Photo: Marion Grundy Ridewood

The geology of the Great Orme, Llandudno

Geoscience Wales Limited

Excursion: Thursday 11th July 2013, 6.30pm to 9.30pm

Field Guide

Introduction

The Great Orme is, in my opinion, one of the great treasures of North Wales. To the non-geologist it is a place of peace, tranquillity and outstanding natural beauty. To the geologist, it is also one of the most remarkable continuous outcrops of Carboniferous limestone sequences in the UK. Due to such extensive exposure, the formations and structural features of the Great Orme practically describe the changing environments of deposition, and do so within the context of changing sea-level and of structural deformation caused by contemporaneous movement of the Aber Dinlle and Great Orme faults.

This field guide is comparatively brief. It is intended to accompany the observations made along the route, which progresses through the sequence from oldest to youngest formations.

Most of the details, figures and photos herein are derived from extensive field work completed across the Great Orme as a part of my 3rd Year dissertation project, for which I have received two awards, during my undergraduate studies at the University of Liverpool. This work is currently unpublished and as such, they are primarily my own observations and interpretations and I therefore welcome open discussion during this field excursion as we move upward through the succession – alternate perspectives and fresh ideas are the essence of creating good science!

Of all the regions in which I worked, the Great Orme was my favourite. Thus I have tailored this excursion to show you some of the best, most informative sections, and I do hope that this trip whets your appetite for many more visits to the Great Orme.

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Location, geologic and tectonic setting

The Carboniferous was a period of major geotectonic change, characterised by northward drift of the continents across the equatorial belt and the oblique collision of Gondwana with Laurussia during the Variscan Orogeny. The Variscan Front is situated across Devon and Cornwall in the UK, with the main orogenic belt to the south across France, Spain, Germany and the Czech Republic. Thrusting of the front caused northward migration of flexural subsidence which reactivated pre-existing structures and led to progressively younger basin sedimentation towards the north (Woodcock and Strachan, 2000)

Early Carboniferous, Dinantian, limestones of the Carboniferous Limestone Supergoup record the establishment of platform carbonates resulting from Visean marine transgression of the Wales - London - Brabant Massif (Waters, 2009) (Fig. 1) during which deposition was strongly influenced by movement along pre-existing fault zones, such as the Welsh Borderland, Bala and Menai Straits fault zones (Howells, 2007).

The Precambrian NE/SW Menai Straits Fault Zone comprised Precambrian SE dipping normal faults whose sense of movement was reversed during the Late Palaeozoic (Blenkinsop et al., 1986). Brittle reactivation of the fault zone during the Acadian (Late Devonian) and Variscan (Carboniferous) orogenies formed a series of discrete fault zones. These include the Variscan NW dipping Aber Dinlle Fault which divides the Great Orme from the Little Orme (Needham and Morgan, 1997).

In North Wales, the Dinantian limestones compile the Clwyd Limestone Group and crop out extensively east of the Clwydian Range, through Llangollen, around Oswestry, from Colwyn Bay through Denbigh, across the south and east of Anglesey and on the Great and Little Ormes (Fig. 2).

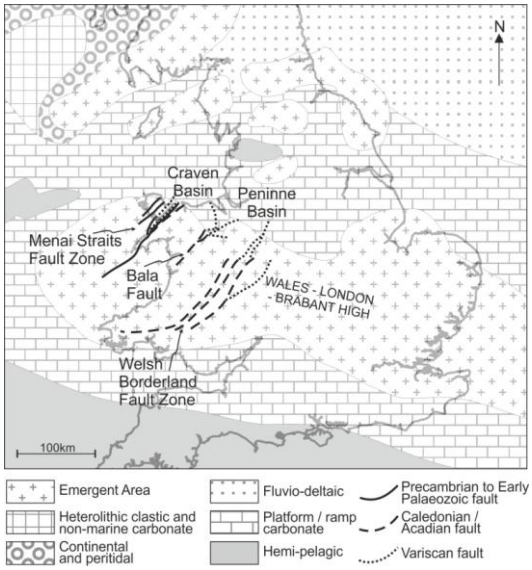

Fig. 1: Palaeogeography of the UK during the Early Carboniferous (Early Visean) and major Carboniferous fault zones (adapted from Woodcock and Strachan, 2000; Howells, 2007; Waters, 2009).

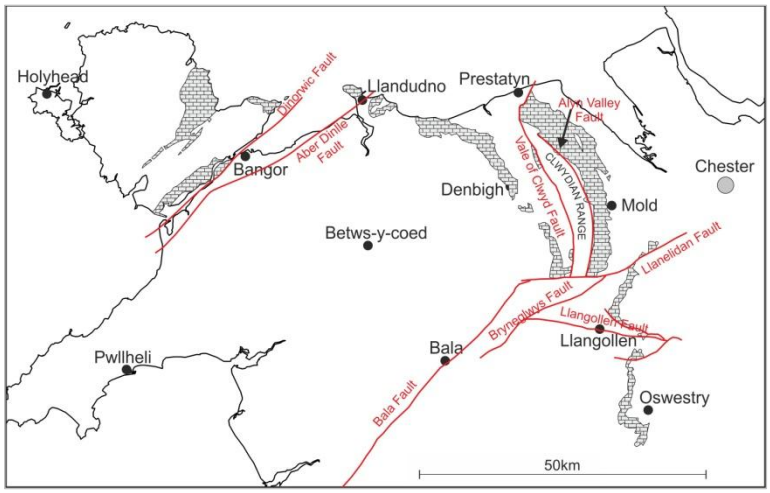

Fig. 2: Outcrops of the Clwyd Limestone Group in North Wales with major fault zones (adapted from Woodcock and Strachan, 2000; BGS, 2007; Howells, 2007)

Stratigraphy

At the Great Orme the basement is not exposed. The Dinantian succession comprises five formations (Fig. 3).

- Llanarmon Limestone Formation, a dolomitic packstone extending 2.5km around the western coast and 1.5km in the south east;
- Leete Limestone Formation (Tollhouse Mudstone Member), a calcareous mudstone and argillaceous limestone extending 4km from the north west to the south east;
- Loggerheads Limestone Formation, a thickly-bedded massive limestone with localised dolomitisation extending over 5.5km^2 of the mapped area;
- Craig Rofft Sandstone Member, a calcareous pebbly sandstone and sandy limestone of very limited extent in the upper sequence of the Loggerheads Ls. Fm. at Mynedd Isaf;
- Cefn Mawr Limestone Formation, a thinly-bedded argillaceous wackestone extending 1km^2 of the central area;
- Red Wharf Limestone Formation, a cherty packstone of limited extent of 0.75km^2 in the central area

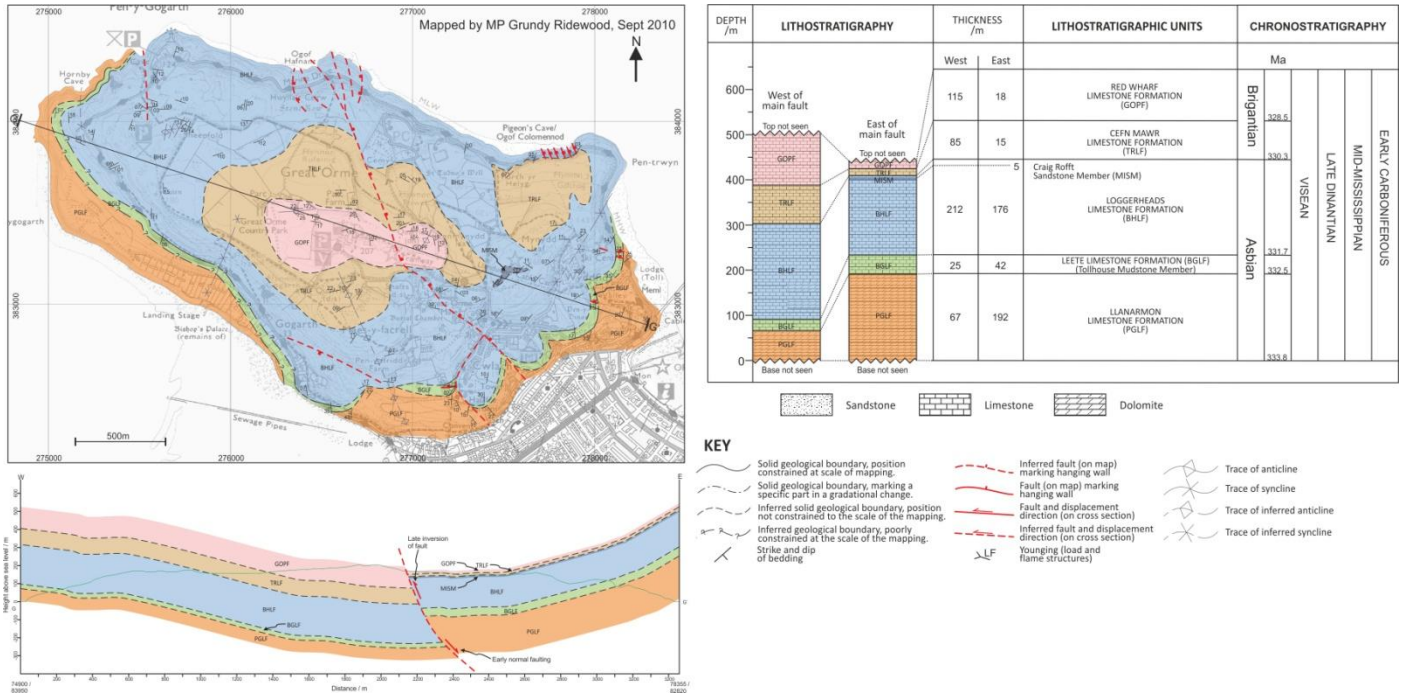

Fig. 3: Geologic map, cross section and GVS of the Great Orme region (Grundy Ridewood, 2010)

The geologic map of the Great Orme produced by the BGS has changed significantly in a short space of time (Fig. 4). However, these do not illustrate the true extent of the formations as observed in the field.

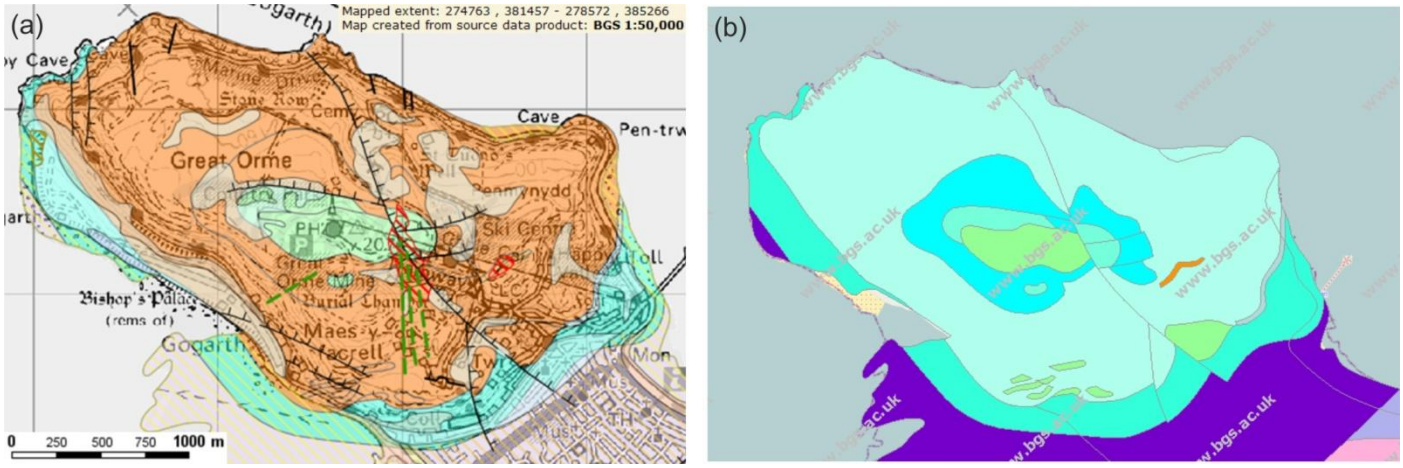

Fig. 4: BGS geological maps of the Great Orme: a) Digimap version, 2010; b) Online Geology of Britain viewer, 2013

Itinerary

Our route will take us on a journey up through the stratigraphy as indicated in Fig. 5.

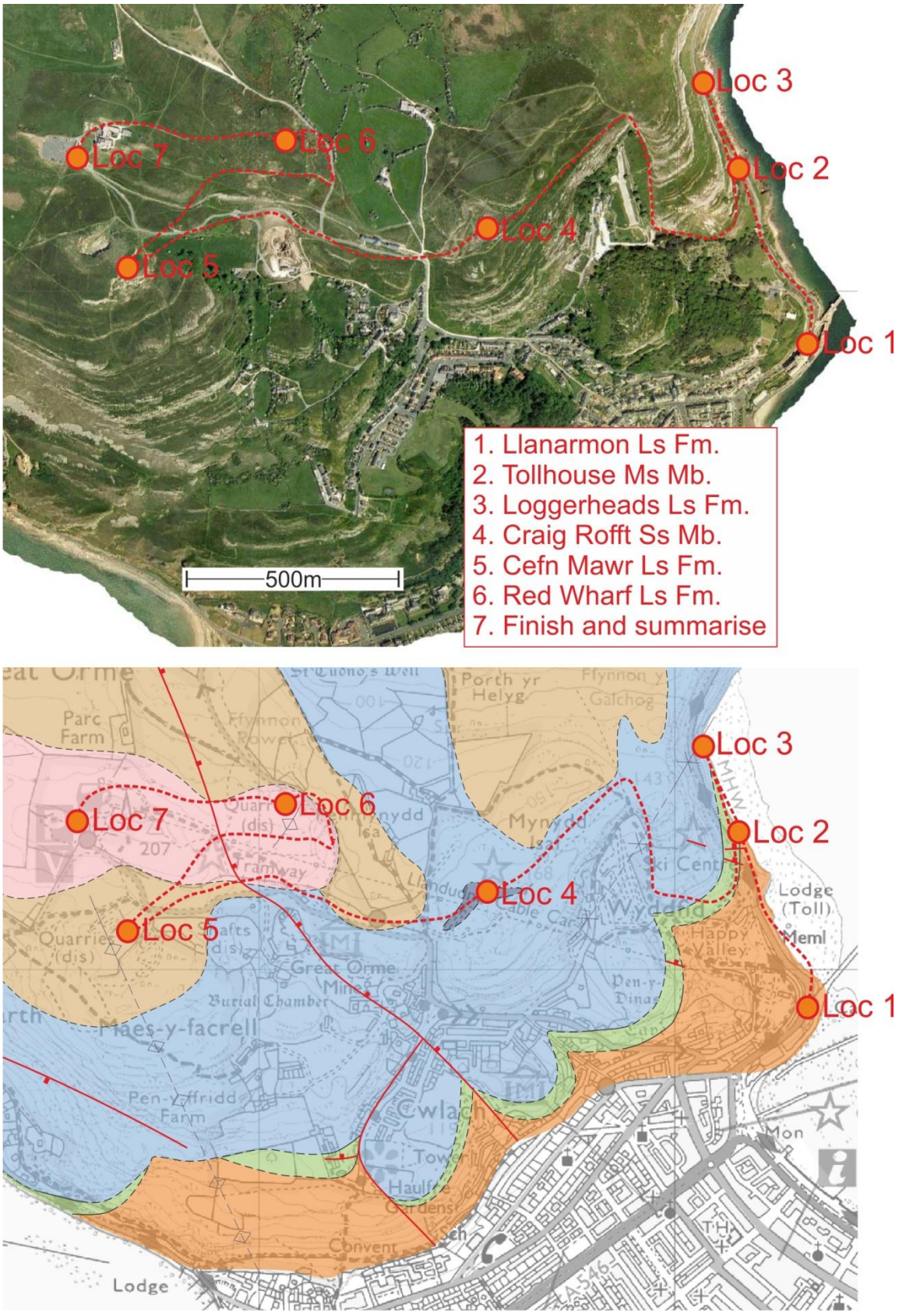

Fig. 5: Itinerary for field trip on 11th July 2013: a) outcrops and locations as visible on satellite imagery; b) the position of the locations within the stratigraphic units as mapped by Grundy Ridewood (2010).

Location 1 – The Llanarmon Limestone Fm.

The BGS Lexicon of Named Rock Units - Description
Lithological Description: Predominantly pale, thick-bedded, locally cross-stratified, shelly limestones (packstones and grainstones), subordinate thinner bedded dark grey limestones (packstones) and oolitic limestones. Upper parts (of early Asbian age), which interdigitate with the Leete Limestone Formation, include limestones rich in peloids, plates of dasycladacean algae, oncoids and reworked micrite intraclasts. On the Great Orme, the formation is extensively dolomitised. The Llanarmon Limestone Formation records the intoduction of carbonate depositional environments across North Wales during a major and sustained Arundian marine transgression. The initial distribution of facies suggests a ramp-like setting, with darker off-shore limestones deposited in the north and east (of the Clwydian Range) and shallower, inner ramp facies to the west (Vale of Clwyd). Subsequently, during the late Arundian, these high energy, inner ramp limestones prograded northwards and eastwards to establish a low-gradient carbonate platform. During the early Asbian, these shoal facies withdrew to the outer edge of the platform to form a protective barrier to the peritidal facies of the Leete Limestone Formation. **Definition of Lower Boundary:** East of the Clwydian Range, the base is taken at lowest massive, thick-bedded packstones and grainstone above thinner bedded, heterolithic sequences of the Foel Formation. West of the Clwydian Range, the Llanarmon Limestone Formation rests conformably on red beds of the Ffernant Formation, or sits unconformably on older Silurian rocks. **Definition of Upper Boundary:** Where overlain by the Leete Limestone Formation, the top is taken at the lowest porcellaneous limestone diagnostic of this formation; however, east of the Clwydian Range, the Leete Limestone Formation passes laterally northwards into the Llanarmon Limestone Formation so that north of Nannerch the top of the latter is taken at the entry of pseudobrecciated and mottled packstone of the Loggerheads Limestone Formation. **Thickness:** Ranges from 75m in the Vale of Clwyd to 280m in the Dyserth-Caerwys area. **Geographical Limits:** Crops out on the Great Orme at Llandudno [SH7683] and along the west side of the Vale of Clwyd [SJ1060]; in fault slices along the Vale of Clwyd Fault [SJ 1267]; in its type area east of the Clwydian Range between Dyserth [SJ0779 and Llandegla [SJ1852].

Observations

The character and lithology of the Llanarmon Limestone Formation varies across the Great Orme. To the south-west of Cwlach the Llanarmon Limestone Fm. is a pale orange-brown fine granular wackestone, interbedded with thinly bedded coarse dolomite. In the east at Happy Valley, it is a minimum of 192m thick (base below sea level) and is a dark-orange coarse dolomite with abundant crinoid ossicles and easily identifiable bedding sequences in the lower section.

The vuggy textures at the pier also evidence several stages of diagenesis, with dissolution of primary calcite, dolomitisation and secondary growth of zoned calcite spar infilling the vugs (Fig. 6). The timing for dolomitisation is uncertain and may have occurred during more than one interval of the formation's burial history. What do you think?

Fig 6: At Llandudno Pier, location 1, vugs may result from the dissolution of macrofauna (Photos: Grundy Ridewood, 2010)

Location 2 – Leete Limestone Fm. / Tollhouse Mudstone Mb.

The BGS Lexicon of Named Rock Units – Description – Leete Ls. Fm.
Lithological Description: Lithologically varied comprising diagnostic porcellanous and fenestral limestones (wackestones and calcite mudstones) interbedded with dark, foetid argillaceous limestone (packstones), and pale skeletal peloidal limestones (packstones and grainstones) including beds rich in oncoids. Thin grey and green mudstone beds and rare coals are present locally. Lithologies are arranged in shoaling-upwards rhythms, each capped by a porcellanous limestone. **Definition of Lower Boundary:** Lowermost porcellanous limestone overlying coarser-grained and thicker-bedded limestones of the Llanarmon Limestone Formation. **Definition of Upper Boundary:** Uppermost porcellanous limestone underlying rubbly and pseudobrecciated limestone of the Loggerheads Limestone Formation. Thickness: 150 to 175m **Geographical Limits:** Crops out on Anglesey [SH5982] in northwest Wales; at Llandulas [SH9078] and along the western side of the Vale of Clwyd [SJ1252]; along the eastern side of the Vale of Clwyd in fault slices along the Vale of Clwyd Fault [SJ1267]; in its type area east of the Clwydian Range between Nannerch and Llanelidan [SJ1852]; and south of the Bala Fault Zone between Minera and Oswestry [SJ2722].

The BGS Lexicon of Named Rock Units – Description – Tollhouse Ms. Mb.
Lithological Description: Fossiliferous, dark grey, calcareous mudstone and highly argillaceous limestone. The Tollhouse Mudstone is a widely recognised bed of marine mudstone occurring within the late Asbian platform carbonate succession of North Wales. Recognised on Anglesey and at Llandudno, it appears to record a temporary cessation of limestone deposition and (or caused by) an increase in the volume of terrigenous mud supplied to this northwestern portion of the platform. **Definition of Upper Boundary:** In its type section, the base is taken at the contact between the mudstone and underlying dolomitised limestones (formerly part of the Llandudno Pier Dolomite, but now included in the Loggerheads Limestone Formation). **Definition of Upper Boundary:** In its type section, the top is taken at the entry of overlying, pale, thick-bedded limestones. **Thickness:** To 2m **Geographical Limits:** Anglesey (SJ 50 87) and the Great Orme (SJ 77 83), northwest Wales.

Observations

At the Great Orme, the Leete Limestone Fm. is not mapped by the BGS or other workers. However, the Tollhouse Mudstone Member is mapped at a scale not in accord with the thickness documented for the member, whilst the descriptions given are in accord with observations of the Leete Limestone Fm. elsewhere.

At Happy Valley, as elsewhere, the sequence is divided into three facies types. The base beds of the lower facies comprise thick heavily bioturbated marls rich in macrofossils (Fig. 7a) and thick cross bedded dark argillaceous mudstones. The middle facies comprise karst-topped thickly-bedded boundstones containing crinoids and corals overlain by laminated crusts containing algal mats(Fig. 7b). The upper facies are thinly-bedded wackestones rich in brachiopods with interbedded bioturbated mud containing a few branching corals. This three-facies sequence is repeated only in the east of the Great Orme, but not elsewhere across North Wales. Why would this be the case?

Fig 7: Macrofauna: articulate Spirferida in lower muds at Cwlach and a Crinoid assemblage in middle facies at Happy Valley, location 2, (photos: Grundy Ridewood, 2010)

Location 3 – The Loggerheads Limestone Fm.

The BGS Lexicon of Named Rock Units - Description
Lithological Description: Thickly bedded, massive, pale grey shelly limestones (packstones and grainstones), locally mottled and pseudobrecciated, arranged in shoaling upwards cycles capped by calcretes, hummocky palaeokarstic surfaces and associated thin bentonitic clay seams (palaeosols) and rare coals. Locally dolomitised and with scattered chert nodules. The Loggerheads Limestone Formation records late Asbian platform carbonate deposition on the North Wales Dinantian shelf. Each cyclic sequence records a shoaling upwards unit developed in response to transgressive and regressive movements in sea level. Many regressions culminated in emergence of the platform surface and the formation of calcrete and karstic dissolution features. During these periods of emergence, wind blown volcanic ash accumulated on the platform surface to form thin bentonitic soils. **Definition of Lower Boundary:** Top of highest porcellanous limestone of underlying Leete Limestone Formation. **Definition of Upper Boundary:** Base of lowest sequence of thinly interbedded dark-grey limestones and mudstones of overlying Cefn Mawr Limestone Formation. **Thickness:** To 275m **Geographical Limits:** North Wales between Anglesey [SH5080] and Oswestry [SJ2723]; including the Corwen Outlier [SJ0542].

Observations

To the south of Mynydd Isaf, the Loggerheads Limestone Fm. is a maximum of 176m thick, comparatively thinly-bedded. Southwest of the main fault at Maes-y-facrell, the Loggerheads Limestone Fm. is only 130m thick. Dolomite is a dominant lithology of the lower sequence in this location (and further west), wherein thick beds of dolomite are interbedded with, infill, and overlie thinly-bedded karst-topped creamy brown wackestones and grainstones. Intermittent scarps of rubbly-based thickening upwards packages are characteristic of the upper sequence at this location.

In the east at Happy Valley, the Loggerheads Limestone Fm. is 225m thick and forms steep cliffs. Base beds are thinly-bedded, coarse texture white wackestones overlain by c10m thick beds of medium texture creamy-white grainstones. Within this bed, c2.5m from the base, is a distinctive undulating bed of clast supported breccia (Fig. 8a) in which the clasts are of country rock and show preferred orientation to the bedding plane. How do we interpret this breccia?

Upsequence, patch reefs are evident from their morphology (Fig. 8b), bedding generally thins, becomes more rubbly and texture coarsens, while in the upper most beds texture becomes granular and the colour changes to medium brown.

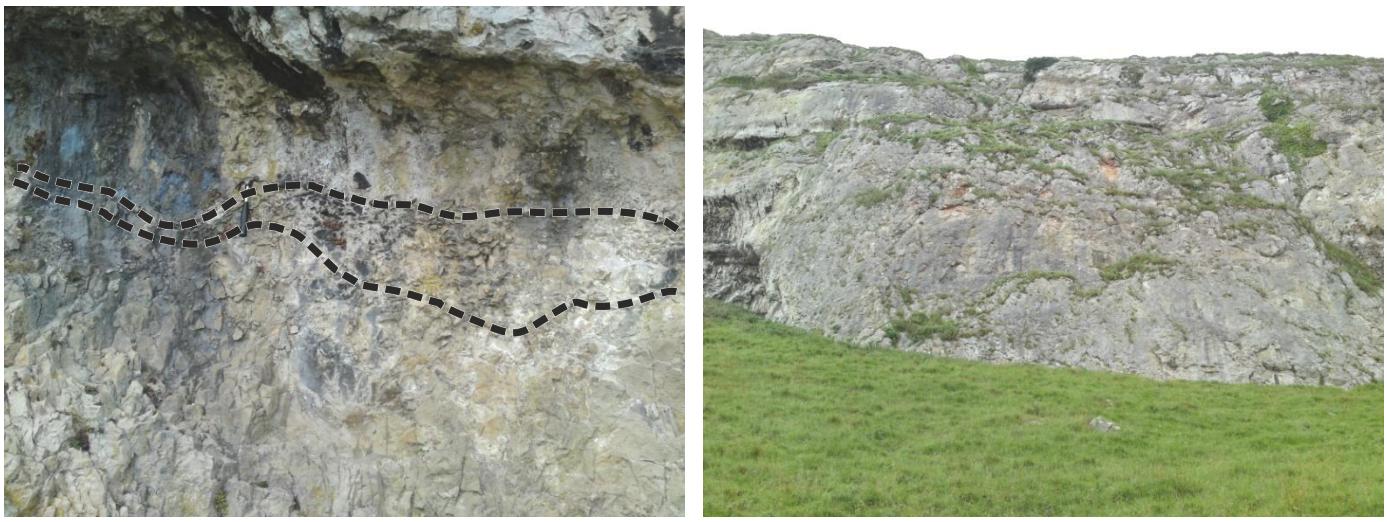

Fig. 8: Features potentially observable from location 3: a) breccia bed within the lower massive bed; b)patch reefs in the upper middle beds of the Loggerheads Limestone Fm. (photos: Grundy Ridewood, 2010)

The path to location 4 will take us up Happy Valley, through the bedding sequences of the Loggerheads Limestone Fm. Notice the packages of rubbly-based, thickening upwards beds, separated by discrete but laterally-persistent strongly-bioturbated red marls. Are they indicative of deep-water environments or of shallow, terrestrially-influenced ones?

Location 4 – The Craig Rofft Sandstone Mb.

The BGS Lexicon of Named Rock Units - Description
Lithological Description: Red and purple, fine- to medium-grained, sandy limestone (grainstone) and calcareous sandstone with scattered quartz pebbles and lenses of coarse shell material. Lower part is bioturbated and mottled; upper 2m are cross-stratified. The sandstone forms the upper part of a Brigantian shoaling-upwards cycle and formed in a shallow water, upper shoreface setting. The Craig Rofft Sandstone is currently shown on Sheet 94 within the Great Orme Limestone, a redundant Asbian formation now superceded by the Loggerheads Limestone Formation. However, unpublished foraminiferal dating by BGS has shown that limestones underlying the limestone member are Brigantian in age. These limestones therefore equate with the Cefn Mawr Limestone Formation and their lithology (dark grey packstones) confirms that they should be included in that formation, as must the Craig Rofft Sandstone. **Definition of Lower Boundary:** Base not exposed, but should be taken at entry of sandy limestones and calcareous sandstones above underlying sand-free limestones of the Cefn Mawr Limestone Formation. **Definition of Upper Boundary:** Undulating upper surface of calcareous sandstone beneath a thin, impersistent, calcretised porellanous limestone bed exposed in Craig Rofft Quarry. **Thickness:** 4 to 5m **Geographical Limits:** Great Orme at Llandudno (SH 76 83), North Wales.

Observations

The Craig Rofft Sandstone Mb. is only exposed at a small disused quarry south of Mynydd Isaf peak on the Great Orme, Llandudno. It is up to 5m thick and lies between the uppermost beds of the Loggerheads Limestone Fm. with an erosive contact.

The most easterly exposure evidences that the member may pinch out over 5-10m to the north. At the base it is an orange-coloured, pebbly, coarse sandstone with lenticular bedding. Upsequence, bed thickness and effervescence decrease and organic content increases. The quarry face extends for c100m from east to west in which colour zoning is observed in the sandstone. The pink / red sandstone pinches out c50m to the west and the orange sandstone is gradually replaced by a coarse granular pale brown micrite, the latter of which is the only lithology observed in the south western extension of the quarry.

According to the BGS (2013), the base is not exposed. However, take a look at the outcrop here at Location 4. Do you agree with the BGS?

Most authors attribute this member as belonging to the uppermost sequence of the Loggerheads Limestone Fm. However, the BGS (2013) now attribute it to the Cefn Mawr Limestone Fm. due to the ages of foraminiferal assemblages in the underlying limestones. Take a look around the area, see where the Cefn Mawr crops out and the bedding tracks, and the locations of the outcrops of the red clays. Do you think that these underlying beds are the Cefn Mawr Limestone Fm.?

Fig. 9: Outcrops of the Craig Rofft Sandstone Mb at location 4.: a) multi-coloured sands, b) lenticular thin pebbly bedding (photos: Grundy Ridewood, 2010)

Location 5 – The Cefn Mawr Limestone Fm.

The BGS Lexicon of Named Rock Units - Description
Lithological Description: Thinly interbedded dark grey argillaceous limestones (wackestones and packstones) and mudstones with intercalated thick-bedded to massive, pale shelly limestones (packstones and grainstones) and lenticular, cross-bedded, coarsely crinoidal limestone (rudstone) bodies. Lithologies are arranged in cyclic sequences. Limestones at the top of each cycle commonly display calcrete and palaeokarstic features locally overlain by bentonitic clay palaeosols. Thin chert beds and nodules in upper part; rare sandstone beds. The Cefn Mawr Limestone Formation records principally Brigantian platform carbonate deposition on the North Wales Dinantian shelf. Each cyclic sequence records a shoaling upwards unit developed in response to transgressive and regressive movements in sea level. Many regressions culminated in emergence of the platform surface and formation of calcrete and karstic dissolution features. The sequences of thinly interbedded dark grey limestone and mudstone, diagnostic of the Formation, record deposition during marine transgressions, which repeatedly established deeper platformal conditions than ever prevailed during deposition of the preceding and similarly cyclic Loggerheads Limestone Formation. **Definition of Lower Boundary:** Upper palaeokarstic surface/palaeosol of the Loggerheads Limestone Formation; base of lowest sequence of thinly interbedded, dark grey limestone and mudstones of the Cefn Mawr Limestone Formation. **Definition of Upper Boundary:** Where overlain by the Minera Formation, the top is taken at the base of the lowest sandstone within the latter; where overlain by the Pentre Chert Formation, the top is taken at the disconformable base of the latter. **Thickness:** 40 to 275m **Geographical Limits:** Crops out on Anglesey [SH5080] and the Great Orme [SH7483] (Llandudno) in northwest Wales, in its type area to the east of the Clwydian Range [SJ2063], and at Llangollen [SJ2345] and near Oswestry [SJ2825] in northeast Wales. Also in the Corwen Outlier [SJ0543].

Observations

In Llandudno, the Cefn Mawr Limestone Fm. reaches a maximum thickness of 85m in the west of the Great Orme and 15m in the east. Good exposure is limited to c3m exposed at Parc Farmhouse in the north, and to Bishops Quarry at Maes-y-facrell where c14m of the 60m total thickness at this location is exposed.

The Cefn Mawr Limestone Fm. comprises comparatively thin well bedded very dark brown argillaceous mudstones and wackestones which are rich in very large brachiopods, small gastropods and crinoid ossicles (Fig. 10a). A distinct concentration of the brachiopods occurs in the lower section, wherein an inverted coral is also observed (Fig 10b). At Mynedd Isaf, base beds are a medium brown micritic grainstone containing peloids.

In a few isolated areas of the Great Orme, limited exposures of the Cefn Mawr Limestone Fm. located close to the upper boundary evidence a medium brown micritic grainstone containing peloids. This lithology is very similar to the beds overlying and passing laterally from the Craig Rofft Sandstone Mb. So are these actually upper beds of the Loggerheads Limestone Fm. or upper beds of the Cefn Mawr Limestone Fm. or does the gradational boundary between the two formations disguise the date of deposition of the Craig Rofft Sandstone Mb?

Fig. 10: Macrofauna in the Cefn Mawr Limestone Fm at Bishop's Quarry, location 5.: a) very large productoids observed in the southern side of the quarry; b) overturned colonial coral on the northern side of the quarry (photos: Grundy Ridewood, 2010)

On the walk to location 6, when crossing the tramline, look south at the valley which cuts through the Orme. It passes from Cwlach, through the mine and off to Ogof Hafnant to the north. This is the line of the main Great Orme Fault.

Location 6 – The Red Wharf Limestone Fm.

The BGS Lexicon of Named Rock Units - Description
Lithological Description: Massive or irregularly bedded skeletal limestones (packstones and grainstones), commonly sandy, with abundant chert nodules. The formation comprises a series of shoaling upwards cycles capped by palaeokarstic surfaces commonly overlain by beds of sandstone infilling karstic pipes, or by channel-filling sequences of conglomerate, sandstone and silty mudstone. The Red Wharf Limestone Formation records late Brigantian, mixed carbonate-siliciclastic shallow marine deposition at a time of increased supply of siliciclastic detritus to the North Wales Dinantian platform. Each cycle represents a shoaling upwards sequence formed in response to transgressive and regressive movements in sea level. Many regressions culminated in emergence of the platform surface and the formation of karstic dissolution feartures and of channels that were filled by fluvial conglomerates and sandstone and estuarine mudstones. **Definition of Lower Boundary:** Not exposed, but assumed to be a contact between massive sandy limestones with abundant chert nodules and lithologically more varied limestone sequence of the underlying Cefn Mawr Limestone Formation. The contact is likely to be taken at a palaeokarstic surface developed at the top of the uppermost Cefn Mawr Limestone cycle. **Definition of Upper Boundary:** In its type section, the Red Wharf Limestone Formation is overlain by a 6m-thick unit of bedded cherts, which was previously included in the Formation as the Castell Mawr Chert Member, but which may now be viewed as a local representive of the Pentre Chert Formation. **Thickness:** c.55m **Geographical Limits:** Western side of Red Wharf Bay on Angelsey [SH5381], and Great Orme at Llandudno [SH7483], North Wales.

Observations

The Red Wharf Limestone Fm. is well exposed in the west and east of the Great Orme with minimum thicknesses of 115m and 18m respectively.

At the quarry south of the summit cafe, the base beds comprise fine texture pink-grey granular wackestone. It contains small quantities of lenticular red chert which pass upward to interbedded laminar chert and nodular chert with thin muds. The chert nodules may have formed from precipitation of biogenic silica within burrow structures.

Upsequence, the chert becomes more pervasive and darker in colour, forming both laminar and tangential bedding features suggesting a greater degree of migration (Fig. 11a). The upper sequence is an entirely clastic facies of fine siltstone and sandstone in which the chert becomes whiter and macrofauna, such as branching corals and large brachiopods, become common.

Base beds at the quarry beside the summit car park are fine siltstones and the chert nodules are white and rare. These beds exhibit a vuggy texture (Fig. 11b) similar in characteristics as those seen in the Llanarmon Limestone Fm. at the pier (location 1). What does this tell us about the environment of deposition?

Fig. 11: Textural features of the Red Wharf Limestone Fm.: a) migration of chert at the quarry south of the summit cafe,; b) vugs are infilled with secondary sparry calcite at the quarry beside the summit car park (photos: Grundy Ridewood, 2010)

Location 7 – Summary at the summit cafe

Here, we will have a brief, open discussion to summarise our observations and thoughts regarding the stratigraphic and structural features seen today. Please feel free to contribute – the more ideas and hypotheses we can accumulate, the more insight we can gain!

And finally…

I do hope that you have enjoyed your day, and that this trip has succeeded in sparking your interest in the geology of the Great Orme ☺

Fig. 12: Evening sunshine highlights the Loggerheads Limestone Formation, the Leete Limestone Formation and the Llanarmon Limestone Formation, at Hornby Cave in the north-west of the Orme. Note the wave-cut platform in the latter, oldest formation (photo: Grundy Ridewood, 2010).

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