicily (Catalano, 1979., Esteban and Catalano, 1982) and in SE Spain (Esteban *et al.,* 1977). These atypical, monospecific coral reefs with their rod-like, aberrant growths are thought to have developed during the Late Miocene close to basin facing breaks of slope. The rod-like growth-form of *Porites* is considered by Esteban (1979) to develop as a rapid growth response to an increased sedimentation rate. However, a study of central Sicilian reefs (Grasso and Pedley, in press) suggests that it developed as a growth response, for maintaining optimum colony position in areas prone to tectonic or eustatic change. The Għar Lapsi outlier reef-wall faces south (Fig. 5) and is located immediately to the south of a similar trending fault-line (marked by a monoclinal flexure in Pedley and Waugh, 1976 Fig. 5). This fault is thought to have undergone Late Miocene synsedimentary movement and provided a submarine break of slope upon which the reef-wall developed. The reef wall is badly fractured in all outcrops, and portions of it may have collapsed during development at Għar Lapsi to produce the rotated reef wall blocks seen in sea cave sections.

The *Porites* reef breccias lie south of the reef wall in the Ta' Berwick sections (Fig. 3 and 4). The close association of these friable, unsorted, monomict breccias with the reef-wall, and their crudely defined off-reef dips, readily identifies the breccias as proximal fore-reef talus deposits. Volumetrically, they are much more important than the reef-wall.

The thick succession of bioclastic wackestones and packstones (rarely grainstones) of Ix-Xaqqa are only found to the north of the reef-wall. Their fair to well sorted nature, cross-stratification and absence of planktonic elements indicate that they are part of a turbulent water succession. Unfortunately the one contact between the two units, at Ta' Berwick, has suffered (? syndepositional) faulting which may have brought the reef-wall up into a juxtaposed position with respect to the packstones and grainstones. In other areas NW of Għar Lapsi the packstones and grainstones appear to be slightly younger than the reef-wall. They correspond probably to the 'calcareous lagoon' deposits in a general Miocene reef model proposed by Esteban (1979).

The expanded thickness of these bioclastic strata in the vicinity of the Magħlaq Fault at Ix-Xaqqa suggest fault movement during deposition. Some planar surfaces now dip towards the fault and are succeeded by further wedges of sediments which have restored horizontality. The sediment yield appears to have been locally derived possibly from areas to the east of the Magħlaq Fault. The presence of *Halimeda* plate levels abundant Miliolacea and ooidal beds in the sequence relates them closely to the top of the Tal-Pitkal Member and possibly also to the Ġebel Imbark Member of the standard Maltese succession (Pedley, 1978, 1983).

### 2. *Younger sediments*

Present day coastal erosion to the south of the reef-wall deposits has removed laterally penecontemporaneous beds, however, a thin development of the mudstone laminites typical of those developed at Ras il-Ħamrija lies directly on reefal talus at Ta' Berwick (bedded lens beneath question mark in Fig. 4) and demonstrates the laminites to be younger. Collectively, the laminar nature, occasional normal grading of units, basal erosion surfaces and ripple bed-forms typical of these lime mudstones indicates that they are likely to be the product of deposition from low-viscosity density flows. The absence of channelling and large lithoclasts argues against a point source fan deposit, but is compatible with a scarp or shelf edge sheet (cf. Crevello *et al.*, 1985). Current vectors (Fig. 5) indicate that the flows (calciturbidites) emanated from the NE, down a gentle palaeoslope. The subsequent preservation of bedforms points to tranquil conditions between events.

In conclusion, it would appear that the depositional setting developed in response to syndepositional downfaulting of the block to the south of the reef-wall. This created a local deeper water area which acted as a trap for shallow shelf derived resediment.

The lithoclast floatstone breccias show evidence of having moved by viscous flow.

The planar, erosional basal contact of the breccias is closely associated with soft sediment drag folds in the underlying mudstone laminites. Large volumes of mudstone laminite material have been ripped up in both lithified and unlithified states and have been included in the deposit.

The floatstones matrix, however, with its miliolid foraminifers, echinoids and bivalve debris of embayment or lagoonal aspect is not recognised elsewhere at outcrop and appears to represent soft sediment stripped from carbonate shelf areas once lying immediately to the NE of the Magħlaq Fault. Above the basal metre, several thinner (5-10cm) debris flow units alternate with cms-thick, normally graded couplets. Collectively, these probably represent Bouma-type Tab turbidite cycles, deposited close to source and demonstrate that the lower levels of the gravity flow deposit are of subaqueous origin. These sediments are closely comparable with descriptions of debris flow deposits in the literature (e.g. Middleton and Hampton, 1973; Fisher, 1971; Carter, 1975; Lowe, 1976). They do not, however, appear to show reverse grading at outcrop though Quaternary diagenesis has obscured primary textures in most sections.

Massive bedded micritic levels occurring at the top of the preserved succession between Għar Lapsi and Ras il-Ħamrija show diagenetic growth of vadoids (up to 20mm diameter), and laminar calcrete. Parts of the micrite deposit show autobrecciation associated with rhizocretion fabrics (principally alveolar texture), Although it cannot be stated unequivocably that these youngest strata are contemporaneous with the floatstone breccias, their pale grey colour (cf. reddened colour and friable nature of all local Quaternary palaeosol phenomena) suggests that they are Late Miocene in age. It has also been observed in this study that other rhizoid fabrics have penetrated the reef-wall outcrops at Ta' Berwick and the ooidal levels (Ġebel Imbark Member) of the Rabat Plateau near Ta' Żuta. In all cases, the absence of haematitic staining abnormal for Quaternary fabrics on Malta suggests an earlier Miocene subaerial episode connected with the latter part of the floatstone breccia deposition.

## Palaeoenvironmental Model

Gravity flow deposits are an unusual aspect of Maltese Miocene sedimentation (for exceptions see Pedley, 1980; Pedley and Bennett, 1985). It is, therefore, necessary to fit the Għar Lapsi occurrence into a regional context.

The simplest interpretation is that the Magħlaq Fault together with the *Porites* reef-wall, lying on the shoulder of a splay fault from the Magħlaq Fault, lay at the edge of the carbonate shelf. Sediment prisms, developed in deeper water against the faulted shelf margins, were derived from SE Malta.

This interpretation is unsatisfactory. Firstly, a total absence of planktonic microfossils but abundance of Miliolacea in the Għar Lapsi succession (only minor percentages of planktonics present in the Filfla succession) suggests deposition on shelf rather than in basin. Secondly, the presence of subaerial features in the uppermost floatstone breccia deposits is incompatible with a basinal setting. Finally, the absence of reef material in both the floatstone breccias and mudstone laminite deposits argues against a typical platform margin reef-wall development along a submarine fault scarp.

Nevertheless, contemporaneous faulting is also well documented in other parts of the Pelagian Block such as in SE Sicily (Ghisetti and Vezzani, 1980) and Lampedusa (Grasso *et al.*, 1985) and is related to plate collision far to the north.

The depositional setting of the Għar Lapsi carbonates is speculative, however, the

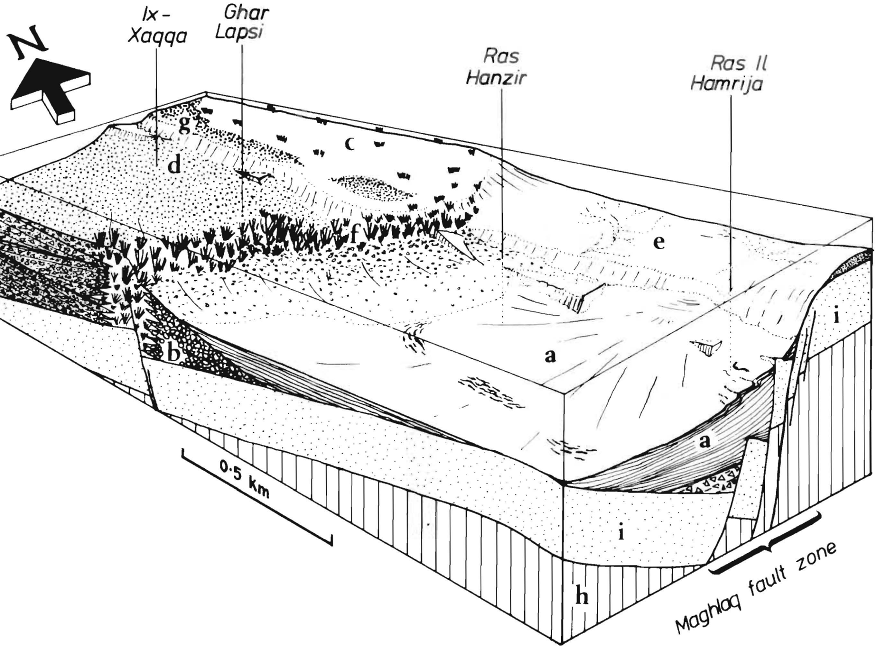

**Fig. 6.** Block model to illustrate the hypothetical interrelationships between faults and sedimentary packages. The model depicts a time immediately prior to the terminal floatstone breccia episode. (a) lime mudstone laminites; (b) reef talus; (c) inner shelf of standard sequence carbonates with scattered patch-reefs and miliolid-rich shelf sediments; (d) back-reef bioclastic and ooidal packstones derived in part from the stable shelf are to the northeast of the Magħlaq Fault zone; (e) Eastern Malta shelf area which sourced the laminite and debris flow deposits, (strata younger than *Globigerina* Limestone (Serravallian), not now preserved in this area except at San Leonardo near Żabbar); (f) *Porites* reef-wall with fringing fore-reef tallus.; (g) ooidal shoal waters contributing sediments to area (d); (h) Blue Clay Formation with glauconitic remains capping (Greensand); (i) shallow marine wackestones and packstones of the Mtarfa Member.

absence of gravity flow deposits in the Filfla section argues for an intra-shelf graben or half-graben setting. By implication this suggests that the Magħlaq Fault is not a master fault of the Malta Graben but is of secondary status.

There can be little doubt that the *Porites* reef complex developed as an accretionary prism against a fault (c.f. Speksnider, 1985) but this was a local branch fault of the larger Magħlaq system. Shelf sedimentation and subsidence kept pace with each other for a time. Figure 6 demonstrates the hypothetical relationships between the evolving Għar Lapsi succession and adjacent Maltese areas.

The arrival of calciturbidite deposits above the reef complex is the first proof of a significant step along the Magħlaq scarp but the sudden arrival of these gravity flow deposits may well indicate the intervention of eustatic events which were ultimately to lead to subaerial emergence of the entire shelf.

*Eustatic sea level fall:* Palaeosol fabrics associated with the floatstone breccias also affect other Upper Coralline Limestone units in the vicinity of Ta' Żuta and Għar Lapsi during a period when regional tectonic trends suggest continuing subsidence of the outlier (Reuther, 1984). The emergent fabrics of Ta' Żuta occur at the top of a regressive sequence and as such are predictable; these contemporaneous Għar Lapsi outlier features however mark a sudden change from deeper marine to subaerial deposition and are interpreted as recording a sudden eustatic sea level fall.

A Late Miocene desiccation of the Mediterranean Sea is well documented in the literature (e.g. Ruggieri and Sprovieri, 1976) and resulted from isolation of the sea from the World oceans followed by partial evaporation of contained waters. The earliest effects of this in the Maltese area are seen to be associated with the Late Tortonian Tal-Pitkal Member (Pedley, 1983). These correlate well with emergent events in SE Sicily generally associated with reef tops in the Carlentini Formation (Grasso *et al.*, 1982). The youngest marine Miocene strata of the region appears, on lithostratigraphical grounds, to be Early Messinian in age. Marine Pliocene is unrecorded from the Maltese Islands and the Ragusa Platform of SE Sicily, both areas of which apparently became subaerial simultaneously and only received a patchy marine Quaternary cover.

It is concluded that the floatstone breccias of the Għar Lapsi outlier are the only onshore Maltese representatives of a thick resediment succession reflecting emergence and stripping off of unconsolidated, latest Miocene lower Messinian strata from the south Malta area during the initial stages of Mediterranean desiccation.

## Conclusions

The Għar Lapsi succession is a syntectonic sediment accumulation recording subtle Late Tortonian and Early Messinian movements of the Magħlaq Fault zone. The general absence of planktonic microfaunas in the outlier and low percentages in the Filfla section argues for deposition of the fault-bounded sediments in an intra-shelf graben and, therefore, reduces the status of the Magħlaq Fault. Hitherto, this fault was considered a master fault of the Malta Graben; here it assumes secondary status.

The Għar Lapsi carbonates are mainly a resediment sequence eroded from south eastern Malta. The petrographic details of these re-sediments provide a unique record of sediment types no longer preserved.

Syndepositional changes from submarine to subaerial conditions are the result of a principal drawndown event associated with the desiccation of the Mediterranean Sea. The event was basin wide and permits direct correlation with the base of the Lower Evaporite Complex (lower Messinian) of Sicily.

It is to be mentioned that the last statement-hypothesis is a controversial subject. A final confirmation of its validity depends upon a comprehensive knowledge of mercury biogeochemistry in the Mediterranean Sea.

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# Trace Metal Contamination in Marine and Riverine Sediments around San Rossore Park (Italy).

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## ABSTRACT

Surficial sediments collected in 1984 and 1985 in the marine coastal belt and in the final stretch of rivers flowing in the San Rossore zone were analyzed for ten trace elements using atomic absorption spectrophotometry.

Inter-element relationships as well as those with grain size and organic carbon contents were examined before interpreting the data obtained. The results indicate that rivers flowing in this area and especially the river Morto, are subject to anthropogenic input of Cr, Cd, Hg, Pb, Cu and Zn.

The remobilization of several elements in the estuarine zone and their possible involvement in the deterioration processes of coastal vegetation of the San Rossore park, are discussed.

## Introduction

The presidential farm of San Rossore is a natural park of about 5,000 Ha, covered by pine forest (*Pinus pinea* and *Pinus pinaster*) and broadleaf woods (alders, oaks, white poplars and ash-trees). The park lies between the Arno and the Serchio rivers, the Tyrrhenian Sea and the suburbs of Pisa (Fig. 1). The two rivers receive the sewage, which has undergone little treatment, from the most industrialized and densely populated areas of Tuscany. Moreover, the Morto river, a canal built in 1939, flows through the middle of the park after receiving industrial and urban waste waters.

In this area westerly winds prevail and the south-westerly one (libeccio) is dominant, while proximal and distal drifts flow consistently northwards (Rapetti and Vittorini, 1983). Thus a large portion of pollutants carried by the rivers is pushed towards the

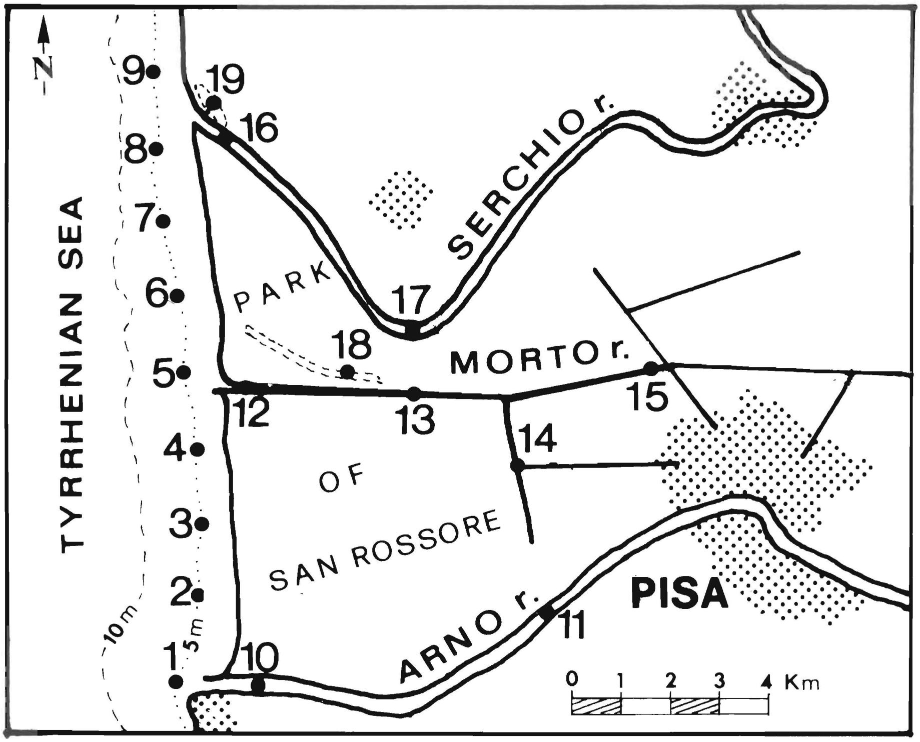

**Fig. 1** Study area and sampling locations.

coastal zone of the park. The effects of pollution are dramatically shown by the serious deterioration of the coastal vegetation: in a 1 km-wide belt along the coastline the pine trees are almost all dead. Several studies since the outset of the deterioration process (Lapucci *et al.*, 1972; Gellini *et al.*, 1983) have found evidence for a close relationship between the damage to the vegetation and the pollution of the sea by anionic surfactants. As reported for other marine coastal areas (Pitman *et al.*, 1977; Dowden and Lambert-Marcia, 1979) surfactants are concentrated in the sea-spray, carried coastward by the wind and deposited on the leaves of trees. They damage the wax that protects the epicuticle and the pre-stomatal chamber (Bussotti *et al.*, 1984), causing a substantial increase in the uptake of phytotoxic substances from sea-spray or from the air. It is likely that certain trace metals can also exert a harmful effect in synergism with other pollutants. It is known that relatively low concentrations of Pb, Cd, Ni and other elements can inhibit photosynthesis and transpiration or interfere with mitochondrial respiration (Ormrod, 1984).

In the framework of a research project on the cause of deterioration in San Rossore park, the present study was undertaken to analyze trace elements in surficial sediments of the coastal zone and in the final stretches of the rivers flowing in this area. A high level of trace metals in the sediment would provide further reason to suspect their involvement in the degradation of the vegetation.

## Materials and Methods

Surficial sediments (top 3 cm) were collected three times in 1984 and once in 1985 at 19 stations (Fig. 1). Samples were stored frozen in PVC vessels and before analysis, subsamples were dried at 105°C to determine water content. For trace element determinations, sediments were digested with conc. $HNO_3$ at 120°C for 6 h in Teflon decomposition vessels. Analyses were performed by A.A.S. using the cold vapour stream for Hg, the air/acetylene flame for Cr, Cu, Zn, Ni, Co, Fe, Mn and the graphite furnace for Cd and Pb.

Five replicates of two samples were run and the coefficient of variation ranged from 3.9 to 12.3%, depending on the element. Using sediment subsamples, the percentage of sand (by wet sieving through a 63 um sieve) and the percentage of organic carbon (following the procedure suggested by Gaudette *et al.*, 1974) were also determined.

## Results and Discussion

According to the environment of collection, samples show very different features: whereas marine sediments are oxidate sands with a low content of organic carbon; riverine and estuarine samples have very variable grain size, redox conditions and organic matter content. Thus it seems more difficult to interpret the results of sediment analysis summarized in Table 1.

Concentrations of trace elements are far higher in river sediments, especially in those of the Morto river and in those with the finest grain size. Their degree of pollution could be estimated assuming as background values those of samples 18 and 19, collected in the former bed of the Morto and in the former mouth of the Serchio respectively. Moreover, from a comparison with previous data on sandy and silty sediments analyzed with comparable procedures (Pearce and Yasso, 1973; Perkins *et al.*, 1973; Bargagli *et al.*, 1985) or assuming as anomalous values those $> \bar{x} + 2s$ (where $\bar{x}$ is the mean concentration of all samples and s is the standard deviation) (Chester *et al.*, 1985), several values (marked in Table 1 with an asterisk) are clearly polluted.

A correlation coefficient matrix for all the analyzed parameters was calculated (Table 2). At the 0.001 probability level very significant and positive correlations occur between Cd, Cu, Fe, Hg, Pb, Ni, and Zn, i.e. the metals dumped into the rivers, especially the Morto, in large quantities. Cr, which arises above all from the Arno, is related only with Fe, Cu, and Ni, moreover it is not correlated with organic carbon contents. Except for Mn, which tends to be incorporated into larger inorganic particles (Baldi and Bargagli, 1978; Forstner *et al.*, 1982) it is known that trace elements concentrations increase as sediment grain size decreases or that they may be associated to organic materials. Nevertheless, the significant relationship between many elements and the organic matter is probably also a consequence of the fact that organic rich sediments are finer in size (Bargagli and Baldi, 1983). Thus the percentage of sand exercises a determining influence on the concentrations of the other parameters. In fact, the coarse-grained quartz, feldspar and carbonate are rather chemically inert in comparison with clays, hydrates or organic substances. Hence, without a correction for grain size, a mutual comparison of metal data in marine and fluviatile samples is impossible.

In order to reduce these effects the linear regression equations of each elements vs. the sand content of samples was calculated and values above the 95% confidence belt of the regression line were considered polluted. Obviously, heavily contaminated

Table 1 Sand, organic carbon and trace elements in surficial sediments around the San Rossore park (average values±SD of analytical determinations performed in the four samples collected at each sampling point).

| St. | Sand | Org.C | Fe | Cd | Co | Cr | Cu | Hg | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | | µg/g | | | | |
| 1 | 93.6±1.8 | 0.20±0.04 | 1.96±0.21 | 0.18±0.06 | 21.2±5.6 | 98.6±16.6 | 46.9±7.5 | 0.17±0.04 | 562±115 | 52.4±12.3 | 12.2±3.2 | 77.2±13.4 |
| 2 | 85.1±1.4 | 0.21±0.04 | 1.98±0.25 | 0.34±0.06 | 20.4±4.9 | 120 ±19 | 39.8±9.4 | 0.18±0.06 | 727±84 | 50.4±14.3 | 14.2±4.1 | 81.6±15.9 |
| 3 | 87.5±1.9 | 0.40±0.10 | 1.53±0.18 | 0.14±0.05 | 17.5±4.0 | 72.9±13.2 | 18.1±3.5 | 0.10±0.02 | 590±77 | 46.9±10.6 | 15.5±4.2 | 55.0±17.5 |
| 4 | 93.6±1.0 | 0.19±0.04 | 1.92±0.27 | 0.06±0.02 | 17.9±3.7 | 67.6±12.4 | 10.4±2.4 | 0.09±0.02 | 516±83 | 42.3±4.9 | 15.8±5.6 | 67.6±23.1 |
| 5 | 96.8±1.3 | 0.21±0.04 | 1.36±0.19 | 0.07±0.02 | 14.0±3.8 | 64.4±15.4 | 14.6±2.2 | 0.05±0.02 | 598±101 | 31.9±8.4 | 10.2±3.6 | 49.7±13.2 |
| 6 | 97.6±2.3 | 0.11±0.04 | 1.40±0.12 | 0.05±0.01 | 9.1±1.6 | 47.5±10.9 | 16.8±2.7 | 0.06±0.02 | 533±112 | 35.5±7.9 | 12.2±4.5 | 43.2±11.3 |
| 7 | 95.4±1.9 | 0.17±0.05 | 1.79±0.23 | 0.07±0.03 | 14.1±2.6 | 62.7±16.5 | 18.7±4.8 | 0.08±0.02 | 514±98 | 37.1±8.6 | 11.8±3.7 | 44.4±12.2 |
| 8 | 90.8±2.2 | 0.19±0.04 | 1.73±0.33 | 0.09±0.02 | 15.8±3.5 | 73.7±15.9 | 18.1±5.4 | 0.11±0.03 | 612±111 | 39.4±9.2 | 13.6±2.8 | 50.9±13.6 |
| 9 | 98.2±1.1 | 0.09±0.01 | 1.45±0.25 | 0.08±0.02 | 13.3±1.9 | 56.3±15.6 | 15.1±5.3 | 0.09±0.02 | 504±61 | 39.7±10.6 | 7.9±2.4 | 41.5±11.5 |
| 10 | 32.5±2.9 | 1.80±0.38 | 3.30±0.91 | 0.36±0.13 | 20.2±4.9 | 263 ±63* | 70.0±26.4 | 0.29±0.08 | 484±73 | 61.6±18.0 | 34.2±12.5 | 150 ±20 |
| 11 | 31.5±2.7 | 2.37±0.50 | 3.49±0.43 | 0.64±0.23 | 32.1±9.4 | 248 ±42* | 66.6±14.4 | 0.34±0.10 | 890±112 | 83.8±16.9 | 50.2±9.9 | 217 ±22 |
| 12 | 81.4±1.7 | 1.08±0.15 | 2.18±0.41 | 0.30±0.11 | 17.9±6.0 | 141 ±33 | 32.1±11.2 | 0.32±0.09 | 607±146 | 56.4±17.1 | 19.6±5.7 | 108 ±28 |
| 13 | 86.8±2.6 | 1.40±0.08 | 2.53±0.56 | 0.38±0.09 | 20.5±3.0 | 152 ±24 | 32.6±12.5 | 2.51±0.45* | 341±62 | 61.5±15.4 | 30.7±9.6 | 122 ±24 |
| 14 | 39.1±3.7 | 7.83±1.06* | 3.83±0.53* | 2.40±0.47* | 32.1±4.7 | 140 ±15 | 107 ±19* | 32.8±4.6* | 474±76 | 74.4±16.2 | 144 ±28* | 710 ±103* |
| 15 | 32.4±3.3 | 5.71±1.77 | 3.15±0.42 | 2.60±0.84* | 28.5±4.2 | 122 ±22 | 122 ±21* | 68.5±15.8* | 604±97 | 79.7±8.8 | 216 ±24* | 428 ±75* |
| 16 | 85.2±1.9 | 0.64±0.22 | 2.16±0.58 | 0.61±0.11 | 28.8±6.8 | 82.6±15.1 | 42.5±12.4 | 0.16±0.05 | 783±189 | 64.8±20.2 | 50.2±14.6 | 90.5±11.4 |
| 17 | 85.6±2.1 | 0.71±0.15 | 2.23±0.20 | 0.62±0.12 | 20.5±3.7 | 96.7±13.5 | 19.9±3.5 | 0.28±0.05 | 802±121 | 63.4±14.7 | 50.4±13.2 | 156 ±35 |
| 18 | 74.7±2.6 | 5.80±1.34 | 1.84±0.38 | 0.26±0.07 | 11.7±4.3 | 60.0±13.7 | 20.1±5.3 | 0.12±0.04 | 1433±431 | 52.3±16.7 | 19.3±5.9 | 71.5±16.4 |
| 19 | 97.7±2.1 | 0.07±0.02 | 1.11±0.22 | 0.07±0.02 | 12.0±2.9 | 50.3±17.6 | 8.3±2.1 | 0.04±0.01 | 797±116 | 30.5±7.2 | 7.9±1.7 | 37.0±12.8 |

* Values clearly anomalous ( above the mean concentration of all samples $\bar{x}+2s$ ,where s is the SD).

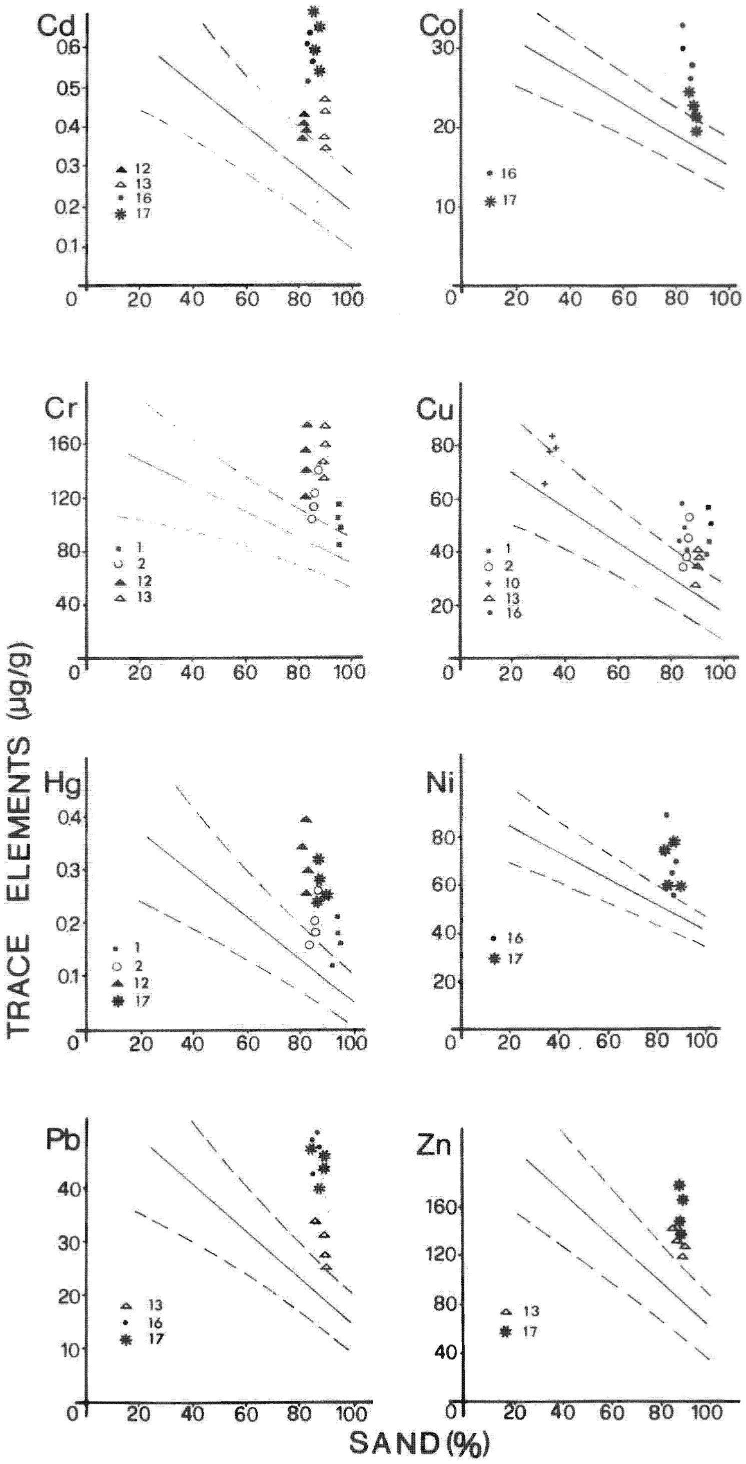

**Fig. 2** Trace element concentrations as function of % of sand. Samples above the 95% confidence belts of regression lines (broken lines) are indicated.

Table 2 Sand, organic carbon and interelement correlation coefficients
( $n=76$; if $r > 0.35$ , $P<0.001$ )

| | Sand | Org.C | Fe | Cd | Co | Cr | Cu | Hg | Mn | Ni | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Org.C | -0.71 | | | | | | | | | | |
| Fe | -0.83 | 0.61 | | | | | | | | | |
| Cd | -0.70 | 0.79 | 0.65 | | | | | | | | |
| Co | -0.61 | 0.40 | 0.22 | 0.23 | | | | | | | |
| Cr | -0.75 | 0.24 | 0.72 | 0.25 | 0.11 | | | | | | |
| Cu | -0.84 | 0.70 | 0.60 | 0.23 | 0.66 | 0.56 | | | | | |
| Hg | -0.57 | 0.67 | 0.47 | 0.89 | 0.41 | 0.09 | 0.74 | | | | |
| Mn | -0.08 | 0.26 | -0.07 | -0.08 | 0.07 | -0.08 | -0.12 | -0.11 | | | |
| Ni | -0.66 | 0.47 | 0.67 | 0.60 | 0.64 | 0.54 | 0.64 | 0.44 | 0.04 | | |
| Pb | -0.70 | 0.74 | 0.51 | 0.96 | 0.59 | 0.23 | 0.83 | 0.94 | -0.07 | 0.59 | |
| Zn | -0.73 | 0.81 | 0.70 | 0.91 | 0.64 | 0.35 | 0.83 | 0.73 | -0.12 | 0.56 | 0.84 |

samples (marked in Table 1 with an asterisk) were excluded from calculations and are not reported in Figure 2. Following this procedure, less contaminated samples were displayed and more information on the metal distribution and on the pollution sources may be achieved.

Surficial sediments of the Morto river are polluted by almost all the analyzed metals. Those of the Serchio are slightly contaminated by Cd, Co, Ni, Pb, and Zn, while in those of the Arno particularly high is the Cr content. The contamination of this river by Cr was first reported by Taponeco and Giaconi (1969), who ascribed it to the chrome plating and tanning industries; our data indicate that this pollution probably continues or at least, that sediment constitutes a sink for the metal dumped in the past. Downstream from rivers metal concentrations decrease considerably; this fact, which has already been reported from other estuaries (DeGroot *et al.*, 1971; Forstner and Wittmann, 1983) has been explained by remobilization processes which occur in the passage from fresh to marine water and by mixing between the more polluted riverborne materials and the sea-derived particles. Marine sediments are slightly contaminated by Cr, Cu, and Hg only near the mouth of the Arno (st.1 and st.2); all the others do not seem to be affected by the Morto or Serchio input. Blundo *et al.* (1984) too, in a physico-chemical investigation on the coastal water of this area did not find evidence of inputs in front of these two rivers. This fact was ascribed, in the case of the Morto, to the small amount of water that it conveys (mean flow rate 1.2m$^3$/s) and, in that of the Serchio, to its satisfactory water quality. In agreement with our results, the above mentioned authors, found that 4-5 km from the mouth of the Arno (mean flow rate 1.2m$^3$/s) concentrations of nutrients and surfactants in seawater had typical Mediterranean coastal water values.

Although surficial marine sediments are almost uncontaminated, probably some trace elements are involved in the deterioration processes of coastal vegetation. In fact in the river-sea mixing zone significant quantities of phytotoxic metals such as Pb, Cd or Cu are transferred from suspended materials and from sediments (Salomons and Eysink, 1979) to estuarine waters. In the San Rossore coastal area the occurrence of these processes seems confirmed by the highest concentrations of heavy metals found (in the framework of the same research project) at the mouth of the three rivers by Betti *et al.* (1985).

Considering that these rivers, besides trace elements convey to the sea large amounts of surfactants (Gellini *et al.*, 1981) and that metals are 'stripped' very effectively from seawater polluted by surfactants (Kim and Zeitlin, 1971); it seems likely that heavy metals, as has been recognized (Lemlich, 1972; Mac Intyre, 1974), accumulate on spray drops. Moreover, the prevailing coastal drift and wind of this area support the transport and deposition of these pollutants on coastal vegetation.

Researches are in progress on the chemical composition of the coastal marine aerosol and on the metal content in pine needles collected both in the damaged coastal belt and inside the park.

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# Comparison of morphomeristical variations of Mediterranean and Red Sea populations of the Suez Canal migrant *Sargocentron rubrum*

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## ABSTRACT

Nine morphomeristical characters of squirrelfish, *Sargocentron rubrum* (Forsskal 1775) were compared between Mediterranean and Red Sea populations to examine changes caused by different environments. The significantly lower number of lateral line scales and vertebrae in the Mediterranean fishes is attributed to the higher temperature during the spawning season. The significant difference of the proportion of suborbital spinulation and the shape of the anterior tip of the nasal bone is inferred to be due to a founder effect. No significant difference was found in the relationship between eye diameter and preopercular spine length and standard length, nor in the number of dorsal and anal rays and nostril spinulation.

## Introduction

The opening of the Suez Canal in 1869 created a faunistic passageway between the Red Sea and the Mediterranean Sea, two bodies of water which differ considerably in many hydrological and faunistic aspects. It is now apparent that the so-called ''Lessepsian migration'' involves movement mainly from the Red Sea into the Mediterranean, although some organisms, possibly of Mediterranean origin, have been found in the Red Sea. Most species are limited to the Levant region of the eastern Mediterranean (Por, 1978).

The influx of tropical Indo-Pacific organisms into the sub-tropical eastern Mediterranean has enabled a scientific monitoring of short term dispersal and colonization processes that under natural conditions occur over far longer periods. In particular, the establishment of new populations, separated from their source, has provided a unique opportunity to study aspects of speciation in nature.

MacArthur and Wilson (1967) claimed that a colonizing species was likely to undergo adaptive changes within a few generations. Recently, findings of Parsons (1983) supported this hypothesis. Tortonese (1973) and Kosswig (1974) postulated that both phenotypic and genotypic changes may have occurred in fish of Red Sea origin which colonized the Mediterranean Sea, although they could not substantiate their hypothesis.

Among the various known Red Sea colonizers, forty-one species of fish have been recorded in the eastern Mediterranean (Golani and Ben-Tuvia, 1986). Some of the immigrant fish, e.g., *Upeneus moluccensis, Siganus rivulatus* and *Saurida undosquamis*, have established large populations, contributing considerably to the local fishery (Ben-Tuvia, 1985).

The squirrelfish, *Sargocentron rubrum* (also known in older literature by the generic name *Holocentrus* or *Adioryx*), was one of the first Indo-Pacific fish to be recorded in the Mediterranean (Haas and Steinitz, 1947). Its known distribution in the Mediterranean reaches Greece in the northwest (Laskaridis, 1950) and Libya in the southwest (Stirn, 1970). Various aspects of the biology of *S. rubrum* have been recently studied along the Israeli coastline (Ben-Eliahu, *et al.*, 1983; Golani, *et al*. 1984; Golani and Ben Tuvia, 1985).

In the present study, the morphomeristical characters of Red Sea and Mediterranean populations of *S. rubrum* were compared, in order to determine whether morphomeristic changes had occurred as a result of colonization.

## Materials and Methods

Specimens longer than 40 mm SL were examined in this study, since it has been found (Golani and Ben-Tuvia, 1985) that above this size the morphomeristic changes are negligible. Most Mediterranean fish were obtained during the period October 1979 to October 1980 from commercial trammel nets in the fishing harbour of Akko (Acre). The remaining Mediterranean fish and all of the Red Sea fish were preserved specimens from the museum collections of the Hebrew University of Jerusalem, Tel-Aviv University (Israel), the Field Museum of Natural History, Chicago (USA), and the Rijksmuseum van Natuurlijke Historie, Leiden (Holland). Of the 80 Red Sea specimens, 69 originated from its northern part, i.e., the Gulf of Aqaba (Gulf of Eilat) and 11 were collected in central and southern regions. No differences were found in the fish originating from these various regions of the Red Sea. Basic meristic counts follow Hubbs and Lagler (1947), adjusted to the genus *Sargocentron* adopted from Shimizu and Yamakawa (1979) and Randall and Heemstra (1985). Standard length was measured to the nearest mm. Eye diameter and preopercular spine length were measured to the nearest 0.1 mm.

The last soft rays of the dorsal and anal fins, which are usually divided almost to the base, were considered to be one ray. Lateral line scales included only scales with tubes. Preopercular spine length was measured from the vertical line of the preoperculum to the tip of the spine. Vertebrae of the Mediterranean specimens were counted after removing the musculature of the fleshy exterior, while the vertebrae of Red Sea and preserved Mediterranean specimens were counted from X-ray plates.

Other morphology examined were nasal fossa spinulation, suborbital spinulation and shape of anterior nasal bone. These features are considered specific to diagnosis of

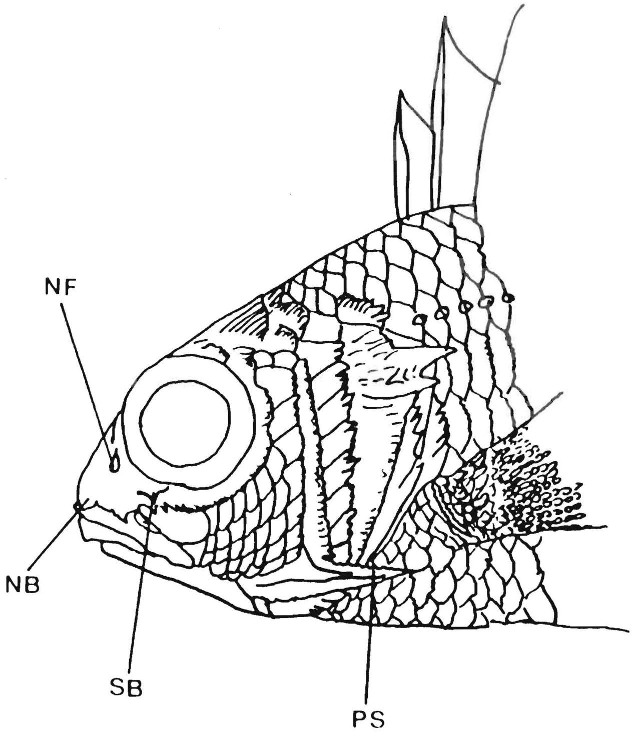

**Fig. 1.** Head of *Sargocentron rubrum.* NF, nasal fossa; NB, nasal bone; SB, suborbital bone; PS, preopercular spine.

*S. rubrum* and have been often used in literature to differentiate it from closely related species (Montilla, 1938; Shimizu and Yamakawa, 1979; Shen, *et al.*, 1980). Counts of nasal fossa spinulation included both sides. Spinulation of the suborbital bone was counted on the left side only; three variations were observed: one outward spine, two outward spines, or serrated, i.e., a series of three or more such spines. The anterior part of the nasal bone was usually rounded or ended in a blunt spine, which were considered as one category. The other categories were two or three diverging spines on each side of the symphysis (Fig. 1).

Relationship of eye diameter and preopercular spine length to standard length was tested by analysis of covariance, while all the other character variations were tested by chi square test for independence in contingency tables.

## Results

The relationship between eye diameter (E) and standard length (SL) was calculated as the regression line:

$E = 0.084\ SL + 3.904$ ($r = 0.678$, $N = 282$)

for the Mediterranean fish, and

$E = 0.082\ SL + 4.483$ ($r = 0.934$, $N = 60$)

for the Red Sea. The test showed no significant difference ($P > 0.999$, $F = 0.00$) between the two populations.

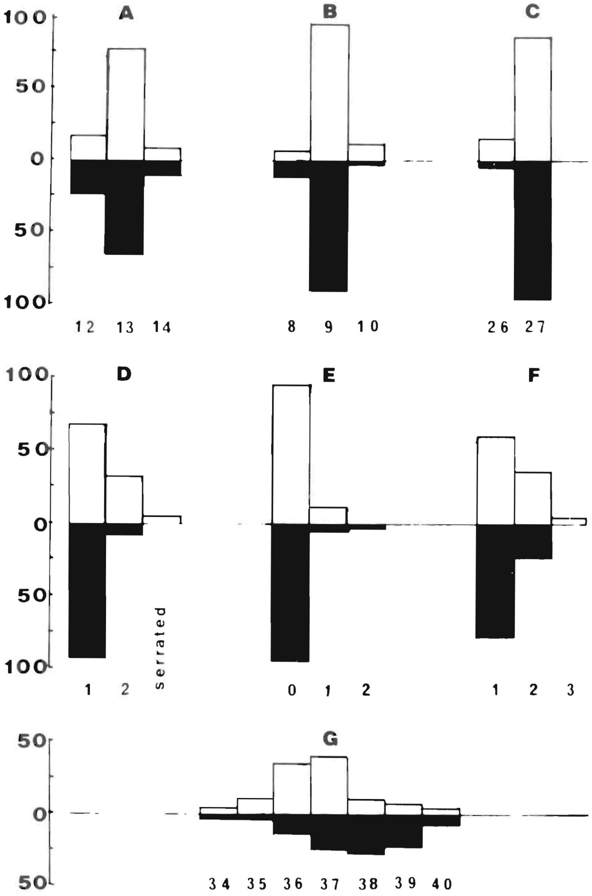

**Fig. 2.** Comparison of the frequency of occurrence of morphomeristical variations of Mediterranean (open bars) and Red Sea (solid bars) populations of *Sargocentron rubrum.* A – dorsal rays, B – anal rays, C – vertebrae, D – suborbital spinulation, E – nostril spinulation, F – spines on tip of nasal bone, G – lateral line scales.

A similar result was reached concerning the relationship between preopercular spine length (PS) and SL. It was calculated as the regression lines:

$PS = 0.086\ SL + 0.657$ ($r = 0.522$, $N = 282$)

for the Mediterranean, and

$PS = 0.096\ SL + 0.203$ ($r = 0.835$, $N = 60$)

for the Red Sea. No significant difference ($P > 0.518$, $F = 0.44$) was found in this character between the Mediterranean and Red Sea fish.

Frequency of occurrence, expressed as the percentage of each variation in both populations, is shown in Fig. 2. The number of fish examined and significance levels of difference are given in Table 1.

In three cases, the number of dorsal rays, anal rays and the nasal fossa spinulation, no significant differences were found between the two populations. However, the number of lateral line scales and vertebrae, suborbital spinulation and the shape of the anterior nasal bone differed significantly (Table 1).

## Discussion

Testing the applicability of the theory that a colonizing population will tend to differ from the source population due to necessary adaptive changes to their new hydrological condition, is one of the most interesting questions arising from study of the phenomenon of Lessepsian migration.

**Table 1.** Sample sizes and results of $\chi^2$ test comparing morphomeristical variations of Mediterranean and Red Sea populations of *Sargocentron rubrum*

| | dorsal rays | | anal rays | | l.L. scales | |
|---|---|---|---|---|---|---|
| Mediterranean | 249 | $\chi^2_{0.130,2}$ | 249 | $\chi^2_{0.108,2}$ | 78 | * $\chi^2_{0.002,7}$ |
| Red Sea | 80 | | 80 | | 79 | |

| | Vertebrae | | nostril spinulation | | suborbital spinulation | | nasal bone shape | |
|---|---|---|---|---|---|---|---|---|
| Mediterranean | 70 | * $\chi^2_{0.016,1}$ | 204 | $\chi^2_{0.136,2}$ | 204 | * $\chi^2_{0.0007,2}$ | 204 | * $\chi^2_{0.022,2}$ |
| Red Sea | 53 | | 57 | | 57 | | 57 | |

* significant difference

The significantly lower number of lateral line scales and vertebrae in the Mediterranean population is probably due to the higher water temperature during the spawning season. Golani and Ben-Tuvia (1985) showed that the spawning season of *S. rubrum* in the Levant extends from July to August. The water temperature at that time reaches a monthly average higher than that of any month in the Gulf of Aqaba (northern Red Sea) (Oren, 1962). This negative correlation between water temperature and number of vertebrae and lateral line scales is a well-documented phenomenon (Hubbs, 1922; Kwain, 1975; Lindsey and Arnason, 1981).

The variation of the suborbital spinulation and the shape of the anterior tip of the nasal bone is significantly different between the two populations. None of these characters appears to have any ecological advantage in either the old or the new habitat. Mayr (1963) and MacArthur and Wilson (1967) theorized that genetic differences in a colonizing population may be due to accidental differences in gene proportions in the individual founders as compared to those in the source population. Thus it may be inferred that the changes were not caused by natural selection but rather by founder effect.

Five of the characteristics compared in this study, eye diameter, preopercular spine length, dorsal and anal rays, and nostril spinulation, showed no significant difference.

In summation, the results of this study suggest that as a result of its colonization of the Mediterranean Sea, some morphomeristical changes have occurred in *S. rubrum*. Additional comparative studies, especially electrophoretic analysis must be done in order to evaluate the magnitude of the differences between the two populations. This initial separation of the Mediterranean population may lead eventually to formation of a new taxon.

## ACKNOWLEDGEMENTS

I thank Prof. A. Ben-Tuvia and Dr A. Diamant for their useful comments and suggestions. I am grateful to Dr M. Goren of Tel-Aviv University, Dr K. C. Johnson and Dr D. Stewart of the Field Museum of Natural History, Chicago (U.S.A.), and Dr M. Boesman of the Rikjsmuseum van Natuurlijke Historie, Leiden (Holland), for providing specimens for this study and to Ms B. Appelbaum for drawing the figure.

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# Contribution à la Connaissance d'une Poussée Extraordinaire d'Algues Unicellulaires (Adriatique Septentrionale)

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## ABSTRACT

The phenomenon known as "sea-water bloom" ("mare sporco", "Meeresblüte") was observed in the northern Adriatic in summer 1983. It appears as a gelatinous, dense mass floating at the sea surface.

Samples from Crikvenica (July) and Lopar, Rab Island (August) were analysed. A total of 58 diatoms, of which 32 benthic species, 25 dinoflagellates and 10 coccolithophorids were identified by microscopy. A recently described genus, *Spatulodinium* Cachon & Cachon, represented by the type species *S. pseudonoctiluca* (Pouchet) Cachon & Cachon, was also found.

With respect to the known ecology of individual algal groups it may be concluded that benthic diatoms had reproduced intensively at the sea bottom a long while before the phenomenon became visible at the sea surface. Reproduction is also the period of the most intensive secretion of mucus. Release of the gelatinous mass from the sea bottom at summer temperatures which are unfavourable for diatoms, is actually the end of the bloom. A gelatinous mass full of gases released by bacterial degradation begins to ascend and on its way towards the sea surface, it embeds plankton organisms. In the final stage torn mucus descends to the bottom where it is gradually completely degraded.

## Introduction

Dans toute la baie de Kvarner (Adriatique septentrionale) on a pu observer, au cours de l'été 1983 (juillet, août), une poussée extraordinairement intense de la microflore marine, connue sous le nom de "floraison de la mer" ("mare sporco", "Meeresblütë).

Tableau 1. ''Floraisons de la mer'' notées jusqu'à présent dans l-Adriatique

| Auteur | Lieu | Année |
|---|---|---|
| *Sirsky & Castracane | Trieste, Pesaro | 1872 |
| *Castracane | Fano | 1880 |
| *De Toni & Levi Morenos | Adriatique du Nord | 1891 |
| Babić (1911) | Adriatique du Nord | 1903 |
| Cori (1905) | Trieste | 1905 |
| *Forti (1906) | Chioggia | 1905 |
| *Zacharias (1906) | Trieste | 1905 |
| Issel (1922) | Rovinj | 1921 |
| *Schreiber (1928) | Venezia, lagunes | 1927 |
| *Zanon (1931) | Baie de Rijeka | 1930 |
| Marchesoni (1954) | Chioggia | 1949 |
| Jurilj & Johanides (1974) | Golfe du Kvarner<br>(Novi Vinodolski) | 1973 |
| Pucher-Petković & Marasović | Golfe du Kvarner<br>(Crikvenica, Lopar) | 1983 |

*Auteurs cités d'après Marchesoni (1954)

Ce phénomène s'est manifesté par d'amples masses mucilagineuses flottant à la surface de la mer, et englobant une grande quantité d'algues unicellulaires. Par endroit cette masse a obtenu une telle densitè qu'on aperçoit son ombre au fond de la mer. La masse montrait une bioluminescence intense. Bien qu'il ne soit pas fréquent, ce phénomène a été noté plusieurs fois, toujours au cours de la période estivale, dans l'Adriatique septentrionale, peu profonde (Tableau 1).

Le but du présent travail a été d'analyser la cause de ce phénoméne et d'identifier les organismes englobés dans cette masse mucilagineuse.

## Résultats

On a effectué l'analyse microscopique de deux échantillons très abondants en mucus, recueillis dans les eaux côtières de l'Adriatique du Nord, l'un près de Crikvenica (en juillet) et l'autre près de l'île de Rab (Lopar) au début d'août. Les déterminations ont île été accomplies sur le matériel complet phytoplanctonique et microphytobenthique (Diatomées pennées) contenu par la masse gélatineuse. L'identification des espèces s'est révélée difficile à cause du même coéfficent de réfraction de la masse et des organismes englobés, fait déjà noté précédemment par Jurilj et Johanides (1974). Ce n'est qu'après le dessèchement du mucilage à l'air que les organismes sont devenus visibles et prêts à la détermination. Dans quelques sous-échantillons la matière organique a été brûlée pour rendre plus facile l'identification des Diatomées pennées. Ailleurs, le mucus contenait des Diatomées planctoniques, des Dinoflagellés et des Coccolithophorides. Les Silicoflagellés ont été absents ce qui est normal pour la saison estivale et vu le rôle secondaire de ce groupe d'organismes dans les communautés planctoniques en Adriatique. De même, les ''Microflagellés nus'' n'ont pas été observés. On suppose qu'ils étaient, ou masqués par le mucilage, ou détruits dan les échantillons brûlés. Autrement, ce groupe d'organismes est très bien représenté dans les eaux côtières de l'Adriatique orientale. A titre d'example on a rapporté les abondances relatives des divers groupes phytoplanctoniques dans la baie de Rijeka, ce qui permet de conclure à la proportion non négligeable des "Microflagellés" dan ces eaux (Tableau 2).

A part ces groupes d'algues unicellulaires, le mucus comprenait beaucoup de Cyanophycées, apportées du fond et, en plus, des champignons, des stades de résistance phytoplanctoniques, des fragments d'algues benthiques et de Phanérogames, des copépodes et leur fragments du pollen de pins, des écorces épidermiques de plantes terrestres et des quantités considérables de détritus d'origine organique et inorganique.

Le comptage du matériel n'a eu aucun sens, car des parties isolées du mucilage du même échantillon montraient des compositions qualitatives et quantitatives très diverses (selon le lieu d'origine de la masse). Pourtant, les densités étaient toujours exceptionnellement élevées. Sur le Tableau 1 de l'annexe figure l'examen des espèces présentes dans les prélèvements de Crikvenica et de Lopar.

Tout d'abord on a pu constater que les Diatomées ont été les mieux représentées (bien que leur nombre soit encore plus grand si toutes les déterminations pouvaient être exécutées jusqu'à l'espèce). Au total, 58 espèces de Diatomées sont déterminées, parmi lesquelles 32 formes benthiques, 25 représentants de Dinoflagellés et 10 représentants des Coccolithophorides. L'échantillon de Crikvenica, obtenu en juillet, contenait un nombre plus élevé de Diatomées que celui de Lopar qui a été prélevé en août, une quinzaine de jours plus tard. Ce dernier a indiqué une poussé de Dinoflagellés, étant donné que la relation entre les nombres d'espèces diatomiques et ceux des Dinoflagellés a été 1, 2 : 1, à la différence du premier échantillon (Crikvenica) d'une proportion de 6 : 1. L'intervalle de temps entre les deux échantillonnages a pu influencer ces différences dans les compositions des espéces.

L'analyse des populations diatomiques a démontré une prédominance des espèces benthiques (55%), dont beaucoup sont connues comme des formes tychopélagiques. Dans l'échantillon de Crikvenica étaient présentes aussi quelques Diatomées d'eau douce, comme *Eunotia flexuosa*, *Epithemia* sp. et *Diatoma elongatum*. Parmi les espèces planctoniques les plus importantes étaient les Diatomées néritiques tandis que les formes océaniques étaient représentées par cinq espèces seulement: *Asteromphalus heptactis, Chaetoceros peruvianus, Bacteriastrum delicatulum, Rhizosolenia alata* et *Rhizosolenia calcar-avis.* Toutes ces Diatomées océaniques représentent des éléments floristiques des eaux chadues et tempérées, et caractéristiques dans la mer Adriatique pendant la période chaude de l'année (Pucher-Petković, 1966).

Les Dinoflagellés enregistrés, sont des espèces néritiques-océaniques, d'une composition qui caractérise la région côtière de l'Adriatique orientale.

Tableau 2. Proportions des divers groupes phytoplanctoniques dans la baie de Rijeka (valeurs moyennes dans la colonne d'eau – VI, IX, XII 1976, II-III 1977) (D'après Pucher-Petković et al., 1983)

| Groupe systématique | Baie de Rijeka intérieure % | Baie de Rijeka extérieure % |
|---|---|---|
| Diatomées | 54,8 | 29,9 |
| Coccolithophorides | 12,2 | 17,2 |
| Dinoflagellés | 9,5 | 16,3 |
| "Microflagellés" | 23,4 | 36,5 |
| Silicoflagellés | 0,1 | 0,1 |

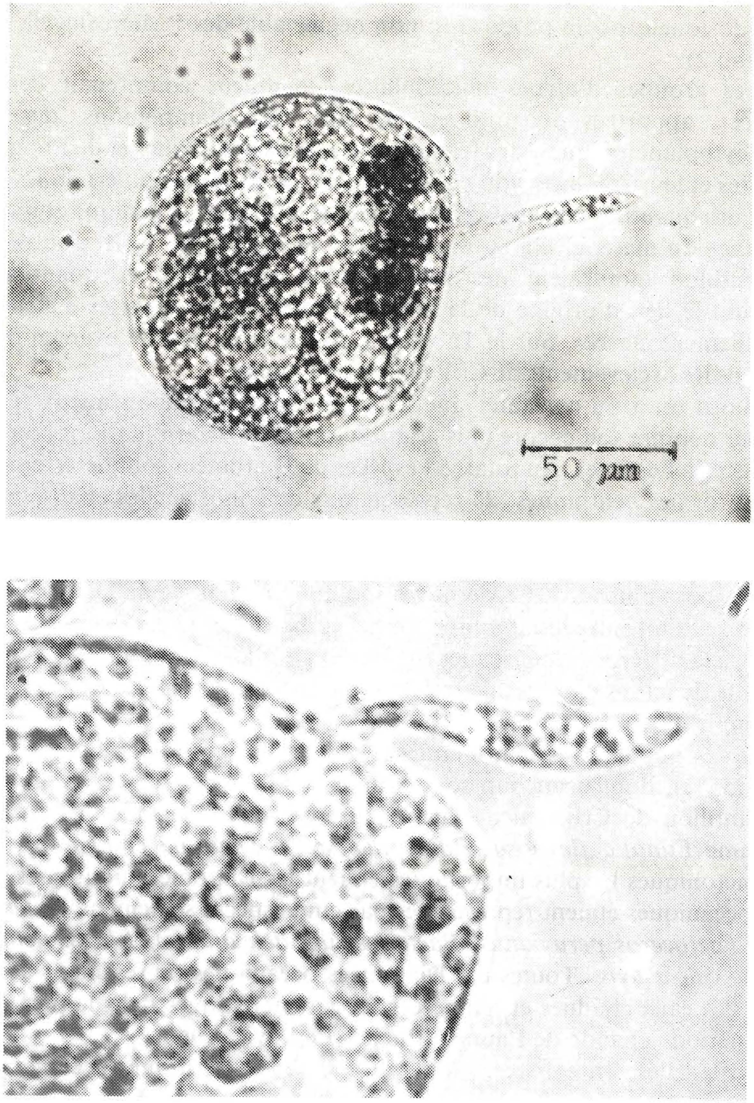

**Fig. 1** *Spatulodinium pseudonoctiluca (a, b)*

Le nombre et la densité des espèces benthiques dépendaient en premier lieu du volume et de la densité du mucilage échantillonné, tandis que le nombre et la densité des populations planctoniques sont dus à la profondeur dont la masse mucilagineuse a tiré son origine et au temps qu'elle a passé, flottant sur la mer et filtrant comme un filet les organismes planctoniques. La seule position de l'échantillonnage dans le cas de ce type de floraisons n'a pas beaucoup de signification, parce que la masse gélatineuse a pu être transportée d'un lieu plus ou moins éloigné avant d'être capturée. Les amas muqueux montraient une luminescence intense. Hormis les photobactéries, agents principaux de bioluminescence en mer, on a pu consater aussi la présence de Dinoflagellés, possédent eux aussi ce caractére: quelques espéces des genres

*Protoperidinium, Ceratium, Prorocentrum* et surtout *Warnowia, Noctiluca* et *Pyrocystis.*

En outre, il faut mentionner la présence abondante de **l'espèce** *Spatulodinium pseudonoctiluca* (Famille de Noctilucacées) dans l'échantillon de Lopar, tandis qu'à Crikvencia sa quantité a été moindre. On ne sait pas si cette espèce possède la qualité de bioluminescence. Vue que, dans notre cas, il s'agit de la **première** trouvaille de *Spatulodinium pseudonoctiluca* en Adriatique et que, d'ailleurs, cette espèce a été signalée sur un nombre très limité de localités, on donne une description générale de l'espèce ainsi que sa représentation photographique (Fig. 1).

*Spatulodinium* Cachon & Cachon, avec **l'espèce** typique *Spatulodinium pseudonoctiluca* (Pouchet) Cachon & Cachon a été décrit comme nouveau genre (Cachon et Cachon, 1967). La description concerne le stade mûr de cette espèce, caractérisé par un corps latéralment aplati, par un épicône, réduit à une mince bandelette et surtout par l'existence d'un long tentacule mobile, ventral. Les longueurs, indiquées pour ce stade, sont de 100 à 163 µm, et les largeurs en varient entre 89 et 120 µm. La longueur du tentacule est de 100 à 168 µm. Les dimensions de nos spécimens variaient dans les sudites limites de grandeurs.

L'espèce est signalée au dehors des côtes nord-est et nord-ouest de l'Angleterre, dans les eaux écossaises, méditerranéennes et dans les eaux côtiéres coréennes. Hormis les trouvailles adriatiques, mentionnées ci-dessus, quelques exemplaires de plus y ont été récemment notés (Fig. 2). Toutes ces trouvailles concernent les stades mûrs.

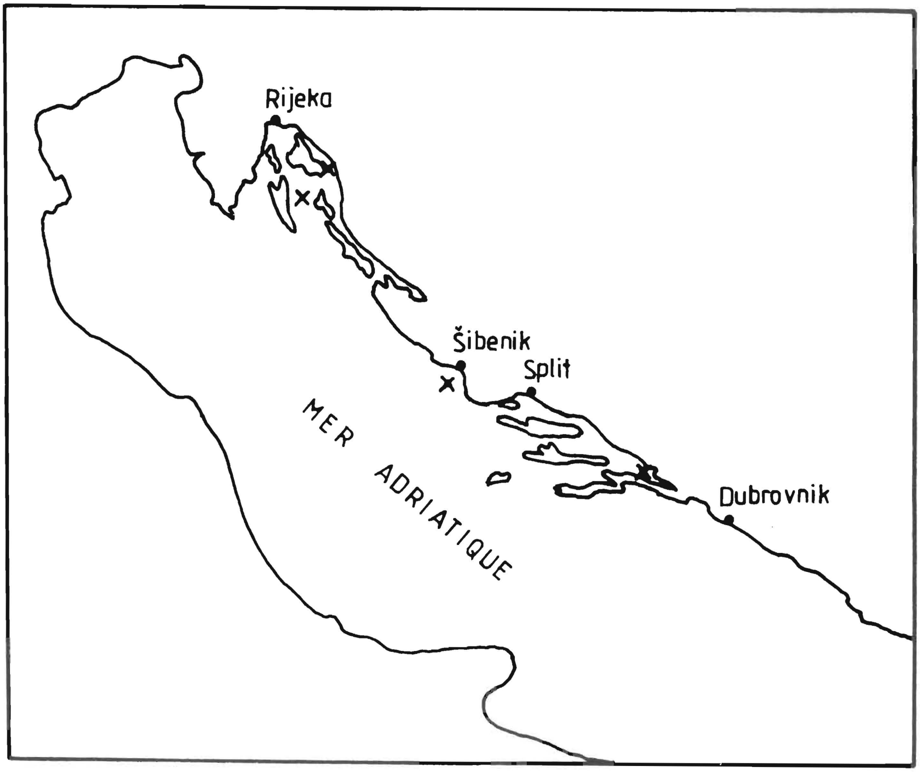

**Fig.** 2 Trouvailles de *Spatulodinium pseudonoctiluca* en Adriatique

L'ancien synonime, *Gymnodinium pseudonoctiluca*, Pouchet 1885, concerne seulement les formes juvéniles, gymnodiniennes de cette espèce et on le désigne ainsi pour les îles Faroe, la côte britannique et la Méditerranée. Ce stade possède un épicône discret, mais bien distinct, tandis que l'hypôcone en est allongé, élargi dans sa partie postérieur, arrondi ou doucement quadrangulaire. Le sillon sagittal est clairement marqué tandis que celui longitudinal est à peine identifiabe. Comme on connait bien, sa division se fait par simple division longitudinale et la cellule commence à s'arrondir et à développer le tentacule ventral. D'après Pavillard (1921, cité d'après Lebour, 1925) l'espèce est holozoïque, mais d'après Lebour (1925) l'existence des corpuscules verdâtres pourrait indiquer des chromatophores.

Cachon & Cachon (1967) n'ont pas réussi à maintenir en culture *Spatulodinium pseudonoctiluca*, mais ils ont reconnu certaines étapes de l'évolution de ce Protiste (stades gymnodiniens).

## Discussion

### *Sécrétion du mucus et formation des colonies diatomiques*

Les amas mucilagineux, flottant à la surface de la mer, sont des produits de l'excrétion des Diatomées. Le lieu d'origine de la formation du mucus est le fond de la mer et les Diatomées qui le produisent sont des formes benthiques. Etant donné qu'elles sont autotrophes et qu'elles vivent sur le fond marin, il est facile de comprendre pourquoi ce phénoméne se manifeste seulement dans la partie septentrionale, peu profonde de l'Adriatique. Comme il est bien connu, hormis les Diatomées benthiques, des espèces planctoniques excrètent également du mucus qui est formé, chez elles, en filaments très fins ou en coussinets, à l'aide desquels les cellules sont unies en colonies souples, ce qu'on considère comme l'adaptation à la vie pélagique. En général, l'excrétion du mucus est plus abondante chez les Diatomées pennées que chez les centriques, surtout chez les formes possédant un raphé qui leur donne la possibilité de se mouvoir. On croit que la formation des colonies muqueuses est une sorte d'adaptation à la vie sessile, dans le sens de la protection contre l'ensevelissement par la vase et, peut-être, la protection des consommateurs. Hendey (1964) fait mention des colonies de *Navicula grevilleana*, formant des tubes gélatineux de 6 à 8 cm de longueur, qui, parfois, contiennent quelques dizaines de millions de cellules. Chez la même espèce l'enveloppe muqueuse est présente de manière permanente ou bien, seulement pendant un temps déterminé. Il est bien connu que certaines espèces excrètent du mucus au cours de la phase plus intensive de la multiplication, et sa production pourrait être le résultat du métabolisme intensifié. On sait aussi que l'auxosporulation est souvent liée à l'excrétion intensive du mucilage. Certaines espèces se débarrassent du mucus à la fin de la période végétative et passent la mauvaise saison sous forme de spores résistantes, s'activant dès que les circonstances deviennent convenables. Sous le nom de "floraison de la mer" on comprend la phase visible à la surface de la mer qui, en vérité, représente déjà la fin de la poussée diatomique. Sur le fond de la mer les Diatomées se sont reproduites intensivement déjà un mois auparavant ou plus. La montée du mucilage du fond, qu'on a pu observer en juillet et en août, à l'oeil nu, signifie que les conditions optimales du développement des Diatomées benthiques ont déjà été remplies. Le mucus a commencé à être décomposé par l'activité bactérienne et, rempli des gaz et des Diatomées enveloppées, il a commencé à s'élever vers la surface. Sur sa route le mucilage a incorporé les organismes planctoniques et les diverses particules organiques et inorganiques, fait discuté plus haut. Le processus de dégagement graduel de la masse muqueuse du fond par la force ascensionnelle et son flottement sont mieux visibles à l'état calme de la mer, tandis que la désintégration et la descente du mucilage vers le fond sont plus rapides en présence du vent et des vagues. Le processus peut être représenté par le schéma suivant:

Reproduction végétative intense
des Diatomées benthiques

Auxosporulation
Stades de résistance

} Formation du mucus
↓
Soulevement du mucus,
englobant des Diatomées
benthiques
↓
Flottement du mucus et
incorporation du plancton
("floraison de la mer")
↓
Descente des fragments
mucilagineux au fond

Décomposition bactérienne
des enveloppes muqueuses }

*Périodicité de la végétation et facteurs influant sur la "floraison de la mer"*

Des groupes systématiques singuliers d'algues, examinés comme un tout, montrent une périodicité de développement qui dépend, sans doute, en premier lieu de la température. En Adriatique les Diatomées montrent leur développement optimal aux températures d'environ 14°C dans la période autumno-hivernale, et environ 17°C au temps de la poussée printanière. Des températures plus hautes, de 20°C, ont un effet défavorable sur leur développement (Pucher-Petković, 1966). Vu le cycle saisonnier des Diatomées d'une part et d'autre part le fait que la masse mucilagineuse s'élève du fond au cours d'été, à des températures désavantageuses pour elles, on peut conclure que la poussée intense a eu lieu 1 à 2 mois auparavant et que la masse mucilagineuse s'est mise en mouvement grâce à la décomposition bactérienne.

Parmi les Dinoflagellés, l'ordre des Gymnodiniales atteint en Adriatique le maximum de développement vers la fin du printemps et au début de l'été et les ordres des Dinophysiales et des Peridiniales le font à des températures dépassant 20°C (Ercegović, 1936), ce qui explique leur abondance dans l'échantillon de l'août 1983.

Les Coccolithophorides atteignent en Adriatique leur maximum vers la fin du printemps, ou le début de l'été. On peut trouver les Silicoflagellés seulement de temps en temps, en majorité à la suite de la période froide de l'année.

Une floraison des Diatomées benthiques de dimensions telles qu'elle s'est présentée dans notre cas, hormis la température adéquate de la mer et la lumière favorable, a besoin de la présence abondante de composés organiques autochtones et allochtones d'origine terrestre.

Au cours des dernières 20 années on s'aperçoit que l'influence de l'homme sur la production primaire dans les régions côtières de l'Adriatique orientale augmente graduellement. A titre d'illustration de tels faits peut nous servir la baie de Kaštela près de Split (Adriatique moyenne), pour laquelle nous possédons le plus grand nombre de données. On a constaté qu'il y existe une augmentation des phosphates lente, mais permanente, suivie par une augmentation paralléle de la production primaire (Tableau 3).

En plus, des dernières années, la partie Est de cette baie est un lieu du développement régulier de l'eau colorée (*Gonyaulax polyedra*) à la suite des mois d'été (Marascović et Pucher-Petković, 1985).

Nous considérons que dans les conditions de l'eutrophisation excessive, notée dans plusieurs régions de la côte orientale de l'Adriatique, des floraisons extraordinaires des algues unicellulaires, pareilles à celle décrite ci-dessus, pourraient, dans l'avenir, se manifester plus souvent que jusqu'à présent.

Tableau 3. Fluctuations des phosphates ($P-PO_4$ µg at $l^{-1}$) et de la production primaire (g C $m^{-2}an^{-1}$) dans la baie de Kaštela, entre 1962 et 1977 (D'après Pucher-Petković & Marasović, 1980)

| Période | $P-PO_4$ µg at $l^{-1}$ | g C $m^{-2}an^{-1}$ |
|---|---|---|
| 1962 – 1966 | 0,049 | 115,5 |
| 1963 – 1967 | 0,052 | 121,2 |
| 1964 – 1968 | 0,059 | 136,1 |
| 1965 – 1969 | 0,061 | 159,4 |
| 1966 – 1970 | 0,062 | 168,5 |
| 1967 – 1971 | 0,070 | 185,9 |
| 1968 – 1972 | 0,075 | 196,9 |
| 1969 – 1973 | 0,077 | 196,6 |
| 1970 – 1974 | 0,084 | 198,8 |
| 1971 – 1975 | 0,088 | 202,5 |
| 1972 – 1976 | 0,083 | 206,3 |
| 1973 – 1977 | 0,080 | 206,3 |

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Nous profitons de cette occasion pour adresser nos remerciements au directeur de la Station Marine de Roscoff, Monsieur Alain Sournia, qui nous a aimablement mis à la disposition les ouvrages sur *Spatulodinium* et auquel nous sommes redevables de beaucoup de conseils utiles.

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## ANNEXE

Tableau I. Liste des espèces

| | Crikvenica (VII 1983) | Lopar (VIII 1983) |
|---|---|---|
| Diatomeae | | |
| *Melosira nummuloides* (Dillw.) Agardh | + | |
| *Paralia sulcata* (Ehrenb.) Cleve | + | |
| *Schroederella delicatula* (Per.) Pavill. | + | |
| *Leptocylindrus adriaticus* Schröder | + | |
| *Leptocylindrus danicus* Cleve | + | |
| *Dactyliosolen mediterraneus* Perag. | + | |
| *Coscinodiscus* sp. | + | |
| *Actinoptychus adriaticus* Grun. | + | + |
| *Asteromphalus heptactis* (De Breb.) Ralfs ex Pritch. | | + |
| *Actinocyclus octonarius* war. *ralfsii* (W. Sm.) Hendey | + | |
| *Hemiaulus hauckii* Grunow ex Heurck | + | + |
| *Cerataulina pelagica* (Cleve) Hendey | + | + |
| *Chaetoceros curvisetum* Cleve | | + |
| *Chaetoceros lorenzianum* Grun. | | + |
| *Chaetoceros peruvianum* Bright | + | |
| *Chaetoceros pseudocrinitum* Ostenf. | | + |
| *Chaetoceros* spp. | + | |
| *Bacteriastrum delicatulum* Cleve | | + |
| *Rhizosolenia alata* Bright. | | + |
| *Rhizosolenia alata* f. *gracillima* (Cleve) Gran | + | + |

| | | | |
|---|---|---|---|
| *Rhizosolenia calcar-avis* Schultze | | | + |
| *Rhizosolenia delicatula* Cleve | | | + |
| *Rhizosolenia fragilissima* Bergon | | | + |
| *Rhizosolenia stolterfothii* Perag. | | | + |
| *Rhizosolenia styliformis* Brightw. | | + | + |
| *Guinardia blavyana* Perag. | | | + |
| *Guinardia flaccida* (Castr.) Perag. | | + | |
| *Fragilaria* sp. | | + | |
| *Synedra undulata* Bailey | | + | |
| *Thalassiothrix frauenfeldi* Grunow ex Cleve & Grunow | | + | + |
| *Licmophora dalmatica* (Kütz.) Grun. | | + | |
| *Licmophora* spp. | | + | + |
| *Grammatophora oceanica* Ehrenb. | | + | |
| *Grammatophora* spp. | | | + |
| *Eunotia flexuosa* Kütz. | | + | |
| *Achnanthes* spp. | | + | |
| *Campylodiscus fastuosus* Ehrenb. | | + | |
| *Campylodiscus horologium* Williams | | + | |
| *Cocconeis scutellum* Ehrenb. | | + | |
| *Navicula* spp. | | + | + |
| *Trachyneis aspera* (Ehrenb.) Cleve | | + | |
| *Mastogloia fimbriata* (Bright.) Cleve | + | | |
| *Mastogloia* sp. | | | + |
| *Pleurosigma angulatum* (Quekett) W. Smith | | + | |
| *Amphiprora* spp. | | + | |
| *Amphora ovalis* Kütz. | | + | |
| *Amphora* spp. | | + | + |
| *Epithemia* sp. | | + | |
| *Nitzschia closterium* (Ehrenb.) W. Smith | | + | + |
| *Nitzschia delicatissima* Cleve | | | + |
| *Nitzschia insignis* Greg. | | + | |
| *Nitzschia longissima* (de Breb.) Ralfs ex Pritch. | | + | |
| *Nitzschia seriata* Cleve | | + | + |
| *Nitzschia sigma* (Kütz.) W. Smith | | + | |
| *Nitzschia tenuirostris* Mer. | | + | |
| *Nitzschia* sp. | | + | |
| *Surirella fastuosa* Ehrenb. | | | + |
| *Diatoma elongatum* C.A. Agardh | | + | |
| Dinoflagellata | | | |
| *Prorocentrum lima* (Ehrenb.) Dodge | | | + |
| *Prococentrum micans* Ehrenb. | | | + |
| *Prorocentrum scutellum* Schröder | | | + |
| *Prorocentrum triestinum* Schiller | | + | |
| *Protodinium simplicius* Schiller | | + | + |
| *Amphidinium flagellans* Schiller | | | + |
| *Cochlodinium archimedes* (Pouchet) Lemm. | | | + |
| *Gymnodinium caput* Schiller | | + | + |
| *Gymnodinium grammaticum* (Pouchet) Kofoid et Swezy | | + | |
| *Gymnodinium ostenfeldii* Schiller | | + | + |
| *Gyrodinium falcatum* Kofoid et Swezy | | | + |
| *Warnowia* sp. | | + | + |
| *Noctiluca* sp. | | + | + |
| *Spatulodinium pseudonoctiluca* (Pouchet) Cachon & Cachon | | + | + |

| | | |
|---|---|---|
| *Pyrocystis noctiluca* Murray ex Haeckel | + | |
| *Glenodinium* sp. | | + |
| *Protoperidinium* sp. | | + |
| *Gonyaulax kofoidii* Pavillard | | + |
| *Gonyaulax polygramma* Stein | | + |
| *Gonyaulax turbynei* Murr. et Whitt. | | + |
| *Ceratium carriense* Gourr. | | + |
| *Ceratium massiliense* (Gourr.) | | + |
| *Oxytoxum gladiolus* Stein | | + |
| *Oxytoxum* sp. | | + |
| *Goniodoma ployedricum* (Pouchet) Jörg. | | + |
| Coccolithophoridae | | |
| *Emiliania huxleyi* (Lohm.) Hay et Mohler | | + |
| *Calyptrosphaera insignis* Schiller | | + |
| *Galyptrosphaera oblonga* Lohm. | | |
| *Calyptrosphaera sphaeroidea* Schiller | + | |
| *Pontosphaera* spp. | + | + |
| *Scyphosphaera apsteinii* Lohm. | | + |
| *Syracosphaera pulchra* Lohm. | + | |
| *Syracosphaera* spp. | + | + |
| *Rhabdosphaera erinaceus* Kampt. | | + |
| *Rhabdosphaera hispida* Lohm. | | + |

## SUMMARY

During the summer of 1983 an extraordinary intensive "sea water bloom" ("floraison de la mer", "mare sporco", "Meeresblüte") was recorded all over the Bay of Kvarner (northern Adriatic). The phenomenon appears as a dense mucilaginous mass, floating on the sea surface, which embeds a high quantity of unicellular algae. Although the occurrence of this phenomenon is infrequent, it has been recorded on several occasions in the shallow northern Adriatic; always during the summer.

Two samples from Crikvenica (July) and Lopar, Rab Island (August) were analysed. A total of 58 diatom species, of which 32 benthic species, 25 dinoflagellates and 10 coccolithophorids were identified by microscopy. In addition to these groups of unicellular algae, considerable quantities of blue-green algae, carried from the sea bottom, as well as fungi, resting stages of phytoplankters, fragments of benthic algae and seagrasses, copepods and their fragments, pine pollen, epidermic scales of terrestrial plants and remarkable quantities of organic and inorganic detritus were observed.

The number and density of benthic species depend mostly on the volume and density of the gelatinous mass, while the qualitative-quantitative composition of plankton populations depends on the depth from which the gelatinous mass originates and on the time taken by the floating mass in filtering plankton organisms.

The gelatinous accumulations showed intensive bioluminescence. Apart from photobacteria, the principal agents of bioluminescence in the sea, some bioluminescent dinoflagellate species were also recorded.

The presence of a recently described dinoflagellate genus, represented by the type species *Spatulodinium pseudonoctiluca* (Pouchet) Cachon & Cachon was identified from both samples and constitutes its first record for the Adriatic.

The gelatinous mass floating on the sea surface is the excretion product of diatoms. Mucus is produced at the sea bottom by benthic diatom species.

With respect to the known seasonal cycle of diatoms in the Adriatic it may be concluded that benthic diatoms had reproduced intensively a long while before the phenomenon became visible at the sea surface. This phase – the so called "water bloom" – in fact represents the end of the diatom bloom. Release of the gelatinous mass from the sea bottom is due to bacterial degradation. As a consequence, the mass becomes full of gases and begins to ascend incorporating plankton organisms on its way to the surface. Finally, small particles of torn mucus sink again to the bottom where they are completely degraded.

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