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SYNTECTONIC DEPOSITION OF AN OLIGO-MIOCENE PHOSPHORITE CONGLOMERATE BED IN MALTA

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ABSTRACT

A succession of Oligo-Miocene sediments at Sliema, Qawra and Migra Ferha includes a 10-20cm phosphorite conglomerate bed capping the terminal hardground of the Lower Coralline Limestone Formation (Oligocene) which consists of carbonate platform sediments. The conglomerate bed always occurs in areas of significant thinning of the overlying Lower Globigerina Limestone. These palaeohighs have been linked to NNE-SSW trending lineaments.

At Sliema, allochthonous phosphatised conglomerate infill NW-SE trending Neptunian dykes that dissect the platform sediments. These Oligo-Miocene syntectonic deposits were later cemented and vertically displaced by minor faulting trending NW-SE. Tectonic features at Sliema are linked to the regional N-S extensional regime and tentatively interpreted to have developed from stresses caused by displacement along the western margin of a NNE-SSW trending strike-slip fault. East of this fault, synclinal subsidence created the Valletta Basin and set conditions for current upwelling. Phosphatogenesis occurred along the basin margin swept by the prevailing westward currents. Phosphatised pebbles and ahermatypic corals were transported westward of palaeohigh margins in central and western Malta and deposited on the terminal hardground of the drowned Oligocene carbonate platform.

INTRODUCTION

The Maltese Islands are located about 100km south of Sicily (figure 1a) and consist of an Oligocene to Miocene succession (Trechmann, 1938) forming one of the emergent eastern parts of the Pelagian block which extends from eastern Tunisia to the Ionian Basin (Burollet *et. al.,* 1978). Murray (1890) named the five Maltese Formations shown in figure 1b. The oldest consists of the Late Oligocene sediments of the Lower Coralline Limestone Formation (Felix, 1973). These shallow marine carbonate sediments are terminated by an Oligo-Miocene hardground in the Maltese Islands that marks a change to the overlying Miocene pelagic sediments of the Globigerina Limestone Formation.

This paper is first to record a 10-20cm phosphorite conglomerate bed at west Sliema, Qawra and Migra Ferha (figure 1c) overlying the terminal hardground of the Lower Coralline Limestone Formation. Phosphorite conglomerates terminating the Lower Coralline Limestone Formation have been generally overlooked by most authors, although Cooke (1896) describes a "seam of phosphatic nodules" without disclosing its location. Felix (1973) locates a brown hardground or "pebble bed" at il-Qaws [Grid Reference 418 697]. Dispersed phosphorite pebbles outcrop northwest of il-Qaws in western Malta (figure 1c).

Several Early Miocene phosphorite conglomerate beds extending from Sicily to Malta have been described by Carbone *et. al.* (1987). In Malta, the formation and occurrence of this earliest phosphorite conglomerate bed is linked to active tectonism as well as pre-existing tectonic or biogenic features that resulted in local palaeohighs. At Sliema, the conglomerate bed infills a series of Neptunian dykes that cut across the terminal

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hardground and the Late Oligocene platform sediments. The NE-SW extension also created minor faulting that vertically displaced the phosphorite conglomerate bed. These Oligo-Miocene syntectonic deposits precede any recorded for the Maltese Islands by Illies (1981), Reuther (1984), Grasso *et.al.* (1986) and Dart *et.al.* (1993) and are here associated with the formation of the poorly-known Valletta basin.

Although accessible outcrops of phosphorite conglomerate beds are limited to only narrow coastal zones, the available evidence has been used to construct a depositional model to explain the deposition of this Oligo-Miocene phosphorite conglomerate over the terminal hardground. The extensional discontinuities at Sliema are also related to the tectonic framework of the Pelagian Block and its three principal trends of faulting shown in figure 1a.

LATE OLIGOCENE LITHOSTRATIGRAPHY

The 140m thick Lower Coralline Limestone Formation is interpreted by several authors as being deposited along a shallow marine carbonate platform (Felix, 1973, Pedley *et.al.* 1976, Bennett, 1980). Sedimentation was controlled by three factors: (1) a depositional surface that deepened eastward (Bosence, 1991) along a slope <1°, which is characteristic of a ramp system (Burchette & Wright, 1992); (2) westward flowing sea currents (Pedley, 1987, Gatt, 1992) and; (3) a series of patch reefs in central Malta. These are interpreted by Pedley (1987) as having developed along a N-S palaeohigh (Rabat axis) related to pre-Oligocene tectonism (Pedley, 1990), although Saint Martin *et.al.* (1998) discards the notion of a palaeohigh basement and interprets these sediments as biogenic buildups consisting of corals and rhodoliths that accreted over time.

Four successive Facies Associations are identified in Malta and are here related to sequence-stratigraphic concepts:

Facies Association I: Lowstand sediments are exposed in the lower part of the Formation and consist mainly of fine-grained foraminiferal mudstones, algal debris wackestones (Bennett, 1980) and coral framestone deposited in an inner ramp lagoon-type of environment.

Facies Association II: A transgressive sequence consisting of horizontal thick red algal debris and rhodolithic beds, reaching a thickness of >20m (Gatt, 1992). These truncate the framestone coral heads of Facies Association I at Wied Znuber [557 630], Mosta [488 758] and Migra Ferha gorge [405 705]. These inner ramp sediments were deposited in an environment under constant wave agitation and are terminated by a sharp erosional surface.

Facies Association III: Foraminiferal and algal debris packstones and grainstones showing westward prograding cross-bedding. These sediments extend from Wied iz-Zurrieq [506 643] in the south to Bahar ic-Caghaq [510 776] and west Sliema (figure 1c) in the north (Gatt, 1992). Pedley (1987) interprets these coarse-grained sediments as a N to S trending facies deposited by powerful traction currents.

This sandbody is considered by Pedley (1987) to be laterally penecontemporaneous to expanded sequences of packstone and wackestone beds with abundant *Lepidocyclina* and *Amphistegina* in east Malta. At Xghajra [593 718], 1m thick well-sorted beds of these giant foraminifera show oblique and edgewise imbrication formed by bi-directional storm sea currents (Gatt, 1994) in a mid-ramp environment.

The topmost sediments are locally dominated by the echinoid *Scutella subrotunda*. Sections in east Malta consist of wackestones capped by a pectenid bivalve pavement and bryozoans (Gatt, 1994). These sediments become increasingly coarse-grained and dominated by large foraminifera towards central Malta. At Qammieh [400 811] in west Malta, Pratt (1990) describes beds of packstones of bryozoans, echinoids and the giant benthic foraminifer, *Lepidocyclina*. These sediments are terminated by a ubiquitous hardground surface formed during the drowning of the carbonate platform.

Facies Association IV: The western part of central Malta is dominated by a number of patch reefs that show highstand shedding of algal sediments followed by incipient drowning. At Naxxar [498 741], a biogenic buildup of corals succeeded by algal sediments and rhodoliths reaches a thickness <70m (Saint Martin *et.al.*, 1998) and forms large prograding clinoforms of well-sorted algal debris and rounded rhodolith beds dipping 20° to the SE (Gatt, 1992). The clinoforms are onlapped by pelagic sediments of the Globigerina Limestone Formation (Gatt, 1992), deposited along this persistent biogenic build-up during the final drowning of the platform.

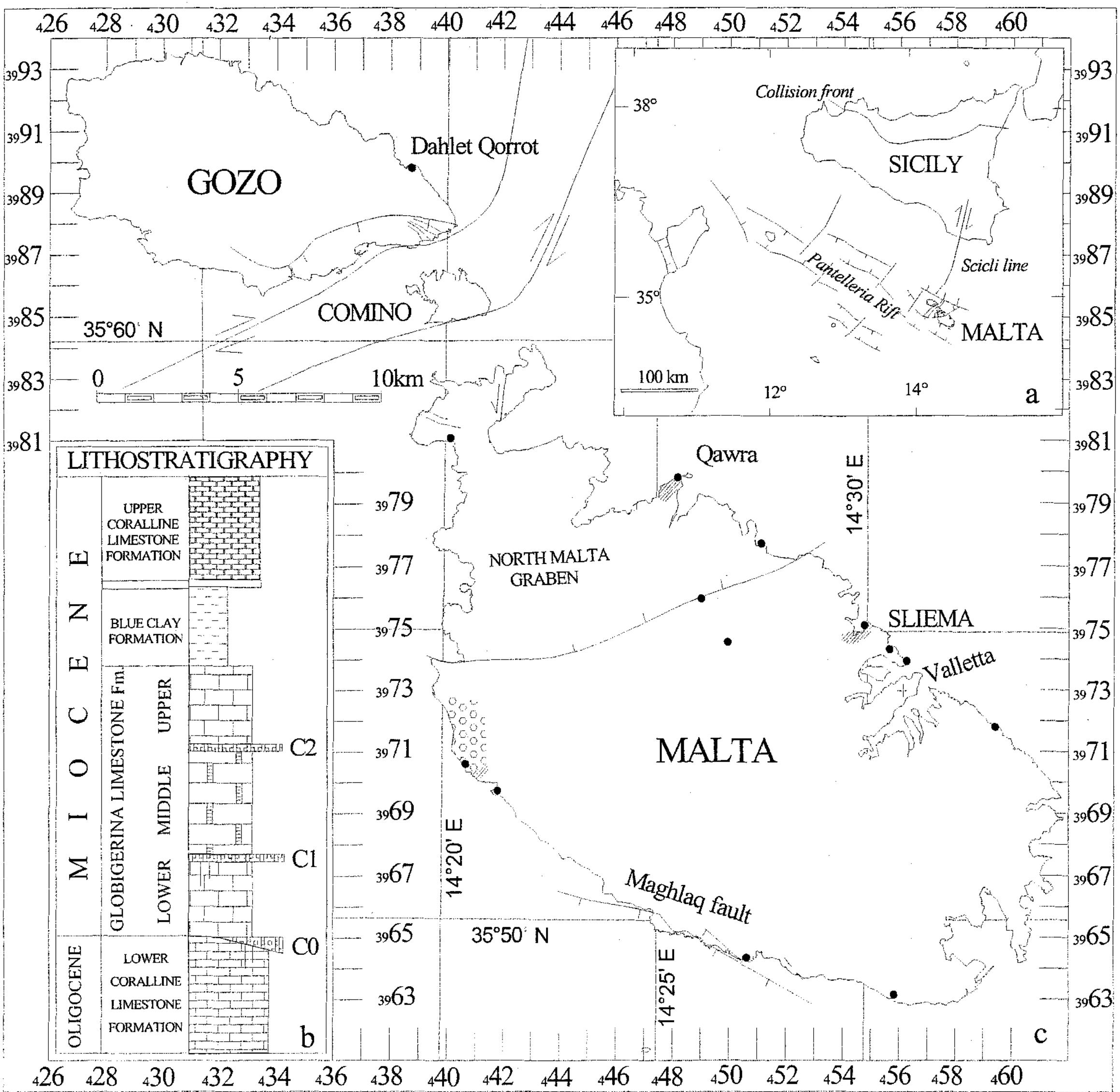

Fig. 1 (a) Main tectonic structural trends in the Central Mediterranean (partly based on Reuther, 1984 and Grasso *et. al.*, 1993) ; (b) Lithostratigraphy of the Maltese Islands; (c) Sections and main faults (partly based on Reuther, 1984 and Illies, 1981) in the Maltese Islands. Oligo-Miocene C0 phosphorite conglomerate bed shaded in stripes where C0 bed >10cm thick; in circles where only phosphorite pebbles (<5cm) are present

REGIONAL SETTING OF OLIGO-MIOCENE HARDGROUNDS AND CONGLOMERATES

Three main regional hardgrounds mark the stratigraphic boundaries of the Oligo-Miocene succession comprising the Lower Coralline Limestone and Globigerina Limestone Formations. The terminal Lower Coralline Limestone hardground is the oldest and marks the end of shallow marine platform sedimentation which is considered by several authors to coincide with the end of the Oligocene (Felix 1973, Pedley *et. al.*, 1976, Challis, 1979, Pedley, 1987). Some authors consider Oligocene sedimentation to have extended to the Lower Member of the Globigerina Limestone Formation (Giannelli & Salvatorini, 1972, Mazzei, 1985, Rose *et.al.* 1992), although all authors confirm that the Lower Coralline Limestone Formation is of Late Oligocene age.

The succeeding two main hardgrounds subdivide the Globigerina Limestone Formation into the three

Members, named by Rizzo (1932) as the Lower, Middle and Upper Globigerina Limestone. The hardgrounds are overlain by the ubiquitous C1 and C2 phosphorite conglomerate beds respectively (figure 1b) described by Felix (1973), Pedley *et.al.* (1976), Bennett (1980) and Pratt (1990). The phosphorite conglomerate bed described in this paper has been designated as the C0 bed accordance to this nomenclature.

These three principal hardgrounds have been correlated with the global eustatic sea-level curves of Haq *et. al.* (1987). The terminal hardground is associated with the beginning of the Aquitanian global eustatic rise in the TB1 supercycle. The two main hardgrounds in the Globigerina Limestone Formation are interpreted by Rose *et.al.*, (1992) to have formed during Miocene episodes of global marine transgression and were capped by condensed sections, the C1 and C2 conglomerates.
The occurrence of the C0 bed is limited to three areas in Malta seen in figure 1c. At Sliema and Qawra, the C0 bed exceeds 10cm in thickness and consists of 5-10cm subrounded pebbles, coral fragments and disarticulated pectenid bivalves. The C0 bed at Qawra is very limited in outcrop and its surroundings modified by Recent subaerial process. Only the Oligo-Miocene sediments at southwestern Malta and Sliema are described in detail.

THE C0 PHOSPHORITE CONGLOMERATE BED AT SOUTHWESTERN MALTA

The Lower Coralline Formation in western Malta forms vertical coastal cliffs which, according to Pedley *et. al.* (1976) are capped by a ubiquitous thin bed of the Lower Globigerina Member. Rose *et.al.* (1992) name these pectenid-bryozoan packstone sediments as the Gnejna bed, which extends around a synsedimentary high centred at il-Qaws where the Lower Globigerina Member is absent. In this paper, the Gnejna bed is reinterpreted as the topmost Lower Coralline Limestone Formation which correlates to other bryozoan beds within the Formation in east Malta and Qammieh (Pratt, 1990), although in southwestern Malta it is locally capped by the C0 bed.

The size of phosphorite pebbles in the C0 bed varies along a gradient from large (>5cm) sub-rounded conglomerate associated with ahermatypic corals and intraclasts of phosphatised burrows at Grid Reference 408 702 near Migra Ferha, to smaller (<5cm) well-rounded, discrete phosphorite pebbles further northwest (figure 1c).

THE C0 PHOSPHORITE CONGLOMERATE BED AT SLIEMA

Coastal outcrops of facies associations II and III in west Sliema are overlain by the Globigerina Limestone Formation along most of the coast (figure 2), which comprises four facies grouped into units A and C, separated by a C1 phosphorite conglomerate bed (unit B);

A. The Middle Member outcrops close to sea level and estimated to be 18m thick;

1. About 10cm of fine-grained low-angle cross-bedded laminae at Qui-si-Sana [556 744] passing upward to a thicker bioturbated sequence which is mostly inaccessible in outcrop. This facies is an unrecorded outlier of the Middle Member of this Formation.

B. The C1 conglomerate phosphorite bed (figure 3) is of regional extent and outcrops from Qui-si-Sana to Dragut
point [562 739], overlying a hardground;

2. This bed consists of brown-coloured phosphorite pebbles with serpulid encrustations, echinoids (some intact) and ahermatypic corals in a white sandy matrix overlying a phosphatised hardground. The pteropod *Gamopleura melitensis* in this bed is commonly associated with the C1 phosphate bed (Janssen, 2003).

C. The thickness of the Lower Globigerina Limestone Member is < 20m at west Sliema and consists of two main ichnofacies;

3. A set of poorly-defined mudstone/wackestone beds which are intensely bioturbated with alternating beds showing burrows of *chondrites* and *thalassinoides* exposed along most of the northeast facing coast.

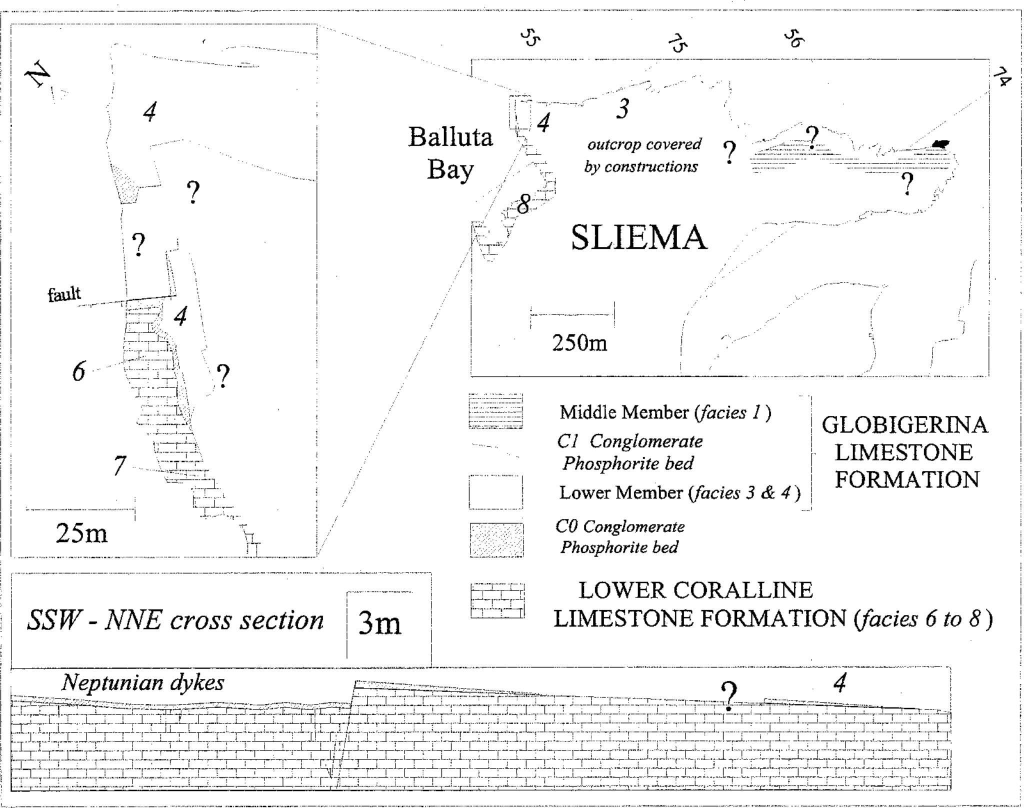

Fig. 2. Sliema: facies distribution and cross section at west Sliema

4. About 4m of globigerinid wackestone and mudstone that abruptly overlie the CO bed in west Sliema (fig. 2) with no evidence of reworked phosphorite intraclasts. The basal sediments show poorly preserved small straight burrows which further up pass to large bow-form burrows *circa* 0.5 to 1m long with a *Cylindrichnus*-mode of infill (Goldring *et.al.*, 2002).

D. The C0 conglomerate bed, overlying the terminal hardground;

5. A 10 to 20cm bed consisting of irregular-shaped dark brown phosphatised pebbles and ahermatypic corals within a white sandy matrix. The bed has a wavy surface and infills the underlying Neptunian dykes with corals and *pecten*. A minor normal fault along a NW-SE strike (130°) with an offset of 1m cuts the C0 bed and underlying sediments (shown in cross section in figure 2).

E. The top part of the Lower Coralline Limestone Formation shows a regional low dip (<5°) towards the northeast and outcrops along the coast around Balluta bay (figure 2) where it consists of three facies;

6. The topmost facies of about 1.5m of coarse-grained foraminiferal packstones with preserved echinoid tests of *Scutella subrotunda*, oysters and *pecten*, ending in the terminal hardground. At Grid Reference 547 751, the hardground is dissected by 40 to 200cm deep Neptunian dykes trending between 120° and 140°, which are infilled with sediments from the C0 phosphorite conglomerate bed. The dykes cut across the stratification at steep angles.

7. Two metres of cross-bedded coarse-grained sediments consisting of echinoid bioclasts and the large foraminifera *Lepidocyclina* and *Amphistegina*. The cross-beds show westward prograding foresets. This facies corresponds to Pedley's (1978) Xlendi Member

8. An intensely bioturbated medium-to-coarse–grained red algal debris packstone abruptly terminated by an erosion surface about 0.5m above sea level at Balluta Bay [543 749].

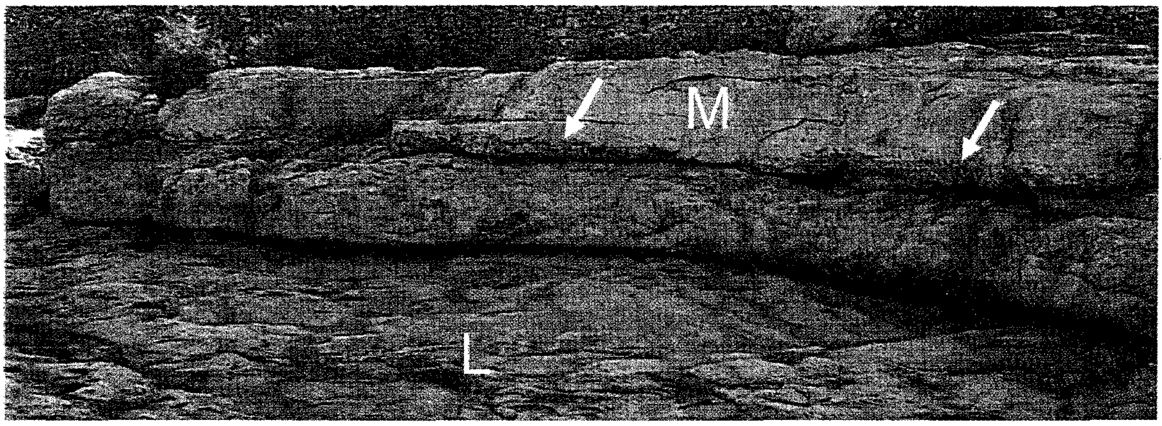

Fig. 3. Sliema (Qui-Si-Sana): C1 Conglomerate Phosphorite bed (arrows) overlying the Lower Globigerina Limestone (L). The Middle Globigerina Limestone (M) shows cross-bedding.

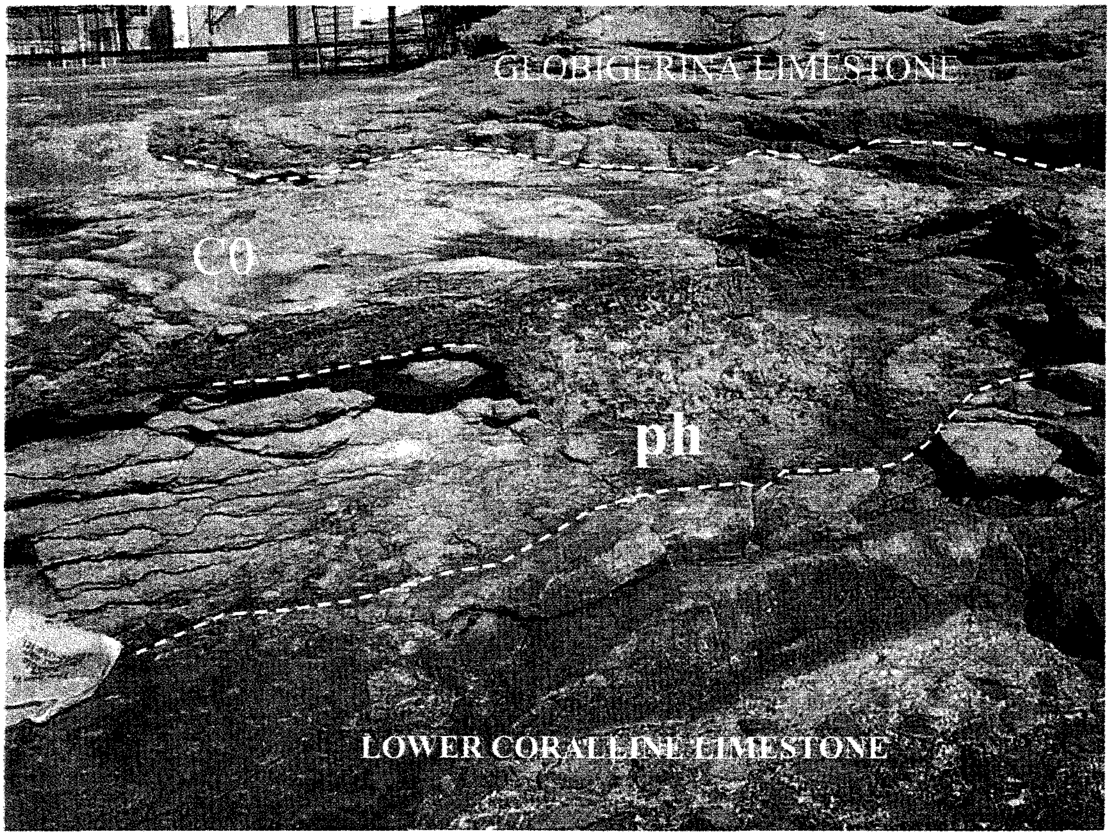

Fig.4. Partly eroded phosphorite sediments (ph) infilling a Neptunian dyke at Sliema [547 598]. The eroded foreground has exposed the dyke in vertical section. Phosphorite conglomerate bed (C0) in background.

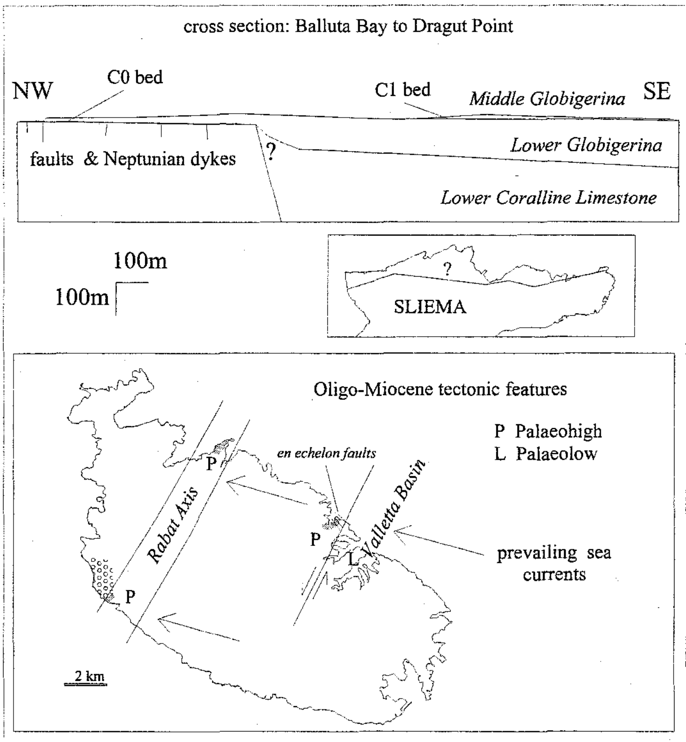

Fig. 5 top: Cross-section along Sliema showing stratigraphic thickening of Lower Globigerina capped by Middle Globigerina; bottom; tectonic setting of Rabat Axis (partly based on Pedley, 1987) and Valletta basin along a strike-slip fault showing NW-SE *en echelon* faults and Neptunian dykes at west Sliema. The C0 bed is located in areas of palaeohighs.

DEPOSITIONAL SETTING AND TECTONISM

The sediments at Sliema reflect successive relative sea level variations resulting from a combination of adjustments in carbonate sediment production, eustatic sea level changes and tectonic controls. The coarse-grained sediments forming the top part of the Lower Coralline Limestone Formation (facies 7) were deposited in a high hydrodynamic energy environment associated with a sea depth of <5m (Davies, 1976). The topmost condensed section (facies 6) reflects a drop in sedimentation rate at the onset of a marine transgression that created conditions for early cementation of the seabed leading to the formation of the terminal hardground. Rapid relative sea level rise terminated platform sedimentation and drowned the carbonate platform.

During this hiatal phase in sedimentation, the platform is interpreted to have underwent extension that created the Neptunian dykes which dissect the terminal hardground at west Sliema. The C0 phosphorite conglomerate bed infilling the dykes is interpreted as being allochthonous since the terminal hardground surface does not show *in situ* phosphatisation. Further extensional stresses along the platform generated NW-SE trending faults and created the small vertical displacements at west Sliema cutting into the cemented C0 bed.

The heightening of the marine transgression by eustatic and possibly tectonic controls, produced open marine conditions on the platform area at Sliema and the deposition of the Lower Member of the Globigerina Limestone Formation. The lime mud sediments were bioturbated by a succession of burrowers that reflect cyclic changes in the availability of oxygen at the seabed. Ichnofacies with larger burrows (facies 4) formed during episodes of shallower sea level or increased current activity that oxygenated the seabed. The *Chondrites* burrows in facies 3 are an indicator of minimal oxygenation at the seabed (Goldring, 1991).

At Qui-si-Sana, the Lower Member is terminated by the C1 phosphorite conglomerate bed overlying a phosphatised hardground. These autochthonous sediments are indicative of a hiatus in sedimentation and early cementation of the sea bed. The current-swept C1 bed was succeeded by cross-bedded carbonate sediments (facies 1) deposited during an increase in the sedimentation rate under moderate current energy conditions. These conditions later subsided and sediments become increasingly bioturbated further up.

DISCUSSION

The C0 phosphorite conglomerate bed is limited to particular western and central sections where the Lower Globigerina Member shows local thinning to <20m. In western Malta, these palaeohighs are related to highstand deposits of Facies Association IV overlying a NNE-SSW trending tectonic lineament. In central Malta, Neptunian dykes and faults at west Sliema provide tectonic evidence related to the formation of another palaeohigh adjacent to a subsiding seabed. The succeeding C1 and C2 beds in the Globigerina Limestone Formation are condensed sections formed during peak global marine transgressive episodes and consequently differ from the C0 bed in being ubiquitous in Malta and of regional extent.

Depositional model

The proposed depositional model in this paper is of a drowned homoclinal carbonate ramp that becomes distally steepened east of Sliema. This model is supported by west-to-east stratigraphical data for the Globigerina Limestone Formation in central Malta that points to the formation of the Valletta basin east of Sliema. Different interpretations on the extent of the Valletta basin have been described by Pedley *et.al.* (1976), Pratt (1990), Pedley (1990) and Rose *et.al.* (1992). The Lower Member (facies 3 and 4) at the basin margin in west Sliema reaches a thickness of <20m. Further east, hydrological borehole data indicates an unusual thickening of the Lower Member, where it reaches a maximum of >100m at Valletta. These sediments are capped by an outlier of the Middle Member in eastern Sliema (figure 5).

The basin environment created conditions for upwelling of sea currents that brought an influx of nutrients along the basin margin. Upwelling of water has been linked to phosphatogenesis (Kazakov, 1937, McKelvey, 1967) which can occur in current-swept environments (Jarvis, 1992). These westward-flowing sea currents transported the subrounded phosphatised pebbles and corals at Sliema over a relatively short distance.

In western Malta, the C0 bed at Migra Ferha and Qawra are also indicative of a nearby current-swept zone of phosphatogenesis which may be related to highstand sediments of Facies association IV. At Migra Ferha, phosphorite pebbles become smaller and more rounded towards the northwest, indicating longer transportation and re-working by westerly currents.

Tectonic setting and the evolution of the Maltese Islands

The linking of the dykes and faulting at west Sliema to the tectonic evolution of the Maltese Islands is problematic because they precede syntectonism in the Maltese Islands described by Pedley *et.al.* (1976), Illies (1981), Reuther (1984), Grasso *et.al.* (1986) and Dart *et.al.* (1993). Three principal tectonic trends found in the region of the Maltese Islands are described and their possible relation to the formation of the C0 bed discussed:

1. The earliest phase of rifting in Malta is described by Illies (1981) to have produced a set of faults striking 50° to
70° in the Miocene that created the NE-SW trending horst-ridge morphology in the North Malta Graben (figure1c). Syntectonic sedimentation of a phosphorite bed has been recorded in these Miocene sediments by Pratt (1990) at Dahlet Qorrot in Gozo (figure 1c). Extensional faulting produced Neptunian dykes at the crest of the uplifted footwall which dissected the Lower Globigerina Member. This tectonic activity coincided with the deposition of the C1 phosphorite conglomerate bed that infills the dykes.
2. A second set of faults, the Maghlaq fault system strikes 120° (figure 1c) and crosscuts the NE-SW trending set of older faults (Grasso *et.al.*, 1986). Faulting extends to Miocene sediments in Sliema and the

Valletta area (Illies, 1980). The Maghlaq fault is considered by Illies (1969) to be the outermost master fault of the Pantelleria Rift (figure 1a) which developed from the Messinian onwards when the Pelagian Block was governed by NE-SW extension. Significantly, the strike of the Neptunian dykes at west Sliema parallels that of the Maghlaq fault system, although they precede its formation.

3. Dart *et. al.* (1993) reinterpret Maltese tectonics and consider the different rifting phases as coeval, produced by a N-S extensional regime proposed by Argnani (1990) for the Central Mediterranean. Rifting is considered to have commenced after the deposition of the Lower Coralline Limestone Formation. North-south extension affecting the Pelagian Block also generated strike-slip faulting in the Hyblean plateau in SE Sicily forming the Scicli Line (Grasso *et.al.* 1986) which is regarded by Pedley (1987) to extend to near Comino in the Maltese Islands (figure 1a,c). In Malta, N-S trending lineaments described by Pedley (1987, 1990) consist of an Oligo-Miocene palaeohigh in western Malta (Rabat axis) and a palaeolow in eastern Malta (Valletta basin). The geometry and occurrence of the C0 bed transported under the prevailing westerly flowing sea currents support this interpretation (figure 5).

The Valletta basin

The tectonic features at west Sliema and the formation of the Valletta basin are here considered within the framework of the regional N-S extensional regime proposed by Dart *et.al.* (1993). Pedley (1990) considers the Valletta basin to have a N-S alignment subparallel to underlying Mesozoic lineaments and the Miocene Scicli Line, although the actual tectonic mechanism leading to the formation of the Valletta basin have not been described.

The Valletta basin is tentatively interpreted to have developed along a NNE-SSW trending sinistral strike-slip fault terminating in Malta (figure 5). The NW-SE trending fault at west Sliema forms the tail end of a set of en-echelon faults with associated Neptunian dykes which released stresses along the strike-slip principal displacement zone. This faulting on the western margin oblique to the transform fault also produced a step-like topography shown in cross-section in figure 2.

An asymmetric syncline developed east of the strike-slip fault that was infilled by the Lower Globigerina Limestone and capped by the Middle Globigerina Member, which is preserved as an outlier in Sliema (figure 5a). The strike-slip motion that created the Valletta basin may form the southeastern flank of the block bounded on the west by the Scicli Line dextral shear. Further studies covering a wider area are required to reinforce this tentative interpretation of the Valletta basin.

CONCLUSIONS

1. The Oligo-Miocene carbonate sediments of Malta show three regional hardgrounds, each overlain by a phosphorite conglomerate bed.
2. The carbonate ramp sediments of the Late Oligocene Lower Coralline Limestone Formation are terminated by the first regional hardground that marks the drowning of the platform.
3. Regional N-S extension and the development of a NNE-SSW trending principal strike-slip fault may explain the development of minor faults and several Neptunian dykes at Sliema oblique to the principal fault.
4. The development of the Valletta basin east of Sliema created conditions for phosphatogenesis at the current-swept basin margin. These phosphatised sediments were transported westward by the prevailing sea currents and deposited at Sliema as a bed of phosphorite conglomerate consisting of subrounded pebbles with ahermatypic coral bioclasts that infill Neptunian dykes.
5. This bed also locally caps the terminal hardground of areas in western Malta where the overlying Lower Globigerina Member shows significant thinning. Here, pebble size decreases westwards.

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