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EDITORIAL NOTE

The first issue of CENTRO brings together a collection of papers from various disciplines which seemingly have nothing in common to share as central theme except the superficial description that they are all scientific studies related to regions within the Mediterranean. This appears to be too conspicuously in conflict with the declared objectives of CENTRO.

A closer analysis of the current scientific activity within the region we are concerned with, however, reveals why we insisted on putting across this collection; disjointed as it might appear. We offer it as a starting point, indicative in more ways than one, of what we feel is too little an effort put into seeing beyond the territorial boundaries charted out historically by different scientific disciplines and traditions. The virtues of an integrated approach towards the study of a particular region, we hope, need not be emphasised though they can hardly ever be overstated. On the other hand one should not fail to add that quite a few efforts in this direction, inspired by bold attempts of the more enterprising intellectuals in some cases aided by government and international agencies, date to several decades back. Hopefully CENTRO will be yet another.

The present situation displays two main directions in need of development. The first involves studies of a basic nature: collection of primary data, their compilation and organisation into an information system which offers schematised and easily accessible outlets. Needless to say this would eventually have to evolve into a computerised database system with an intelligent layout reflecting the appropriate conceptual scheme of the information structures, activated by suitable cross-referencing and linked data structures. This line would offer plenty of scope for research within specific disciplines in its initial phase.

The second direction would necessarily evoke more global considerations. Conceived in the spirit of the more progressive trends of thought within evolutionary epistemology, it would be an all-embracing approach. Environment and its constituents would be thought of as inter-acting in a two-way process, no longer visualised within the narrow perspectives of cause-and-effect and the crushing influence of dominating metaphysical forces of nature on passive occupants of a doomed environment. On a more practical level we hope to stimulate a general systems approach leading to the formulation and validation of computer models to act as simulators of the real-world systems of interest. This should in turn generate a dialectic supported with scientific information which can go into details relating to economic, demographic, political, sociological, cultural and physical aspects. Any naïve proposal for improvement in whatever sense cannot be taken seriously if it excludes purposely the problem of what makes the obvious measures inpractical to push at a national or even international level. The legislative machinery and political milieu, for example, which operate within a region forms as much an integral, if not decisive, constituent of it as its fauna, vegetation or physical features.

In future we hope to emphasise these lines by actively encouraging works which broadly comply with the above philosophy and by inviting selected authors to give us contributions on specially chosen areas of study for publication in CENTRO.

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Tectonics of the Maltese Islands

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ABSTRACT

The Maltese Islands are a key area in the Central Mediterranean for understanding the development of faulting and foreland reactions on the northern edge of the African plate. Convergent and lateral motions along the Afro-Eurasian plate boundary generated different and superimposed stress regimes in the sedimentary cover, which governed the fracture pattern and fault processes.

Structural evolution of the Maltese Islands:

(1) Lower Miocene: Synsedimentary NE–SW (50 – 70°) trending extension fractures developed.

(2) Upper Tortonian: Synsedimentary normal faults, trending 150°, reflect the first tectonic impulse in the formation of the Pantelleria Rift (W of Malta) which interrupts in a NW–SE direction the shelf bridge that connects northern Africa with southern Sicily.

(3) Post Tortonian-Lower Messinian and pre Quaternary: NE–SW to ENE–WSW (60 – 80°) trending horsts and grabens which traverse the islands were formed. At the same time the Pantelleria Rift evolved with its climax in the Pliocene. The contemporaneousness of both events might be due to a mantle updoming which hit pre-existent crossing weakness zones in the overlying crust.

(4) Quaternary-recent: Normal faulting orientated 120° and associated with the Pantelleria Rift. Continuous rifting leads to ongoing shoulder unwarping, with Maltese Islands tilting towards NE.

Some of the NE–SW trending normal faults are neotectonally remodelled into

strike slip faults. The kinematic analysis of the fracture pattern on E–Gozo results in a general model for a shear process within an interstratification of competent and incompetent rocks.

Introduction

The Maltese Islands are situated in the Strait of Sicily between Italy and North Africa. The distance to the southern coast of Sicily is about 90 km and to the eastern Tunisian coast about 300 km. The archipelago has a length of 45 km with Malta as the largest island in the south (246 km^2) and the island of Gozo (67 km^2) in the north. Between Malta and Gozo, separated by the 1 km wide North Comino, and the 2 km wide South Comino Channel are the islets of Comino and Cominotto with a total area of 2.5 km^2. 4.5 km off the southern coast of Malta lies Filfla Island, only some hundred square metres in size (Fig. 1).

The Maltese Islands, which rise up to 253 m above sea level, form an emerged part on the southern upwarped NE–shoulder of the Pantelleria Rift which interrupts the shallow shelf platform connecting Europe and Africa (Illies 1981). The fracture pattern of the islands has been created by tectonic processes governed by the relative motions between the European and African plates. The plate boundary runs about 200 to 400 km to the north of Malta from Tunisia to Sicily (Fig. 11).

Maltese strata and structures were first described by Spratt (1854) and Hobbs (1914). Further data on the geology were given by Hyde (1955). An excellent base for detailed studies on Maltese rock succession and tectonics is presented in the Geological Map of Malta (1:31 680) by the BRITISH PETROLEUM Co. Ltd. (1957). Additional data on the stratigraphy and structures were given by House *et al.* (1961), Felix (1973), Pedley *et al.* (1976), Pedley & Waugh (1976), Zammit-Maempel (1977) and Pedley *et al.* (1978). The analysis of the complex joint pattern of the islands was one of the main aspects in the geological, structural and geomorphological study of Vossmerbäumer (1972). The first kinematic interpretations of Maltese tectonics have been carried out by Illies (1980, 1981).

The Maltese strata comprise hard, massive sometimes reefal, tectonically competent coralline limestones, ductile fine grained biomicrites and plastic marls and clays of a tectonically incompetent behaviour. The litho- and chronostratigraphical rock succession and the paleoenvironment of the Maltese Islands have been studied in detail by Murray (1890), Felix (1973), Pedley (1978), Pedley *et al.* (1978), Di Geronimo *et al.* (1981). According to these authors they consists of the following formations:

- Upper Coralline Limestone Formation: up to 162 m thick, represented by shallow water facies ranging from subtidal through intertidal and supratidal environments.
- Greensand Formation: up to 12 m glauconitic limestones.
- Blue clay Formation: up to 65 m slightly consolidated marls which have been deposited in an open marine environment at sea-depth between 200 and 40 m.
- Globigerina Limestone Formation: a 23 – 207 m thick sequence of fine-grained biomicrites with intercalated layers of phosphorite nodules. These series have been deposited at water depth between 40 and 150 m in a shallow shelf area.
- Lower Coralline Limestone Formation: exposed above sea level up to 140 m, represented by a shallow water facies formed at sea-depth of less than 50 m.

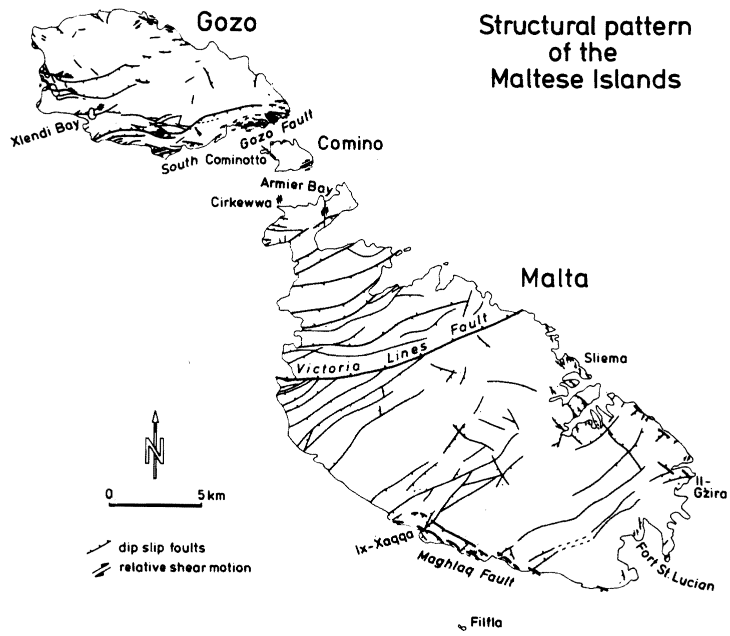

Fig. 1. Structural pattern of the Maltese Islands (modified after BP Geological Map 1957, House *et al.* 1961, Pedley & Waugh 1976 and Illies 1982)

After Felix (1973) the Lower Coralline Limestone corresponds to the Chattian stage of the Upper Oligocene and the overlying strata to the Aquitanian through to Tortonian age. Giannelli & Salvatorini (1975) proposed a Messinian age for the Upper Coralline Limestone Formation and Di Geronimo *et al.* (1981) considered a Langhian to Tortonian age for the Blue Clay Formation. Pedley (1983) supposes that during the Lower Messinian, oscillations of the sea level have produced erosion surfaces within the Upper Coralline Limestone Formation. No strata of Pliocene age is known so far from the Maltese Islands. Quaternary deposits are restricted to isolated patches of paleosoils, fluvial gravels, alluvial fans, dunes and infillings of fissures.

Evolution of Maltese fault tectonics

The fracture pattern of the Maltese Islands is governed by two intersecting fault systems which alternate in tectonic activity. A NE–SW to ENE–WSW trending fault system traverses the islands and is crossed by a NW–SE trending fault system (Fig. 1) parallel to the Malta trough, the easternmost graben of the Pantelleria-Rift System.

The oldest tectonic movements observable on the Maltese Islands are synsedimentary NE–SW trending extension features formed during the deposition of the

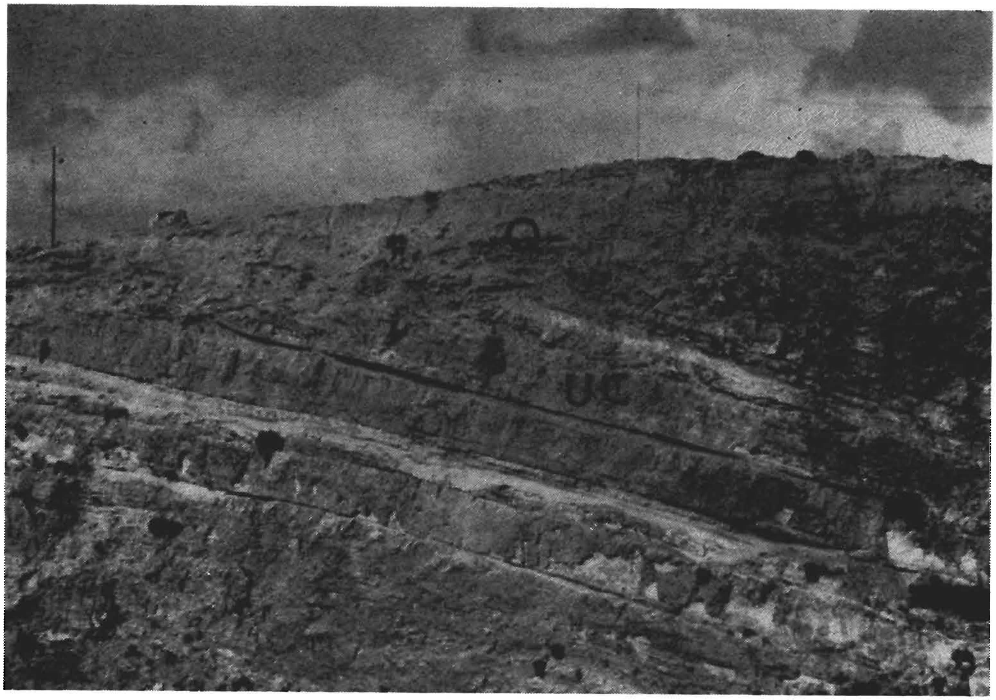

Fig. 2. Unconformity between Quaternary deposits (Q) and the Upper Coralline Limestone Formation (UC) on West Malta at Fomm-ir-Riħ Bay north of Victoria Lines Fault.

Globigerina Limestone Formation. These structures were interpreted first by Illies (1980) who described growth faulting with a trend of 55°, south of Xlendi Bay on Gozo. These synsedimentary movements took place before the deposition of the first main phosphorite layer which marks the top of the Lower Globigerina Limestone Formation and corresponds to the Aquitanian/Burdigalian boundary (Felix 1973). Sedimentary dikes in the Lower Globigerina Limestone infilled with material of the phosphorite layer and trending parallel to the growth fault, as observed by Illies (1980) on Gozo, are also developed in southern Malta, e.g. near Il-Gzira where they trend 70°. The decrease in thickness of the Lower Globigerina Limestone towards the Comino Channels (Pedley *et al.* 1976) is caused, according to Illies (1980, 1981), by a slight regional syndepositional rift uparching which preceded the formation of the NE–SW trending basin-and-range structure between the Victoria Lines Fault on central Malta and the South Gozo Fault. Parallel to these faults growth faulting affected as well the basal part of the Upper Coralline Limestone Formation (Bosence & Pedley 1982). The main dip-slip events forming the NE–SW trending horsts and grabens, which are also topographically very well pronounced, took place after the deposition of the Upper Coralline Limestone Formation. The throw along the northward dipping Victoria Lines Fault reaches 183 m on the west coast of Malta and decreases towards the east coast to about 90 m (House *et al.* 1961). The vertical displacement of the South Gozo Fault, dipping southwards, is about 100 m. This graben generation, traceable to the Aquitanian, became extinct before the Quaternary (Illies 1980, 1981). No vertical displacements of Quaternary deposits at this fault generation are known on the islands;

rather the fault scarps are unconformably capped by Pleistocene sediments (Fig. 2). However, during the sedimentation of the Upper Coralline Limestone Formation, NW–SE trending normal faulting had occurred already and this is interpreted to be connected with the initial movements of the Pantelleria Rift System. In the Upper Coralline Limestone, for example, south of Ix-Xaqqa at the southern coast of Malta, a yellowish limestone layer, about 80 cm thick, reveals 150° trending step faulting (Fig. 3). These vertical displacements decrease into the overlying sediments. The yellowish layer rests upon an up to 1 m thick concretionary limestone horizon, which according to Zammit-Maempel (1977), marks the base of the uppermost division in the Upper Coralline Limestone Formation (Lower Messinian, Pedley 1983). Upper Messinian sediments are lacking on the Maltese Islands. Strong vertical displacements in the upper Miocene related to the Pantelleria Rift are indicated in the Upper Messinian graben fillings of the Malta and Linosa troughs which consists of calcarenites bearing an oligotypic pelagic fauna (Colantoni & Borsetti 1973). The main subsidence lasted through Pliocene (Finetti & Morelli 1973), and some faults of the Pantelleria Rift are considered to be active up to present times.

Faults on the Maltese Islands associated with the Pantelleria Rift are represented by the NW–SE trend. The most prominent young tectonic feature is the system of the Magħlaq Fault (Pedley & Waugh 1976) SE of Ix-Xaqqa along the southern coast of Malta with a vertical displacement of at least 240 m to the SW (House *et al.* 1962). The 120° trending fault shows neotectonic activity. An interstratification of red soil, breccia and caliche at Ras il-Bajjada (3 km SE of Ix-Xaqqa) is cut by the fault and slickensided (Fig. 4). At Ix-Xaqqa young sediments of probably Quaternarian age are smeared

Fig. 3. Synsedimentary 150° trending faults in the upper part of the middle Upper Coralline Limestone Formation at Ix-Xaqqa.

Fig. 4. Neotectonic 120° trending dip slip fault plane with vertical slickensides of the Magħlaq fault system 3 km SE of Ix-Xaqqa at the southern coast of Malta.

in the fault plane. Quaternary and post Quaternary tectonics along the Magħlaq fault have also been mentioned by Trechmann (1938) and Illies (1980, 1981). The NW–SE trending faults crosscut and displace the previous structures (Illies 1980, 1981; Reuther 1983b). This is to be observed in Central Malta and along the southern and northern coast of SE–Malta. A very expressive exposure showing the displacement of a 70° striking normal fault along two 135° trending normal faults, is to be seen in the Globigerina Limestone at Il-Gzira on the eastern coast of Malta (Fig. 5).

Besides normal faulting the Maltese Islands have also been affected by horizontal movements. This is indicated at many sites by the formation of second order tension – and-shear fractures. These staggered arranged features specify the relative sense of strike slip movements. The second order shear structures visible in the Globigerina Limestone at the northern coast of Malta in the Sliema region can be interpreted to be related to sinistral strike slip movements trending between 140° and 160°. The shear structures are exposed in the vicinity of 120/50SW orientated normal faults. The tension joints in the Globigerina Limestone near Fort St. Lucian in SW–Malta described by Vossmerbäumer (1972) might be related to the same NNW–SSE trend of shear motion. Second order faulting at Cirkewwa on N–Malta in the Upper Coralline Limestone reveals also sinistral strike slip motion but with a NNE–SSW trend. Parallel to this trend horizontal slickensides occur in the Upper Coralline Limestone near Armier Bay/N-Malta (Vossmerbäumer 1972). Small scale shear structures are very well developed in the Lower Globigerina Limestone on the northern coast of

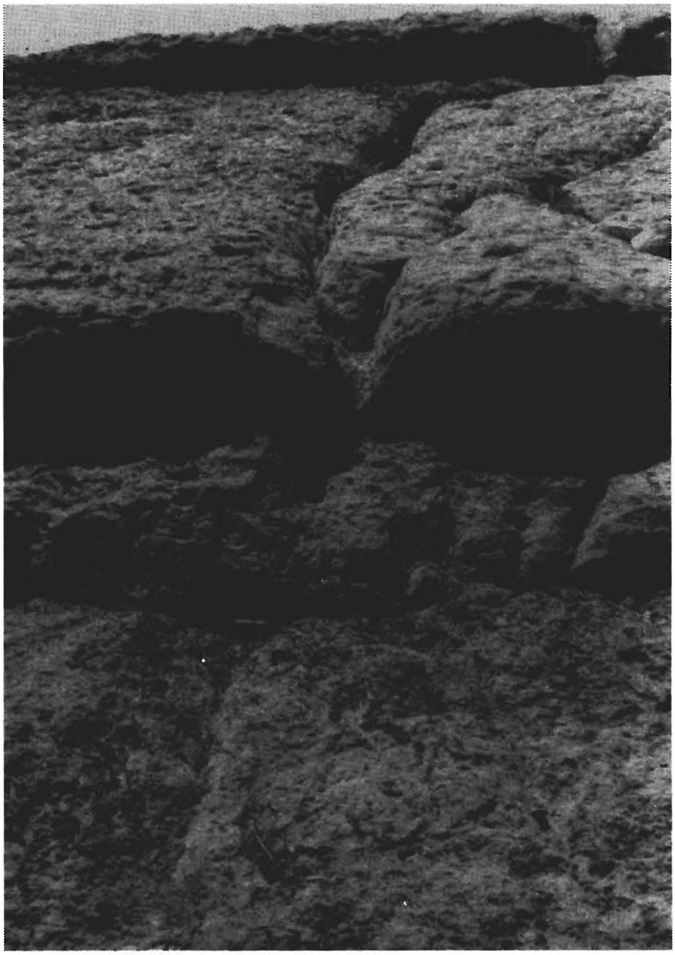

Fig. 5. Vertical displacements of a 70° trending dip slip fault along two parallel 135° trending dip slip faults in the Globigerina Limestone at Il-Gzira.

Gozo. In general the NE–SW shear direction is of dextral polarity while the NW–SE direction is of sinistral polarity. In western Gozo, subcircular intra-Tertiary subsidence structures (Pedley 1974) with diameters up to 500 m are crossed by strike slip and oblique slip faults which displace the margins up to 50 m. Illies (1980) refers this kind of shear to be controlled by the regional stress regime, gravitational sliding towards the subsidence structures and/or the superposition of both these processes. The most spectacular shear structure of the Maltese Islands is exposed on East Gozo where a dextral strike slip motion trending 90° to 65° has created a large scale en echelon structure (Illies 1980, 1981; Reuther, 1983c).

Formation of large scale Feather within Feather Structures on East Gozo

The block faulted area of east Gozo (Fig. 6) has been formed by the superimposition of two tectonic processes, different in relative fault displacement and in age. The South Gozo Fault originated as a normal fault and forms the northern master fault of the horst and graben system traversing the Maltese Islands. The dip slip fault has been remodelled into a dextral strike slip fault. On the fault plane horizontal slickensides are observed to overprint vertical slickensides. Illies (1980, 1981) attributed the dextral motions and its resulting first and second order shear structures on east Gozo and northwest Malta (Fig. 1) to transform faults of the Pantelleria Rift which trace a preexistent weakeness zone in the Comino Channels.

The excellent exposures on east Gozo enable a "three-dimensional" mapping of shear structures within an interstratification of competent and incompetent rocks. So the temporal state of formation, succession and interaction of tension and shear fractures related to a strike slip fault could be reconstructed step by step.

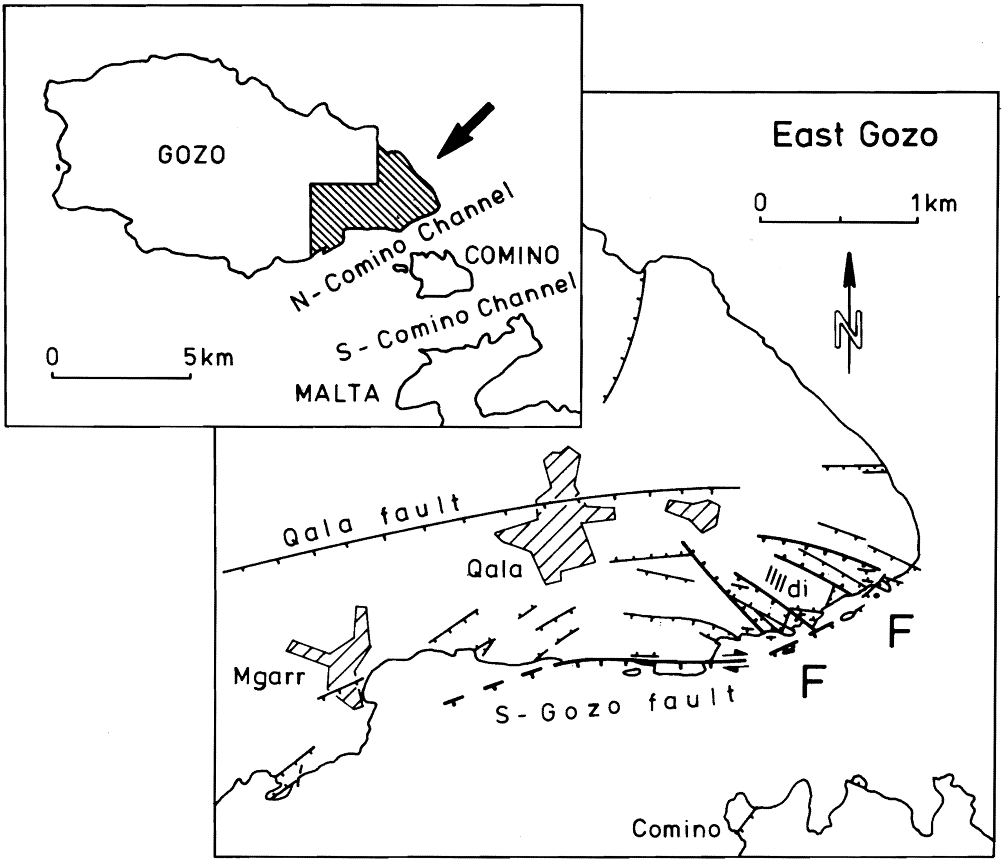

Fig. 6. Structural map of east Gozo: S–Gozo fault and Qala fault as well as some parallel faults in between developed as normal faults. During a later tectonic stage the S–Gozo fault has been remodelled into a dextral strike-slip fault. As a consequence of the strike slip motions large scale feather within feather structures (F) have been formed oblique to the S–Gozo fault.

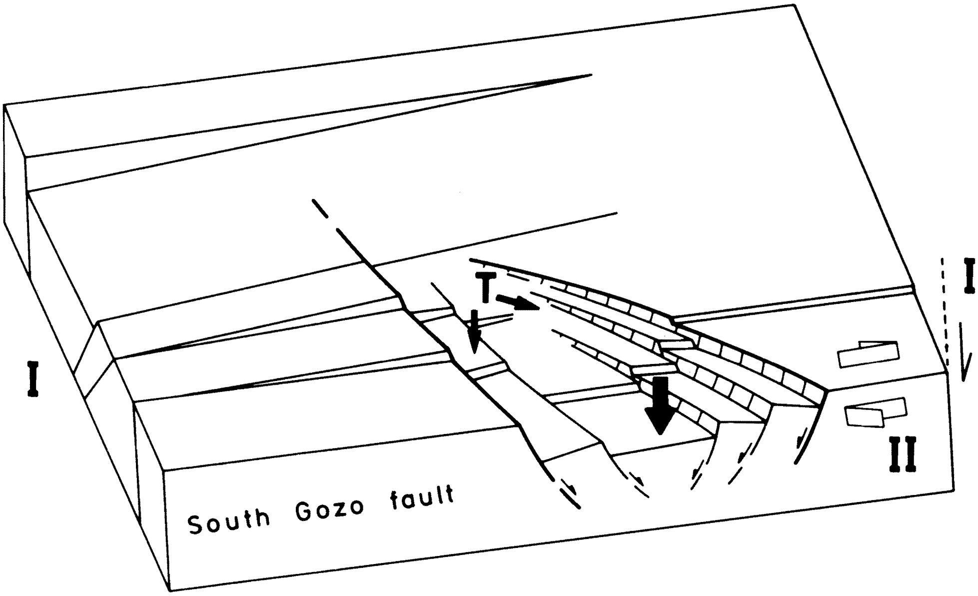

Fig. 7. Large scale feather structures 700 × 250 m. Tension (T) and subsidence (black arrows) increase towards the S–Gozo fault (I: first tectonic stage of normal faulting, II: second tectonic stage with dextral strike slip along the S–Gozo fault). The feather structure crosses and displaces the previous (I) structures.

As a consequence of the dextral motion, large scale tension gashes or feather structures have been formed (F in Fig. 6). These structures crosscut and displace the previously developed normal faults parallel to the South Gozo fault. The highest amount of extension within the feather structures is along the dextral strike-slip master fault. Due to this opening of the feather structures, the vertical displacement (black arrows in Fig. 7) along the individual tension faults increases towards the strike-slip master fault. The incompetent Globigerina Limestone and its overlying rock succession became downwarped into the Lower Coralline Limestone (Fig. 8). The maximal vertical displacement observed in the feather structure amounts to 50 m near the dextral master fault. In the field one can follow the outcropping curved hinge faults up to the outer end of the mega fissure where the vertical displacement is only a few centimeters within one layer of the Upper Coralline Lst. Form. The feather structures on east Gozo are exposed up to a length of 700 m and a width of 250 m. They form an angle of 55° to 70° with the dextral master fault. Continuous shear has led to a rotation of these initial feather structures until no further extension was possible. Outside the mega fissures, in the Lower Coralline Limestone, dextral strike-slip faults are to be recognized forming a more plane angle with the master fault. They are interpreted as Riedelshears (Riedel 1929). These Riedelshears cut off and displace previous large tension gashes (Reuther 1983b). Within the large scale feather structure in the downwarped incompetent rock, fault planes are observable with oblique slickensides. These faults are interpreted as rotated Riedelshears which have got a tensional component during the ongoing shear process. Additionally to horizontal mega shear lense rotations up to 20° between the Riedelshears, subsidence between the rotated

Fig. 8. View of large scale feather structure on the southern coast of E–Gozo. Globigerina Limestone (G) and Blue Clay (B) have been downwarped into the Lower Coralline Limestone (LC).

Riedelshears finally also occurred. Second feather structures have been formed (F′ in Fig. 9) inside the initial feather structures (F in Fig. 6) and have created a feather within feather structure (Reuther 1983a). The faults forming the F′ structure die out towards the outer hinge faults of the initial F structure. The schematic block diagram of Fig. 9 is based on geological field mapping on a scale 1:2500.

Vertical displacement along rotated Riedelshears is also to be observed along Riedelshears with a length of 1 to 3 m in several places on Gozo (Reuther 1983c). This corresponds to the widened shear joints in Riedel's experiment (Riedel 1929).

Near the South Gozo fault a lateral extension of about 11% has been calculated for the total structure. The extension has led to internal tilt-block rotations. Some blocks of Upper Coralline Limestone are inclined 30° (a in Fig. 10). Due to the intersection of the F and F′ structures some blocks became totally isolated (Fig. 9) and have tilted arbitrarily (b in Fig. 10).

In the Upper Coralline Limestone Formation a dense pattern of calcite veins is to be recognized (di in Fig. 6). These fractures might be interpreted as conjugate Riedel elements (Illies 1981). In general these microfaults show extension rather than horizontal offset. Measurement of the joint spaces result in a total dilatancy of 2.5% related to a 250 m long territorial section.

Neotectonic movements affecting the feather within feather structures during or after Quaternary times might be indicated in slickensided brown-reddish infillings of fissures in the Lower Coralline Limestone in the easternmost part of Gozo (see also Hyde, p. 59). Minimal, probably post Bronze aged, offset is implied in sinistral bending of the ancient cart tracks which cross on a length of about 200 m the above mentioned microfaults corresponding to the conjugate Riedelshears of the shear zone.

The detailed structural mapping of east Gozo leads to the conclusion that during the shear process, tension fractures occurred at first. These tension fractures have been pierced during further shear by shear fractures which have also widened due to continous shear motion. The individual large scale shear structures correspond in geometry and succession to one of Riedel's clay experiments (Riedel 1929).

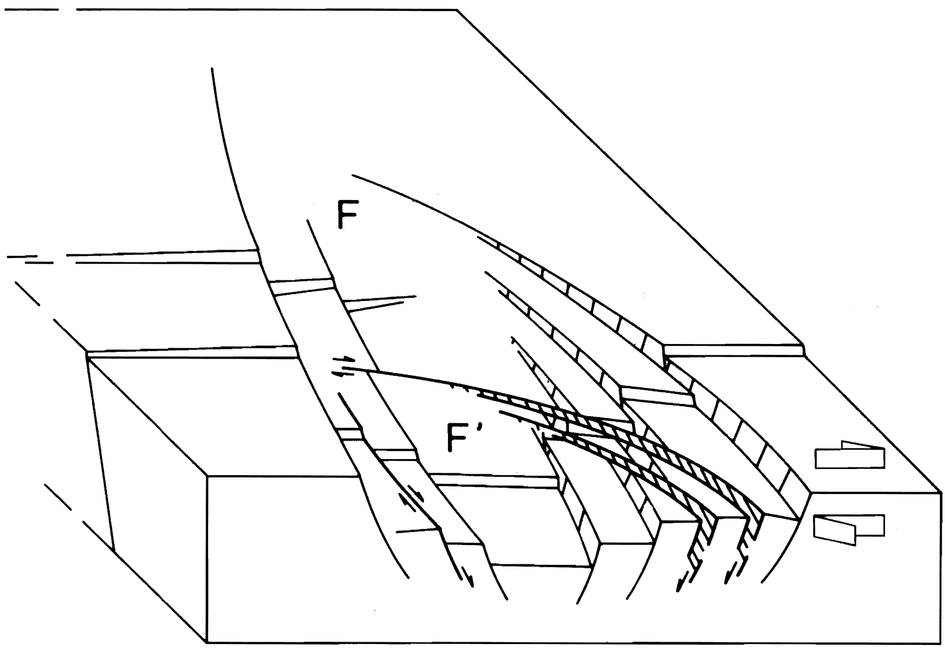

Fig. 9. Feather-within-feather structure: Within the rotated initial feather structure (F) a second feather structure (F′) has developed, formed by rotated and widened Riedelshears (up to 450 m long), caused by a continuous shear process.

Structural Setting of the Maltese Islands in the Strait of Sicily–Central Mediterranean Sea

In terms of plate tectonics the Maltese Islands belong to the African plate and are an emerged segment, on the shallow shelf bridge of the Strait of Sicily, of the Pelagian Sea that connects the Ragusa plateau of southern Sicily with the Tunisian plateau (Morelli et al. 1975, Burollet et al. 1978, Finetti 1982). The Afro-Eurasian plate boundary is marked by an active seismic belt which runs from the Azores across Gibraltar and North Africa to northern Sicily (McKenzie 1970, 1972). The tectonic evolution on the plate margins has been controlled since the Upper Triassic through to present times by the relative motions between Africa (Gondwana) and Europe (Eurasia) (Smith 1971, Smith & Woodcock 1982). From the Upper Triassic to the Upper Cretaceous the African plate moved south-eastwards revealing a sinistral megashear movement along the plate boundary. During this time span the northern edge of the African plate was governed by extensional tectonics and meanwhile oceanic crust was produced between the diverging African and European plates (Barberi et al. 1974). Compressional continental collision, affecting a wide deformation zone, set in during the Upper Cretaceous. Palaeo-stress field determinations of Letouzey & Trémolières (1980) in Tunisia show an average stress orientation of 140° in Upper Cretaceous rocks, and 160° in Eocene rocks, which should also have affected the Strait of Sicily. During Late Oligocene and Early Miocene NE–SW palaeo-stress orientations have been observed all around the central Mediterranean (Letouzey & Trémolières 1980). The oldest extensional features on Malta in the Globigerina Limestone Formation have the same trend

Fig. 10. Feather-within-feather structure showing vertical tilt-block rotation (a) and isolated arbitrary tilted blocks (b) due to the opening and the intersection of the faults.

and Illies (1980, 1981) attributed their formation, according to Laughton & Whitmarsh (1974), to a period of sinistral shear motion parallel to the plate boundary which ended about 10 million years ago. During the Tortonian, Tunisia was affected by an important tectonic phase and at the same time the graben structures in the Strait of Sicily appeared (Burollet & Byramjee 1974). This is very well recognized on Malta in 150° trending synsedimentary normal faults in the middle Upper Coralline Limestone. On Lampedusa a synsedimentary fault and fracture zone of about the same trend is observable. The sediments of Lampedusa correspond also to the middle Upper Miocene up to Tortonian (Serge 1964, Colantoni & Borsetti 1973). The northwards directed motion of the African plate against the European plate had induced a stress field that reactivated NNW–SSE trending fault zones which had been already traced out during Late Cretaceous and Eocene times. The preexisting pattern in the subjacent beds of the Maltese Islands, which is supposed by Vossmerbäumer (1972) to be responsible for the NNW–SSE trend in the joint pattern should have been caused by the same stress field.

The predominant structures on Malta are NE–SW trending horsts and grabens which cut through the entire Tertiary rock succession. These dip slip movements took place between Tortonian-Lower Messinian and Quaternary times. At the same time the NW–SE trending Pantelleria Rift System started to evolve. Some of the NE–SW striking faults traversing Malta are hinge faults with an increase of vertical displacement towards the W on to the Panelleria Rift. This might be due to the simultaneous temporary tectonic activity of both graben systems, caused by an updoming mantle leading to regional uplift. From southern Sicily towards Pantelleria the crustal

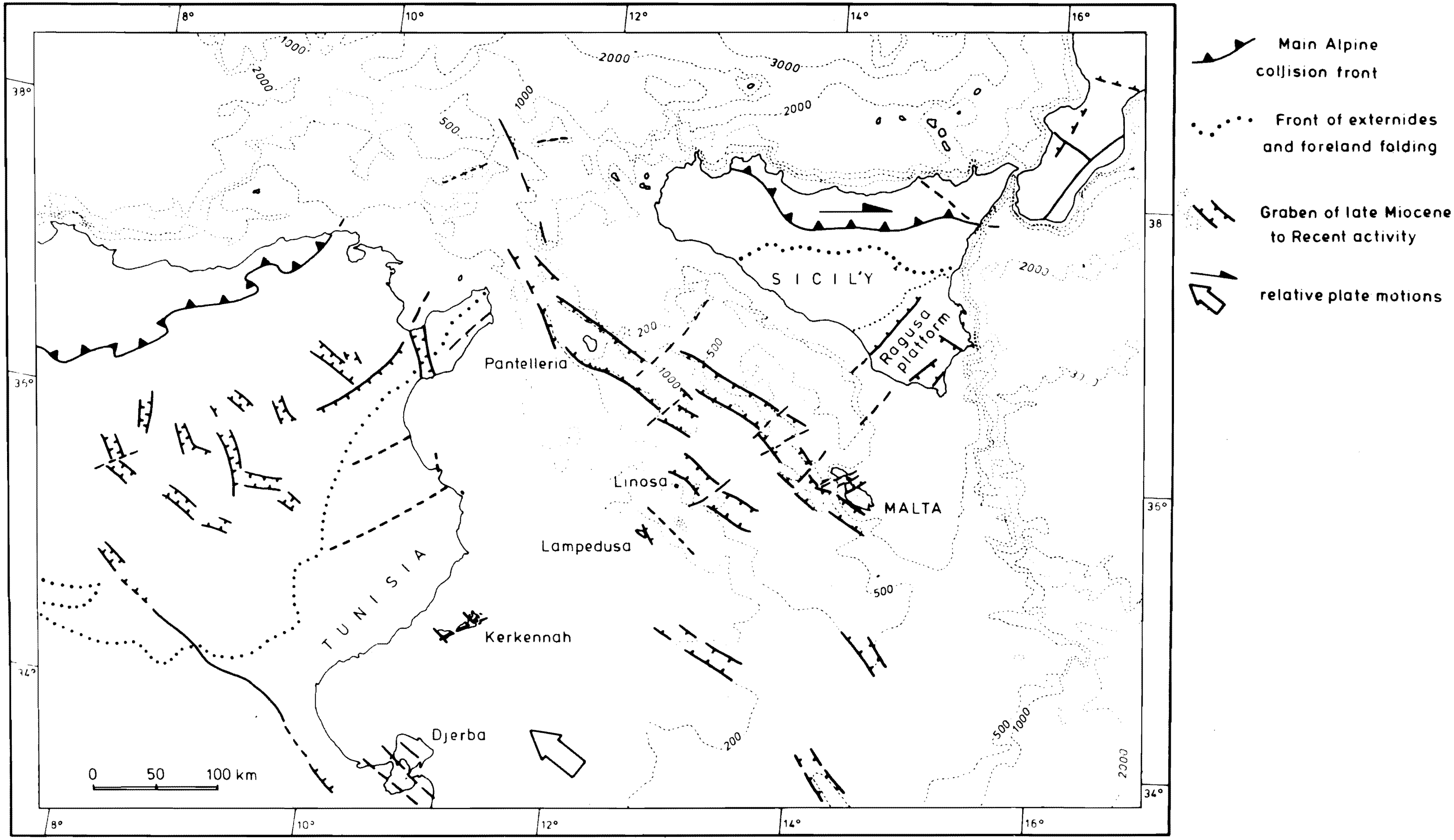

Fig. 11. Structures of the Central Mediterranean Region (compiled after Carte Tect. Int. de l'Europe, Moscow 1964, Burollet 1971 & 1978, Ghisetti & Vezzani 1981, Illies 1981). The Pantelleria Rift System traverses the shelf between Northern Africa and Sicily. The tectonic pattern is governed by the interaction and superimposition of different stress regimes due to the convergent and lateral plate motions between Africa and Europe.

thickness decreases from over 30 km to 21–20 km (Colombi *et al.* 1973, Fig. 1).

The NW–SE staggered arranged individual fault troughs of the Pantelleria Rift System foundered mostly during Pliocene and basalt injections along the faults widened additionally the grabens (Morelli *et al.* 1975). The unloading of the Upper Mantle caused subsequent density reduction and upbulging (Illies 1981).

The upwarped shoulders of the rift are mostly shallow banks and rise above sea level with the Pelagian Islands of Lampedusa and Lampione on the western shoulder and the Maltese Islands on the eastern shoulder. Due to this shoulder upwarping the Maltese Islands are tilting towards NE. Post Quarternary tilting is indicated on northern Malta (Vossmerbäumer 1972). Quarternary beds are inclined up to 3° to the NE.

The study of the recent stress field around the Pantelleria Rift System has been started by a group of the Geologisches Institut, Universität Karlsruhe, in 1983. First results of in-situ stress measurements show an actual direction of maximum horizontal compression between 115° and 125° (pers. com. Dipl.-Geol. V. Bräuer). The sites of stress measurements are located on the northern coast of Malta in the Lower Coralline Limestone Formation.

However the same faults bordering the different grabens of the Pantelleria System have been also affected by slight horizontal movements. Staggered arranged feather joints in the late Quaternary Green Tuff on the northern coast of Pantelleria Island can be related to dextral horizontal shear motions trending 130°. This fits the model of Illies (1980, 1981) of extensional en echelon faulting of the graben segments in the sense of second order faulting related to a dextral compressional megashear parallel to the Mediterranean plate boundary (Illies 1980, 1981). Convergent and lateral plate motions characterize the Afro-Eurasian plate boundary (Caire 1978, Ghisetti & Vezzani 1981, Udias 1980, 1982). The two superimposing processes induce different stress regimes in which due to some blockage of the northeastern edge of the African plate either compressional stress or shear stress activates or reactivates the fault pattern (Fig. 11).

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The Occurrence of Coastal Swarms of the Scyphomedusa, *Pelagia Noctiluca* (Forskål) Around the Maltese Islands

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ABSTRACT

Data on the occurrence of coastal swarms by *Pelagia noctiluca* around the Maltese Islands for January, February and March 1984 is presented, together with details of the characteristics of such swarms and relevant environmental parameters. The small average size of the component individuals indicates that they are representatives of recent spawning. It is suggested that such swarms reached the islands from the NW sector.

Introduction

Since 1977 there has been a number of reports on the occurrence of coastal swarms of the scyphomedusa, *Pelagia noctiluca* in several Mediterranean regions (e.g. Rottini-Sandrini and Stravisi, 1980; Vučetić, 1983; Axiak, 1983). Such swarming has elicited interest and indeed concern due to its potential health hazard to swimmers and also due to possible interference with fishing activities (Rottini–Sandrini *et al*, 1983b). The recent coastal swarms of this species around the Maltese Islands were first reported in 1980 (Axiak, 1983). In the present paper, some observations on this phenomenon for the period January to March 1984 will be reported.

Methods

Since 1982, a monitoring programme to identify the extent and seasonal occurrence of such blooms, was carried out. Much of the data is provided by the Maritime Section of the Task Force (local coast guard authority) whose personnel are asked to report sightings of such swarms at sea together with other relevant information on special forms. Data collected during the first quarter of 1984 will be presented here. Other data for 1983 have been presented elsewhere (Axiak, 1983). Meteorological data presented in this study have been collected from the Meteorological Office, Malta. More recently this monitoring programme has been extended to include the participation of other volunteers such as coastal hoteliers and beach management authorities.

Results

Figure 1 represents the locations and date of occurrence of the major swarms for the period under consideration, together with information regarding wind speed and direction for the whole period as well as for the 15 day period prior to each sighting. On the 8 January a very large swarm was sighted 6 km off the north coast of the island of Gozo. The average density was recorded at greater than 10 individuals per m^3 forming wind rows about 2 m wide and approximately 190 m apart. This swarm extended over several km^2. The majority of the medusae were of small size ranging from 10 to 20 mm in umbrellar diameter. The surface sea water temperature (SST) was 10°C with wind blowing from the SW with force 5. Another major swarm was sighted in the South Comino Channel, on the 5th February. This was again composed of relatively small individuals of up to 15 mm in diameter at an average density of greater than 10 individuals per m^3. The SST was 15°C with a wind direction from the NE and wind force 4 to 5. On the 21 February a large swarm was reported about 2 km off the NW coast of Malta. Individuals were again small in size ranging from under 10 mm up to 20 mm. The recorded SST for the day was 14°C and at the time of sighting there was no wind. The last swarm for this period was reported on the 17th March in the South Comino Channel with an average density of 15 individuals per m^3, and average umbrellar diameter of 10 to 20 mm. The wind was blowing from the SW with force 3, while the SST was 15°C.

As indicated in figure 1, the prevalent wind directions for this period were NW and WNW with a speed greater than 40 km/h for 8% of the time. Moreover the prevelant wind directions for the 15 day periods prior to three of the swarming reports were also NW and WNW.

Table 1 represents the mean monthly SST ($\pm$SD) for the period 1966 to 1971 which may be taken to be representative of "no swarming" years, as well as for the years 1979 and 1980 when the recent swarms were first reported and for January, February and March, 1984.

Discussions and Conclusions

No satisfactory hypothesis has yet been proposed to explain the recent coastal *Pelagia* swarms in the Mediterranean and the environmental factos which control such a phenomenon have yet to be identified. One major difficulty is the lack of precise data on the occurrence and characteristics of such swarms. The generally accepted idea is that this is a manifestation of natural fluctuations in the population densities of this species which may be related to long term environmental changes in the water mass dynamics (Vučetić, 1983) and to general climatic conditions (UNEP, 1983). In fact reports of *Pelagia* blooms in the Mediterranean date back as early as 1802 (Goy, 1983).

From the data presented here and elsewhere (Axiak, 1983) it may be concluded that in this region, large coastal *Pelagia* swarms may occur throughout the year and not necessarily in summer. Moreover, swarms appearing during the first three months of the year are characterized by the small size of their component individuals, compared to summer swarms. These small medusae are presumably representatives of recent spawning. Rottini *et al* (1983a) found that there is no direct correlation between the reproductive maturity of *Pelagia* and its umbrellar diameter in the range 30 to 60 mm. Although no direct proof is available, the smaller size of the medusae in this case indicate their reproductive immaturity. Although work by Rottini *et al* (1983a) indicated that *Pelagia noctiluca* breeds all through the year in the central Mediterranean region and though ephyrae have been collected from Maltese waters in April (Axiak, 1983) and in February, May, July and December (Rottini *et al*, 1983a) the present work suggests that in this region the breeding of *Pelagia* may be more pronounced during Autumn or early Winter.

The horizontal mobility of *Pelagia* is generally determined by surface sea currents. Figure 1 indicates that the northwesterly winds were prevelant for the period under

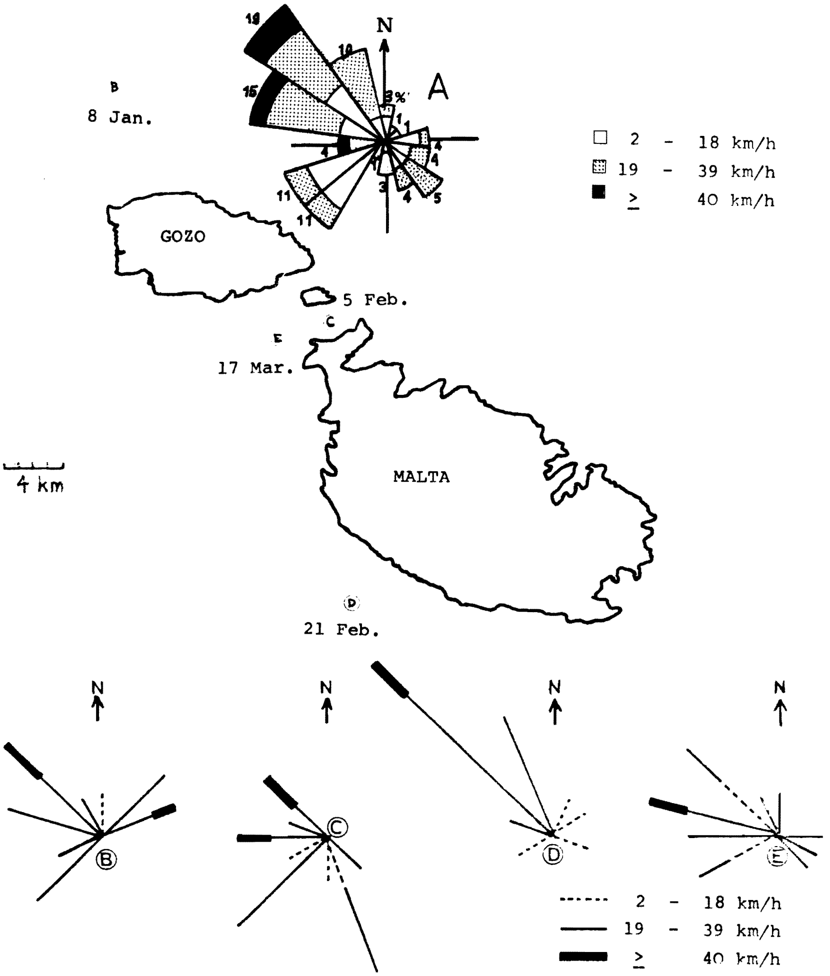

Fig. 1. Occurrence of coastal swarming of *Pelagia noctiluca* during January, February and March 1984, showing location and date, together with percentage frequencies of wind speed and direction for this three months period (A); and for the 15 day period prior to each report of swarming (B, C, D and E).

consideration. Havard (1980) found that during periods of light surface winds (less than 18 km/h) the surface sea current sets along the coast to the southeast for the greater part of the day. During periods of stronger northwesterly winds (more than 40 km/h) the current sets always to the southeast with a maximum velocity of 0.5 m/sec. with a diurnal variation in speed but not in direction. The data on wind directions and speeds presented here suggests that the recorded swarms reached local waters from the NW sector.

The appearance of coastal swarms of *Pelagia* at Villefranche (Goy, 1983) and at the Gulf of Trieste (Atravisi, 1983) has been tentatively correlated with warm winter SST anomalies. The data presented here does not indicate that this observation is applicable to the Central Mediterranean region. The recent swarmings of *Pelagia* around Malta were first reported in 1980. From table 1, it is evident that while the lowest seasonal SST recorded for the 'no swarming' period (1966 to 1971) was 15.2°C, this was 15.9°C for 1979, 14.7°C for 1980 and 14.5°C for 1984. Thus, while there is an indication that for 1979 the lowest winter SST was slightly higher than usual, the same does not apply for 1980 or 1984.

Our understanding and knowledge of biological responses to long term environmental fluctuations require a general integrated approach to the problem with contributions from many sciences. This particular case of recent jelly fish swarming in coastal Mediterranean regions with its possible economic implications may well provide the Mediterranean scientific community with just such an exercise.

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Marine Brachyura (Crustacea: Decapoda: Brachyura) from the Maltese Islands and Surrounding Waters (Central Mediterranean)

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ABSTRACT

Based on a review of the literature and examination of several collections made in Maltese waters, 60 species belonging to 14 families of brachyuran decapods are reported from the Maltese Islands and surrounding area. Of these, 5 species are considered doubtful records in need of confirmation, while another 12 species have not been previously reported from the region. The Maltese brachyuran fauna is typical of the Central Mediterranean and shows strong affinities with that of the West Basin. A brief synopsis of the abundance, distribution and habitat preferences of the commoner species is given.

Introduction

Several works on the decapod crustaceans of the Maltese Islands have been published. The earliest appears to be that of Gulia (1858–59) who mentions 7 species of brachyuran crabs followed by a list by Medlycott (in Sedall, 1870) with 21 species. While in the latter a subjective estimate of abundance is given for each species listed, in a few cases only is information given about distribution and/or locality of capture and habitat. Gulia's (1873) list is rather more informative. This includes 36 species of marine brachyurans. Additional information, including Maltese and/or English names, some indication of abundance, distribution, habitat, notes on identification and other general notes are also given for some species. Gulia's coverage of the different species is rather uneven and no reference is made to Medlycott's earlier list. An account of the natural history of the Maltese Islands by Gulia's son, Giovanni (Gulia, 1889–90) includes 10 species of brachyurans, all of which were already recorded by Gulia *pater*. Micallef & Evans (1968) record 29 species of brachyuran crabs in their list of the marine fauna of the Maltese Islands. Apart from the name of the species, no other information is given and no reference is made to any previous work. The most recent list is that of Števčić (1979) who studied a collection of decapod crustaceans obtained from 8 stations off the coast of Malta ranging in depth from 5 to 145 m. Of the 20 species found, half were brachyurans. Števčić appears to be only aware of Micallef & Evans' list and consequently records some species already reported previously as new for the region.

Apart from the lists mentioned above, other works recording a limited number of species as well as a number of semi-popular articles on the brachyuran fauna of the Maltese Islands have also appeared (Despott, 1930; Lanfranco [G.], 1954, 1957, 1973; Bonnet, 1972; Agius *et al.* 1977; Schembri & Jaccarini, 1978; Lanfranco [E.], 1979).

Given the scattered literature on Maltese brachyurans, the lack of cross-references in the various lists as well as the suspect identifications of some workers and recent advances in our knowledge of Mediterranean decapods, necessitating many taxonomic changes, it is clear that a revised list of Maltese brachyuran crabs is now due.

The present work attempts to provide such an updated list. Apart from reviewing and cross-referencing all previous literature on Maltese brachyuran crabs known to us and updating the nomenclature, we have also examined a substantial collection of brachyurans from the Maltese Islands and surrounding waters. This has enabled us to confirm (and in some cases refute) previous records, add new species to the Maltese list and gain some idea of the present abundance and distribution of the species. It is clear that our knowledge of the Maltese brachyuran fauna is nowhere near complete but we hope that this report will serve to highlight areas needing further study and provide a basis for future work.

Material

None of the material survives on which the older lists of Gulia (1858–59; 1873), Medlycott (in Sedall, 1870), and Micallef & Evans (1968) were based. Inclusion of these authors' records in the present report is therefore based entirely on their published works, none of which includes illustrations. It is reported that Medlycott produced a set of colour drawings of Maltese crustaceans found by him (Gulia, 1858–59; Tallack, 1861 p. 178) but these could not be traced.

A total of 207 specimens of brachyurans collected from the Maltese Islands and surrounding waters were examined. This material included that in the authors' own collections (coded PJS and EL respectively in the species list below) and in the collections of G. Lanfranco (GL), J. L. Cilia (JLC), M. Micallef (MM) and M. Briffa (MB). Identifications were made using published descriptions and keys while some difficult species were checked by Dr. R. W. Ingle of the British Museum (Natural History), London. Specimens marked BMNH have been deposited in the collections of this institution.

Species List

In the following list, the name of the species is followed by previous records from the Maltese Islands, material examined during the present study and comments where necessary, in that order. All localities reported are in the island of Malta unless otherwise stated. In the list we follow the systematic arrangement given in Zariquiey Alvarez (1968) incorporating recent nomenclatural changes as given in Ingle (1980) and Manning & Holthuis (1981)

DROMIIDAE

Dromia personata (*Linnaeus, 1758*)

Dromia rumphii (Feb) [sic!]; Gulia (1858–59)
Dromia vulgaris; Medlycott (in Sedall, 1870)
Dromia vulgaris Edw.; Gulia (1873)
Dromia vulgaris; Gulia (1889–90)
Dromia vulgaris; Lanfranco (1954)
Dromia vulgaris Milne-Edwards; Micallef & Evans (1968)

1♂: ex Valletta Fish Market 1954–56 (GL); 1♂,2♀: landed by fishermen at St. Julians Bay Jul. 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS); 1♂: off Fawwara (Dingli Cliffs) 5.3.77, rocky bottom, 13 m (PJS); 1♂: off Għar Hasan (SE Malta) 12.3.77, rocky bottom, 10 m (PJS).

HOMOLIDAE

Paromola cuvieri (*Risso, 1816*)

Homola cuvieri Leach; Gulia (1873)
Homola cuvieri; Lanfranco (1954)

Not recorded during the present study.

Homola barbata (*Fabricius, 1793*)

Homola spinifrons Leach; Gulia (1873)
Homola barbata (Fabricius, 1793); Števčić (1979)

1♀ (juv.): landed by fishermen at St. Julians Bay (date unknown) (MM); 1♂,2♀♀: landed by fishermen at St. Julians Bay Jul. 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS).

LATREILLIIDAE

Latreillia elegans *Roux, 1830*

Latreillia elegans Roux, 1830; Števčić (1979)

Not recorded during the present study. Stevčić's specimen was collected from a depth of 110 m off the south coast of Malta.

DORIPPIDAE

Ethusa mascarone (*Herbst, 1785*)

Ethusa mascarone Roux; Gulia (1873)
Ethusa mascarone; Lanfranco (1954)
Ethusa mascarone (Herbst); Micallef & Evans (1968)

1♂: San Anard Nov. 1976, rock bottom, 10 m, carrying valve of *Lima* sp. (PJS).

Medorippe lanata (*Linnaeus, 1767*)

new record

1♂: off Fomm ir-Riħ Summer 1980, 300 m (MM); 1♂: between Malta and Filfla Is. 9.5.83, 80 m (MB); 1♂: Medina Bank (15°37′E:34°32′N) 18.8.77, mud, 70–100 m (PJS); 1♂,1♀: 96 km SE of Lampedusa Is. 21–26.8.77, mud, 100 m (PJS).

CALAPPIDAE

Calappa granulata (*Linnaeus, 1758*)

Calappa cristata (M.Ed.); Medlycott (in Sedall, 1870)
Calappa granutata Fabr. [sic!]; Gulia (1873)
Calappa granulata; Lanfranco (1954)
Calappa granulata (L.); Micallef & Evans (1968)
Calappa granulata L.; Lanfranco (1979)

1♂: ex Valletta Fish Market 1954–56 (GL); 1♂: off Fomm ir-Riħ Summer 1980, 300 m (MM); 2♂♂: 3 km E of Gozo Is. 12.4.83, 80 m (MB); 1♂: between Malta and Filfla Is. 9.5.83, 80 m (MB); 1♂: landed by fishermen at St. Julians Bay Summer 1974, leg. B. Warrington (EL); 2 specimens (chelae only): landed by fishermen at St. Julians Bay May 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS); 1♂: off Marfa 29.2.76, 165 m (PJS).

The specimen from between Malta and Filfla Is. was much like the 'southern form' of *C. granulata* described by Bouvier (1940 p. 204).

LEUCOSIIDAE

Ilia nucleus (*Linnaeus, 1758*)

Ilia rugosula (M.Ed.); Medlycott (in Sedall, 1870)
Ilia nucleus Leach [and] *I. rugosula* Leach; Gulia (1873)
Ilia nucleus; Lanfranco (1954)
Ilia nucleus (Herbst); Micallef & Evans (1968)

1♂: Daħlet il-Fekruna 22.8.74, mud, 3 m (PJS); 1 specimen (chela only): Mistra Bay 20.7.80, gravel, 2 m (PJS).

Ilia rugosula Risso, 1826 reported by Gulia (1873). is considered a mere variety of *I. nucleus* (Bouvier, 1940; Zariquiey Alvarez, 1968).

Ebalia *spp.*

Seguin (1968) records zoea larvae of *Ebalia* from plankton samples taken in Maltese waters but does not identify the species.

Ebalia tuberosa (*Pennant, 1777*)

Ebalia tuberosa (Pennant, 1777); Śtevčić (1979)

Not recorded during the present study. Śtevčić's specimen was collected from a depth of 75 m off the south coast of Malta.

Ebalia edwardsi *Costa, 1838*

new record

1♀: Wied iż-Żurrieq 10.8.77, in sediment on cave floor, 22 m (PJS).

PIRIMELIDAE

Pirimela denticulata (*Montagu, 1808*)

Pirimela denticulata; Medlycott (in Sedall, 1870)
Pirimela denticulata Leach; Gulia (1873)
Pirimela denticulata (Mont.); Micallef & Evans (1968)

1♂: Exiles (Sliema) Aug. 1975 (EL); 2 specimens (damaged): washed ashore at Xatt l-Aħmar (Gozo Is.) May 1973 (PJS); 1♂: Buġibba 11.6.74, 3 m (PJS); 3♂♂: Marsaxlokk Bay 6.4.77, buried in sand, 0.1 m (PJS); 1♂: same data (BMNH) [det. R. W. Ingle, 1977].

Sirpus zariquieyi *Gordon, 1953*

new record

1♂: Santa Marija Bay (Comino Is.) 18.6.77, 5 m (PJS); 1♂: St. Paul's Bay 5.8.83, on fouling community on submerged buoy, 2 m (PJS).

PORTUNIDAE

Carcinus aestuarii *Nardo, 1847*

Carcinus maenas Leach; Gulia (1858–59)
Carcinus menas (Leach) [sic!]; Medlycott (in Sedall, 1870)
Carcinus maenas Leach; Gulia (1873)

Carcinus moenas [sic!]; Gulia (1889–90)
Carcinus maenas; Lanfranco (1954)
Carcinides maenas Rathke; Micallef & Evans (1968)
Carcinides maenas; Bonnet (1972)
Carcinus mediterraneus Czerniavsky; Agius *et al.* (1977)
Carcinides mediterraneus (Czerniavsky); Lanfranco (1979)

2♂♂: Marsaxlokk 1.8.73 (GL); 2♂♂,1♀: Malta (no other data) (GL); 1♂: ditto (JLC); 1 specimen (carapace only): ditto, leg. J. Sciberras (PJS); 1♂,1♀: Marsamxett Harbour near Manoel Island 1973 (PJS)

Until the late 1950's, only one species of *Carcinus, C. maenas* (Linnaeus, 1758) was recognized. However detailed investigations of Atlantic and Mediterranean populations assigned to this species showed that in actual fact two taxa were present. Holthuis & Gottlieb (1958) have shown that Linnaeus' description was based on Atlantic specimens and therefore the name *maenas* should be retained for the Atlantic species of *Carcinus*. These authors further proposed the name *C. mediterraneus* Czerniavsky, 1884 for the Mediterranean species of *Carcinus*, this being the oldest available one known to them. This nomenclature has been in use until recently when it was pointed out by Manning & Holthuis (1981) that *mediterraneus* is a junior synonym of *C. aestuarii* Nardo, 1847. All Maltese records of *C. maenas* and *C. mediterraneus* therefore refer to *C. aestuarii.*

Portumnus latipes (*Pennant, 1777*)

Platyonichus latipes Edw.; Gulia (1873)
Platyonicus latipes [sic!]; Lanfranco (1954)

Not recorded during the present study. Gulia (1873) gives the following synonyms for this species: "=*Portunus depurator* Latr. *Cancer ranipes* Barrel. *Cancer depurator* Scop.". Both *P.depurator* and *C.depurator* refer to *Liocarcinus depurator*, a species also recorded by Gulia and not to *Portumnus latipes.*

Liocarcinus spp.

The genus *Macropipus* has been recently redefined by Ingle (1980) and the bulk of the species previously included in this genus are now placed in the genus *Liocarcinus* (see also Manning & Holthuis, 1981).

Liocarcinus arcuatus (Leach, 1814)

Portunus arcuatus; Medlycott (in Sedall, 1870)

1♂: Ta' Kanini (Mellieħa Bay) Jan. 1976, 12 m (PJS); 1 specimen (carapace only): Mistra Bay 20.7.83, 2 m (PJS).

In view of the consistent morphological differences between Atlantic and Mediterranean populations of this species, Zariquiey Alvarez (1968) considers the Mediterranean populations to be a distinct subspecies: *L. arcuatus rondeletii* (Risso, 1816).

Liocarcinus puber (Linnaeus, 1767)

Portunus puber Leach; Gulia (1873)
Portunus puber; Gulia (1889–90)
Portunus puber; Lanfranco (1954)

Not recorded during the present study.

Liocarcinus corrugatus (*Pennant, 1777*)

Portunus corrugatus (Leach); Gulia (1858–59)
Portunus corrugatus; Medlycott (in Sedall, 1870)
Portunus corrugatus Leach; Gulia (1873)
Portunus corrugatus; Lanfranco (1954)
Portunus corrugatus (Penn.); Micallef & Evans (1968)

1♂: Malta (no other data) (GL); 1♂: landed by fishermen at Marsaxlokk 1978 (MM); 1♂: Malta (no other data) (PJS); 1♂: landed by fishermen at St. Julians Bay 24.4.74 (from nets set NE Malta), leg. J. L. Schembri (PJS).

Liocarcinus zariquieyi (*Gordon, 1968*)

new record

1♂: Wied ix-Xaqqa 31.5.77, 7 m (PJS)

(?) **Liocarcinus bolivari** (*Zariquiey Alvarez, 1948*)

new record (?)

1♀ (juv.): Daħlet il-Fekruna 14.7.83, 8 m (PJS)

The only specimen studied was damaged and lacked the pereiopods thus making definite identification difficult. The carapace characters, however, agree well with the description of *L. bolivari* as given in Zariquiey Alvarez (1968) as does the colour pattern. This species has for a long time been confused with *L. depurator* which it closely resembles. Medlycott's record (in Sedall, 1870) of "*Portunus* (?) A species nearly allied to *P. depurator*" may well be the present species.

Liocarcinus depurator (*Linnaeus, 1758*)

Portunus plicatus Risso; Gulia (1873)
Portunus depurator; Lanfranco (1954)
Portunus depurator (L.); Micallef & Evans (1968)

1♀: Mellieħa Bay 4.3.73 (GL); 3♂♂: Malta (no other data) (JLC); 1♀: between Malta and Filfla Is. 9.5.83, 80 m (MB); 1♀,1 incomplete specimen: Mellieħa Bay 19.7.73, sand (PJS); 1♂: Exiles (Sliema) Jun. 1974, sand (PJS)

Macropipus tuberculatus (*Roux, 1830*)

new record

1♂: Medina Bank (15°37′E:34°32′N) 18–20.8.77, mud, 70–100 m (PJS); 4♂♂,2♀♀:96 km SE of Lampedusa Is. 21–26.8.77, mud, 100 m (PJS); 2♂♂: same data, (BMNH) [det. R. W. Ingle, 1977]

Polybius henslowi *Leach, 1820*

Polybius henslowi Leach; Despott (1930)
Polybius Henslowii; Lanfranco (1954)

Not recorded during the present study.

Bathynectes longipes (*Risso, 1816*)

Portunus longipes Risso; Gulia (1873)
Portunus longipes; Lanfranco (1954)
Portunus longipes (Risso); Micallef & Evans (1968)

Not recorded during the present study.

Callinectes sapidus *Rathbun, 1896*

2♂♂: Marsaxlokk Bay 20.11.72, trapped by 'nassa' (basketwork trap) at 8 m (G. Zammit Maempel personal communication)

This species is native to the east coast of America but has been introduced into European Atlantic coastal waters and the Mediterranean (see Holthuis & Gottlieb, 1958). The two Maltese specimens were purchased by the National Museum of Natural History, Mdina, Malta and are currently on exhibit there.

Portunus hastatus (*Linnaeus, 1767*)

Lupea hastata Edw.; Gulia (1873)
Lupa hastata; Lanfranco (1954)
Neptunus hastatus L.; Micallef & Evans (1968)

1♂: Comino Is. 1958–60 (GL)

XANTHIDAE

Pilumnus spinifer *H. Milne—Edwards, 1834*

Pilumnus spinifer (M.Ed.); Medlycott (in Sedall, 1870)
Pilumnus spinifer H. Milne—Edwards, 1834; Števčić (1979)

1♂: between Malta and Filfla Is. 9.5.83, 80 m (*MB*); 1♀: 96 km SE of Lampedusa Is. 21–26.8.77, mud, 100 m (PJS) [det. R. W. Ingle, 1977]

Pilumnus villosissimus (*Rafinesque, 1814*)

Pilumnus villosus Risso; Gulia (1873)

Pilumnus hirtellus (L.); Agius *et al.* (1977)

1♀: Malta (no other data) (PJS); 1♂: Daħlet il-Fekruna 18.7.74 (PJS); 1♀: Marsaxlokk Bay 23.3.76, rocky bottom, 3 m (PJS) [det. R. W. Ingle, 1977]; 1♀: Mistra Bay 26.3.76. on fouling community on submerged buoy, 3 m (PJS)

The specimens on which the record of *P. hirtellus* by Agius *et al.* (1977) was based have been re-examined and found to belong to the present species (R. W. Ingle, personal communication).

(?) **Pilumnus hirtellus** (*Linnaeus, 1761*)

Pilumnus hirtellus (L.); Micallef & Evans (1968)

Not recorded during the present study. Since all shallow water *Pilumnus* collected from the Maltese Islands, including the '*P. hirtellus*' of Agius *et al.* (1977) (see above) were *P. villosissimus*, and since the source of identification used by Micallef & Evans (1968) does not differentiate between *P. hirtellus* and its Mediterranean cogeners, these authors' record of *P. hirtellus* must be regarded as unconfirmed pending collection of further material of this species.

Paragalene longicrura (*Nardo, 1868*)

Paragalene longicrura Staz. Zool.; Despott (1930)
Paragalene longicrura; Lanfranco (1954)

Not recorded during the present study.

Eriphia verrucosa (*Forskal, 1775*)

Eriphia spinifrons (Lat.); Gulia (1858–59)
Eriphia spinifrons; Medlycott (in Sedall, 1870)
Eriphia spinifrons Savigny; Gulia (1873)
Eriphia spinifrons (Herbst); Micallef & Evans (1968)
Eriphia spinifrons; Bonnet (1972)
Eriphia verrucosa Forsk.; Lanfranco (1979)

1♂: Malta (no other data) (GL); 1♂: Exiles (Sliema) Summer 1971 (EL); 2♂♂: Manoel Island 1971 (EL); 1 specimen (incomplete): Malta (no other data) (PJS); 1♀: Kalkara Creek Oct. 1973 (PJS); 1♀: Birzebbuga 13.4.75 (PJS); 1 specimen (carapace only): Mistra Bay 20.7.83, 2 m (PJS)

Xantho *spp.*

Prior to Drach & Forest's (1953) review of the systematics of European species of *Xantho*, there was much confusion in the literature as to the correct nomenclature of these crabs. Three Mediterranean species are currently recognized: *X. poressa* (Olivi, 1972); *X. pilipes* A. Milne–Edwards, 1867; and *X. incisus* (Leach, 1814) represented in the Mediterranean by the subspecies *granulicarpus* (Forest, 1953), the nominal subspecies being restricted to the Atlantic. It is difficult to assign the older Maltese records of *Xantho* to the correct species, mainly because of the confused synonymy of the group. In drawing up the lists below we have followed the synonymy as given by Zariquiey Alvarez (1968). This problem is discussed further below.

Gulia (1889–90) records two species of *Xantho* without giving specific names. It is likely that this author was referring to the same two species as in his father's list (Gulia, 1873) (see below under *Xantho poressa*).

Xantho poressa (*Olivi, 1792*)

Xantho rivulosus (M.Ed.); Medlycott (in Sedall, 1870)

Xantho floridus Leach = *Cancer poressa* Olivi [and] *Xantho rivulosus* Risso. Edw. = *X. florida* var. b. Leach; Gulia (1873)
Xantho rivulosa; Lanfranco (1954)
Xantho hydrophilus (Herbst); Micallef & Evans (1968)
Xantho hydrophilus; Bonnet (1972)
Xantho hydrophilus (Herbst) (= *X. rivulosus* Risso); Lanfranco (1979)

1♂: Malta (no other data) (GL); 1♀: St. Thomas Bay 18.8.66 (GL); 2♂♂: Baħar iċ-Ċagħaq 2.8.72 (GL); 1♂,1 ♀ (juv.): Malta (no other data) (JLC); 1♀: Exiles (Sliema) Summer 1971 (EL); 2♂♂,1 incomplete specimen: Malta (no other data) (PJS); 1♂: Daħlet il-Fekruna Aug. 1973 (PJS); 1 specimen (incomplete): St. Paul's Bay 23.8.74, under rocks, 1 m (PJS); 1♂: Marsaxlokk Bay 22.3.76, under rocks, 3 m (BMNH) [det. R. W. Ingle, 1977]; 1♂: Marsaxlokk Bay 6.4.77, 0.1 m (BMNH) [det. R. W. Ingle, 1977]; 2♂♂: Mistra Bay 5.7.78 (PJS); 1♂: Marsa Aug. 1980, leg. G. Bonnet (PJS); 2 specimens (carapace only): Mistra Bay 20.7.83, 2 m (PJS)

Gulia (1873) records two species of *Xantho* from the Maltese Islands giving them as reproduced above. Although both species as named by Gulia translate to what is currently called *Xantho poressa* (Olivi), it is quite likely that one of the species reported by this author is actually *X. incisus granulicarpus* (Forest), the other common Maltese species of the genus (see below).

Zariquiey Alvarez (1968) hesitantly synonymizes *Cancer hydrophilus* Herbst, 1790 with *Xantho pilipes* Milne-Edwards, 1867 although other authors consider Herbst's species synonymous with *X. poressa* (Olivi) (e.g. Holthuis & Gottlieb, 1958). Reference to the original source of identification used by Micallef & Evans (1968) reveals that these authors' record of *X. hydrophilus* refers to the present species, not *X. pilipes* and similarly Bonett's (1972) and Lanfranco's (1979) records.

Xantho incisus granulicarpus (*Forest, 1953*)

Xantho florida; Lanfranco (1954)
Xantho floridus (Mont.); Micallef & Evans (1968)
Xantho incisus granulicarpus (Forest); Schembri & Jaccarini (1978)

1 specimen (carapace only): Mellieħa Bay Sept. 1975 (PJS); 1 specimen (incomplete): Malta (no other data) (PJS); 1♂: Daħlet il-Fekruna 20.7.73 (PJS); 1 specimen (incomplete): Mellieħa Bay Reef 25.8.73 (PJS); 1♀: Mellieħa Bay Apr. 1974 (PJS); 1♂: Exiles (Sliema) 25.6.74, leg. S. P. Schembri (PJS); 1 specimen (incomplete): Marsascala Jul. 1974, 5 m (PJS); 1♂: Daħlet il-Fekruna 27.7.74, 2.5 m (PJS); 1♀: Marsaxlokk Bay 3.10.75, in rock burrows of *Upogebia deltaura*, 3 m (PJS) [det. R. W. Ingle, 1977]; **1♂**: Marsaxlokk Bay 23.3.76, in rock burrows of *Upogebia deltaura*, 3 m (BMNH) [det. R. W. Ingle, 1977]; 1 specimen (carapace only): Mistra Bay 20.7.83, 2 m (PJS).
This species may also have been reported by Gulia (1873) (see above under *X. poressa*).

Paractaea rufopunctata (*H. Milne—Edwards, 1834*)

new record

1 specimen (cheliped only): Tigne 30.9.82 (EL); 1♀: Qawra 14.3.76, under rocks; 5 m (PJS); 1 specimen (incomplete): Wied iż-Żurrieq 10.8.77, in sediment on cave floor, 22 m (PJS)

PINNOTHERIDAE

Gulia (1858–59) records "*Pinnotheres*" without identifying the species.

Pinnotheres pisum (*Linnaeus, 1767*)

Pinnotheres pisum Latr.; Gulia (1873)
Pinnotheres pisum; Lanfranco (1954)

Not recorded during the present study.

Pinnotheres pinnotheres (*Linnaeus, 1758*)

Pinnotheres veterum Edw.; Gulia (1873)
Pinnotheres veterum; Lanfranco (1954)
Pinnoteres pinnoteres (L.); Micallef & Evans (1968)

Not recorded during the present study.

GONEPLACIDAE

Goneplax rhomboides (*Linnaeus, 1758*)

Gonoplax angulata Edw.; Gulia (1873)
Gonoplax rhomboides [and] *G. angulata*; Lanfranco (1954)
Gonoplax angulata (Penn.); Micallef & Evans (1968)

1 specimen (juv.): off Fomm ir-Riħ Summer 1980, 300 m (MM); 1 ♀: Medina Bank (15°37′E:34°32′N) 18–20.8.77, mud, 70–100 m (PJS); 1♂: 96 km SE of Lampedusa Is. 21–26.8.77, mud, 100 m (PJS)

Two forms of this species exist in the Mediterranean. In one of these there is an additional tooth behind the anterolateral tooth of the carapace [=*G. angulata* (Pennant, 1777)] and in the other none, or only a small tubercle [=*G. rhomboides* (Linnaeus, 1758)]. These are considered by some to be distinct species or subspecies although all intermediate stages between the two extremes are present (Bouvier, 1940; Zariquïey Alvarez, 1968). In the specimens examined during the present study the second tooth is either absent or at most is represented by a small tubercle, therefore all fall within the taxon *rhomboides* whatever its status. Gulia (1873) however reports both forms (as "*G. bispinosa* Leach" [=*G. angulata*] and "*G. rhomboides* Desm") as being found in Maltese waters, as does Lanfranco (1954).

GRAPSIDAE

Pachygrapsus marmoratus (*Fabricius, 1787*)

Grapsus varius; Medlycott (in Sedall, 1870)
Grapsus varius Latr.; Gulia (1873)
Grapsus varius; Gulia (1889–90)
Pachygrapsus marmoratus; Lanfranco (1954)

Pachygrapsus marmoratus (Fabr.); Micallef & Evans (1968)
Pachygrapsus marmoratus; Bonnet (1972)
Pachygrapsus marmoratus Fabr.; Lanfranco (1979)

3♂♂: Fond Għadir (Sliema) 12.8.66 (GL); 1♀: Manoel Island 29.7.73, with *Sacculina* (GL); 1♀: Grand Harbour 21.12.73 (GL); 1♂,6♀♀,3 specimens (juv.): Malta (no other data) (JLC); 1♂: Sliema Summer 1971 (EL); 1♂,2♀♀: Daħlet il-Fekruna 1973, shore (PJS); 1♀,1 specimen (juv.): Birzebbuga 13.4.75, shore (PJS)

Planes minutus (*Linnaeus, 1758*)

New record

1♂: Marsaxlokk 6.4.77, stranded in rockpool (PJS)

Crabs of the genus *Planes* are pelagic, being found mainly on floating weed but also on other floating objects and on marine turtles. The specimen from Marsaxlokk was obviously stranded on the shore perhaps following beaching of the flotsam with which it was originally associated.

Costa (1982) has recently reported the presence of *Planes cyaneus* Dana, 1851 in the Mediterranean, identified on the morphometric and morphological criteria of Chace (1951). These criteria were also applied to the single specimen collected from Malta. In terms of carapace length (17.0 mm) and carapace width (16.9 mm) and their ratio, the Maltese specimen is intermediate between *P. minutus* and *P. cyaneus*. In terms of the ratio of the length of the three distal segments of the 2nd walking legs to carapace length (=0.91) it is closer to *P. minutus* (range 0.83–1.07) than to *P. cyaneus* (range 0.68–0.89). In terms of the morphology of the abdomen and especially the terminal segment, the Maltese specimen is closer to *P. cyaneus*.

In view of the rather marginal differences between these two species of *Planes*, the intermediate characters of the only specimen available for study and the lack of information about variability in Central Mediterranean populations of *Planes*, together with the fact that Costa (1982) has reported *P. cyaneus* from the Mediterranean on the basis of 3 specimens also showing rather intermediate characters, we feel that it is best to regard the Maltese *Planes* as *P. minutus* pending study of a larger number of specimens.

PARTHENOPIDAE

Parthenope angulifrons (*Latreille, 1825*)

Lambrus angulifrons Edw.; Gulia (1873)
Lambrus angulifrons (Latr.); Micallef & Evans (1968)
Lambrus angulifrons Latr.; Lanfranco (1973)
Lambrus angulifrons Latr.; Lanfranco (1979)

1♀: Malta (no other data) (GL); 1♂: Marsamxett Harbour 1960 (GL)

Parthenope macrochelos (*Herbst, 1790*)

Lambrus mediterraneus Roux; Gulia (1873)

1♂: off Fomm ir-Riħ Summer 1980, 300 m (MM); 1♀: 96 km SE of Lampedusa Is. 21–26.8.77, mud, 100 m (PJS)

Parthenope massena (*Roux, 1830*)

Lambrus Massena Roux; Gulia (1873)
Lambrus massena Roux; Micallef & Evans (1968)

Not recorded during the present study.

MAJIDAE

Maja squinado (*Herbst, 1788*)

Maia squinado (Lamk.); Gulia (1858–59)
Maia squinado; Medlycott (in Sedall, 1870)
Maia squinado Latr.; Gulia (1873)
Maja squinado; Gulia (1889–90)
Maia squinado; Lanfranco (1954)
Maia squinado (Herbst); Micallef & Evans (1968)
Maia squinado Herbst; Lanfranco (1979)

2♂♂,1♀: Malta (no other data) (GL); 1♂: Marsa 1954–58 (GL); 1♂: ex Valletta Fish Market 1954 (GL); 1♀: Sliema 1971 (EL)

The largest specimen studied (male from Valletta Fish Market: carapace length, 15.1 cm; rostral spine length, 2.2 cm; carapace width, 12.7 cm) agrees well with the description and morphometry of *M. squinado* as given in Bouvier (1940) and Zariquiey Alvarez (1968). The other specimens were much smaller and although these also agreed well with the published descriptions of *M. squinado*, they were closer to *M. crispata* with respect to the ratio of rostral length to total carapace length than to the present species.

Maja crispata (*Risso, 1827*)

Maia verrucosa (M.Ed.); Medlycott (in Sedall, 1870)
Maia verrucosa Milne Edw.; Gulia (1873)
Maia verrucosa; Lanfranco (1954)
Maia verrucosa Milne-Edwards; Micallef & Evans (1968)
Maia verrucosa; Bonett (1972)
Maia verrucosa Milne-Edwards; Lanfranco (1979)

1 specimen (incomplete): landed by fishermen at Il-Prajjet (Anchor Bay) 30.8.73 (PJS); 1♂: landed by fishermen at St. Julians Bay May 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS); 1♂: Exiles (Sliema) 26.7.74, 2.5 m, leg. S. P. Schembri (PJS); 1♂: Daħlet il-Fekruna 27.7.74, rocky bottom, 1m (PJS)

Pisa *spp.*

There is much confusion in the older literature on Mediterranean species of *Pisa*. The *P. tetraodon* of older authors has been split into three separate species: *P. tetraodon* s.str., *P. muscosa* (Linnaeus, 1758) and *P. corallina* (Risso, 1816) (Holthuis & Gottlieb, 1958). Apart from these, another three species are also known from the Mediterranean (Zariquiey Alvarez, 1968). Because of these taxonomic changes, the older Maltese records of *Pisa* spp. are considered unreliable.

Pisa tetraodon (*Pennant, 1777*)

Pisa tetraodon [and] *Pisa hirticornis* (Herbst); Medlycott (in Sedall, 1870)
Pisa tetraodon Leach; Gulia (1873)
Pisa tetraodon; Lanfranco (1954)
Pisa tetraodon Penn.; Micallef & Evans (1968)
Pisa tetraodon Penn.; Lanfranco (1979)

4♂♂,1♀: Grand Harbour Aug. 1958 (GL); 2♂♂: Fond Għadir (Sliema) (date not known) (GL); 2♂♂: St. Julians Bay (date not known) (MM); 1 specimen (carapace only): Tigne 30.9.82 (EL); 1♂,1♀: Malta (no other data), leg. R. Agius (PJS); 1♂,1♀: landed by fishermen at St. Julians Bay May 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS); 1♀: Marsaxlokk Bay 6.4.77, 0.1 m (BMNH) [det. R. W. Ingle, 1977]

(?) **Pisa corallina** (*Risso, 1816*)

Pisa corallina Edw.; Gulia (1873)
Pisa corallina; Micallef & Evans (1968)

Not recorded during the present study. Maltese records of this species may actually refer to other species of *Pisa* and are to be confirmed.

Pisa muscosa (*Linnaeus, 1758*)

new record

1♂: Malta (no other data) (PJS); 1 specimen (carapace only): Mistra Bay 20.7.83, 2 m (PJS)

Pisa nodipes (*Leach, 1815*)

New record

1♀: Il-Barranija (24 km off SE Malta) Winter 1981, 100 m (MM); 1♂: 3 km E of Gozo Is. 26.4.83, 82 m (MB); 1♂: between Malta and Filfla Is. 9.5.83, 80 m (MB); 2♂♂: Malta (no other data) (PJS); 1♂: landed by fishermen at St. Julians Bay Jun. 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS); 1♀: Malta 1975 (PJS)

(?) **Pisa armata** (*Latreille, 1803*)

Lissa armata; Micallef & Evans (1968)

Not recorded during the present study and to be confirmed.

Herbstia condyliata (*Fabricius, 1787*)

Herbstia condyliata (M.Ed.); Medlycott (in Sedall, 1870)
Herbstia condyliata Edw.; Gulia (1873)

1 specimen (juv.): Malta (no other data) (MM); 1♂: Malta (no other data) (PJS); 1♂:

landed by fishermen at St. Julians Bay May 1974 (from net set NE Malta), leg. J. L. Schembri (PJS)

Lissa chiragra (*Fabricius, 1775*)

Lissa chiragra Leach; Gulia (1873)
Lissa chiragra; Lanfranco (1954)
Lissa chiragra (Herbst); Micallef & Evans (1968)
Lissa ciřagra [sic!]; Bonett (1972)
Lissa chiragra (Fabricius, 1775); Števčić (1979)

1♂: landed by fishermen at St. Julians Bay May 1974 (from nets set NE Malta), leg. J. L. Schembri (PJS)

Eurynome aspera (*Pennant, 1777*)

Eurynome scutellatus (Risso); Gulia (1858–59)
Eurynome aspera; Medlycott (in Sedall, 1870)
Eurynome aspera (Pennant, 1777); Števčić (1979)

Not recorded during the present study.

Acanthonyx lunulatus (*Risso, 1816*)

Acanthonyx lunulatus (M.Ed.); Medlycott (in Sedall, 1870)
Acanthonyx lunulatus Latr.; Gulia (1873)
Acanthonyx lunulatus; Gulia (1889–90)
Acanthonyx lunulatus (Risso); Micallef & Evans (1968)
Acanthonyx lunulatus (Risso); Lanfranco (1979)

3♂♂: Fond Għadir (Sliema) Jul. 1974 (GL); 1♂: Malta (no other data) (JLC); 1♀: Exiles (Sliema) Summer 1971 (EL); 2♂♂,2♀♀: St. Georges Bay (Birżebbuġa) 9.6.74, on *Cystoseira* sp. just below water level (PJS)

Inachus sp. [(?) **dorsettensis** (*Pennant, 1777*)]

Inachus dorsettensis (Pennant, 1777); Števčić (1979)

Not recorded during the present study. Manning & Froglia (1982) have recently separated Mediterranean '*I. dorsettensis*' into two taxa: *I. dorsettensis* s. str. and *I. parvirostris* (Risso, 1816). The latter is a deep water species (>90 m), smaller and more slender than *I. dorsettensis* s. str. In light of this, records of '*I. dorsettensis*' from deep water, including those of Števčić (1979) from Maltese waters, need to be re-examined.

Inachus thoracicus (*Roux, 1830*)

Inachus thoracicus (M.Ed.); Medlycott (in Sedall, 1870)
Inachus thoracicus Roux; Gulia (1873)
Inachus thoracicus Roux; Micallef & Evans (1968)
Inachus thoracicus Roux, 1830; Števčić (1979)

2♂♂: landed by fishermen at Marsaxlokk 1978 (MM); 1♂,3♀♀: 3 km E of Gozo Is., 82 m (MB)

Achaeus cranchii Leach, 1817

Achaeus cranchii Leach, 1817; Števčić (1979)

Not recorded during the present study. Števčić's specimen was collected from a depth of 75 m off the south coast of Malta.

Achaeus gordonae *Forest & Zariquiey Alvarez, 1955*

new record

1♂,1♀: Bugibba 11.6.74, on weed, 2 m (PJS)

Macropodia spp.

Five species of *Macropodia* are currently known to inhabit the Mediterranean (Zariquiey Alvarez, 1968). Since some of these were only recognized as distinct species after the publication of some of the Maltese lists, or after publication of the sources of identification used to compile these lists, the older Maltese records must be considered unreliable as they may refer to species other than those actually listed.

Gulia (1889–90) records two species of "*Steuorynchus*" [sic!] without giving specific names. It is likely that this author was referring to the same two species recorded in his father's list (Gulia, 1873) (see below under *Macropodia longirostris*).

Lanfranco (1954) records "*Stenorynchus phalangium*" without giving an authority. Since the specific name *phalangium* has been applied to different species by different authors, the identity of Lanfranco's species cannot be ascertained.

(?) **Macropodia rostrata** (*Linnaeus, 1761*)

Macropodia rostrata (L.); Micallef & Evans (1968)

Not recorded during the present study. Since the source of identification used by Micallef & Evans (1968) does not include all the species of *Macropodia* currently known from the Mediterranean and since theirs is the only record from Maltese waters, *M. rostrata* has to be confirmed for the region.

Macropodia czerniavskii (*Brandt, 1880*)

new record

1 specimen: landed by fishermen at Marsaxlokk 1978 (MM); 1♂: Malta (no other data) (PJS)

Macropodia linaresi Forest & Zariquiey Alvarez, 1964

Macropodia linaresi Forest et Zariquiey Alvarez, 1964; Števčić (1979)

Not recorded during the present study.

Macropodia longirostris (*Fabricius, 1775*)

Stenorynchus longirostris (M.Ed.); Medlycott (in Sedall, 1870)
Stenorynchus aegyptius Edwards = *S.phalangium* Audouin [and] *Stenorynchus longirostris* Edwards; Gulia (1873)

Macropodia longirostris (Fabr.); Micallef & Evans (1968)

Not recorded during the present study. Holthuis & Gottlieb (1958) report that a syntype of *Stenorynchus aegyptius* H. Milne—Edwards, 1834 (= *S. phalangium* Savigny & Audouin, 1826) examined by them proved to be *Macropodia longirostris* (Fabricius, 1775). Gulia's (1873) record of *S. aegyptius* is therefore included with the present species.

Discussion

To date, 60 species of brachyuran crabs are known from the Maltese Islands and surrounding waters. Twelve of these are recorded here for the first time while another 16 previously reported species have not been met with during the present study. Of the 60 species listed, 5 are considered doubtful records pending confirmation.

Some 115 brachyuran crabs are known from the Mediterranean Sea of which approximately 13 species are recent immigrants from the Red Sea via the Suez Canal. A few other species have been introduced accidentally from elsewhere but only one of these, *Callinectes sapidus*, seems to have established itself in the Mediterranean where it is known from scattered localities in both the West and East Basins, and now from the Maltese Islands. None of the Red Sea immigrant species have reached the Central Mediterranean as yet.

Not counting immigrants, some 58% of all Mediterranean species also occur in Maltese waters. This high proportion of occurrences is hardly surprising considering the central position of the Islands and that some 86% of indigenous Mediterranean brachyurans are found throughout the Mediterranean, only few species being restricted to a particular region of this sea. However, the affinities of the Maltese brachyuran fauna are clearly closer to that of the West Basin than to that of the eastern Mediterranean. Of those indigenous species known only from the western half of the Mediterranean, some 44% (4 species) occur also in Maltese waters whereas none of the exlcusively eastern Mediterranean indigenous species occur around the Maltese Islands. Moreover, for another 5 West Basin/Maltese species, the only East Basin records to date are from the Adriatic Sea and environs. No detailed biogeographical analysis of the Mediterranean brachyuran fauna is possible at present however, given the uncertainty of many older records and the paucity of our knowledge of the fauna of all but a few areas in the region.

A review of the available literature on Maltese brachyurans and the authors' own field observation's allow a few general remarks to be made on the abundance, distribution and habitat preferences of the commoner species within the Maltese Islands.

There are no supralittoral crabs *per se* in the Maltese Islands although the very abundant *Pachygrapsus marmoratus* of rocky shores is frequently found supralittorally in calm weather. Also on rocky shores and in calm weather, *Eriphia verrucosa* is found in the uppermost regions of the mediolittoral but this crab retreats to deeper water in rough weather. On lower mediolittoral/upper infralittoral algae, principally *Cystoseira* spp., are found large populations of *Acanthonyx lunulatus* clinging to the fronds.

On soft substrata in the upper infralittoral *Carcinus aestuarii* is common on mud or fine sand while *Liocarcinus arcuatus* and *Pirimela denticulata* are both common on coarser sand in which they bury themselves. The last named occurs in quite shallow water and occasionally in the sediment at the bottom of rock-pools. Also buried in the sediment but in deeper water are found a number of other species. *Liocarcinus depurator* is found on middle infralittoral sand while *Ilia nucleus* apparently prefers coarser material. Species of *Ebalia* are found in the lower infralittoral while *Calappa granulata* is common in coarse sand and gravel in the same depth zone but also circalittorally. *Goneplax rhomboides* constructs burrows in lower infralittoral and upper circalittoral mud while *Medorippe lanata* is found on circalittoral mud. Other species found on soft substrata are the middle infralittoral *Parthenope angulifrons*, the lower infralittoral *Inachus thoracicus* and the circalittoral *Parthenope macrochelos* and *Macropipus tuberculatus*, all on fine sand or mud.

A number of species are found on mixed bottoms. These include *Ethusa mascarone*, *Liocarcinus corrugatus* and the two species of *Maja* in the upper to middle infralittoral and *Lissa chiragra*, *Herbstia condyliata* (both mainly on coralligenous bottoms) and *Macropodia czerniavskii* in the lower infralittoral. Both species of *Maja* are common, *M. crispata* being found in shallower water than *M. squinado*. *Pisa muscosa* is found in the middle infralittoral while *P. tetraodon* is found in the same region mainly in or round *Posidonia* praries. *P. nodipes* occurs in the lower infralittoral and extends into the circalittoral while *Pilumnus spinifer*, *Homola barbata* and the rare *Latreillia elegans* are circalittoral species.

On hard bottoms, *Achaeus gordonae* is found on weed in the upper infralittoral, *Sirpus zariqueyi* is also found on weed in the same region and in deeper water while *Xantho poressa*, *X. incisus granulicarpus*, *Pilumnus villosissimus* and *Paractaea rufopunctata* are found throughout the infralittoral zone on or under rocks. The first 3 species named are very abundant. *Dromia personata* is common on mid-infralittoral rocky bottoms while *Achaeus cranchi* is apparently a circalittoral species.

Finally several species live in special habitats. These include *Pinnotheres pinnotheres* in the mantle cavity of *Pinna*, *P. pisum* in the mantle cavity of other bivalves and *Planes minutus* which lives on floating weed, marine turtles and flotsam. Two pelagic species, *Polybius henslowi* and *Portunus hastatus* are also occasionally found in Maltese waters.

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Note on the Ecology of Mollusca Collected in Haifa Bay (Israel)

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ABSTRACT

Four surveys concerned with heavy metal pollution were carried out during July, November 1980 and July, September 1981 in Haifa Bay. Observations were made at a number of stations at four depths on the occurrence of various species of molluscs and their environment (type of sediment, temperature, pH, dissolved oxygen and salinity of the water) at each site. General conclusions are drawn on the distribution of the species at these depths. *Arcularia gibbosula* proved to be the most abundant living species in the bay as well as a suitable indicator for mercury pollution.

Introduction

Coastal and estuarine waters are being increasingly burdened by metal pollution. Populations of benthic communities may be damaged if such pollution continues. Studies on trace metal pollution in the sea have generally utilized bivalve molluscs as indicators of metal concentrations in their environment (Eisler *et al.*, 1972; Cunningham and Tripp, 1975; Phillips, 1977; Gordon, 1980). During our study on heavy metal pollution in Haifa Bay the gastropod, *Acularia gibbosula* was found to be the most suitable bioindicator for mercury pollution. (Hornung *et al.*, 1984).

The distribution of the bottom dwelling and burrowing molluscan species and the ecology of their habitat are discussed in this paper. A study of the macrobenthos of

Haifa Bay was carried out by Gilat (1959) and Tom (1976). These studies were made using a Petersen grab and a triangular dredge as sampling gear. The depths investigated varied from 10 to 97 m.

Samples for the present study (sediments and fauna) found in the surface layers (0–10 cm depth of the bottom) at water depths from 3 to 12 m were collected by SCUBA divers during the surveys for the study of heavy metal concentrations in sediments and benthic organisms of Haifa Bay.

Sampling Area and Methods

Haifa Bay forms a sickle-shaped curve between Akko on the north and Cape Carmel on the south. A sandy zone of about 1 km width follows the curve of the shore from a depth of 0–12 m (Nir, 1973).

The depths sampled were 3, 6, 9 and 12 m. The number of sampling stations varied with depth: 8 stations at depth of 3 m, 6 stations at 6 m, 5 stations at 9 m and 4 stations at 12 m (Fig. 1). Four surveys were carried out – July, November 1980 and July, September 1981.

Sediments and benthic fauna (mostly Mollusca) were collected at each sampling site from the surface of one square meter of the sea floor to a depth of 10 cm (Fig. 1). The SCUBA divers collected the sediments using plastic scoops and plastic bags. Nylon

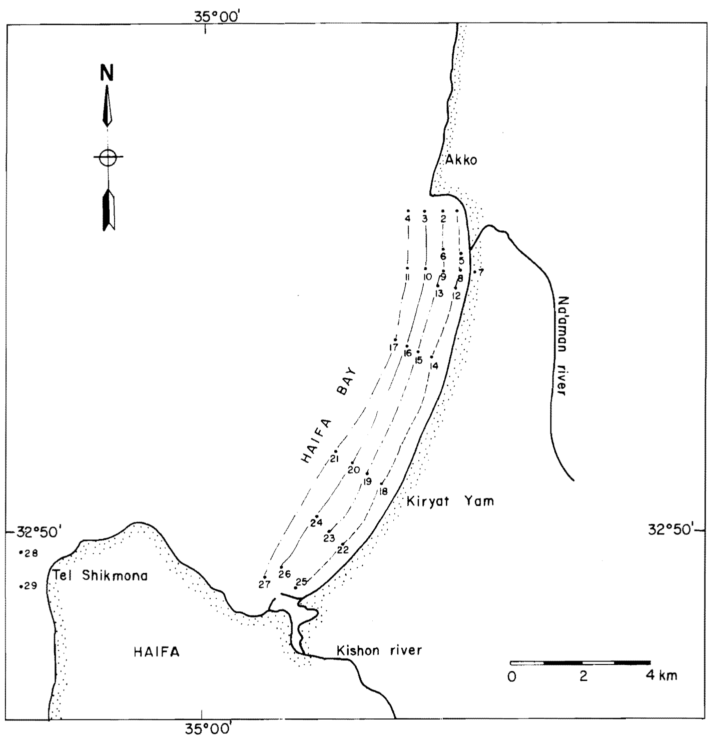

Fig. 1. Location of sampling stations.

sieves with square holes 2.5 mm across were used for separating the animals-molluscs.* Only living specimens were picked out of the sieve; dead and broken shells were ignored.

Water samples were collected at each sampling site from the water-sediment interface layer using a special water sampler. The temperatures of the water layer above the sediment and the whole water column were measured by a cable-thermistor thermometer.

Results and Discussion

a. *Water*. The water temperature of the sediment-water interface, during the sampling periods ranged from 27.1 to 29.2°C in July, from 26.2 to 28.0°C in September and from 22.2 to 22.8°C in November. The pH of the water was the same during the four surveys and ranged from 8.02 to 8.30. The salinity was the same for the whole shoreline during these months for these depths (Oren and Hornung, 1972) ranging from 39.084 to 39.329‰. The dissolved oxygen in the water samples collected from the water layer above the sediment ranged from 3.17 to 5.54 ml/1 with one low value of 2.23 ml/1 at 12 m depth.

b. *Sediments*. The sediments from the shoreline up to 9 m depth are composed mostly of fine sand (250–125 μm fraction) with small quantities of very fine sand (125–63 μm) and silt (<0.063 μm fraction). It can be seen from the granulometric analysis given in Table 1 that the percentage of fine sand grains decreased with distance from shore. From the 12 m depth line the sea floor is composed of submarine reefs and ridges with pockets of very coarse calcareous sand and gravels, and sampling of organisms was almost impossible.

The range for organic carbon in the sediment samples found previously by Roth and Hornung (1975) at the same area was 0.02–0.32%. These values are similar to those given by Nir (1973) for the Israel Mediterranean shelf.

c. *Mollusca*. A total of 18 species were found (Table 2) during the four surveys. Subspecies of 2 species (*Hinia reticulata* and *Mactra corallina*) were also recorded.

Over 700 species of mollusca have been collected in the Mediterranean waters of Israel (Barash and Danin, 1982). These were obtained from shallow water accessible to

Table 1 Grain-size distribution (expressed in weight %) of the analyzed sediments

Water column depth line (m)	Distance from shore (m)	Granulometric fraction (μm)						
		>2000	2000–1000	1000–500	500–250	250–125	125–0.063	<0.063
3	300	0.79	0.60	1.68	6.74	83.68	6.42	0.07
6	500	0.87	0.51	1.45	5.40	76.30	14.77	0.62
9	700	2.32	0.70	2.97	4.86	67.96	18.49	2.70
12	900–1000	13.45	30.46	44.38	10.04	1.55	0.16	0

*Most *Rissoacea* known in this area are above 2.5 mm in height while almost all *Turridae* surpass the height of 2.5 mm (Parenzan, 1970).

shore collectors or taken by dredgings in the infralittoral at depths between 9–200 m. The stretch of the infralittoral between the intertidal zone and 9 m depth had scarcely been investigated, since the research vessels were generally unable to carry out dredgings there. This strip of the infralittoral was explored by diving in our present surveys. Prior to our work in this area, 58 species of Mollusca were collected in the same strip of the infralittoral. These collections were, however, only occasionally carried out by private divers over a period of 18 years (1959–1977).

The composition of the 18 species mentioned in this paper is restricted to the major taxa of Mollusca: Gastropoda – 9 species and Bivalvia – 9 species. It is worth noting that the Bivalvia are represented equally with the Gastropods, despite the preponderance of the latter among the Mollusca in general. (The number of recorded Gastropoda species of the Israeli Mediterranean coast amounts to 474 and that of Bivalvia to 192.)

The most abundant species among those found during the surveys (Table 2, Fig. 2) is *Arcularia gibbosula*, represented by 199 specimens, circa 39% of the 517 specimens in toto. (Tom 1976) found only a few specimens of *Arcularia gibbosula* at Haifa Bay. Barash and Danin (1982) indicated merely as common the frequency of this species in the Mediterranean waters of Israel.)

A great number of specimens was collected during the relatively colder months of the year: November 1980 — 195 specimens, September 1981 — 187 specimens, whereas in

Table 2 List of recorded molluscan species

Family	Species	Specimens	Frequency
	Gastropoda		
	Prosobranchia		
	Mesogastropoda		
Cerithiidae	*Rhinoclavis kochi* (Philippi, 1848)	31 (6.00%)	Rather common
Naticidae	*Neverita josephinia* Risso, 1826	2 (0.39%)	Very rare
	Neogastropoda		
Muricidae	*Trunculariopsis trunculus* (Linnaeus, 1758)	1 (0.19%)	Very rare
	Muricopsis blainvillei (Payrandeau, 1826)	1 (0.19%)	Very rare
Nassariidae	*Sphaeronassa mutabilis* (Linnaeus, 1758)	56 (10.83%)	Common
	Arcularia gibbosula (Linnaeus, 1758)	199 (38.49%)	Abundant
	Arcularia circumcincta (A. Adams, 1851)	50 (9.67%)	Common
	Hinia reticulata (Linnaeus, 1758)	36 6.96%)	Rather common
	Hinia reticulata nitida (Jeffreys, 1867)	1 (0.19%)	Very rare
	Hinia incrassata (Stroem, 1768)	1 (0.19%)	Very rare
	Bivalvia		
	Heterodonta		
	Veneroida		
Cardiidae	*Papyridea papyracea* (Gmelin, 1791)	1 (0.19%)	Very rare
	Rudicardium tuberculatum (Linnaeus, 1758)	11 (2.13%)	Not uncommon
Veneridae	*Venus verrucosa* (Linnaeus, 1758)	1 (0.19%)	Very rare
	Dosina lupinus (Linnaeus, 1758)	7 (1.35%)	Rare
	Venerupis aurea (Gmelin, 1791)	1 (0.19%)	Very rare
	Chamelea gallina (Linnaeus, 1758)	6 (1.16%)	Rare
Mactridae	*Mactra corallina corallina* (Linnaeus, 1758)	40 (7.74%)	Rather common
	Mactra corallina stultorum (Linnaeus, 1758)	21 (4.06%)	Not uncommon
Donacidae	*Donax trunculus* (Linnaeus, 1758)	1 (0.19%)	Very rare
	Donax venustus Poli, 1795	50 (9.67%)	Common
	Total	517 (ca 100%)	

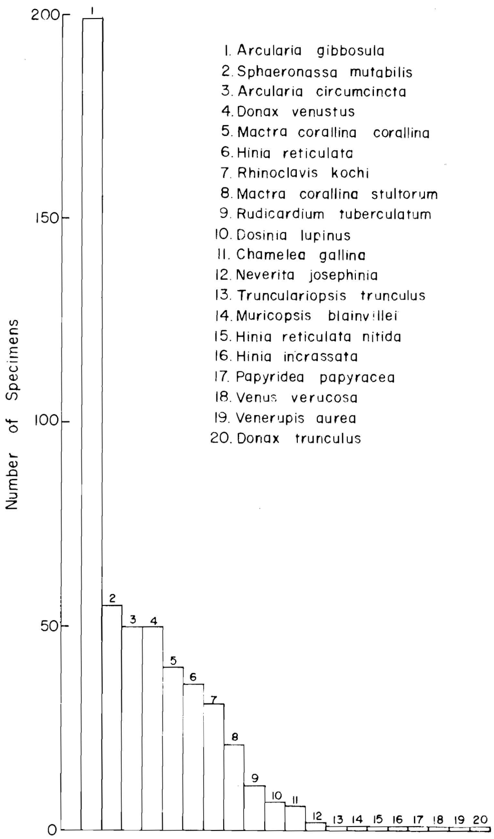

Fig. 2. Occurrence of species.

the warmer season a considerably smaller number of specimens was taken; namely, in July 1980 — 33 specimens, July 1981 — 102 specimens.

It can be surmised that specimens of species hidden under the surface during the warm period appear on the surface when the temperature falls. Tom (1976) found seasonal changes in the composition of species burrowing in the sediments. Certain species appear on the surface of the bottom in the warm months of the year and under the surface in other seasons.

Most species were taken from depths of 3–9 m, from more or less soft bottoms (sand, sandy mud). A smaller number of species (8) was obtained from a depth of 12 m, where the substrate is rather hard (Table 3). Between the 3 and 6 m depth lines 341 specimens were collected (about 24 specimens for each m^2) and between the 9 and 12 m depth lines only 176 specimens were obtained (about 20 specimens for each m^2).

All the species dealt with in this paper are able to burrow in the bottom. Typically infaunal animals are the Bivalvia and the naticid *Neverita josephinia*, which live permanently within the bottom.

The Nassariidae dwell under the surface but are also able to move on the bottom. *Trunculariopsis trunculus* and *Rhinoclavis kochi* are more frequent on and above the sediments. *T. trunculus* burrows shallowly in the sediments in the summer and is abundant above the sediment in the colder months of the year (Spanier, 1981).

Table 3. Vertical and seasonal distribution of species collected by diving in Haifa Bay during 1980–1981
(No. of specimens indicated)

Species	3 m				6 m				9 m				12 m				Total
	1980		1981		1980		1981		1980		1981		1980		1981		
	Jul	Nov	Jul	Sep	Jul	Nov	Jul	Sep	Jul	Nov	Jul	Sep	Jul	Nov	Jul	Sep	
Rhinoclavis kochi	—	—	—	—	—	10	—	—	—	6	—	10	—	5	—	—	31
Neverita josephinia	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	2
Trunculariopsis trunculus	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1
Muricopsis blainvillei	—	—	—	—	—	—	—	—	—	—	—		1	—	—	—	1
Sphaeronassa mutabilis	1	—	1	6	—	1	—	1	1	13	2	6	—	17	—	7	56
Arcularia gibbosula	1	22	19	28	—	54	13	29	—	4	8	22	—	—	—	—	199
Arcularia circumcincta	8	8	6	12	6	—	—	2	8	—	—	—	—	—	—	—	50
Hinia reticulata	—	1	—	—	—	—	—	—	—	7	—	1	—	26	—	1	36
Hinia reticulata nitida	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1
Hinia incrassata	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Papyridea papyracea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Rudicardium tuberculatum	—	—	—	—	—	1	1	2	—	2	1	2	—	—	—	2	11
Venus verrucosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
Dosinia lupinus	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	7
Venerupis aurea	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
Chamelea gallina	—	—	—	—	—	1	1	—	—	2	—	—	—	—	—	2	6
Mactra corallina corallina	2	1	8	10	1	1	4	10	—	—	1	2	—	—	—	—	40
Mactra corallina stultorum	5	—	—	10	—	—	2	2	—	—	1	1	—	—	—	—	21
Donax trunculus	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Donax venustus	—	6	21	6	1	—	5	5	—	4	—	1	—	—	1	—	50
Specimens total	20	39	55	73	8	68	26	52	9	40	14	45	1	48	2	17	517
	187				154				108				68				

Rhinoclavis kochi seems also to be a shallow burrower. The egg masses of this species are covered by sand grains adhering to the gelatinous matrix in which the egg capsules are embedded.

The modes of feeding of the species collected are diverse. Archaeogastropoda were not found during the surveys and hence no typical herbivorous species feeding on macrophyte algae were available. Of the 2 species of Mesogastropoda, *Rhinoclavis kochi* feeds on minute algae and detritus; the other species, *Neverita josephinia*, preys on molluscs, boring holes through their shells and then rasping out the living contents. The other Gastropoda (8 species), belonging to the Neogastropoda, are carnivorous. Of these, the five species of Nassariidae are in the main scavengers, feeding mainly on dead animal matter. The nassariids are of great importance for the ecology of the waters, keeping them clean by disposing of all kinds of decaying organisms.

Our investigations concerning the pollution of Haifa Bay proved that the most efficient species in the uptake of mercury are the nassariids *Arcularia gibbosula* and *Arcularia circumcincta* (Hornung *et al.*, 1984). (*Arcularia circumcincta* is regarded by some authors as a synonym of *A. gibbosula* and by others as a variety.)

The effect of industrial contamination is demonstrated by a comparison of mercury content in bivalve and gastropod species from distant and close sampling sites, where emission of waste water containing mercury takes place (Fig. 3). The decrease of mercury content in the soft tissues of the molluscs with the increasing distance from the pollution source can be seen very distinctly.

Based upon these findings it is clear that *Arcularia gibbosula*, which is the most

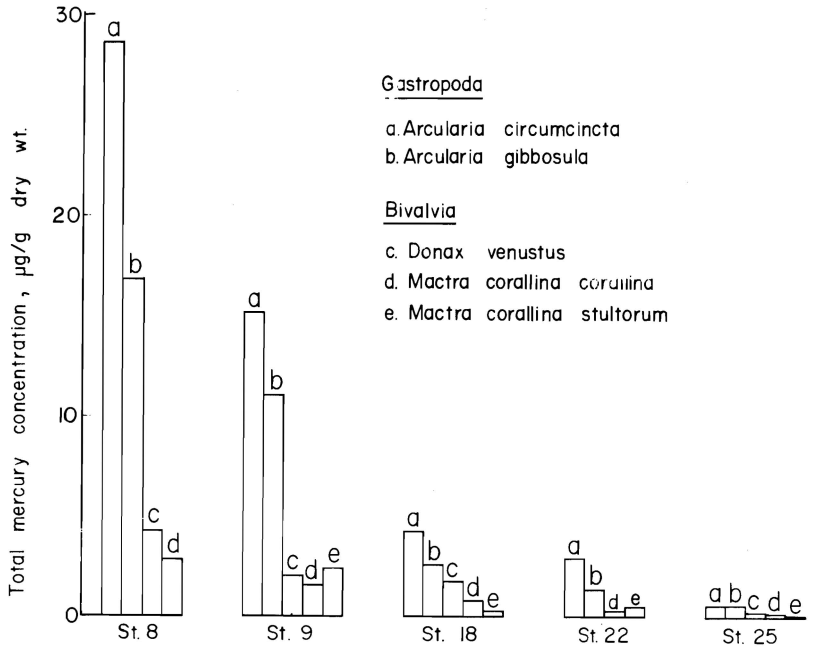

Fig. 3. Total mercury concentrations in molluscs (bivalves and gastropods) along sampling sites in Haifa Bay, 1980–1981 Hornung 1984).

abundant in the area, has possibilities of being useful as an indicator species for mercury pollution.

The Bivalvia collected, belonging to the Heterodonta, are ciliary filter feeders browsing on microscopic plants and animals suspended in the water, brought to them by a water current created by cilia in their body. The accumulation of mercury in their body is much lower than in the gastropods (Fig. 3).

The results of the survey recorded here are valid only for the period studied at Haifa Bay. An extension of the surveys to other seasons of the year and to additional sites and depths, but in the same strip of the infralittoral, would probably reveal additional data on the composition of species, their frequency and seasonal changes in their assemblages.

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