The Geology of Malta and Gozo

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PEDLEY, H. M., M. R.HOUSE & B. WAUGH. 1976. The Geology of Malta and Gozo. *Proc. Geol. Ass.*, **87** (3), 325–341. A review is given of the setting, history of study, sequence and structure of the Oligo-Miocene sediments of the Maltese Islands. Largely carbonate rocks of Chattian to Tortonian age are represented in a sequence of Lower Coralline Limestone, *Globigerina* Limestone, Blue Clay, Greensand and Upper Coralline Limestone Formations. Small-scale geological maps are given, based on a new 6-inch- and 25-inch-to-the-mile mapping. A structure contour map and isopachyte maps for certain units are given for both islands. Sedimentological and palaeoenvironmental interpretations of the succession are presented.

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1. INTRODUCTION

The Maltese Islands owe their historic and strategic importance to their position between the eastern and western Mediterranean basins where Europe and Africa come closest together. One of the finest anchorages in the world is provided in the creeks and inlets around Valletta which originated as drowned valley systems. The Tunisian coast lies 300 km to the west of the islands, Tripoli lies 350 km to the south-south-west, but the Ragusa peninsula of Sicily is only 95 km north across the Malta Channel. The submarine ridge linking Sicily with Malta is mostly less than 90 m in depth, and everywhere less than 200 m. But depths in excess of 1,100 m are recorded in a north-west trending trough only 15 km south-west of the islands, though depths are mostly thereafter substantially less to the African coast. Malta and the Ragusa peninsula of Sicily are usually regarded as part of the African plate.

The Maltese islands comprise Malta, 27 km in length, Gozo, 14.5 km in length, Comino and Cominoto which are in the straits separating the two larger islands, and Filfla which lies 4 km off the south-western coast of Malta. The total land area of the islands is 316 km².

The islands are almost wholly composed of mid-Tertiary rocks in a simple succession which has long been recognised as follows:

Upper Coralline Limestone	seen to 162 m
Greensand	0–11 m
Blue Clay	0–65 m
Globigerina Limestone	23–207 m
Lower Coralline Limestone	seen to 140 m

This succession represents a varied cross-section of Oligo-Miocene lithologies and facies, but they are almost wholly of carbonates. The rocks are very gently flexured, and only in one place are they locally inverted. Normal faulting is widespread. Northern Malta is dominated by a horst and graben structure trending east-north-east. The faulting is reflected in the topography, and so is the simple stratigraphy. The Upper and Lower Coralline Limestones usually form bare karstic plateaux. The widespread *Globigerina* Limestone gives much gentler topography and the meagre soil is intensively cultivated and terraced. The fertile Blue Clay, aided by water seeps from the overlying units, gives the most lush vegetation on the islands.

2. PREVIOUS WORK

What is probably the earliest surviving reference to fossils is a comment on those of Malta by Xenophanes of Colophon, born about 570 B.C., which has come down through the writings of Origen (A.D. 185–254). During medieval times, Malta was famous as a source of *Glossopetrae*, the teeth of the shark *Carcharodon megalodon*. Steno (1667, 61), in his classic solution of the problem of *Glossopetrae*, refers to the 'vast number of teeth which every year are brought out of Malta, seeing that no ship goes thither but it brings back some of them'. There is evidence that Seino visited Malta (Zammit-Maempel, 1975) and he may well have become acquainted with *Glossopetrae* first in the 1650s when he was preparing his catalogue, or *Indice*, of the material in the Medici collection in Florence. *Glossopetrae* were revered for their supposed medicinal value and as charms, and they may still be (Zammit-Maempel, 1968). This view may have been enhanced by the supposition that they were the teeth lost by snakes following the miracle of St. Paul after his shipwreck on Malta. Thereafter they have also been known as *Linguae Melitense* or *Linguae Sancti Pauli*. Adams (1938) gives other variants of the legend similar to that of St. Hilda and the Whitby ammonities.

With the description of some Maltese fossils by Scilla the Sicilian (1670) systematic description can be said to have begun, but it progressed slowly. Commander Spratt (1843; 1852) gave the first comprehensive geological descriptions. The famous bone remains from caves and fissures were made known through the writings of Spratt (1867) and especially Leith Adams (1864; 1870;

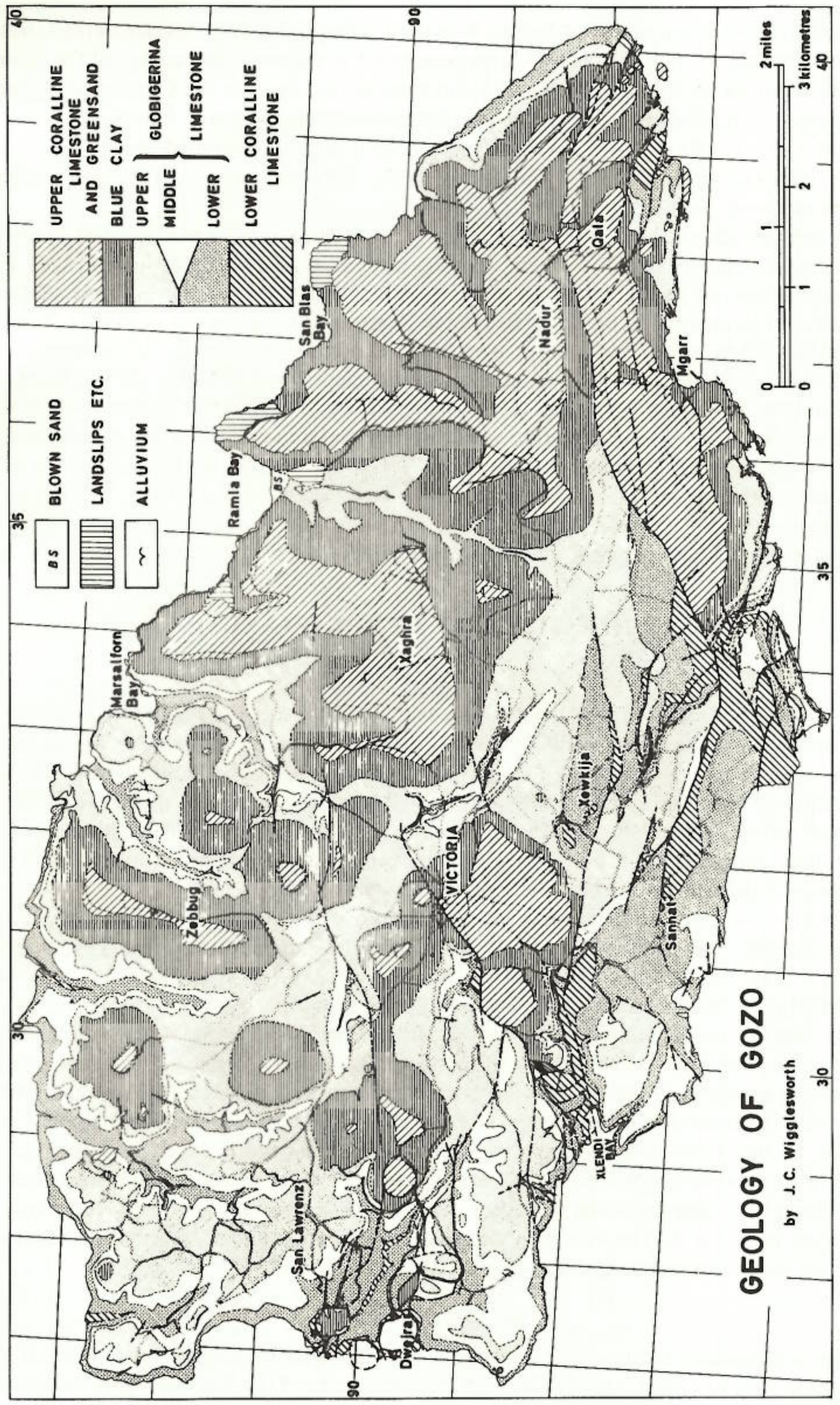

Fig. 1. Geology of Gozo, based on mapping on the scale of twenty-five inches to the mile, by J. C. Wigglesworth, with slight revisions

1879). Fuchs (1874) attempted correlations with the Vienna Basin and Davidson (1864) described the brachiopod faunas. In 1890, John Murray produced a review of the geology of the islands: he wrote with great authority on oceanic sedimentation, having been on the Challenger Expedition, and his interpretations demand respect even if they are often countered herein. Murray's work stimulated J. H. Cooke, a local resident, to produce a series of detailed studies on particular problems (Cooke, 1891; 1893; 1893a; 1896; 1896a; 1896b). Gregory (1891) described the celebrated echinoid fauna.

In this century advance has been slow. Hobbs (1914) interpreted and described many of the faults and structures and the Quaternary deposits were described by Trechmann (1938). Further studies were made on the echinoids (Stefanini, 1908; Wigglesworth, 1964; Zammit-Maempel, 1969; Rose, 1975), and on the bivalves (Roman & Roger, 1939; Eames & Cox, 1956). Substantial detailed information, particularly on the structure is contained in the study of water resources by Morris (1952) and Newbery (1968). General reviews include those of Rizzo (1932), Reed (1949), House, Dunham & Wigglesworth (1961), and especially Hyde (1955) and Vossmerbäumer (1972), but these were largely collative of earlier work. Substantial unpublished work is contained in the theses of Wigglesworth (1964) and Pedley (1975). The foraminiferal succession, and the designation and description of several stratigraphical units, were given by Felix (1973); in his work are given arguments for the correlation with the international stages adopted here (Table I). Evans (1971) has given a general review of Maltese prehistory.

3. STRATIGRAPHY OF THE ISLANDS

(a) General

Because of the simple structure of the Maltese Islands and the gentle regional dips to the strata the lithostratigraphy has been well known since the time of Spratt (1843). The current terminology applied to the individual formations originated from the detailed work of Murray (1890). Although Murray's lithostratigraphy is still generally accurate, recent work by Pedley (1975) has substantially improved the detailed understanding of both lithostratigraphy and palaeoecology, especially within the two Coralline Limestone formations. Spratt (1867) was the earliest worker to publish on the Quaternary geology.

Despite acceptance of lithostratigraphic subdivision of the sequence the biostratigraphy and chronostratigraphy has remained a subject for debate since the earliest times. This is primarily due to the isolated position of the archipelago. Fuchs (1874) first appreciated the mid-Tertiary age of the Maltese strata but this was followed by other comparisons by Gregory (1891), using echinoids. Bather (*in* Trechmann, 1938) established the occurrence of both Oligocene and Miocene strata, and House & others (1961) assigned the Lower Coralline Limestone and Lower *Globigerina* Limestone to the Aquitanian (following Eames & Cox (1956)) and the remaining *Globigerina* Limestone and Blue Clay to the Burdigalian and the Greensand and Upper Coralline Limestone to the Tortonian. In recent years foraminiferal studies have been used to aid in attempts at international correlation. Eames, Banner, Blow & Clarke (1962) provide one of the earliest attempts of note but more recently Felix (1973) has given a comprehensive scheme which is illustrated in Table I. The currently accepted stratigraphy and formation distributions are depicted on two accompanying maps (Figs. 1, 2).

(b) The succession

The entire sedimentary sequence of the islands is dominated by marine carbonates of shallow water aspect. They are most comparable with the carbonates of the Ragusa region of Sicily to the

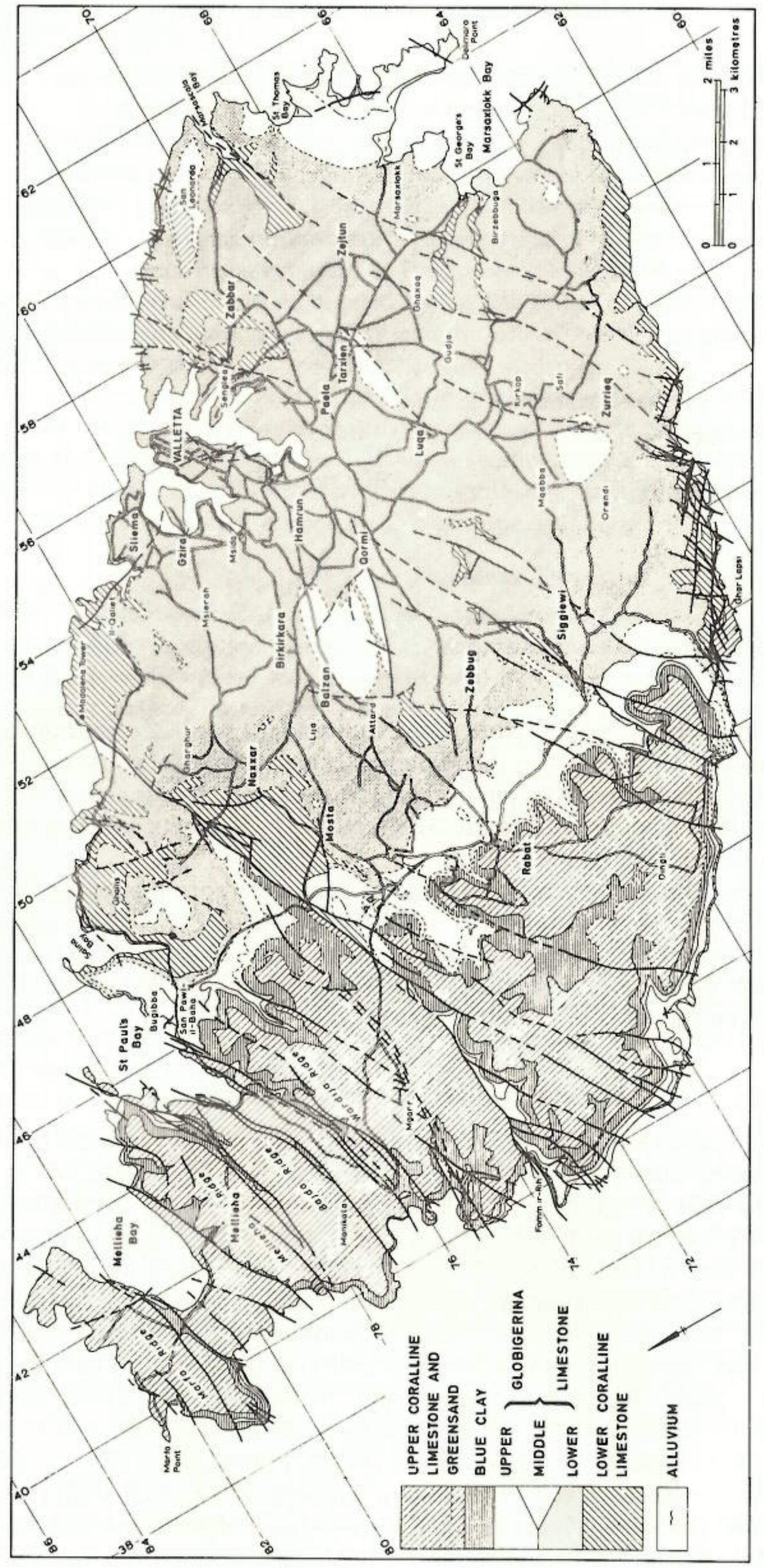

Fig. 2. Geology of Malta, based on mapping on the scale of six inches to the mile, by H. M. Pedley (northern and western Malta and some other areas), K. C. Dunham (around Rabbat and Attard), A. A. Wilson (around Masta, Gharghur and Birkirkara) and M. R. House (southern and south-eastern Malta)

Formation		Stage	
Upper Coralline Limestone		Tortonian	Miocene
Greensand		Serravallian	
Blue Clay			
Globigerina Limestone	Upper	Langhian	
	Phosphorite (C2)		
	Middle	Burdigalian	
	Phosphorite (C1)		
	Lower	Aquitanian	
Lower Coralline Limestone		Chattian	Oligocene

north, and the marine carbonates of the Sirte Basin, Libya, to the south. Recent continental plate margin studies of the region suggest that the Maltese archipelago lies a short distance behind the leading margin of the African plate. Geophysical data from Cooper, Harrison & Willmore (1952) further indicate that the islands are situated above a region of high gravity anomaly values, which are coincidental with the Ragusa–Malta Rise.

Information on pre-Miocene strata is restricted to data from a deep borehole put down by British Petroleum Co. Ltd. at Naxxar, Malta (Grid Reference 4974, Fig. 2). Approximately 3000 m of shallow water limestones, marls and dolomite were penetrated. Much of the strata were highly recrystallised; however, a Cretaceous age was obtained for the oldest strata in the borehole, primarily on the basis of contained spores.

(c) Lower Coralline Limestone Formation

This is the oldest formation visible on the Islands. Outcrops are mainly restricted to coastal sections along the western sides of Malta and Gozo. Vertical cliffs show up to 140 m of Lower Coralline Limestone near Xlendi, Gozo (1987) and somewhat less along the Maltese coastline between Fomm ir-Rih (4073) and Benghisa Point (5863). Inland outcrops are restricted to wied gorge sections, well seen in south-eastern Malta, or faulted inliers such as at Naxxar (5074).

The lowest horizons of the formation are well exposed in cliff-sections around Maghlak, Malta (4865), and consist of yellow biomicrites rich in benthonic foraminifera characterised by *Praerhapydionina* and *Austrotrillina*. Conformably overlying these massive beds are pale-grey, bedded coralline algal limestones, dominantly composed of *Lithothamnion* and *Archaeolithothamnion*. These beds are recognisable throughout both Malta and Gozo and are best seen in the quarries south of Attard, Malta (4972). Fossils, other than rhodolitic algal colonies, are locally abundant, especially in western outcrops where patch reefs are developed. These fossils include the corals *Tarbellastraea*, *Favites* and *Monastraea* and the molluscs *Lithophaga*, *Cardita*, *Natica* and *Strombus*.

Conditions unfavourable to rhodolitic growth occurred towards the top of the Lower Coralline Limestone and the upper 10 m of the formation are represented by coarse bioclastic limestones exhibiting extensive cross-bedding. The echinoid *Scutella subrotunda*, the most common fossil within this subdivision, frequently occurs in a bed towards the top of the succession (the 'Scutella bed' of Spratt (1843) and Roman & Roger (1939), and has been accepted as marking the top of the Lower Coralline Limestone Formation. In eastern areas of Malta the cross-bedded member is poorly developed, its place being occupied by finer grained biosparites and biomicrites containing an extensive foraminiferal fauna dominated by *Lepidocyclina dilatata* and *Heterostegina*. The echinoids *Echinolampas* and *Cidaris* commonly occur, as do pectinids, the brachiopod *Terebratula minor* and abundant bryozoans.

Deposition of the Lower Coralline Limestone appears to have initially been in a shallow gulf-type area (Felix, 1973). Succeeding beds provide evidence of increasingly open marine conditions during which algal rhodolites developed. Finally a shallow marine shoal environment succeeded as the dominant environment in all areas except south-eastern Malta. In this area calmer conditions prevailed in a protected deeper water environment.

(d) *Globigerina* Limestone Formation

The *Globigerina* Limestone Formation is so named on account of the high percentage of planktonic foraminifera comprising the rock. Outcrops of this formation cover the greatest surface area of the Islands but are frequently obscured by housing and agricultural development, which are greatest on these limestones. The most accessible sections in Malta are along the Qammieh coastline (3981) and in Gozo the formation is well exposed in the wied gorges around San Lawrenz (2690). The formation shows marked thickness variations ranging from 23 m near Fort Chambrey, Gozo (3686), to about 207 m around Marsaxlokk, Malta (5965). A thick succession is also developed in the Valletta Basin (Fig. 3). The usual colour of the formation is pale-yellow, although a pale-grey subdivision, bounded both above and below by phosphorite conglomerate horizons, occurs in the middle of the sequence. This formation provides most of the Maltese building stone or 'Franka'.

Lower Globigerina Limestone. Typical samples from this lowest subdivision consist of pale-yellow, massive bedded, globigerinid biomicrites. Selective intra-burrow cementation, together with preferential erosion of the surrounding softer sediment, is responsible for the characteristic honeycomb weathering of the unit.

The maximum thickness of this division probably exceeds 100 m in the Valletta Basin of Malta but on Gozo thicknesses do not exceed 40 m. Isopachyte studies (Pedley, 1975) suggest that the unit may thin out completely in north-western Malta (4078) (Fig. 3). Fossils within these sediments are locally abundant and include the echinoids *Schizaster parkinsoni* and *Eupatagus*. Molluscs such as *Chlamys* and *Flabellipecten* occur and the pteropod *Cavolina* is abundant.

The upper limit of the Lower Globigerina Limestone is taken as the planar top of the lower main conglomerate bed (C1), which caps the unit. This bed averages less than 1 m in thickness and overlies a hard ground carrying extensive pebble-filled thalassinoidean burrow systems. Secondary phosphate-rich solutions have further cemented this conglomerate into a resistant horizon which weathers into a characteristic flat bench at outcrop, well seen at Qammieh, Malta (3980). The phosphorite conglomerate bed contains many derived mollusc and coral casts, together with the teeth of shark such as *Carcharodon megalodon*, *Isurus* and *Odontaspis*. The *in situ* fauna is restricted to *Chlamys* and the echinoids *Eupatagus* and *Spatangus*.

Middle Globigerina Limestone. This unit commences immediately above the eroded upper surface of the phosphorite conglomerate. Typical strata consist of pale-grey globigerinid biomicrites,

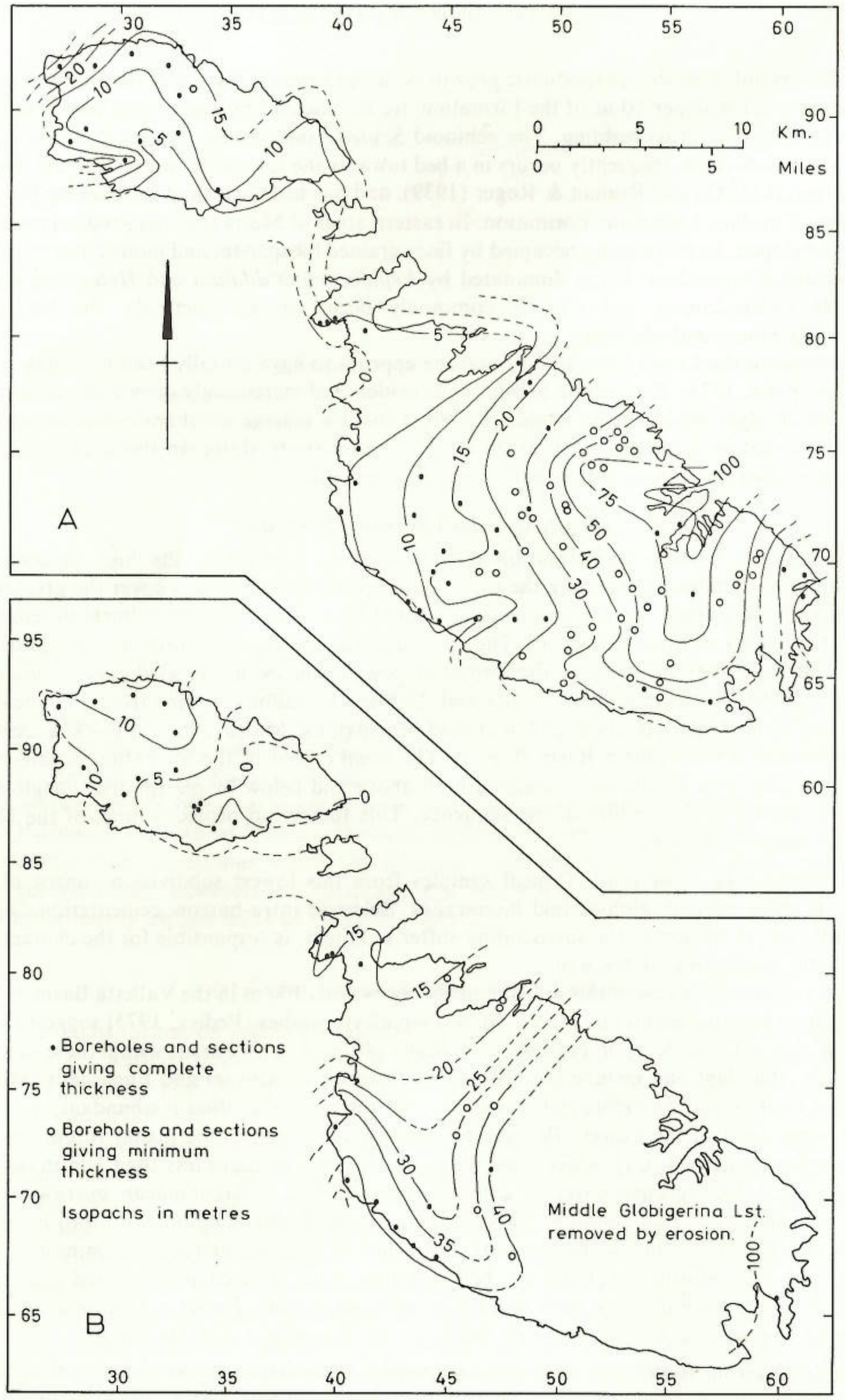

Fig. 3. Isopachyte maps for (A) the Lower *Globigerina* Limestone and (B) Middle *Globigerina* Limetone of Gozo and Malta, based on borehole evidence and sections measured by J. C. Wigglesworth (Gozo) and H. M. Pedley (Malta)

although a pale-yellow basal division is seen in western areas, especially at the top of the sequence in western Gozo (Wigglesworth, 1964). Regional thickness variations are similar to those of the Lower *Globigerina* Limestone but are more difficult to define as post-Miocene erosion has removed much of the strata from central Malta (Fig. 3). In eastern Gozo the Middle *Globigerina* Limestone is missing (Wigglesworth, 1964) except for the upper phosphorite conglomerate bed. Thicknesses up to 15 m occur in western Gozo and Malta, the regional trend showing thickening towards a maximum of 110 m near Delimara Point, Malta (5965). Eastwards from this point the beds are progressively cut out beneath the Upper Coralline Limestone unconformity seen at San Leonardo (5970).

The fauna of these beds is locally abundant and similar to that of the Lower *Globigerina* Limestone. The echinoids *Schizaster eurynotus* and *Brissopsis* are particularly common as are the bivalves *Chlamys* and *Flabellipecten*. Thalassinoidean burrow systems are also prominently developed. The contained vertebrate remains are of special interest and include the crocodile *Tomistoma*, the turtle *Trionyx* and the seal *Phoca*.

Overlying these biomicrites is the upper main conglomerate bed (C2). This is present throughout Malta and Gozo and consists of about 0.5 m of phosphorite pebbles with additional derived, phosphatised casts of the corals *Flabellum foecundum* and caryophyllids, together with phosphatised mollusc casts including *Conus* and *Xenophoria*. Shark teeth including *Lamna*, *Carcharodon megalodon*, *Odontaspis* and *Hemipristis* also occur. The *in situ* fauna mainly comprises the echinoids *Hemiaster* and *Echinolampas*.

Several smaller and less persistent phosphorite horizons occur within the pale-grey biomicrites south of Fomm ir-Rih, Malta. A distinctive nodular khaki chert may also be mapped locally in the same area (House & others, 1961).

Upper Globigerina Limestone. The tripartite nature of this unit, first recognised by Morris (1952), consists of an upper and lower division of pale-yellow globigerinid biomicrites which are separated by a pale-grey marly biomicrite. In eastern Gozo, Delimara, Malta (6064), and the eastern end of the Mellieha Ridge, Malta (4580), the unit attains a thickness of slightly more than 20 m. Isopachyte studies indicate a regional thinning to less than 1 m in a south-westerly direction on Gozo and a possible area of non-deposition in central-eastern Malta.

The fauna is sparse and is generally restricted to occasional pectinid valves, the echinoid *Schizaster* and the gastropod *Epitonium*. *Vaginella*, a pteropod, occurs abundantly in the upper yellow limestone.

Felix (1973) considers that most of the *Globigerina* Limestones were deposited in water depths of 40–150 m. The sudden occurrence of the planktonic foraminifera, such as *Globigerina*, in this shallow-water depositional environment may be explained most readily if it is assumed that these organisms had drifted on to a rise-like area from the surrounding deeper water seas.

(e) Blue Clay Formation

A rapid transitional change, from globigerinid biomicrites to globigerinid marls, occurs over about 1 m at the base of the Blue Clay Formation. This formation never contains more than 30 per cent carbonate material (Murray, 1890). Outcrops occur throughout Gozo and Malta and possibly also at the base of the cliffs on the island of Filfla, off the western coast of Malta. Typically the formation consists of an alternation of pale-grey and dark-grey banding, which corresponds with greater or lesser proportions of contained carbonate. This is usually in the form of foraminifer tests. Towards the Comino Straits the upper part of the formation lacks the paler beds and yields abundant fossiliferous goethite concretions. The maximum recorded formation thickness is 65 m in north-east Gozo and western Malta north of Fomm ir-Rih (4073). The thinnest recorded thicknesses of under 20 m occur south of Kercem, Gozo (3088), and south of Rabat, Malta (4571). The Comino Straits depositional high, recorded in the *Globigerina* Limestone Formation, is again still apparent in the distribution of this unit.

Although common, most fossils are restricted to microfauna or crushed specimens of macrofauna, except in the upper horizons of the Blue Clay around northern Malta and southern Gozo. In this region goethite impregnated specimens of the corals *Balanophyllia*, *Flabellum* and *Stephanophyllia* are common, as are the molluscs *Aturia aturi*, *Sepia*, *Flabellipecten*, *Chlamys* and indeterminate gastropods. The echinoid *Schizaster* and the pteropod *Vaginella* also occur. Vertebrate remains are invariably disarticulated and consist of fragments and centrae of *Phoca*, Cetacea and dugongs.

An open muddy marine environment is envisaged with water depths up to 150 m for the lowest part of the formation. Shallowing probably occurred in the upper parts of the unit to depths less than 100 m.

(f) Greensand Formation

The Greensand Formation is composed of a variable thickness of bioclastic, glauconitic limestones which are very poorly cemented. In fresh sections the formation appears as a greyish rock containing abundant black or dark-green glauconite grains. Weathering leads to the release of iron oxides from the breakdown of the glauconite and imparts an orange-brown colour to the formation. The transitional change upwards from the Blue Clay is frequently sharp, particularly in western areas of the islands, but in eastern parts assimilation of the top of the Greensand into the base of the overlying Upper Coralline Limestone, as a result of bioturbation, has produced the effect of a gradual change in sedimentation.

At Il Gelmus, Gozo (3189), the formation attains its thickest development of 11 m, in a local basinal structure. In a second structure to the north of Il Gelmus 7 m is recorded. Throughout the rest of Gozo and Malta the formation is rarely thicker than one metre.

The formation largely consists of transported material which also includes most of the glauconite grains and derived fossil casts such as *Conus*. An extensive fauna occurs within the Il Gelmus depression and consists of the bivalves *Chlamys*, *Ostrea*, *Glycimeris*, *Thracaea* and *Cardium*, and the echinoids *Clypeaster altus*, *C. marginatus* and *Echinolampas pignatarii*. Other areas of Greensand outcrop yield vertebrate fragments of sharks, Cetacea and smaller marine mammals. The foraminifer *Heterostegina* is common in western areas. The intense bioturbation associated with these deposits suggests deposition under shallow water marine conditions. Much of the sediment was transported into the area from areas of erosion outside the present confines of the islands.

(g) Upper Coralline Limestone Formation

This formation is similar in many respects to the Lower Coralline Limestone Formation, especially in colour and coralline algal content. It is a durable sequence, frequently weathering into steep cliffs and bearing and well-developed karst topography. Outcrops occur on all the islands of the Maltese archipelago but the highly variable nature of the complex facies confuses correlation. At least 160 m is preserved in the Bingemma area, Malta (4374). The lithological sequence is broadly divided into three divisions.

The lowest division is composed of a complex association of distinct, but laterally equivalent, facies. In Gozo, the most westerly facies consists of brownish micrites containing abundant *Heterostegina* which pass eastwards into coarser-grained lithoclast biosparites containing the

bivalve *Chlamys*, the echinoids *Clypeaster altus* and *Echinolampas* and large colonies of the bryo zoan *Cellepora*. A widespread north–south trending coralline algal rhodolite bioherm lies to the east of the previous facies and extends throughout eastern Gozo and western Malta. A richly diverse fauna and flora exists within the facies and includes the coralline alga *Lithophyllum*; encrusting bryozoans, brachiopods such as *Terebratula*, *Aphalesia*, *Megathiris*, *Argyrotheca* and *Mergerlia;* abundant bivalves and echinoids. The most easterly facies of the islands consists of a fine-grained, yellow biomicrite development with a rich echinoid-bivalve fauna dominated by *Schizaster eurynotus* and *Chlamys scrabella*.

The subdivision as a whole shows evidence of increasing turbulence from west to east, culminating in shoal area development of lithoclast biosparites. The coralline algal bioherm represents a slightly quieter area with a stable bottom environment. The eastern yellow biomicrite facies apparently lay on the sheltered leeward side of the bioherm, on the margins of an open shelf environment.

The overlying subdivision is composed of coarser grained bioclastic and oolitic limestones. They are again rich in coralline algae, but also show an additional development of patch reefs in western areas of the Islands. The diverse faunas of these reefs include the bivalves *Lithophaga*, *Gastrochaena*, *Chama*, *Glycimeris* and *Cardita*; gastropods such as *Turritella* and *Strombus* and the corals *Tarbellastraea*, *Acropora* and *Diploastraea*. To the east of these beds, in Comino and north-western Malta, large-scale easterly dipping cross-bedded limestones were deposited in a local tidal delta sequence occurring on the leeward side of the patch reef area.

The highest group of strata is only locally preserved, being extensively found in north-western Malta, and the Bingemma-Fomm ir-Rih areas of western Malta. Cross-bedded, oolitic, pelletoidal and bioclastic limestones, showing ripple-marks and festoon-bedding, are locally important. Although most of these deposits represent shallow subtidal sedimentation, the apparent reduction of microfossil numbers and absence of macrofauna from the highest beds may indicate that intertidal and even supratidal beds are developed. The occurrence of at least one stromatolite horizon supports this view. A peculiar feature of the Oligo–Miocene sedimentation is the development of syndepositional solution subsidence structures, well seen in Gozo (Pedley, 1974).

(h) Quaternary deposits

The sedimentology of these discontinuous deposits is poorly known. They occur as cavern and fissure infillings and thin hillside veneers of calcreted material. A lacustrine deposit consisting of tufa and leaf beds occurs in the Fiddien valley, Malta, near Ghemmieri Bridge (4471). Several episodes of deposition have been recognised in the past and are commented on by Trechmann (1938). Some are characterised by distinctive vertebrate assemblages.

The earliest Pleistocene bone deposits occur in several cave deposits and surface depressions and are typified by the Ghar Dalam cave sequence of Malta. Within these beds occur prolific remains of hippopotami, pygmy elephants and swans. Deer and horse occur in slightly younger deposits. Many fissure deposits in Malta contain faunas of land-snails, deer and remains of the giant dormouse. All these remains suggest that climatic conditions were more temperate than today, with perennial stream-systems and abundant vegetation. It is likely that land connections with Sicily occurred at this time.

The youngest deposits of the islands consist of alluvial fan deposits, caliche soil profiles and calcreted breccias, all of which are stained red by iron oxidation. The first two developments are well seen at Wied Maghlak, Malta (4865), at the foot of the Maghlak fault-scarp. Over 8 m of fanglomerate, and caliche soil horizons, sometimes containing root casts, occur here. Similar fan deposits occur in the Pwales Valley, Malta (4577), near San Pawl il-Bahar. Many of these late deposits contain the remains of land-snails, the deposit at Marfa Point (3982) being noted by Cooke (1896b) in this context. Several raised beaches hold witness to recent land movements within the Islands. Perhaps the best developed occurs about 20 m above sea-level at Ta L-Imgharrqa, Malta (4281). It consists of a wedge of cross-bedded biosparite resting on an eroded *Globigerina* Limestone surface.

4. STRUCTURAL GEOLOGY OF THE ISLANDS

(a) Introduction

The earliest attempts at defining the structural geology of the Maltese Islands were presented in the form of small-scale geological maps, the most notable of which are those prepared by Earl Ducie in 1854 and attached to the publication of Adams (1870), and the more detailed 2 miles to 1 inch map of Murray (1890). Although only the general details are apparent, the latter author named the Maghlak and Grand Faults of Malta and the Grand Fault of Gozo. Several 'circular faults', now known to be associated with solution subsidence structures, were also recorded by Murray (1890).

Hobbs (1914) conducted a detailed tectonic study of the islands, recognising the controlling effects that faulting had on the coastal form. A study of the Grand Fault of Malta by Rizzo is included by Hobbs, and clearly demonstrates that many of the larger faults are composed of a number of zig-zag components, rather than being curved single fractures, Trechmann (1938), in considering the age of the faulting, concluded that the Maghlak Fault along the southern coast of Malta had moved during the Quaternary.

As part of a general survey of the islands' water resources, Morris (1952) accurately located many of the faults, and produced a structure contour map of the central Malta area, north of the Victoria Lines Fault (the Grand Fault of previous authors). This work also includes much valuable borehole and other structural data. In 1955 the British Petroleum Company Ltd. published detailed geological maps of Malta and Gozo on a scale of 2 inches to 1 mile, on which the major fault configuration is clearly depicted. House & others (1961) provide a concise account of the geological structure of the islands, whilst Wigglesworth (1964) and Pedley (1975) have produced structure contour maps of Gozo and Malta, respectively (Fig. 4). Vossmerbäumer (1972) has also analysed the fault and joint patterns of the islands.

The limited stratal succession exposed on the Maltese Islands bears witness to the essential simplicity of the structure. The rocks are affected by very gentle folds, but they are also riven by normal faults of varying magnitude which have a pronounced effect on the islands' topography. An apparent conjugate fault pattern can be recognised (Figs. 1 & 2). Basically, faults trending east-north-east predominate, whilst the north-west trending coasts of north-east and south-west Malta are bounded by major faults of the second component. Only the Maghlak Fault at Ghar Lapsi (4865) illustrates the north-west trending faults well.

It is convenient to review the structure by dividing the islands into three main regions:

(b) Malta, north of the Victoria Lines Fault

The Victoria Lines Fault, which crosses the island from Fomm-ir-Rih (4073) to near Madalena Tower (5276), forms a bold fault scarp which is the most striking topographic feature of the island. The maximum effect of the fault can be seen in central areas where the Upper Coralline Limestone on the northern downthrown side of the fault is brought into juxtaposition with the Lower Coralline Limestone (Fig. 2). Throws along the fault vary from about 200 m near the Bingemma Syncline (4473) (Morris, 1952) in the west, to about 100 m in the east near Madalena Tower.

North of the Victoria Lines Fault the structure is dominated by the development of horst and graben blocks, bounded by parallel east-north-east trending normal faults. Such structures are indicated by prominent ridges and valleys, the main units being, from north to south: Marfa Ridge, Mellieha Valley, Mellieha Ridge, Mizieb Valley, Bajda Ridge, Pwales Valley, Wardija Ridge and Bingemma Valley. The island of Comino probably represents the exposed part of an otherwise submerged graben to the north of the Marfa Ridge.

For the most part the faults exhibit throws varying from 10 m to over 100 m, values diminishing eastwards (House & others, 1961). These serve to depress the top of the Lower Coralline Limestone below sea-level for much of this region (Fig. 4). However, in the Ghallis area (4977), to the east of the major dislocations, the Lower Coralline Limestone lies up to 50 m above sea-level, and is associated with a broad culmination, the Ghallis Dome. Minor north–south faults are also associated with this structure.

Apart from a broad shallow culmination centred on (4476), the remaining folds of any consequence are the synclinal structures mapped by Morris (1952) occurring on the downthrow side of the Victoria Lines Fault and the Mizieb Fault (4078 to 4278). The largest is the Bingemma Syncline (4473), associated with the former fault, in which the top of the lower Coralline Limestone is depressed an estimated 120 m below sea-level (Fig. 4).

(c) Malta, south of the Victoria Lines Fault

South of the Victoria Lines Fault a different structural pattern is apparent, in that the horst and graben structures are absent. Further, although normal faults are numerous, the dominant fault trend is north-easterly and with throws invariably less than 20 m, rapidly diminishing eastwards.

In the north-western area of the Rabat Plateau (4071), the faulting is closely associated with the Victoria Lines Fault and all fractures ultimately merge with that fault in an easterly direction. Farther south at Rdum Dikkiena (4566) a second group of normal faults extends north-eastwards into central Malta, whilst faults associated with the Zurrieq–Marsascala system (5265 to 6068) cross the entire width of southern Malta.

Although it is usually considered that the fault pattern of the Maltese Islands constitutes a conjugate system, it is only in southern Malta where the second, north-westerly trending, set is evident. Here, at Ghar Lapsi (4865), the Maghlak Fault, with its smooth, slickensided, seaward facing fault-plane running parallel to the coast, downthrows the Upper Coralline Limestone to the south by at least 230 m, the downfaulted strata being inclined at a high angle. As is common with many of the larger Maltese faults, the Maghlak Fault is not a single fracture but consists, in part, of two closely spaced parallel faults. The result of this is that at several localities along the fault complex, particularly where the Lower and Upper Coralline Limestones are in juxtaposition, slivers of *Globigerina* Limestone and Blue Clay are caught up between the two fault walls. A similar situation can be seen at Fomm-ir-Rih (4073), at the western end of the Victoria Lines Fault, and in the Qammieh Fault (4080) of northern Malta. To the east of the spectacular cliffs formed by the Maghlak Fault, a series of parallel subsidiary fractures occur which increase in effect towards the south-east. Illies (1969) believes that the Maghlak Fault represents part of the northern limb of a complex intercontinental graben, extending from the Rhine Graben in Germany to the Hon Graben in Libya.

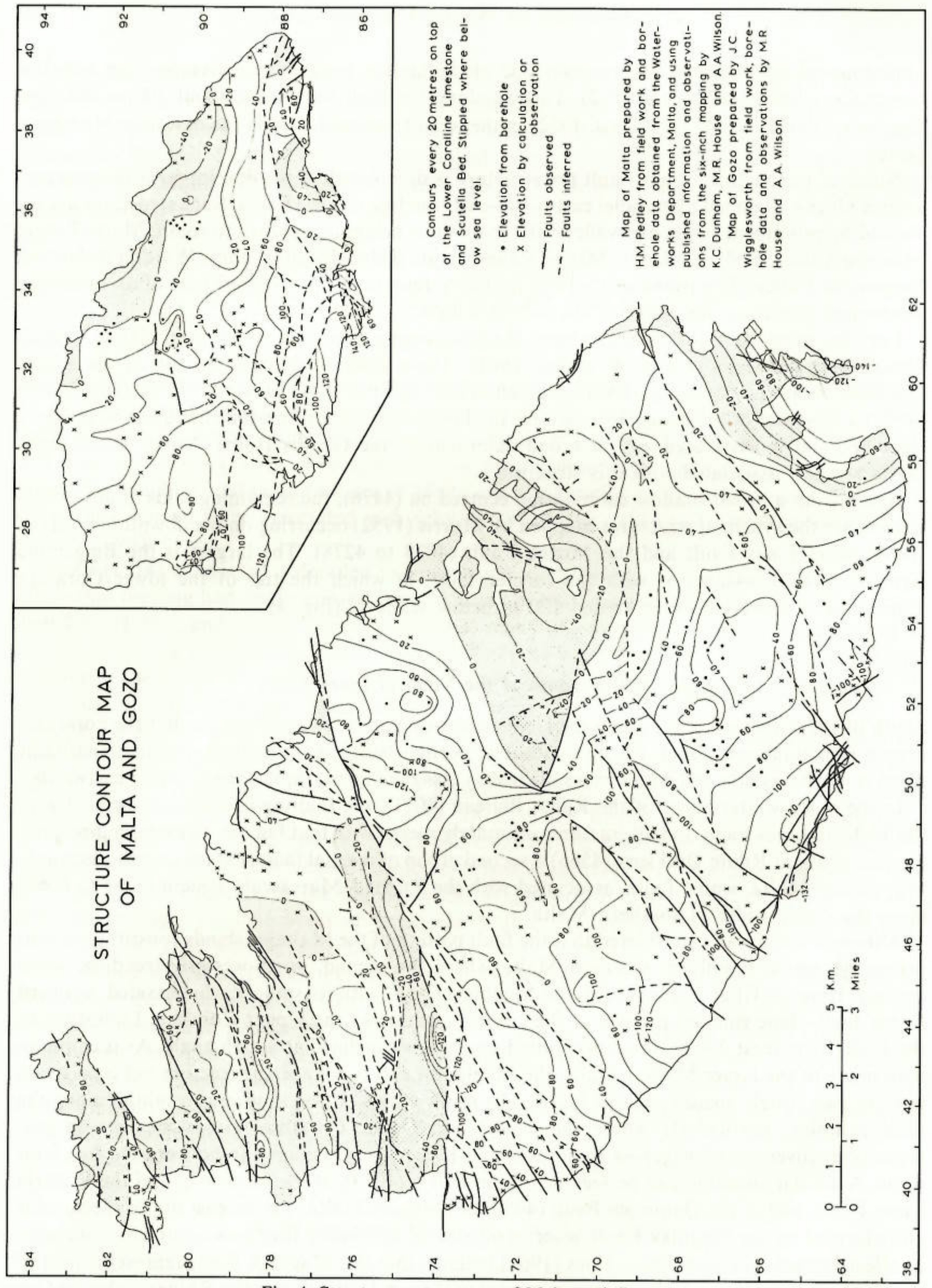

Fig. 4. Structure contour map of Malta and Gozo

The only other north-westerly trending fault is the minor development along the San Leonardo coastline of eastern Malta (6070), but, as indicated earlier, it is possible that the north-west trending coastlines of Malta are bounded by faults of this set.

Apart from faulting, large-scale gentle folding is an important structural feature of central and south Malta. House & others (1961) confirmed the observation of E. B. Bailey that a major structural high passes southwards from the Victoria Lines Fault to Ghar Lapsi. In effect there are several culminations, the largest of which, the Naxxar Dome of eastern Malta, has a main culmination at (4975) with a subsidiary closure at (5274). This structure brings the top of the Lower Coralline Limestone to 120 m above sea-level (Fig. 4). Smaller culminations bring the Lower Coralline Limestone to 80 m and 120 m above sea-level near Zebbug (4970) and east of Ghar Lapsi (4865), respectively. In other regions folding is very gentle and is usually affected by faulting, this being well seen north of Zabbar (5771), where a culmination, abruptly truncated by the Conspicua Fault, brings the top of the Lower Coralline Limestone up to 50 m above sea-level.

At Marsa Creek (5570), around the Grand Harbour of Valletta, a major basinal depression results in the Lower Coralline Limestone being 40 m below sea-level, whilst in a second depression, centred on Delimara Peninsula (6064), the limestone shelves south-eastwards to 130 m below sea-level, extending seawards to unknown depths (Fig. 4).

(d) Gozo

The island of Gozo is characterised by a gentle regional dip to the north-east. Consequently, the Lower Coralline Limestone, which forms vertical cliffs over 120 m in height along the south-western coast, is depressed to over 20 m below sea-level on the northern coast between Marsalforn (3392) and San Blas Bay (3390) (Figs. 1 & 4). This somewhat simple structural style typifies northern parts of Gozo, but south of a line from San Lawrenz (2890) to Qala Point (4087) the structure is more complex. To the west, at Qawra (2790), Dwejra (2789) and Xlendi (2987), three solution subsidence structures with their characteristic circular faults (Pedley, 1974) are associated with east–west trending normal faults, extending eastwards as far as the Victoria–Xewkija region (Fig. 1). Centred on Mgarr ix-Xini (3486) are the two largest faults on Gozo, the Sannat and Qala Faults. The former, extending west-north-west from Mgarr ix-Xini, brings the Lower Coralline Limestone into juxtaposition with the *Globigerina* Limestone on the northern downthrown side of the fault. The ix-Xini–Qala Fault has a north-easterly trend and with a maximum throw to the south of approximately 120 m just to the south of Nadur (3688), this value diminishing both to the east and west. Along the length of this fault the Upper Coralline Limestone on the southern downthrow side successively abuts strata ranging from the Lower Coralline Limestone to the Blue Clay. South of the Sannat-Qala Fault system numerous small faults cut the southern coast, and local flexuring depresses the top of the Lower Coralline Limestone below sea-level at Mgarr (3787) and Qala Point (4087) (Fig. 4).

(e) Age of the tectonic features

The major faults all cut the entire Oligo-Miocene succession, and there is considerable evidence that movement has been continuous since Miocene times. Many of the faults exhibit fresh fault-scarp faces, with mullion-style slickensiding and negligible scarp recession, clearly suggesting that the faulting must in part be quite recent. Trechmann (1938) certainly believed that the Maghlak Fault had moved during the Quaternary, and Pedley (1974) has demonstrated that the solution subsidence structures of the islands, with the characteristic 'circular faults', have been activated at a number of periods since their initiation during the Miocene. More general regional movements in post-Quaternary times have resulted in the development of localised raised beaches, the submergence of Neolithic cart-tracks which enter the sea at St. George's Bay, St. Paul's Bay and Birzebbuga (5765) (Hyde, 1955), and the presence of stalagmites below the breakwater foundations of Valletta Harbour (Rizzo, 1932). Hyde (1955) also records earthquakes in the region occurring intermittently since 1659 to 1856; another was recorded in March 1972.

ACKNOWLEDGMENTS

This work on the geology of the Maltese Islands had its origins when in 1955 a party from Durham University mapped part of the islands on behalf of D'Arcy Exploration Co. Ltd. Parts of the geological maps and isopachytes published here date from then. We are indebted to the British Petroleum Co. Ltd., and to Sir Kingsley Dunham and Dr. A. A. Wilson, for permission to publish some of this work. Dr. J. C. Wigglesworth has allowed publication of his geological map of Gozo and the structure contour maps and isopachytes are partly his, but revisionary and new mapping has been done in all parts of both Malta and Gozo (by M. R. House and H. M. Pedley) (Figs. 1 & 2). One of us (H.M.P.) has completed an extended work on the formations (Pedley, 1975) and written the section on stratigraphy; the structural section was written by B.W. and the remainder by M.R.H. We have appreciated especially the continued interest and help of Dr. G. Zammit-Maempel on all matters relating to the geology of the islands. We thank Mr. P. McSherry and Mr. J. Garner, University of Hull, for preparing most of the illustrations.

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Easter Field Meeting to the Maltese Islands

7–14 April 1974

Report by the Directors: H. M. PEDLEY and B. WAUGH

PEDLEY, H. M. & B. WAUGH. 1976. Easter Field Meeting to the Maltese Islands, 7–14 April 1974. *Proc. Geol. Ass.*, **87** (3), 343–358. The report records an itinerary for a one week Field Meeting to the islands of Malta and Gozo. The objectives of the meeting were to examine the Oligo–Miocene succession of carbonate sediments occurring on the islands, the study of their prolific faunas, to deduce the palaeoenvironments of the varying facies types within the Tertiary formations and to demonstrate the geological structure of the region. One day was devoted to an examination of the Miocene solution subsidence structures on Gozo.

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INTRODUCTION

The Maltese Islands are composed of mid/Tertiary limestones and associated marls occurring in a simple succession formed of the following formations: Lower Coralline Limestone Formation (over 140 m); *Globigerina* Limestone Formation (23–207 m); Blue Clay Formation (0–65 m); Greensand Formation (0–11 m); Upper Coralline Limestone Formation (up to 162 m). Although precise correlation is still the subject of discussion, Felix (1973) regards the Lower Coralline Limestone as of Upper Oligocene (Chattian) age, the overlying formations being of Lower and Middle Miocene (Aquitanian to Tortonian) age.

The purpose of the Field Meeting was to demonstrate the full stratigraphic succession, the varying facies and faunas and the geological structure of the Oligo–Miocene rocks of Malta and Gozo. A detailed review of Maltese geology is presented in the preceding paper of the *Proceedings* by Pedley, House & Waugh (1976), and includes a comprehensive bibliography. Pedley (1974) has also described and discussed the origin of the Miocene solution subsidence structures of the islands, these being the subject of one of the day excursions to Gozo.

It is important to note that the Maltese Government has banned the collection and export of fossils and antiquities from the Maltese Islands.

The grid references used throughout the following account refer to the 2 inch to 1 mile survey map of Malta, Gozo and Comino published by Allied Malta Newspapers Limited.

Sunday, 7 April

Twenty-six members of the Association, including the President, Professor D. V. Ager, left Heathrow Airport on a mid-morning British Airways flight to Malta. On approaching Luqa Airport magnificent aerial views of the Maltese Islands were seen. The party was met on arrival by the local secretary, Dr. George Zammit-Maempel, a medical practitioner resident at Birkirkara, Malta. During the course of the meeting, Dr. Zammit-Maempel was a constant source of information on both the geology and history of the islands, and the instigator for obtaining free passes for the party to several museums and archaeological sites. Indeed, his assistance throughout, both geologically and socially, contributed much to the success of the meeting.

Transport had been arranged to take the party to the Hotel Metropole, Sliema, the headquarters of the Field Meeting, and members spent the remaining part of the day enjoying the Mediterranean sunshine and exploring Sliema.

Monday, 8 April

After a free morning to enable members to cash travellers' cheques and make various purchases, the coach, hired for the duration of the meeting, transported the party to Rdum il-Qammieh

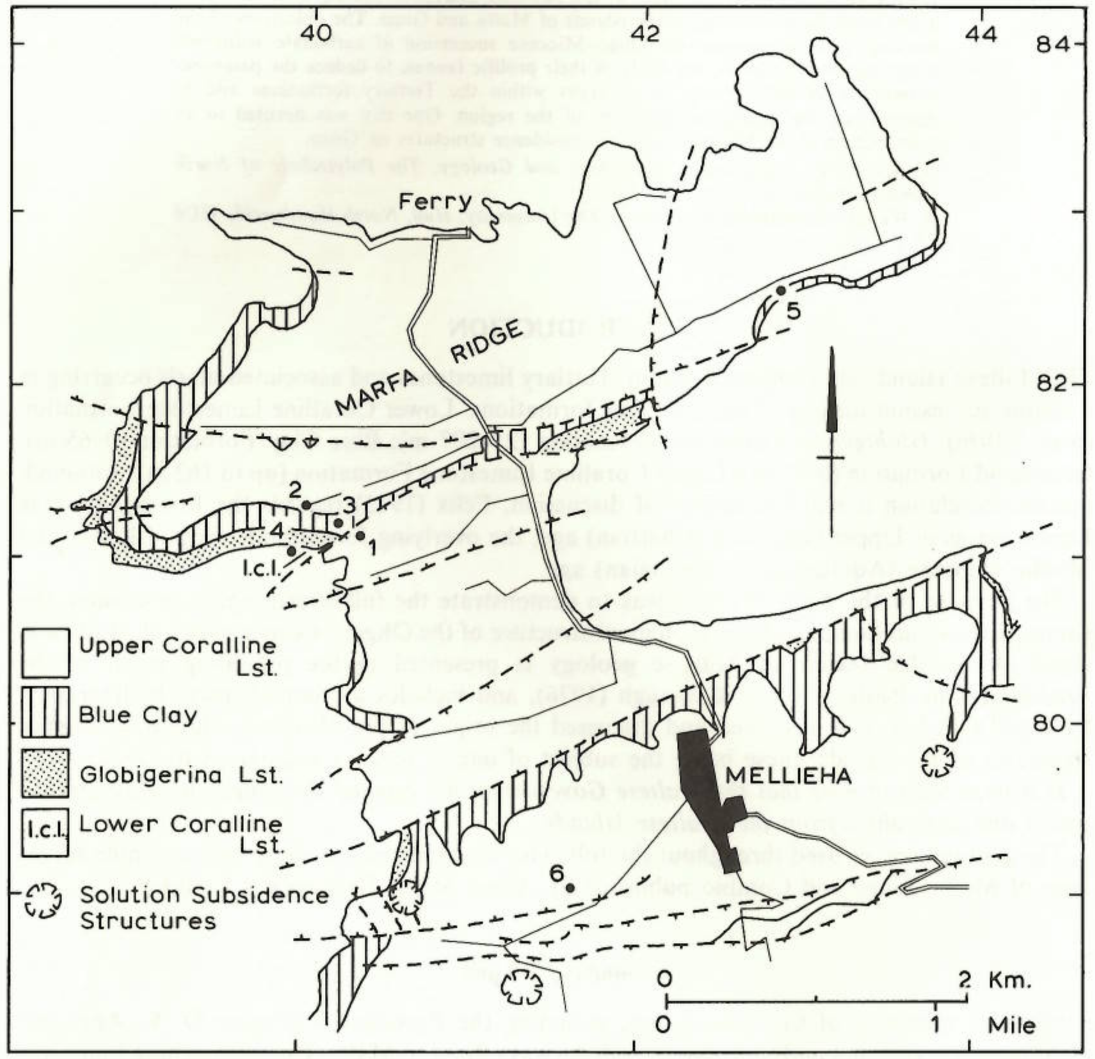

Fig. 1. Geological map of the Marfa Ridge region of north-west Malta. Locality numbers 1–4 refer to the itinerary to Rdum il-Qammieh, details of which are given in Fig. 2. Locality numbers 5–6 are for the itinerary of 12 April

(401811), on the south coast of the Marfa Ridge, north-west Malta (Fig. 1). Dr. Pedley gave a brief outline introduction to Maltese geology, stating that the well-exposed sections around Rdum provide one of the most complete successions seen on the islands, each of the Oligo–Miocene formations being exposed, at least in part. The itinerary followed during the afternoon descended the stratigraphic succession from the upper part of the Upper Coralline Limestone.

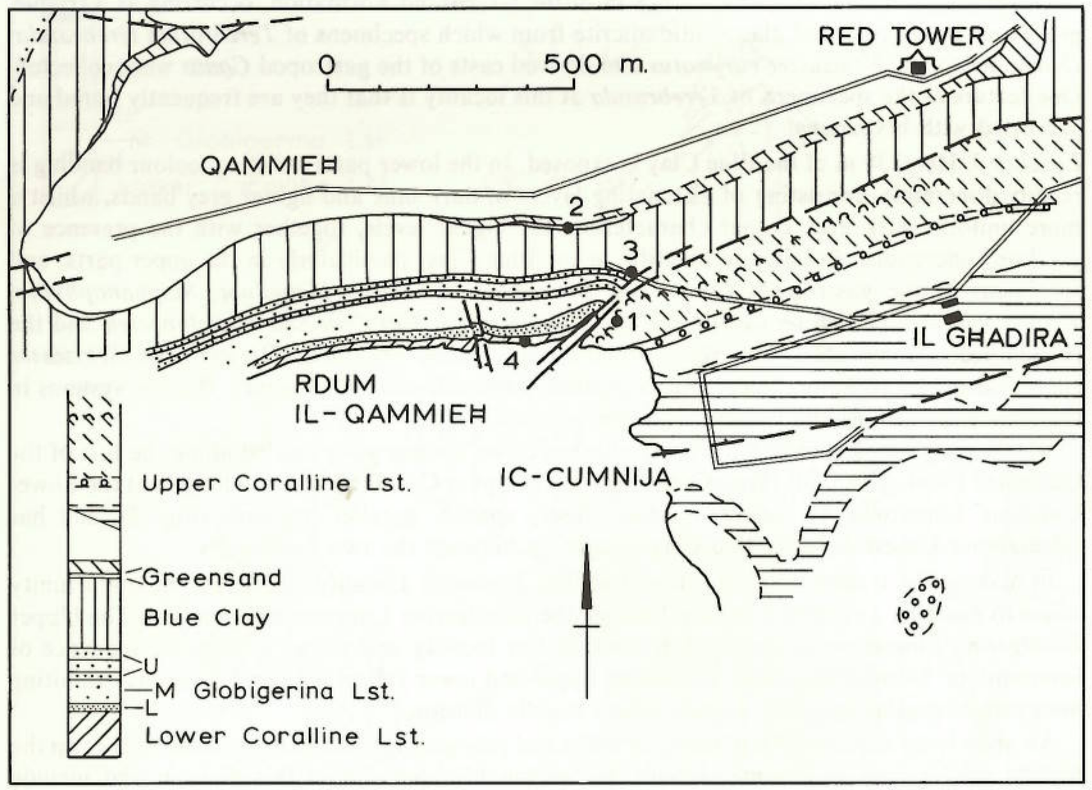

Fig. 2. Geological map of the region around Rdum il-Qammieh, south-west Marfa Ridge

Locality 1 (Fig. 1 with detail in Fig. 2). Strata immediately to the east of the Qammieh Fault expose the upper parts of the Upper Coralline Limestone. The limestone here is extremely fine grained and largely unfossiliferous, although a thin layer showing algal stromatolites is well developed. The algal growth form exhibited is that of the spaced, laterally linked hemispheroids, typical of the inter-tidal zones of modern carbonate mudflat environments. Although not clearly seen at this locality, in many areas of western Malta these limestones are underlain by cross-laminated oolites and pellet limestones, clearly suggesting an association of shallow water lagoonal environments with marginal inter-tidal carbonate mudflats.

Locality 2. In the prominent crags towards the top of the section, approximately 6 m of strata belonging to the lower part of the Upper Coralline Limestone are exposed, in which two distinct lithologies can be recognised. The lower unit is composed of pale yellow to cream coloured biomicrites containing abundant elliptical and spherical rhodolites of the coralline alga *Lithophyllum*. The size of individual rhodolites ranges up to 150 mm in diameter, although, frequently, groups of rhodolites are united to form much larger masses. The algae are often encrusted with bryozoans. This particular facies is interpreted as a coralline algal bioherm, and extends in a narrow, linear belt down the western side of Malta and into eastern Gozo, separating moderate energy, marine basinal carbonates to the west from sheltered shelf carbonates to the east.

Overlying the coralline algal bioherm the limestones are recrystallised, pale grey biosparites containing only a few *Lithophyllum* rhodolites, and occasional specimens of the echinoid *Clypeaster altus*.

Underlying the algal limestone is 1·1 m of the Greensand Formation, occurring as a friable, green and brown coloured glauconitic micrite from which specimens of *Terebratula terebratula*, *Ostrea virleti* and *Schizaster eurynotus* and derived casts of the gastropod *Conus* were collected. One feature of the specimens of *Terebratula* at this locality is that they are frequently bored and encrusted with bryozoans.

Locality 3. Here, 38 m of the Blue Clay is exposed. In the lower parts a distinct colour banding is readily discernible, consisting of alternating layers of dark blue and lighter grey bands, whilst a more uniform dark grey colour characterises the higher levels, together with the presence of goethite concretions. Fossils are plentiful in the Blue Clay, particularly in the upper parts, and specimens of the gastropods *Conus* and *Strombus*, the corals *Flabellum*, *Stephanophyllia*, *Trochocyathus* and *Ceratocyathus*, the bivalves *Chlamys*, *Cardium* and *Flabellipecten* and the cephalopods *Aturia aturi* and *Sepia sepulta* were readily obtained. The echinoid *Schizaster eurynotus* is also common, occurring as crushed tests with associated spines. Burrow systems in the Blue Clay are usually infilled with goethite and pyrite.

South-west from Locality 3 the party climbed down a steep gully eroded along the line of the Qammieh Fault. This fault throws beds high in the Upper Coralline Limestone against the Lower Coralline Limestone. It consists of two closely spaced, parallel fractures (Fig. 2), and has *Globigerina* Limestone and Blue Clay caught up between the two fault walls.

In making the traverse directly from Locality 3 towards Locality 4 (Fig. 2), the opportunity arises to examine a complete section through the *Globigerina* Limestone Formation. The Upper *Globigerina* Limestone is about 19 m thick at this locality and shows a tripartite sequence of foraminiferal biomicrites, these comprising upper and lower yellow coloured divisions exhibiting honeycomb weathering, with a grey, marly middle division.

An underlying sequence, 16 m thick, of white and pale grey marls and biomicrites makes up the Middle *Globigerina* Limestone. Fossils are reasonably common in this division and include *Chlamys* and *Flabellipecten*, together with *Schizaster parkinsoni*; the beds are also locally bioturbated. At the top of this limestone the Upper (C2) Phosphorite Conglomerate Bed is well exposed. Only 0·5 m thick, it is composed of amoeboidal-shaped pebbles and nodules of dark brown collophanite and abundant derived fossils, set in a calcareous and phosphatic cement. The derived fossils include abundant corals, such as *Flabellum* and *Balanophyllia*, *Conus* and the teeth of the sharks *Carcharodon*, *Isurus*, *Odontaspis* and *Hemipristis*. Thalassinoidean burrows extend up to 0·75 m below this bed and are usually infilled with reworked phosphorite pebbles.

The Lower *Globigerina* Limestone, a yellow to cream coloured rock exhibiting honeycomb weathering, is about 4·3 m thick at Rdum. Fossils are fairly common and include *Chlamys* and *Flabellipecten*, *Schizaster* and *Eupatagus* and extensive thalassinoidean burrow systems. The Lower (C1) Phosphorite Conglomerate Bed occurs above this limestone, and is lithologically and faunally similar to the C2 Bed described above. It is characterised by a planar top and irregular base.

At this point several members remained to collect sharks' teeth, whilst about half the party proceeded to Locality 4 (Figs. 1 and 2), where the upper beds of the Lower Coralline Limestone are well exposed on a wave-cut platform. The top of this formation is marked by the abundance of

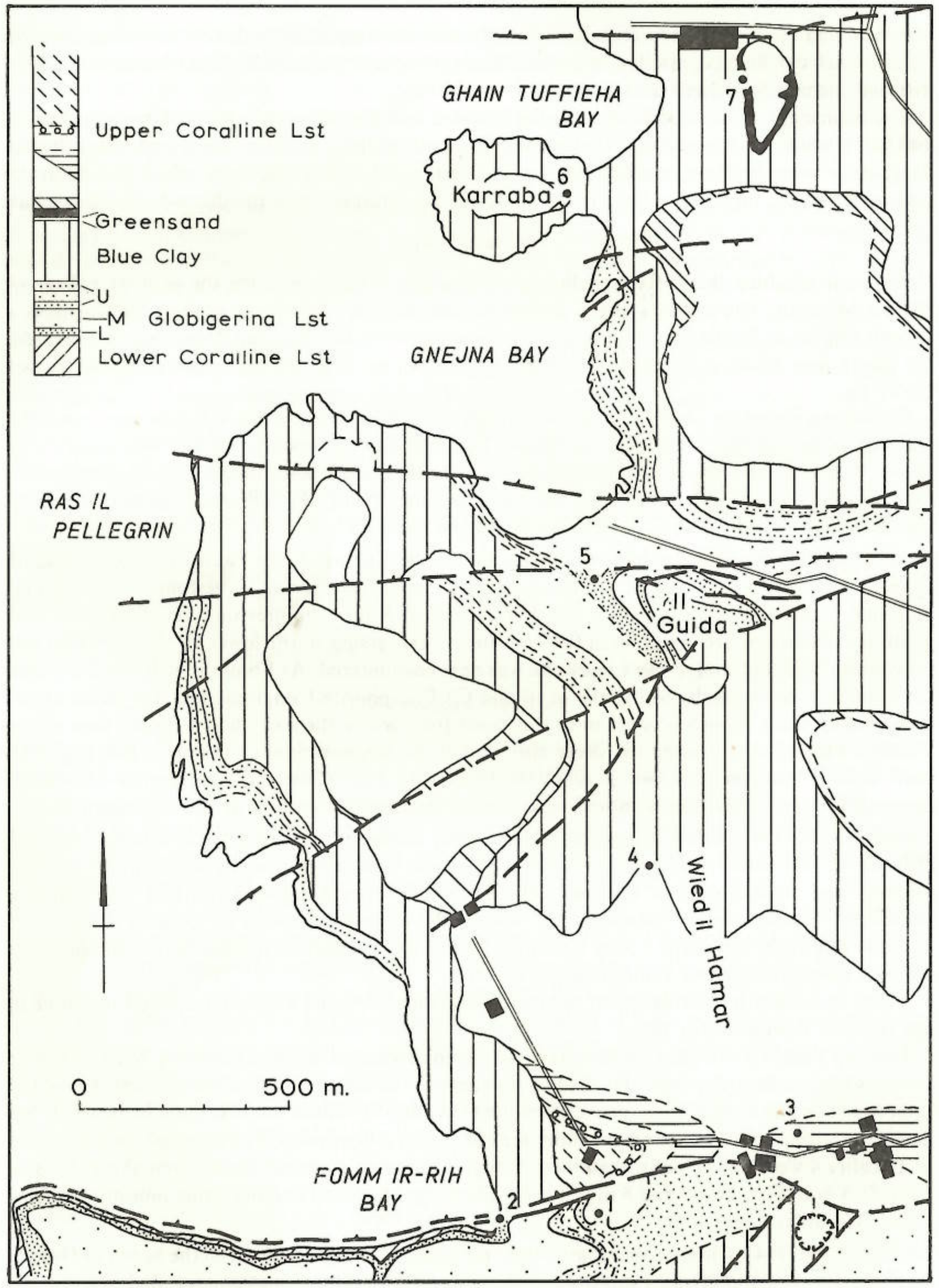

Fig. 3. The geology and itinerary followed between Fomm ir-Rih Bay and Ghain Tuffieha Bay, western Malta

the echinoid *Scutella subrotunda* and constitutes the important marker bed—the *Scutella* Bed—which can be recognised at many localities throughout the islands. Other fossils seen within the bed include *Spatangus* and *Eupatagus*.

On returning to the coach, Dr. Pedley pointed out the view towards Il Ghadira (Fig. 2) (407807), where limestones occurring within the middle of the Upper Coralline Limestone display large-scale cross-bedding, the foresets dipping easterly at 18°. These beds, which pass laterally into a patch reef facies seen later in the meeting, are interpreted as the deposits of tidal deltas.

Tuesday, 9 April

In brilliant sunshine the party travelled to Mdina (462717), to examine the geology gallery of Mdina Museum. The exhibit, which depicts various aspects of Maltese geology and includes a superb display of fossils from the islands, was prepared by Dr. Zammit-Maempel. Afterwards, the party was given a conducted tour round the Museum of Roman Antiquities at Rabat (459716).

On leaving Rabat the coach transported members north-west to Fomm ir-Rih to commence the traverse from Fomm ir-Rih Bay to Ghain Tuffieha Bay in western Malta. The itinerary is shown in Fig. 3. Just before arrival at Fomm ir-Rih, the road crosses the prominent, northwards facing fault escarpment produced by the Victoria Lines Fault, the largest of the north-easterly trending faults of the island. A short walk led the party to:

Locality 1 (408738). This lies on the upthrow side of the Victoria Lines Fault where one metre of Blue Clay is seen as a hill capping. The underlying Upper *Globigerina* Limestone is well exposed here and shows the same tripartite division as seen at Rdum the previous day. Pteropods and geothite concretions are common in the limestones. Traversing to the lower levels, the white and grey marly Middle *Globigerina* Limestone was next encountered. At Fomm ir-Rih this limestone contains thin chert bands, whilst the overlying C2 Phosphorite Conglomerate Bed yields abundant sharks' teeth. Lunch was taken at this point from where the party had a superb view of the Victoria Lines Fault forming the sheer cliff wall at the southern end of Fomm ir-Rih Bay. The fault here is composed of two parallel fractures with Blue Clay and *Globigerina* Limestone between the fault walls, an identical situation to that seen previously at the Qammieh Fault.

Locality 2 (406739). A full succession of the Lower *Globigerina* Limestone is exposed near the cliff-top at this locality. The yellow, coarse bioclastic limestones contain abundant bryozoans, bivalves and thalassinoidean burrows. The C1 Phosphorite Conglomerate Bed also forms a prominent, massive ledge. Although not visited, the cliffs to the west of Locality 2 show the *Scutella* Bed at the top of the Lower Coralline Limestone, overlain by a dense bryozoan limestone of the Lower *Globigerina* Limestone.

Views to the north show excellent sections in the Blue Clay and Upper Coralline Limestone in the cliffs of Fomm ir-Rih Bay.

Leaving Fomm ir-Rih Bay on foot, the party then proceeded northwards down Wied il Hamar towards Gnejna Bay. *En route*, Dr. Pedley pointed out the oolitic and bioclastic limestones of the upper part of the Upper Coralline Limestone (Locality 3). These are the same beds which underlie the stromatolite-bearing limestones seen at Rdum il Qammieh. The crags on the valley side at Locality 4 were not actually examined, though it was reported that the sections show the Blue Clay, 0·5 m of Greensand and 8 m of the coralline algal bioherm and overlying limestones of the Upper Coralline Limestone.

Locality 5 (407754). Close to the point where the Gnejna Valley opens on to the beach of Gnejna Bay, the Lower *Globigerina* Limestone and the Cl Phosphorite Conglomerate Bed are well exposed. The lowest horizons within the limestone include a bed dominated by fenestrate

bryozoans, lying just a short distance above the *Scutella* Bed of the Upper Coralline Limestone.

A pleasant walk then followed across the sandy beach of Gnejna Bay, before the steep ascent of the cliffs of this bay had to be negotiated.The rough climb involved a traverse over the *Globigerina* Limestone, Blue Clay and the coralline algal bioherm of the Upper Coralline Limestone before reaching the plateau of the cliff-top. After a suitable rest period enjoying the sunshine and splendid coastal scenery, the itinerary was resumed by a visit to:

Locality 6 (406763). On the prominent headland of Karraba a thick standard succession of the Blue Clay, which includes a prominent bed of glauconitic sand towards the top, is overlain by a thin development of the Greensand, the contact between the two being marked by a prominent hardground. The Greensand in turn is overlain by the coralline algal bioherm of the Upper Coralline Limestone in which the *Lithophyllum* rhodolites are impressively developed. Approximately 1·5 m above its base the Upper Coralline Limestone contains the *Terebratula* Bed, a shell bed which can be traced over large areas of the islands at this horizon. The bed contains abundant *Terebratula terebratula, Megathiris, Argyrotheca* and *Aphelesia bipartita*.

Locality 7 (411764). At Ta Lippija the section differs from that seen at Karraba, in that approximately 0·5 m of a pale brown calcarenite is present between the Greensand and the Upper Coralline Limestone. Fossils collected from this horizon included various bivalves, *Clypeaster altus* and *Heterostegina*. In parts of Gozo the thickness of the brown calcarenite attains much greater proportions.

From this point the party walked with great haste for much-needed refreshments at the nearby Riviera Martinique café, before returning by coach to Sliema.

In the evening members of the party were entertained to drinks and supper at the home of Dr. and Mrs. Zammit-Maempel in Birkirkara.

Wednesday, 10 April

The purpose of this excursion was to examine the Miocene solution subsidence structures on the island of Gozo. These have recently been described in detail and the mechanism of their formation discussed by Pedley (1974). Basically, it is envisaged that large subterranean caverns were formed in the limestones during a phase of subaerial exposure, possibly during the Palaeogene. Upon resubmergence, marine sediments were deposited until the point was reached when the weight of overburden was sufficient to cause sudden cavern roof collapse, together with possible collapse of the rim shoulder. Subsequent marine sedimentation then infilled the depression.

Transport arrangements were a little more complex for the visit to Gozo as the coach had to convey the party first to the ferry terminal at Ramla Bay on the north coast of the Marfa ridge (Fig. 1). A second coach was waiting for the party when the ferry docked at Mgarr in south-east Gozo. During the crossing the ferry passed close to the island of Comino which is composed entirely of Upper Coralline Limestone. From Mgarr the party travelled via Victoria towards Xlendi on the south-west coast of Gozo. The itinerary is illustrated in Fig. 4.

Locality 1. Xlendi Road (302881). Towards Xlendi the road follows the line of the Xlendi Fault, the fault wall being well exposed within the Lower Coralline Limestone on the south side of the road. The first halt was arranged to give members the opportunity of examining outcrops of the Lower Coralline Limestone, which here consists of coarse bioclastic limestones containing a prominent bed with *Scutella subrotunda* and *Chlamys* just below the bridge.

Localities 2 and 3. Xlendi Solution Subsidence Structure (296879). This structure occurs within the Lower Coralline Limestone and is bounded by vertical, fault-controlled walls of this rock. In the south-west corner the party was shown what was considered by Dr. Pedley to be the Lower

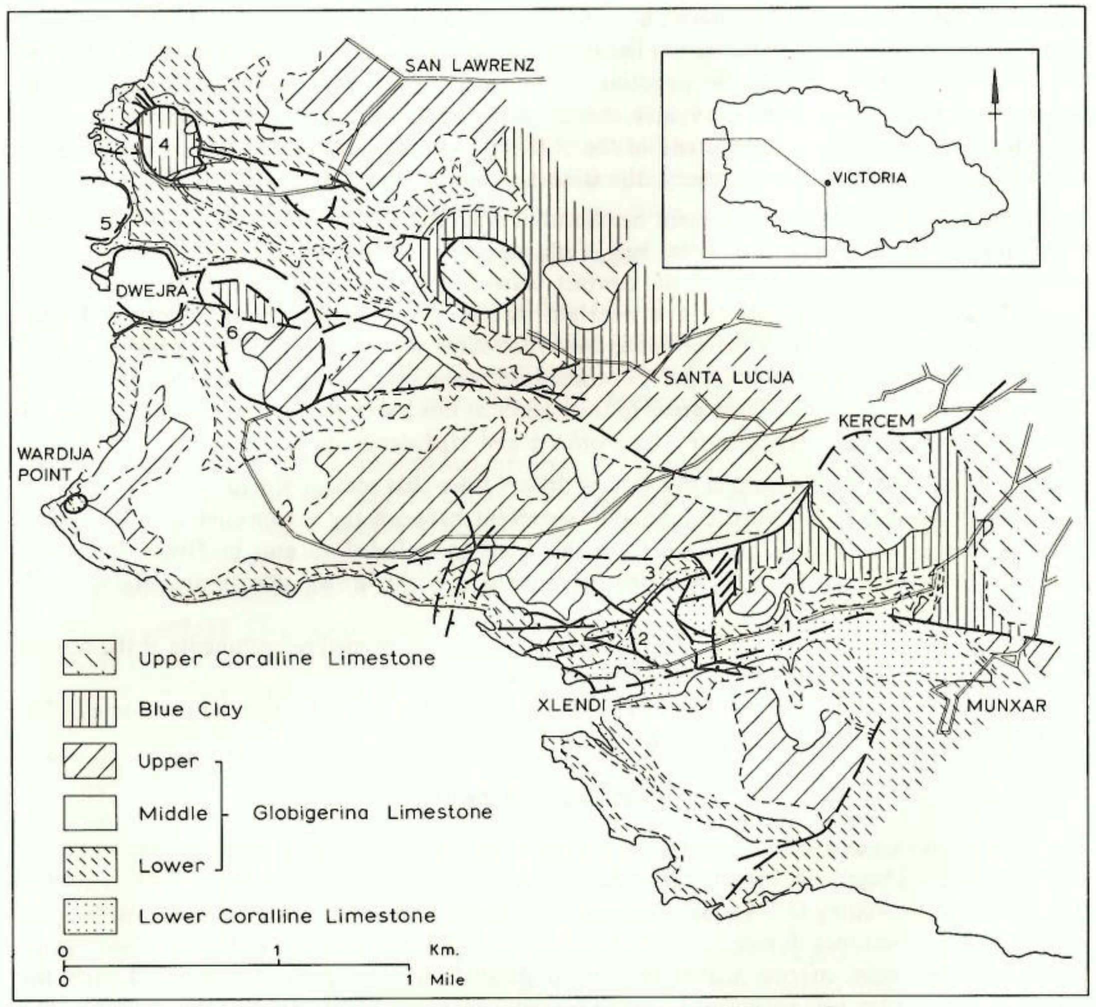

Fig. 4. The Solution Subsidence Structures of south-west Gozo

Globigerina Limestone, containing the pteropod *Cavolina*, deposited prior to subsidence and lowered into the structure during later subsidence. Overlying this the penecontemporary infill deposits consist of coarse *Globigerina* Limestone containing glauconite grains and scattered phosphatic pebbles, overlain by a coarse phosphatic conglomerate thought to be the C1 Bed. These beds are firmly cemented to the rim walls, filling irregularities in the walls, and dip in towards the centre of the structure. Further, they often show a lensoidal thickening towards the centre. Coarse limestones with scour and fill structures overlie the C1 Bed, and are themselves overlain by a thin layer of fine phosphatic pebbles close to the top of the structure.

Locality 4. Qawra Structure (273903). A short drive to the north-west led to the Qawra Structure, perhaps the largest and best exposed example in Gozo. It is approximately 400 m in diameter and is bounded by circular fault walls of Lower Coralline Limestone. Initial collapse is believed to have occurred in *Globigerina* Limestone times, and the sediment infill can be seen at many places within the structure. However, the party spent most of the time examining the sediment infill at the southern end of the structure where golden-brown coloured, laminated Upper *Globigerina* Limestone contains large boulders of phosphorite and phosphorite conglomerate, the boulders

deforming the host sediment lamination. These are interpreted as the product of collapse of boulders from the rim shoulder into unlithified sediment. Articulated shells of the brachiopod *Megerlia* were collected from the infill sediment. Subsequent movement has lowered Blue Clay into the solution subsidence structure.

Locality 5. Dwejra North Structure (271899). Only the eastern half of this structure is preserved, the other half having suffered marine erosion. Measuring approximately 340 m in diameter, the faulted, near-vertical walls of this circular structure are again of Lower Coralline Limestone. The sediment infill is composed of pale grey to cream coloured Middle *Globigerina* Limestone overlying the C1 Phosphorite Conglomerate Bed. These beds are firmly cemented to the smooth and irregular fault walls, they dip in towards the centre of the structure and contain abundant *Cidaris* spines, fragments of *Scutella* and bryozoans, proving the marine origin of the infill.

In the immediate vicinity of the Dwejra North Structure, the Lower *Globigerina* Limestone shows an abundance of the burrows of *Thalassinoides*; the *Scutella* Bed is also well exposed in the Lower Coralline Limestone around the rim shoulder.

Locality 6. Tal Harrax Structure (275894). A short distance to the south-east of Dwejra North is the solution subsidence structure of Tal Harrax. This irregular, elliptical shaped structure has been complicated by later faulting. The infilling sediments are coarse biomicrites with locally abundant *Cidaris* spines, together with khaki coloured cherts containing *Terebratula* towards the centre of the structure. In general, the beds can be seen to thin towards the margins. Middle *Globigerina* Limestone caps the infill, confirming the Middle Miocene age of the collapse. It is believed that post-Miocene subsidence was responsible for the fault-bounded plug of Blue Clay occurring in the northern part of the structure.

Due to the shortage of time, it was not possible to visit the solution subsidence structure of Ghajn Abdul (Locality 7, 286896), and the party thus returned to the coach. A short refreshment stop was made in Victoria before catching the return ferry to Malta.

Thursday, 11 April

A second visit to Gozo planned for this day involved the same transport arrangements as for the previous day. Most of the morning was spent in Victoria. Gozo, to enable members to do some necessary shopping and also to visit the Citadel and Museum.

On leaving Victoria, the party drove approximately one kilometre to the north-west to the prominent flat-topped hill of Il Gelmus (309897). The succession here is:

Upper Coralline Limestone	over 3·0 m
Greensand	10·6 m
Blue Clay	59·0 m

The main reason for visiting Il Gelmus was to examine the Greensand. Indeed, this is the type-locality for the formation on the Maltese Islands, and the thickness of almost 11 m is the thickest development in the island group. In Malta, exposures visited during the previous days rarely exceed one metre in thickness.

The Blue Clay, forming the lower cultivated slopes of the hill, shows a transitional contact with the Greensand, whilst there is a sharp contact between the Greensand and the overlying Upper Coralline Limestone. This latter formation forms the prominent vertical walled-flat plateau to Il Gelmus.

The Greensand Formation here consists of a brownish-green glauconitic limestone, in which the well-rounded grains of glauconite are readily visible to the naked eye. Fossils are abundant, being dominated by shell-casts of the bivalves *Glycimeris*, *Cardium*, *Chlamys*, *Ostrea* and *Thracia*, and the echinoids *Clypeaster altus* and *Schizaster eurynotus*. The rock is extensively bioturbated, and contains an abundance of the giant foraminifera *Heterostegina depressa*.

A brief examination of the basal Upper Coralline Limestone, here over 3·0 m thick, shows it to be a brown calcarenite, similar to that seen previously below the coralline algal bioherm at Ta Lippija in Ghain Tuffieha bay, Malta.

From Il Gelmus the coach returned to Victoria and thence drove northwards to Marsalforn. *En route*, Dr. Pedley pointed out the Dabrani Hill section (322915) from the coach window, where the succession is:

Upper Coralline Limestone	5·5 m
Greensand	1·0 m
Blue Clay	65·4 m

Lunch was taken at Marsalforn (334923), on the north coast of Gozo, after which the party examined a section in the *Globigerina* Limestone in the cliffs to the north-east of the town. The C2 Phosphorite Conglomerate Bed is well exposed here. Considerable time was spent examining the contact relationships between the C2 Bed and the Middle *Globigerina* Limestone, where large burrows extend down by as much as one metre into the limestone, and are infilled with phosphatic pebbles.

Returning to the coach the party returned to Victoria and then travelled on to visit the well-preserved megalithic temple of Ggantija (342896).

The section in Wied il Hanaq (349885) to the west of the road was the next locality visited. Here, due to a marked thinning of the Middle *Globigerina* Limestone, the C1 and C2 Beds are separated by only one metre of limestone.

The final locality of the day was to the cliff-sections in the east of Ramla Bay (360912). The lower parts of the cliff show fine sections in the Blue Clay (over 60 m thick) overlain by a thin development of Greensand. In the upper, more precipitous, sections, the lower horizons of the Upper Coralline Limestone occupied most of the attention of the party. Immediately overlying the Greensand are 11·3 m of an orange-brown, rubbly calcarenite, identical to the facies occurring at this horizon at Il Gelmus, Dabrani and Ta Lippija. The rock contains an abundance of unabraded *Heterostegina depressa*, which are usually orientated parallel to the bedding. Intense bioturbation is perhaps the most obvious feature of the outcrop, the vertical burrows having weathered out in relief. Frequently, the burrow walls are lined with *Heterostegina*. The presence of numerous grains of glauconite in the lower parts of the section may suggest derivation from the Greensand. Specimens of *Clypeaster* were collected from the brown calcarenites. Overlying these beds is 9·0 m of typical coralline algal bioherm.

The party gathered on the sandy beach in Ramla Bay before returning to the coach for the journey back to the Mgarr ferry terminal, and on to the hotel at Sliema.

Friday, 12 April

Departing from the hotel at 9 a.m., the party travelled via Naxxar to a point just north of Naxxar Gap (495761), where the road descends the Victoria Lines Fault escarpment. Here Dr. Zammit-Maempel demonstrated to the party a complex system of cart-tracks of regular gauge, with junctions and cross-tracks, cut into the Lower Coralline Limestone. Of probable Neolithic age, it has been suggested that they were cut during the systematic transportation of soil from the valleys to the more barren plateau areas. The density of the tracks is such that this locality is popularly referred to as 'Clapham Junction'. After a long discussion as to possible alternative origins for the tracks, the party proceeded via Mellieha to the eastern end of the Marfa Ridge (Fig. 1).

At Rdum il Hmar (Locality 5 in Fig. 1; 427825), on the south coast of the Marfa Ridge, the following succession is exposed:

Upper Coralline Limestone	13·2 m
Greensand	0·6 m
Blue Clay	*c.* 50·0 m

This locality is important as it shows a facies of equivalent age to the coralline algal bioherm of the Upper Coralline Limestone, but occurring to the east of the bioherm. The upper 12 m of the limestone consists of white, chalky micrites, containing occasional specimens of *Pecten*, *Pinna* and burrows, the facies being interpreted as the deposits of a sheltered, shallow carbonate platform area occurring to the east of the contemporary algal bioherm. Thin sections show the rock to have suffered advanced micritisation, although samples from some areas show the presence of abundant faecal pellets. The lowest 1·2 m of the limestone are indifferently exposed, consisting of yellow micrites.

The Greensand at this locality is best seen in fallen blocks which contain *Echinolampas*, *Schizaster*, *Terebratula terebratula*, *Chlamys* and *Ostrea*. The underlying Blue Clay shows the presence of goethite-filled burrows and fossil wood.

From here the coach journeyed back to Mellieha, turning south-west out of the town to Tat Tomna (Locality 6 in Fig. 1; 417791). In a disused quarry beds high in the Upper Coralline Limestone are exposed, showing the development of a reef facies. The reef here is composed of two large lobes of limestone with a 'chinastone' texture. Coralline algae, including *Lithophyllum* and *Lithothamnion*, and corals such as *Tarbellastraea*, *Favites*, *Acropora* and an indeterminate compound scleractinian coral, are the major reef builders. These are associated with an abundance of various bivalves, now preserved largely as casts, and showing prolific clionid borings. The reef itself is extensively bored by *Lithophaga*, many of which can be seen to have bored vertically upwards into the underside of reef limestone, suggesting that the reef mounds had overhanging margins. Cavities within the original reef structure show the presence of serpulids, bryozoans and encrusting foraminifera, whilst others show geopetal infill.

Between the two reef lobes of the quarry the coarse bioclastic limestones contain *Halimeda*, *Spondylus*, reef debris and nodule-shaped burrows up to about 5 cm in diameter.

Overlying the reef the bedded limestones include cross-laminated oolites and pellet limestones, clearly suggesting extremely shallow water deposition. It is this facies which occurs below the stromatolite-bearing limestones as seen at Rdum il Qammieh on the first day.

At this point the Directors reviewed the depositional history of the Upper Coralline Limestone of the Maltese Islands. Basically, sedimentation commenced with the deposition of the brown calcarenites of an open marine environment as seen at Ramla Bay, Gozo. The Coralline algal bioherm was then established in western Malta and eastern Gozo, separating a developing basinal marine environment in the west from a sheltered platform area in the east; it was in the latter that the chalky micrites of Rdum il Hmar were deposited. Sediments immediately overlying the bioherm show a marked reduction in the number of algal rhodolites and macrofossils, before the patch reefs of Tat Tomna became established. These are intimately associated with the large-scale cross-bedded limestones as seen at Il Ghadira, and interpreted as probable tidal deltas formed by tidal flow of carbonate detritus between the patch reefs. Later, shallow water lagoonal conditions became prevalent in which the oolites and pellet limestones were deposited, before the final phase of sedimentation seen on the islands resulted in the deposition of micrites with intertidal stromatolites of a carbonate mudflat environment.

The party then returned to the hotel in the early afternoon. This was to enable members to witness the Good Friday religious processions being held in Mosta and Qormi. Most people returned in time for an 8.30 p.m. dinner at the hotel.

Saturday, 13 April

Travelling south-west from Sliema, via Balzan and Rabat and thence south via Verdala Palace and Buskett, the first locality of the day was at Tar-Raba (461683). An old quarry on the north side of the road exposes Upper Coralline Limestone of the same age and facies as seen the previous day at Rdum il Hmar, i.e. white micrites. This is, however, the most prolific fossiliferous locality in these beds, and large numbers of the casts of bivalves, including *Glycimeris*, *Cardium* and *Pecten*, various gastropods and burrow systems were observed.

After a brief stop at Tar-Raba, the party proceeded south-east to the south coast of Malta at Ghar Lapsi. The purpose of the visit to this region was to demonstrate the features of the important Maghlak Fault, the only major north-west-trending fault of the islands. Fig. 5 illustrates the geology of the area and the itinerary followed.

Locality 1. Ix-Xaqqa (473659). In a deeply eroded gully to the west of the road leading down to Ghar Lapsi, the steeply inclined, smooth and slickensided fault-plane of the Maghlak Fault is clearly exposed. The fault throws the Upper Coralline Limestone on the southern, downthrow side against the Lower Coralline Limestone. As with many of the major faults of the islands, the Maghlak Fault is composed of two parallel fractures, and at this locality the Blue Clay is caught up between the two fault walls.

A superb view to the east of this locality shows that the seaward facing fault-plane is responsible for the vertical cliffs along this part of the southern coast of Malta.

The coach left the party at Ghar Lapsi, and at this point several members decided to spend the rest of the day examining some of the archaeological sites in this region.

Locality 2. Ras Hanzir (484651). A short distance to the east of Ghar Lapsi further exposures of the multiplane fracture system of the Maghlak Fault show that both Blue Clay and *Globigerina* Limestone are present between the fault walls. The downthrown Upper Coralline Limestone is tilted at over 40° to the south due to the presence of a monoclinal flexure associated with a branch of the main Maghlak Fault.

Immediately to the east of Ras Hanzir, at the Wied Maghlak, the inclined Upper Coralline Limestone is overlain by Quaternary alluvial fan deposits, composed of ill-sorted gravels and boulder conglomerates, set in a red clay matrix. The fan deposits thicken seawards, the source of the detritus clearly being the Lower Coralline Limestone scarp a short distance inland. Indeed, the fan apex appears to be situated near the mouth of the small valley—Wied Maghlak—incised in the Lower Coralline Limestone. Sections through the alluvial deposits show numerous gravel-filled channels, imbrication of pebbles and the presence of a caliche-like soil profile in which the position of plant roots is marked by carbonate tubes.

Locality 3. Denbil Baghal—Halk It-Tafel (493647). A marked inlet has been eroded by the sea at this locality along the line of the well-exposed Maghlak Fault planes. The area between the fault wall is filled with approximately 18 m of steeply inclined Blue Clay containing a 1·3 m thick glauconitic bed towards the top, similar to that seen previously at Karraba in western Malta. A reduced thickness of *Globigerina* Limestone occurs on the eastern side of the fractures, with Greensand on the western flank.

The glauconite bed within the Blue Clay and the Greensand both contain abundant oysters at this locality, whilst the basal Upper Coralline Limestone yields *Schizaster*, *Chlamys* and *Terebratula terebratula*.

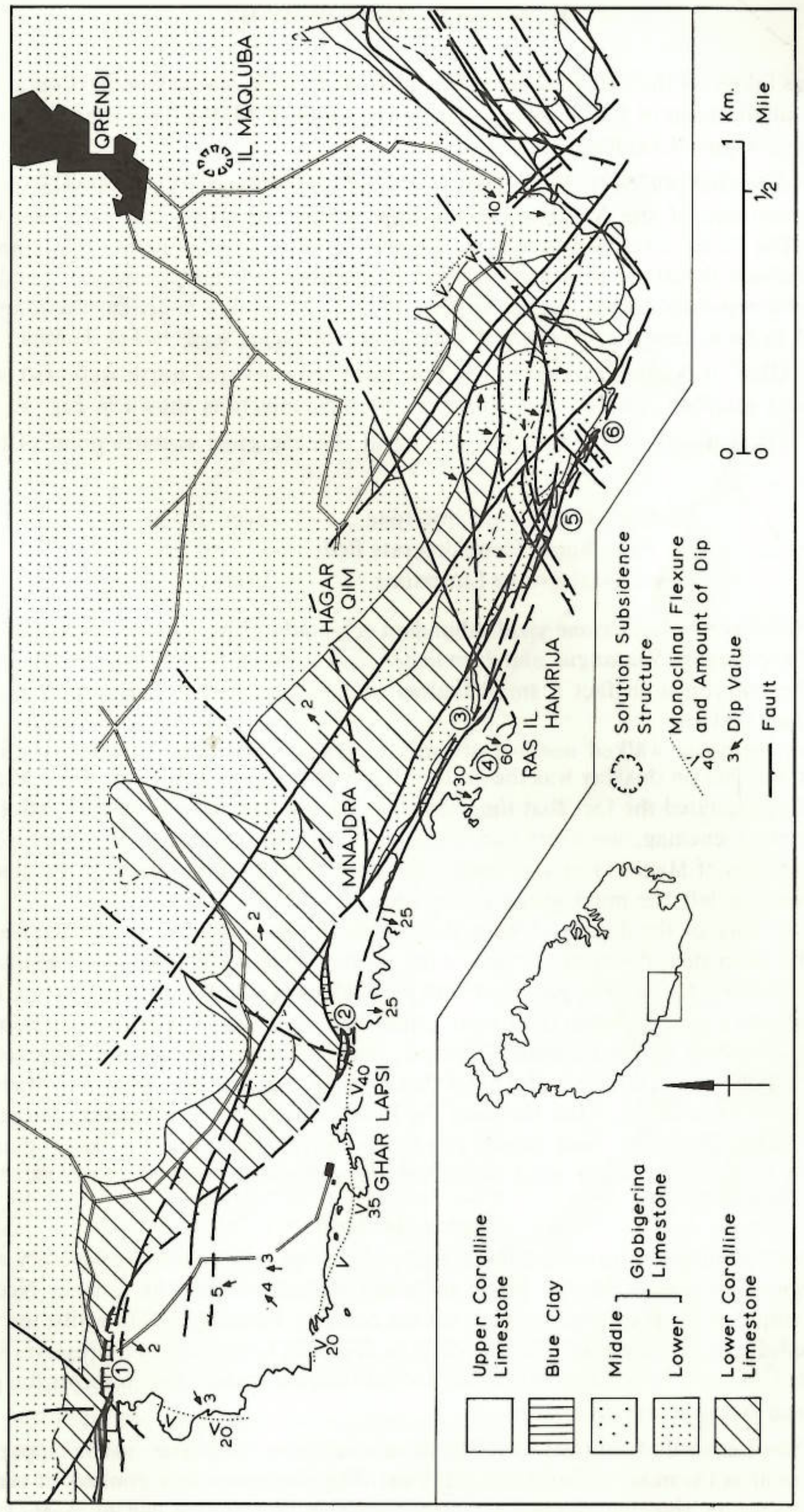

Fig. 5. The geology of the region around Ghar Lapsi, southern Malta, showing the Maghlak Fault Complex

Lunch was taken on the cliff-top above Denbil Baghal, from where members obtained a good view of the small island of Filfla, some 5 km to the south of Malta. This island is composed of Blue Clay and Upper Coralline Limestone.

Locality 4. In Nuffiet (492647). The Upper Coralline Limestone on this peninsula, occurring on the downthrow side of the Maghlak Fault, dips steeply seawards and is at one point just overturned. The facies developed here in the Upper Coralline Limestone is a thinly bedded, pale grey recrystallised limestone showing incipient development of ripples and scour and fill structures, probably representing deposition within a shallow subtidal to intertidal environment. They are believed to be a lateral equivalent of the patch reef facies seen at Tat Tomna.

Locality 5. Ghar ix-Xaghra (499645). In this small bay several north-west and north-east-trending faults intersect, producing a complex outcrop pattern as shown in Fig. 5.

Locality 6. Ras il Bajjada (502643). The section at this the most easterly point of the coastal traverse is:

Middle *Globigerina* Limestone	over 2·5 m
C1 Phosphorite Conglomerate Bed	0·25 m
Lower *Globigerina* Limestone	over 3·0 m

The Lower *Globigerina* Limestone yields abundant echinoids at this locality, including *Schizaster parkinsoni, Eupatagus, Spatangus* and *Hemiaster*, and shows a high density of thalassinoidean burrows. The outcrop is in fact a small faulted outlier, present between branch faults of the Maghlak Fault system.

From here members walked north-westwards to Hagar Qim (Fig. 5) where the coach was waiting. The weather on this day was the hottest of any of the days during the Field Meeting, and members all appreciated the fact that the coach was parked next to a small bar. After a lengthy period of thirst quenching, members had the opportunity of examining the superbly preserved megalithic temples of Hagar Qim and nearby Mnajdra (Fig. 5), and were there greeted by those members who had left the main group earlier that day.

The final locality of the day involved a short drive to the north-east to Il Maqluba (Fig. 5). Following the steep steps down by the side of the church the party entered an impressive solution subsidence structure. Circular in plan and with vertical walls, the Lower *Globigerina* Limestone has collapsed into a cavern within the Lower Coralline Limestone. The interesting point about Il Maqluba is, according to Dr. Zammit-Maempel, that this subaerial collapse occurred in 1343.

At a specially arranged dinner in the hotel that evening, Dr. and Mrs. Zammit-Maempel were the guests of the Association. After the meal the President gave a vote of thanks to the Directors and Dr. Zammit-Maempel, and made presentations of gifts to them as a mark of the Association's appreciation for a most enjoyable and successful Field Meeting.

Sunday, 14 April

As the return to England was scheduled for late afternoon only a half-day itinerary was undertaken to regions in eastern Malta. Some members wished to visit the famous Neolithic underground temple of the Hypogeum and so left the coach at Paola (555700), whilst the rest of the party proceeded to San Leonardo. This region is geologically important as it preserves strata high in the Upper Coralline Limestone in a small unconformable outlier. Fig. 6 shows the geology of the region and the itinerary followed.

Locality 1. San Leonardo Fort (603706). Strata believed to be the highest in the Upper Coralline Limestone occur in the moat of San Leonardo Fort. The succession here consists of two horizons of coarse biosparites showing channel structures with an intervening bed of marl, 1 m thick.

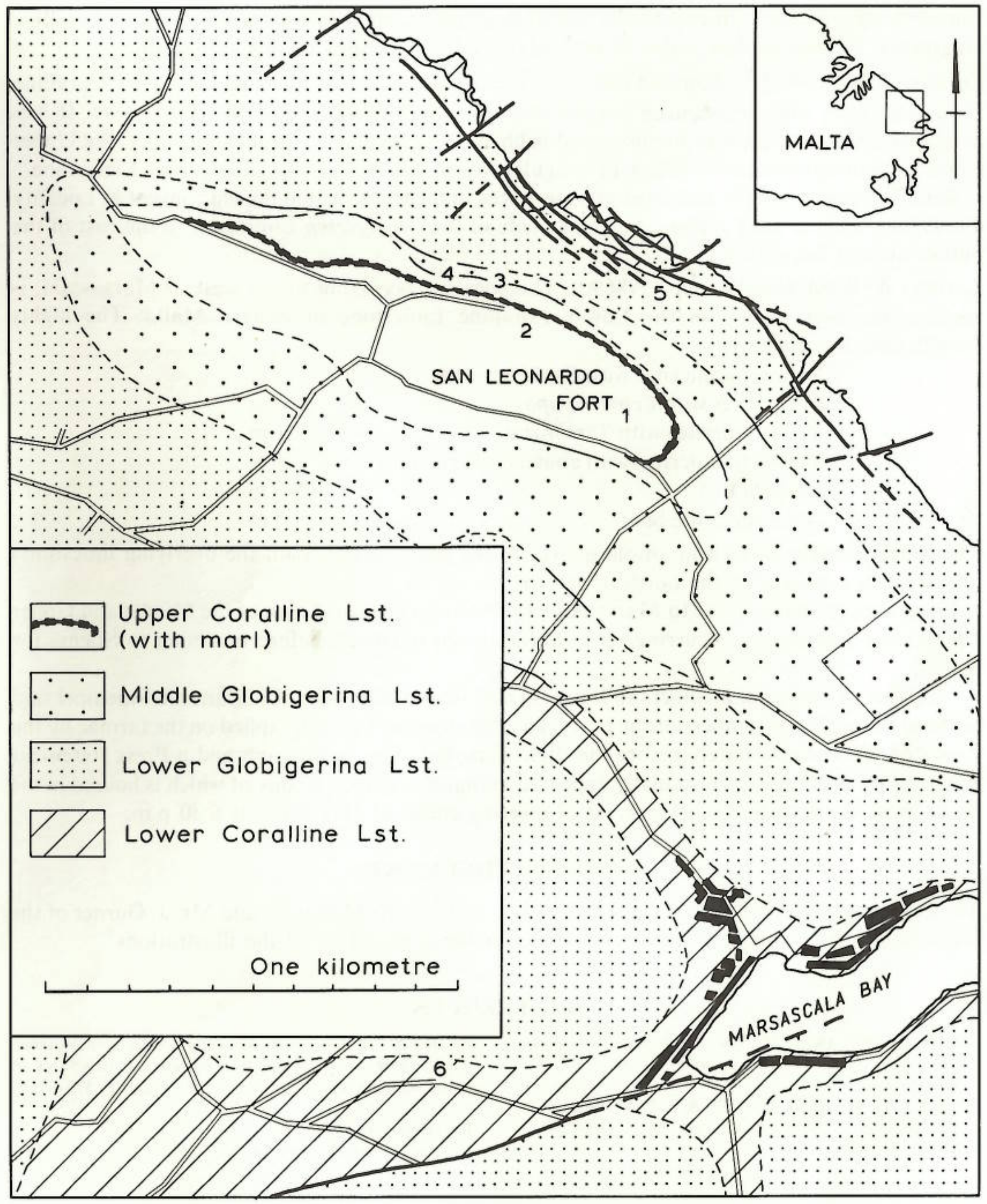

Fig. 6. The geology of the region between San Leonardo and Marsascala, eastern Malta, illustrating the unconformable outlier of the Upper Coralline Limestone

Locality 2 (601708). The same succession, although more accessible for examination, occurs in two old quarries to the north-east of the fort. Here, the marl bed is well exposed, and Dr. Pedley reported that he had obtained charophytes from this horizon. The underlying limestone shows pronounced scour and fill structures and festoon cross-bedding, and a large channel structure in the north-eastern side of the northerly quarry contains rounded pebbles of limestone and mollusc fragments. A very shallow water to intertidal origin is ascribed to this succession.

Locality 3 (600709). One hundred metres to the north-east of the quarries the Upper Coralline Limestone rests with pronounced unconformity on the Middle *Globigerina* Limestone. It was demonstrated that there was an absence of pebbles along the line of the unconformity, the Upper Coralline Limestone merely filling in irregularities in the underlying *Globigerina* Limestone.

Similar exposures of the unconformity were seen in the track behind the old convent at Locality 4 (599708), while a brief examination was made of the *Globigerina* Limestone to the east of the outlier around Locality 5.

Locality 6. Wied San Antonio (598690). This locality, occurring to the west of Marsascala, is perhaps the best section in the Lower Coralline Limestone of eastern Malta. The highly fossiliferous succession is:

Yellow biomicrites with *Lepidocyclina*	2·5 m
Biosparites with *Echinolampas*	0·3 m
Yellow micrites with *Terebratula*	3·1 m
Yellow biomicrites with abundant bryozoans	2·1 m
Scutella Bed	0·5 m
Algal rhodolite beds	over 3·5 m

The lowest horizon is seen in an old quarry to the south of the road, the overlying limestones occurring in a quarry to the north of the road.

From here the party drove to Marsaxlokk (590666) for a general view of the Middle and Upper *Globigerina* Limestones occurring on Delimara Point (605642), before returning to Sliema for lunch.

A fleet of cars took members to Luqa Airport in mid-afternoon. Dr. Zammit-Maempel said his final farewells to members of the party, and the group was photographed on the tarmac by the *Times of Malta* immediately before the flight departed. The photograph and a Press statement prepared by the Directors eventually appeared in that newspaper, a copy of which is housed in the archives of the Association. A successful meeting ended at Heathrow at 6.30 p.m.

ACKNOWLEDGEMENTS

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