YORKSHIRE GEOLOGICAL SOCIETY

Cadeby Formation (Upper Permian) of the Boston Spa-Thorp Arch area

Leaders

Alison Tymon, Doug Holliday and Michael Mawson

and members of the Boston Spa and District Geological Research Group and

the West Yorkshire Geology Trust

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INTRODUCTION

The Upper Permian Cadeby Formation (formerly Lower Magnesian Limestone) is exposed at numerous localities in the area around Wetherby and Boston Spa. In addition to a plethora of small 18th and 19th century quarries for building stone, there are several large road and abandoned railway cuttings which supplement data from the natural sections in the banks of the River Wharfe. It is surprising, therefore, that there is no detailed published account of the geology of this area and that few of the exposures have been described and studied in detail. The formation is divided into two members (Wetherby and Sprotborough) and both are well exposed in the area. The numerous, well displayed exposures of the Hampole Beds at the base of the Sprotborough Member is one of the more significant features of these localities.

The Boston Spa and District Geological Research Group (BADGERS), mainly comprised of local amateur geologists, has been established with the aim of locating, restoring, measuring and describing these sections. They intend to provide for the first time a complete, permanent record for posterity of this great wealth of geological data, while it is still accessible, in order to provide a more complete knowledge and a greater understanding of the geological history of the area. Together with the West Yorkshire Geology Trust, an interpretation board has been installed at a locality in Boston Spa and an explanatory leaflet explaining and illustrating the local geology has been issued. The purpose of this excursion is to demonstrate the current state of progress of this on-going work and to make it known to a wider audience.

PALAEOGEOGRAPHY AND STRATIGRAPHY

Throughout much of Permian time (*c*. 300-250 Ma), the Boston Spa district was largely an area of non-deposition in an arid desert. Locally, thin breccias were formed from loose rock material eroded largely from the underlying Carboniferous rocks. In some places, small aeolian sand dunes were formed. The district was on the western edge of a large inland depression, much of which was below contemporary sea level, in the area of the present-day Southern North Sea. Here dune sand, wadi and salt lake deposits were laid down.

However, in Upper Permian times, around 260 Ma, the sea broke into this depression from the north totally transforming the geography and nature of the rocks formed. The land-locked basin became a sea (Zechstein Sea) extending from the Pennines in the west to Poland and the Baltic States in the east. The Zechstein Group of eastern and north-eastern England contains the carbonate and evaporite sedimentary accumulations of this sea and their related marginal terrestrial deposits. One of the main features of the group is the evidence it provides for several marine transgressions and intervening periods of low sea level or even total withdrawal. During periods of high sea level, carbonate sedimentation was dominant; at times of lower levels, gypsum, anhydrite, halite and, more rarely, potash salts were laid down and terrestrial sedimentation spread into the basin from the margins. Throughout the deposition of the group, the climate remained dominantly arid, though some plant remains have been found suggesting vegetation was able to survive locally in the surrounding dry landscape as in modern deserts. The salinity of the seawater was probably above normal marine levels

(hypersaline), particularly in shallow marginal areas. During phases of evaporite deposition, the salinity of the sea water and of the sediment pore waters would have been even more greatly enhanced.

The deposits of the initial marine incursion into the Wetherby area comprise the **Cadeby Formation**. During its deposition, in eastern Yorkshire and the North Sea, the sea is thought to have been relatively deep, but nearer to the western margin of the basin, including the Boston Spa district, shallow water sedimentation is evident. From the preserved rock record in Yorkshire and adjacent areas, it has been possible to deduce in the middle part of the formation a period of slightly lower sea level and temporary terrestrial exposure close to the basin margin. The rocks around Thorp Arch and Boston Spa provide particularly good evidence of this.

The lower part of the Cadeby Formation, **Wetherby Member** (<40 m thick), contains bedded dolomite with bryozoan-microbial patch reefs and stromatolites at many localities. The beds are commonly oolitic and pisolithic. Around Boston Spa, much of the member is of near-shore, shallow marine to intertidal origin, with a broad shallowing upwards trend to tidal and supratidal flat deposition in the highest beds. The junction between the two members is taken at a significant break in sedimentation, the **Hampole Discontinuity** (Front Cover; Figs 1, 2).

The basal part of the overlying **Sprotborough Member,** the **Hampole Beds**, which overlie the discontinuity, formed during an extended marine lowstand, a period of relatively low basin wide sea-level and subaerial exposure in marginal areas. The overall fall may have been at least 5 m and the Hampole Discontinuity is thought to have formed at the time of lowest sea-level. The thin clastic beds (i.e. clay, silt or sand) within the Hampole Beds may be fluvial in origin, represent palaeosols or consist of aeolian dust, deposited in water; whatever their origin, they are indicative of periods of subaerial exposure. In contrast, the carbonate beds within the Hampole Beds are thought to have been deposited in sabkhas and semi-restricted lagoons (c.f. the modern tidal flats near Abu Dhabi) and represent brief periods of marine incursion. The relatively small amount of terrigenous sediment in the Hampole Beds probably reflects the arid climate of Upper Permian times (little erosion and limited supply of clastic material) and this may also explain the lack of significant dissolution in the underlying carbonate rocks.

Similar tidal and supratidal depositional conditions appear to have continued during the formation of the lowest part (1-2 m) of the Sprotborough Member above the Hampole Beds. From the sections we have examined in the Wetherby-Boston Spa area, the presence of numerous calcite pseudomorphs after gypsum within the laminae of these beds is suggestive of significant penecontemporaneous evaporite formation as in the modern sabkhas around Abu Dhabi.

Much of the remainder of the Sprotborough Member (<40 m thick) comprises cross-bedded oolitic dolomite deposited as subaqueous sand waves, indicative of a return to deeper water (thought to be at least 12 m) sedimentation. The predominant current movement was from the NE. The topmost few metres of the Sprotborough Member (not seen in this excursion) are

dominated by algal laminates indicative of another lowering of basin sea level. This marine withdrawal was more substantial than the earlier regression and terrestrial and evaporite sedimentation (**Edlington Formation**) spread over the district. Exposures of this latter formation around Thorp Arch are now sadly few and of poor quality.

DIAGENESIS AND MINERALISATION

Prior to uplift and erosion, the Cadeby Formation was overlain by evaporitic strata and was proximal to the thick evaporite-bearing strata of eastern Yorkshire. Thus, throughout its burial history the formation was subject to the influx of highly saline migrating fluids which had the ability to modify the composition and character of the rocks. Hence, all the rocks to be seen have undergone varying degrees of diagenetic alteration. Despite their complex history, in many places, the original depositional textures and sedimentary structures are still well preserved.

The original deposits were dominantly composed of the $CaCO_3$ minerals, aragonite and calcite, though aragonite usually undergoes rapid transformation to calcite. The most significant change was the conversion of calcite to dolomite, $CaMg(CO_3)_2$, due to the introduction of saline, Mg-bearing fluids. Dolomite rock (sometimes called dolostone) remains the most important lithology at the exposures to be visited. The timing of dolomitisation ranges from contemporaneous with deposition to much later during burial by younger evaporite-bearing sediments. In tidal and more especially supratidal sediments, interstitial growth of gypsum ($CaSO_4.\ 2H_2O$) and perhaps anhydrite ($CaSO_4$) within the stromatolitic laminae occurred. Around Thorp Arch, these sulphate minerals have not been preserved as such but examples can be seen where they have been replaced (locally pseudomorphed) by calcite. Locally, Mg has been leached from the rocks, dolomite replaced by calcite, and the rocks converted back to limestone, a process known as dedolomitisation.

At various times in the burial of these rocks, localised dissolution of carbonate and sulphate minerals led to the formation of irregularly-shaped open vugs. In the subsurface, the vugs are commonly wholly or partially infilled by carbonate minerals and by gypsum and/or anhydrite but at outcrop the calcium sulphate minerals have been removed by relatively recent groundwater dissolution. Dissolution of carbonate by groundwater continues to the present-day and at most outcrops there is evidence for the widening of joints and the formation of mini-karst systems.

The Cadeby Formation at outcrop locally features subeconomic syngenetic and epigenetic Pb-Zn-Cu-Fe-Ba-F mineralisation. Local attempts have been made to exploit these deposits, e.g. near Knaresborough. Pb-Zn-Fe sulphides occur in vugs and breccias of sedimentary origin whereas much baryte ($BaSO_4$) replaces the host carbonate. Vein mineralisation is rare. Host carbonates appear to overlie major cross-cutting structures in pre-Permian strata; these structures were possible flow channels for mineralising solutions. These occurrences are probably part of the more extensive mineralisation of Carboniferous rocks in the Pennines in which deep circulation of brines derived from the Zechstein Group played a major role.

RIVER WHARFE, UPSTREAM OF THORP ARCH

A walk upstream along the left bank of the River Wharfe provides views of the scattered and only partially accessible exposures of strata in the middle to upper part of the Wetherby Member on the opposite bank of the river. The rocks more clearly visible are dominantly near-shore peritidal and open shelf bioclastic and oolitic carbonate rocks with some prominent bryozoan microbial patch reefs. The higher beds, less visible from the left bank, are suggestive of shallower water origin, and may include the Hampole Beds. The more accessible sections are also under current examination by the group, but due to the steepness of the ground, are unsuitable for visits by large parties.

FRONT WOOD QUARRY

Following recent clearance of the site, the previously undescribed section at Front Wood, Thorp Arch [4308 4605], is presently very well displayed. Here, the topmost 4 m of the Wetherby Member, the Hampole Beds (*c.* 1 m thick) and a further 3-4 m of the Sprotborough Member are exposed (Figs 1, 2).

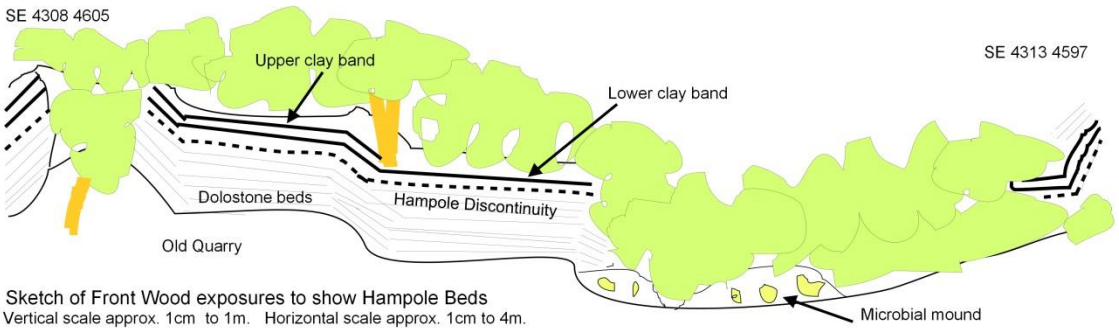

Fig. 1. Sketch geological map of Front Wood Quarry

Bed FW1 contains some broken shell fragments and shows medium-scale cross-bedding, suggesting that all of much of it was deposited under at least a few metres of water. However, the higher part of FW1 and all of FW2 are oolitic grainstones, bound by microbial laminae, with sporadic small-scale tepee structures (hopefully to be demonstrated during the excursion), indicative of a shallower, subtidal, intertidal and supratidal (sabkha) origin. The bedding plane between FW1 and FW2 varies in prominence along the exposed face; no clay has been found at this level but at some places there is a suggestion of minor erosion at this level.

Beds FW3, 4, 5 and 6 have been interpreted as comprising the Hampole Beds. In their thickness and overall character, the Front Wood exposure of the beds closely matches the published details of the type locality and other designated sections. The sharp, well-marked

junction between FW2 and FW3 is taken as the Hampole Discontinuity (Front Cover). There is evidence of some erosion having taken place at this boundary and a thin clay (<1 cm thick) is locally present. (Elsewhere in Yorkshire, there is greater relief, <1 m, at this level.) Bed FW3 is a finely laminated oolitic grainstone, with fenestrae and tepee structures, similar to FW2. It has three distinct continuous partings which contain thin clay layers >1 cm thick. FW5 is a laminated oolitic packstone with many grey or yellow clay intraclasts up to 1 cm in length. There are two distinct partings with thin clay layers between each. Sporadic small (1mm) vugs are present and also stylolites and vertical joints, infilled with manganese oxide.

Above the Hampole Beds, Bed FW7 is also divided by two prominent partings. The basal part of FW7 is a laminated wackestone with hollow ooliths and fenestrae up to 2 cm in length. This part of the bed is partially broken and brecciated. Higher in FW7, the rocks are much more competent and comprise laminated grainstone with fine ooliths and rare fenestrae. FW7 is separated from the overlying FW8 by a thin yellow clay. FW8 is a laminated grainstone, with ooliths up to 1 mm in diameter. Between the laminae, calcite crystals, some pseudomorphs after gypsum, are commonly present; also tepee structures and many thin calcite filled joints. Weathering of the rock has given it a characteristic rough, porous appearance. Above FW8, recent clearance of the site has revealed an additional 1.5-2 m of oolitic grainstone, FW9. The lateral equivalents of FW7, FW8 and FW9 are more accessible for examination at the next locality.

BRIDGE FARM, THORPE ARCH

The lower beds of the Sprotborough Member are particularly well exposed in cliff and small quarry sections on either side of the road at Bridge Farm [432 460] (Fig. 3) and in the adjacent road cutting leading from Boston Spa up the hill from the bridge into Thorp Arch. The precise correlation of these strata with those seen at Front Wood is still under review. Our current view is that the lowest beds seen here are just above the Hampole Beds; the oolitic grainstones of BF1 and BF2 being equated with FW7. The yellow clay between BF2 and BF3 is correlated with that separating FW7 and FW8. BF 3 is a laminated planar bedded oolitic grainstone and, as in its inferred correlative FW8, crystalline calcite (some forming pseudomorphs), apparently replacing gypsum, is a prominent feature. Mineral-coated tubes, < 6 mm in diameter, probably made by burrowing worms contemporary with deposition, are locally a common feature of these beds. Higher strata, BF4 and those in the nearby road cutting, exhibit medium to large-scale cross bedding indicative of a return to open shelf desposition.

BRAMHAM

If time permits, and there is sufficient interest, a road cutting at Bramham [427 425] will be visited where the Sprotborough Member, and perhaps the top part of the Hampole Beds, are

exhibited. The succession exposed is much the same as that seen at the previous locality. However, here, details of the stratigraphy and sedimentology are less clear as the strata are much broken up and replaced by strong baryte mineralisation.

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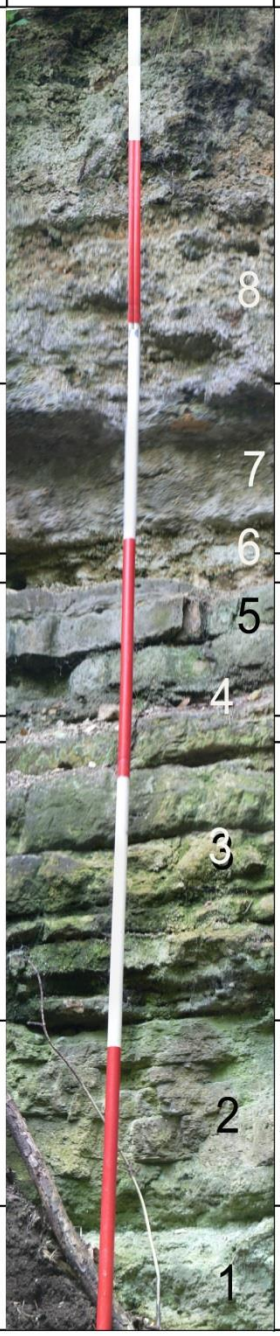
Unit number and thickness (cms)	Weathering profile	Lithology and nature of contact	Colour	Structures	Textures
9 ≈ 160+		Dolostone		Thin wavy beds. Laminae, with tepee structures and vugs.	Ooidal
8 96		Dolostone Very thin yellow clay at base	Ochre, dark orange	Thinly bedded. Characteristic rough, porous, surface weathering. Many thin calcite-filled joints. Tepee structures and vugs, particularly at the base.	Grainstone, very porous at base, Ooids up to 1mm. Laminae 3-5mm wide. Calcite pseudomorphs after gypsum, widespread vugs and infilled veins of calcite at base of unit.
7 28		Dolostone Sharp base	Pale yellow	Three beds, lowest is finely bedded and broken. Middle and upper beds are competent. Linear vugs in middle bed.	Upper and middle beds grainstone with laminae, gypsum pseudomorphs and small vugs. Middle bed has small fenestrae. Lower bed wackestone with fenestrae.
6 5		Clay	Cream		
5 42		Dolostone Sharp base	Pale cream or pale yellow	3/4 main beds, thinly bedded with wavy bedding. Thin clay layers between each. Stylolites and vertical joints, infilled with manganese.	Packstone with clay intraclasts, laminated with wackestone beds. Laminoid fenestrae up to 3cm.
4 0-2		Clay	Cream		
3 61		Dolostone Sharp base, hint of erosion. Icm cream clay in places along contact.	Yellow	Thinly bedded, with 3/4 major bedding places, thin clay layers>1cm between beds. Many 1mm microbial laminae, very closely spaced, tepee structures. Large fenestrae up to 2cm long.	Grainstone with fine hollow ooids inter-bedded with 1mm microbial laminae. 1mm birds-eye fenestrae in grainstones. Laminoid fenestrae, 1-5mm height, 0.5-2cm length, in microbial laminae.
					HAMPOLE DISCONTINUITY
2 56		Dolostone bedding plane varies in prominence. No clay was found. There is a hint of erosion at the base.	Dark yellow	Medium bedding, with consistent thickness. Common microbial laminae with tepee structures.	Grainstone with fine ooids, many hollow. Wavy laminae 1-5mm thick, very closely spaced. Common birds-eye fenestrae.
1 ≈ 350+		Dolostone	Cream, yellow	Very thinly bedded. Microbial laminae with tepee structures. Some cross-bedded sets. Rare broken shells. Fine stylolites.	Grainstone of fine hollow ooids. 2-3mm wavy laminae about 1cm apart. Common birds-eye fenestrae.

Fig. 2. Section of strata at Front Wood Quarry

Fig. 3. Section of strata at Bridge Farm

Unit number and thickness (cms)		Lithology and nature of contacts	Colour	Structures	Textures
4	120+	Dolostone Channelling	Yellow	Horizontal non-parallel beds from 5-15cm thick, some wedging out. Small scale cross-bedding and channelling. Occasional vugs lined with calcite crystals. Laminae seen in some beds.	Grainstone with fine ooids, many hollow. Small calcite pseudomorphs after gypsum. A few thin veins with manganese.
3	143	Dolostone Vuggy base	Dark yellow	Horizontal planar bedding 10-15cm. Laminae.	Grainstone with very fine ooids. Laminae marked by calcite pseudomorphs after gypsum with small vugs and lines of coarser hollow ooids.
2	0.5 - 4	Clay	Grey/yellow		
1	19+	Dolostone	Very pale yellow	Upper bed competent with a few small vugs. Lower bed very weathered with irregular bedding, contains large vugs filled or lined with calcite crystals.	Upper bed grainstone with very fine ooids. Lower bed packstone with very fine ooids. Both have very thin irregular veins with manganese.

Log at Bridge Farm, Thorp Arch SE 4331 4576 May 2013