PETROLOGICAL CHARACTERISTICS OF BLUE LENTICULAR PATCHES OCCURRING IN THE LOWER GLOBIGERINA BUILDING LIMESTONE OF MALTA

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The Lower Globigerina Limestone Member, the earliest member of the Globigerina Limestone Formation, is the lithostratigraphical bed which had provided limestone for the erection of Malta's built heritage since Neolithic times. It is massively bedded, pale yellow in colour and consists predominantly of globigerinid planktonic forminifera. Occasionally, blue coloured lenticular patches occur in this member. The first published research relating to these features was by John Murray in 1890. His results and interpretation were corroborated and refined through a recent publication by the author which noted variations from packstone to wackestone along these patches. This paper further studies their petrological characteristics. Petrographically, the limestone of these patches gradually alternates from wackestone to mudstone to bioclastic wackestone. They are composed of micrite matrix (in varying amounts), ferrugenized unbroken pelagic foraminifera, bioclasts, and terrigenous quartz. The appearance of these blue lenticular patches must be linked to another process other than limestone texture.

***Keywords**: Globigerina Limestone, sol, sol ikħal, blue patches, John Murray, Malta*

1. Introduction

Malta and its sister island Gozo support numerous buildings of cultural heritage significance. Several megalithic architectural structures dating to the Neolithic Period are listed by UNESCO as World Heritage Sites as they are "outstanding example[s] ... which illustrate[s] significant stage(s) in human history" [1]. Similarly, the early Baroque capital Valletta, a city conceived and planned in the late sixteenth century during the administration of the islands by the Order of St John [2, 3] was listed in its entirety by UNESCO in 1980, not only for its outstanding universal cultural value but also as a representative "masterpiece of human creative genius" [4].

This built heritage of Malta is mainly constructed from limestone extracted through open-pit mining from the Lower Globigerina Limestone Member locally referred to as *ġebla tal-franka* (meaning freestone), the oldest member of the Globigerina Limestone Formation [5, 6] (Fig. 1a). Other harder and more durable formations were historically utilized for specialized uses [7]. This member is massively bedded, pale yellow in colour and consists predominantly of tests of globigerinid planktonic forminifera [8, 9]. Its calcerous plankton bio-chronostratigraphy was the theme of [10].

Blue lenticular patches occur within the Lower Globigerina Limestone Member (Fig. 1b). These patches, first studied by Murray [11], were the subject of a recent publication which focused on their mineralogy and geochemistry [12]. This paper focuses on the petrological characteristics of the samples covered in [12]. The aim is to investigate and document them.

2. Materials and methods

The geology of Malta is made up of mid-Tertiary strata of deposits of shallow marine origin. The stratigraphic sequence, starting from the earliest, comprises the following formations: Lower Coralline Limestone, Globigerina Limestone, Blue Clay, Greensand and Upper Coralline Limestone [13-16]. Thus, the Globigerina Limestone Formation overlies the Lower Coralline Limestone Formation and underlies the Blue Clay Formation. It is made up of three distinct members: the Lower, Middle and Upper Globigerina Limestone Members. The transition from one member to the other is marked by < 1m thick lower phosphorite-rich conglomerate bed which runs throughout the island, evidence of interruption in the process of sedimentation [9, 17].

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(a) (b)

Fig. 1 – Lower Globigerina Limestone Member: (a) Auberge de Castille, a fine architectural building which is the seat of the Prime Minister of Malta, is erected in the characteristic building stone of Malta, the Lower Globigerina Limestone, and (b) blue lenticular patches (see red arrows) which became evident during the excavation of a site along Valley Road, Msida.

The petrophysical, textural, geochemical and mineralogical characteristics of the various lithostratigraphic beds of the Lower Globigerina Limestone Member were comprehensively studied in [18]. This research had identified what constitutes first and second, inferior, quality building stones [18]. The main mineralogy of the Lower Globigerina Limestone Member is calcium carbonate with minor inclusions of quartz, K-feldspar, muscovite, glauconite and clays [18-21]. The mineralogy and geochemistry of the blue patches is quantitatively different from the similarly coloured lithostratigraphical unit within the same member referred to by quarrymen as *sol ikħal* [12]. *Sol* refers to the inferior quality limestone within the Lower Globigerina Limestone Member whilst *ikħal* is the Maltese word for blue. Although, qualitatively, variations are minor, the SiO_2 content is a diagnostic characteristic which distinguishes them. In the *sol ikħal* the SiO_2 content is < 10% whilst in the blue patches it is > 10% [12]

According to Murray, these patches contain pyrite, a mineral otherwise absent in the Lower Globigerina Limestone Member, and “often filling the foraminifera and forming casts of the shells” [11]. He had studied a site which was excavated as part of the civil engineering works undertaken in conjunction with the construction of the New Dock.

These excavations exposed large, nearly circular, bluish patches in the bedrock. They occurred at a distance from faults and fissures. He argued that it “appears more than probable that these blue patches will ultimately disappear with further oxidation; indeed it is evident to me that at the time these Globigerina rocks were first raised above the sea they were all of a blue colour, and that the red colour is entirely due to subsequent oxidation, the more porous calcareous beds having been oxidised at a more rapid rate than those containing a large quantity of clayey matter” [11].

Table 1

Mineralogical and geochemical characteristics of samples [12]

		B1	B2	B3
Oxides	SiO_2	17.83	15.20	15.16
	TiO_2	00.40	00.33	00.34
	Al_2O_3	02.99	02.84	03.13
	Fe_2O_3	01.55	01.34	01.62
	MnO	00.04	00.04	00.03
	MgO	01.18	01.07	01.00
	CaO	42.93	42.43	41.55
	Na_2O_3	00.12	04.01	05.69
	K_2O	00.87	00.74	00.70
	P_2O_5	00.23	00.22	00.24
Whole rock	calcite	✓	✓	✓
	quartz	✓	✓	✓
Insoluble residue	quartz	✓	✓	✓
	K-feldspar	✓	✓	✓
	muscovite	✓		✓
Clay fraction	kaolinite	n.d.	✓	n.d.
	illite	n.d.	✓	n.d.
	Smectite	n.d.	✓	n.d.
	quartz	n.d.	✓	n.d.
	zeolite	n.d.	✓	n.d.

n.d.: not determined

Table 2

Petrographical characteristics of samples

	B1	**B2**	**B3**
Matrix	70 %	90 %	80 %
Allochems	30 %	10 %	20 %
Terrigenous components	single; sizes < 0.15 mm	single; sizes < 0.1 mm	single; sizes < 0.1 mm
Classification	Globigerina-bioclastic wackestone	Globigerina mudstone	Irregularly recrystallized, Globigerina wackestone

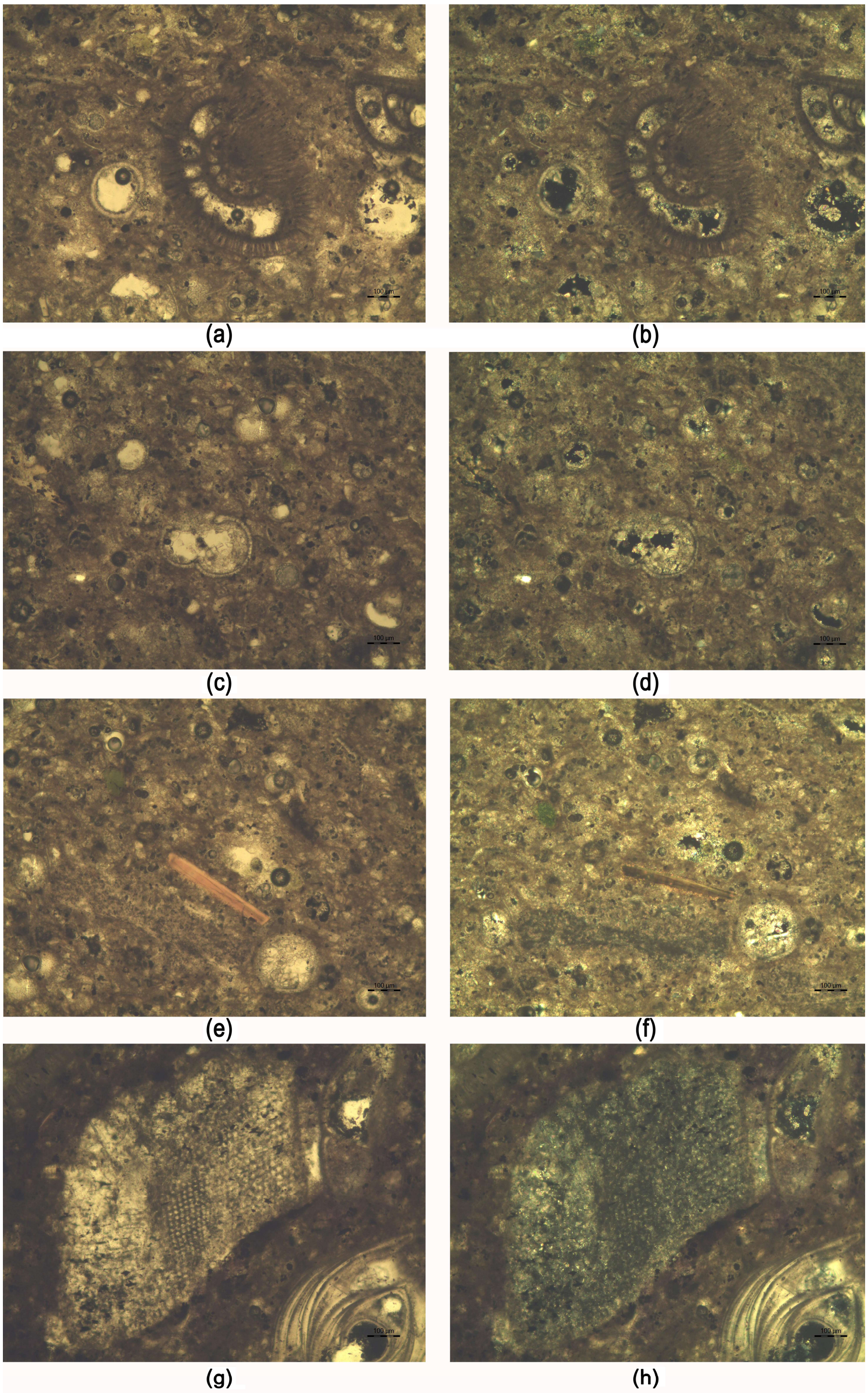

Fig. 2 - Ferrugenized Globigerina-bioclastic wackestone: (a) plane-polarized light: micrite matrix with planktonic Globigerina foraminifera and single quartz grains; (b) cross-polarized light: same view as (a), interparticle porosity is present; (c) plane-polarized light: micrite matrix with planktonic Globigerina foraminifera, rare benthic foraminifera and a quartz grain; (d) cross-polarized light: same view as (c), interparticle porosity is present; (e) plane-polarized light: micrite matrix (in some places is recrystallized to microspar) with planktonic Globigerina foraminifera, a glauconite grain and possibly a phosphatized bioclast; (f) cross-polarized light: same view as (e); (g) plane-polarized light: echinoid bioclast and altered benthic foraminifera and (h) cross-polarized light: same view as (g).

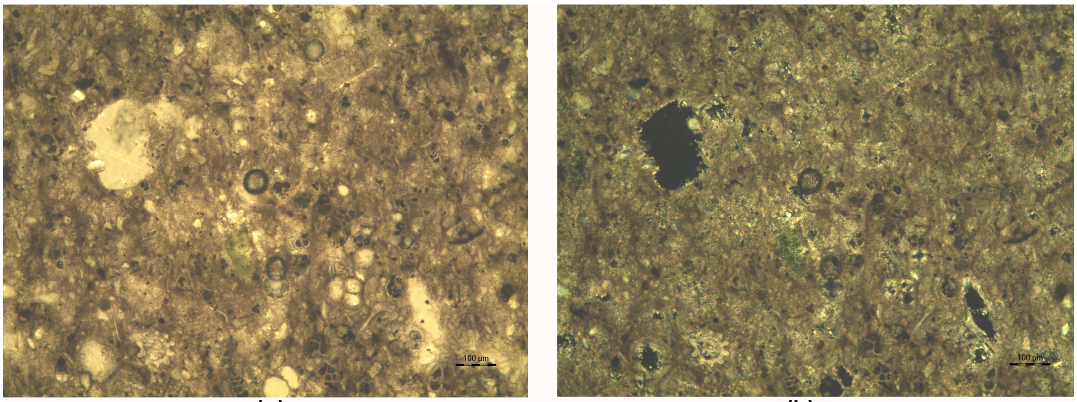
(a) (b)

Fig. 3 - Ferrugenized Globigerina mudstone: (a) plane-polarized light: micrite matrix with planktonic Globigerina foraminifera, benthic foraminifera and a glauconite grain and (b) cross-polarized light: same view as (a), intraparticle porosity is present.

The samples analysed in [12] to identify the mineralogy and geochemistry of blue patches (Table 1) were further studied petrographically in this paper. The same sample reference number is used for ease of cross referencing the research. The location of the sampled site is along a road leading to Valley Road, Msida (UTM ED50 coordinates: 453212E, 3972483N), opposite the site shown in Fig. 1b.

For this petrographical analysis thin sections were examined by Professor Elena Koleva-Rekalova of the Department of Palaeontology, Stratigraphy and Sedimentology of the Geological Institute Strashimir Dimitrov, Bulgarian Academy of Sciences, Sofia [22]. The classification of the limestone was performed according to the scheme of [23]. A Zeiss Axioskop 40 transmitted light-microscope was used. A ProgRes GT3 digital camera was used to take the microphotographs, both in plane-polarized and cross-polarized light.

3. Results and discussion

The respective petrographical characteristics of each sample are given in Table 2. They are all ferrugenized; sample B1 is a Globigerina-bioclastic wackestone whilst B2 and B3 are Globigerina mudstone and irregularly recrystallized Globigerina wackestone respectively.

The micrite matrix in B1 (Globigerina-bioclastic wackestone) is comparatively well preserved and has dark brown coloration due to the presence of Fe-oxides (Fig. 2). The micrite contains small particles of possibly black organic matter. In other areas the micrite is recrystallized to microspar and rarely to pseudospar (as a result of diagenetic neomorphic process according to [24]). In these areas the porosity is higher. Small planktonic Globigerina foraminifera predominate. Usually their chambers are empty, but the filling is preserved in some of them and represents recrystallized micrite to microspar and pseudospar.

There are sporadic large planktonic foraminifera and a relative enrichment of benthic foraminifera that are often deformed. Rare echinoid bioclasts with maximum sizes 1.5 x 0.45 mm occur. Single bivalve fragments are also observed – maximum sizes up to 1.9 x 0.15 mm. Some bioclasts are phosphatized, silicified or glauconized. Single fragments resemble bryozoa and their sizes are < 1.0 mm. Individual glauconite grains with maximal sizes of 0.3 x 0.2 mm are present.

The micrite matrix in sample B2 (Globigerina mudstone) is relatively well preserved (Fig. 3). It has a green-brown colour probably due to the presence of more clay minerals. In the matrix, several black organic particulate matter may be observed. The micrite is recrystallized to microspar in some places where the porosity is slightly increased. The allochems are represented mainly by small planktonic Globigerina foraminifera. Rarely their chambers are silicified. Sporadic benthic foraminifera and bioclasts are present. Glauconite grains are also sporadic.

In some places the sample B3 (irregularly recrystallized wackestone) is composed of micrite, dark in colour and well-defined spots of accumulated brown Fe-oxides are present (Fig. 4). In other places the micrite is recrystallized to microspar to various degrees and there are more pores. Limestone is crossed by two calcite veins 0.15 and 0.2 mm in thickness. Small planktonic Globigerina foraminifera occur; some of their chambers are empty whilst others are filled with brown Fe-oxides. There are rare benthic foraminifera; single ones are strongly ferrugenized. Echinoid and bivalve fragments of insignificant sizes are present.

Petroglogically, the blue lenticular patches are thus mainly composed of unbroken pelagic, predominantly Globigerina, foraminifera. The non-carbonate fraction is made up of quartz, glauconite and iron oxides. Petrographically they are similar to *sol ikħal* [12]. Yet they differ from *sol aħmar*, another type of second quality Lower Globigerina

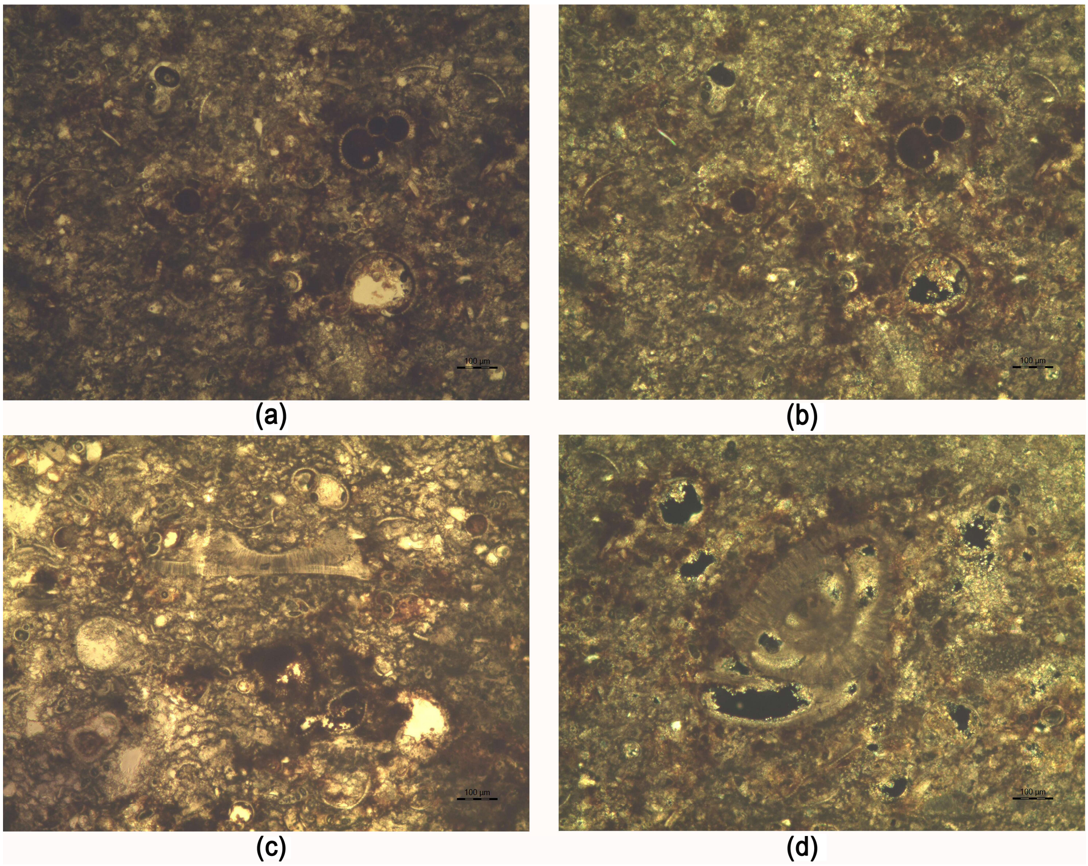

Fig. 4 - Ferrugenized Globigerina wackestone: (a) plane-polarized light: brown in colour micrite matrix with planktonic Globigerina foraminifera and rare quartz grains; (b) cross-polarized light: the same view as 2(a), some chambers of planktonic Globigerina foraminifera are empty, while others are filled with brown Fe-oxides; (c) plane-polarized light: brown micrite matrix in some places recrystallized to microspar, containing planktonic Globigerina foraminifera, some quartz grains and one bivalve fragment and (d) cross-polarized light: micrite matrix with planktonic Globigerina foraminifera and rare quartz grains; intraparticle porosity is present.

which is more durable and utilized as dimension stone in the building industry [6, 19, 21]. Although having minor qualitative variations, the mineralogy and geochemistry of the blue patches are quantitatively different from *sol ikħal,* the latter having lower non-carbonate content [12]. The allochem content of *sol aħmar* is similar to sample B1 and terrigenous components are rare. In the *sol aħmar* the micrite is commonly recystallized to microspar. Planktonic Globigerina foraminifera are present; bioclasts and single benthic foraminifera are rare [22].

The petrographical analysis shows that the texture of limestones forming the blue patches alternates from wackestone to mudstone and bioclastic wackestone. This refines the analysis included in [12] which noted variations from packstone to wackestone. The appearance of these blue lenticular patches must be linked to another process other than limestone texture.

4. Conclusion

Additional petrographical observations of the lenticular blue patches occurring in the Lower Globigerina Limestone Member under transmitted light-microscope (plane-polarized and cross-polarized light) led to the following conclusions:

1. These patches are composed of ferrugenized unbroken pelagic foraminifera abundance, mainly Globigerina;
2. Grains of quartz, the main non-carbonate mineral, are predominant; and
3. Glauconite increases towards the core of the patches when Na_2O_3 content is at its lowest.

Petrographically the variations in the lenticular blue patches are linked to other process/es other than limestone texture. They are similar to *sol ikħal* [12] but differ from *sol aħmar*. In the latter, the micrite is often recystallized to microspar.

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