THE GEOCHEMISTRY AND ENVIRONMENTAL EVOLUTION OF THE HAMPOLE BEDS AT THE TYPE AREA OF THE CADEBY FORMATION (LOWER MAGNESIAN LIMESTONE)

by

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Summary

The Hampole Beds sequence within the type area for the Cadeby Formation is shown to have been deposited over a discontinuity with a magnitude of undulation greater than that usually observed at other Hampole Beds exposures. The depositional environmental history is assessed and shown to have been of mostly supra- or inter-tidal character punctuated by periods of estuarine deposition and subaerial exposure producing a tidal flat in which diagenetic changes occurred. These changes included dolomitisation probably compatible with the evaporite-brine residue model for an arid type sabkha. At time of deposition, the Pot Riding Wood locality was probably at a level of slightly below that of the surrounding region.

Introduction

The Lower Magnesian Limestone is a sequence of upper Permian age dolomitic limestones outcropping in a narrow belt running roughly north-south from near Nottingham to the south of Northumberland. It was first mapped by William Smith in the early nineteenth century and first fully described by Sedgwick (1829).

Permian stratigraphic nomenclature has recently been revised (Smith *et al.* in press) with the re-naming of the Lower Magnesian Limestone as the Cadeby Formation and the lower and upper sub-division being given the names Wetherby and Sprotbrough Members respectively.

The Hampole Beds are a thin sequence of strata located at the junction between the upper and lower sub-divisions of the Lower Magnesian Limestone. They were first noted by Mitchell *et al.* (1947 p. 122–123) at Hampole Limeworks Quarry (515 097) but first defined by Smith (1968).

The exposure described in this paper is located along a cutting of the disused South Yorkshire Junction Railway in woodland known as Pot Riding in the Don Gorge near Doncaster between 527 003 and 530 007 (see Fig. 1) within the type area of the Cadeby Formation as proposed by Smith *et al.* (1974). A brief reference to a "large lense of red marl in woods south of Spotbrough station" in Mitchell *et al.* (1947 p. 115) appears to be the only published details of this exposure, although nearby quarries have been studied recently, notably by Smith (e.g. 1968 pp. 469). A geochemical analysis in Mitchell *et al.* (1947 p. 123, analysis 4) may represent the Lower Dolomite in the Hampole Beds and is the only published analysis from the Hampole Beds prior to this work.

The aims of this paper are threefold, (1) to provide the first comprehensive geochemical account of the Hampole Beds, (2) to assess the environmental history of the Hampole Beds at the type area for the Cadeby Formation, and at a locality where the sequence is typically developed, (3) to test the evidence for the placing of the dividing line between the two members of the Cadeby Formation.

The structure of the beds in Pot Riding is for the most part a simple shallow dip of less than 10°E but which is difficult to evaluate exactly due to the undulating nature of bedding planes. A broad shallow syncline exists over much of the northern part of the Pot Riding locality. In the south, however, there exists a spectacular asymmetric anticline of 5 m amplitude and 25 m wavelength, on whose steeper northern limb, the beds reach dips up to 30°.

Mercian Geologist, vol. 10, no. 2,
Mar. 1986, pp. 115–125, table 1, + 5 figs.

TABLE 1		1a. WHOLE ROCK (OPEN ACID) ANALYSIS.												1b. ACID LEACH (CARBONATE ANALYSIS).						1c. RESIDUE CALCULATION (NON-CARBONATE ANALYSIS).					
		CaO %	MgO %	A1203 %	FeO %	SiO2 %	K2O %	Mn PPM	Na PPM	P PPM	Sr PPM	Cu PPM	Pb PPM	CaO %	MgO %	FeO %	Mn PPM	Na PPM	K PPM	CaO %	MgO %	FeO %	Mn PPM	Na PPM	K PPM
UPPER MUDSTONE	UM1	26.3	13.2	2.65	0.56	12.5	0.7	400	195	25	19	3	7	25.9	13.1	0.37	340	145	930	0.4	0.19	0.19	60	50	6070
	UM2	29.4	13.9	2.3	0.56	4.8	0.96	400	230	100	13	6	13	29.4	13.7	0.39	326	151	720	>0.1	0.16	0.17	74	79	8880
	UM3	29.4	15.3	2.07	0.47	1.74	0.34	495	215	55	13	1	7	29.4	15.2	0.34	425	141	590	>0.1	0.16	0.13	70	74	2810
UPPER DOLOMITE	UD1	30.8	13.9	0.57	0.34	4.74	0.12	480	135	15	26	3	7	30.8	13.9	0.24	410	125	380	>0.1	0.05	0.1	70	10	820
	UD2	30.8	15.6	0.13	0.35	0.62	0.02	500	120	50	23	>1	7	30.7	15.6	0.31	470	120	230	0.1	0.1	0.04	30	10	>1
	UD3a	29.4	15.6	1.5	0.41	1.41	0.36	430	235	60	22	1	6	29.4	15.5	0.28	395	166	800	>0.1	0.12	0.13	35	69	2800
	UD3b	12.6	9.2	10.3	1.19	38.4	3.13	200	465	225	10	5	3	12.6	8.45	0.71	175	116	1990	>0.1	0.79	0.48	25	349	29310
	UD3c	23.2	14.3	3.75	0.66	17.6	0.82	430	280	110	19	3	6	23.1	14.0	0.5	385	130	1310	>0.1	0.29	0.16	45	150	6890
	UD3d	29.0	16.5	0.09	1.14	0.23	0.05	520	190	15	18	>1	7	29.0	16.5	0.45	440	175	240	0.1	0.01	0.69	80	15	260
MIDDLE MUDSTONE	MM1	15.4	9.6	8.5	1.55	32.6	3.73	290	265	275	16	10	7	15.4	9.05	0.81	220	130	2210	>0.1	0.6	0.74	70	135	35090
	MM2	15.4	10.2	7.9	1.43	32.8	2.65	285	465	215	16	3	6	15.4	9.6	0.78	240	180	1890	>0.1	0.56	0.65	48	285	24610
	MM2t	11.9	9.1	11.9	1.67	36.1	4.82	225	550	90	13	11	7	11.9	8.3	0.71	192	1562	400	>0.1	0.84	0.96	33	394	45800
	MM3	11.2	8.9	11.5	1.78	39.7	4.56	260	510	350	13	7	10	11.2	7.65	1.07	205	90	3230	>0.1	0.85	0.71	52	420	42570
	MM3t	25.2	13.9	1.32	0.61	13.8	0.55	470	200	75	16	5	10	24.6	13.9	0.4	405	120	450	0.6	0.1	0.21	65	80	5050
LOWER DOLOMITE	LD1	29.4	13.1	1.97	0.61	7.79	0.6	480	220	50	15	1	7	29.4	12.9	0.38	405	134	690	>0.1	0.15	0.23	75	80	5310
	LD2	25.8	13.6	3.3	0.7	11.6	0.89	435	210	60	15	1	8	25.2	13.4	0.3	375	141	770	0.65	0.25	0.4	60	69	8130
	LD3	29.4	15.2	2.1	0.51	1.79	0.5	455	220	60	19	>1	6	29.4	15.1	0.34	420	134	720	>0.1	0.16	0.16	37	86	4380
LOWER MUDSTONE	LM1	2.31	2.4	24.6	3.1	56.8	7.3	120	1080	850	22	53	25	2.31	0.81	0.38	40	111	1710	>0.1	1.6	2.72	80	969	71290
BASAL DOLOMITES	BD1	25.9	15.4	3.25	0.76	5.96	0.96	430	150	105	17	3	7	25.9	15.1	0.56	380	140	870	>0.1	0.25	0.2	50	12	8730
	BD2	29.5	14.8	2.65	0.71	0.95	0.94	405	270	90	15	1	6	29.4	14.9	0.41	375	136	1650	>0.1	0.17	0.3	29	136	2750
	BD3	15.4	10.4	11.5	2.84	30.8	3.81	310	555	175	20	1	7	15.4	9.63	0.44	235	141	2800	>0.1	0.81	2.4	75	414	35300

Table 1. The sample codes are given for reference with the figures. The letters represent the lithostratigraphic horizon, and the numbers refer to the three collecting localities along the exposure, which are marked on Fig. 1, the sketch map.

The whole rock analyses represent analyses of the total rock, i.e. all mineralogical components. The acid leach analyses refer to the carbonate component only and the residue calculation refers to the non-carbonate component (e.g. quartz and clays). The residue values were calculated by subtracting the acid leach from the whole rock analyses.

(See pp. 120–123 for discussion of these analyses).

Lithostratigraphy

1. Wetherby Beds

Five metres of topmost Wetherby Member are exposed in the Pot Riding cutting. From base to top there is a transition from cross-bedded to parallel laminated oolitic dolomite, coupled with a decrease in bed thicknesses. A minor erosion surface, 30 to 100 cm below the top, is overlain by 20 cm of green silts and coarse grained dolomites which are absent in the north and then by up to a metre of thinly bedded oolitic dolomite (cross-bedded at base, parallel laminated at top) locally replaced by irregulr masses of algal boundstone.

The top of the Wetherby Member is eroded, the erosion surface having an undulation up to 2.5 m in magnitude in the Pot Riding cutting. This is the Hampole Discontinuity which elsewhere has an undulation not exceeding 30 cm. It constitutes an important marker horizon at the base of the overlying Hampole Beds sequence and is described by Smith (1968 p. 465) as a "generally concordant, gently undulate plane". The erosive phase it represents must this have been more severe at Pot Riding than elsewhere producing a relatively large degree of undulation and several small cliffs, clearly visible in Cadeby Quarry (523 015) where they have been noted by Smith (1981 p. 191).

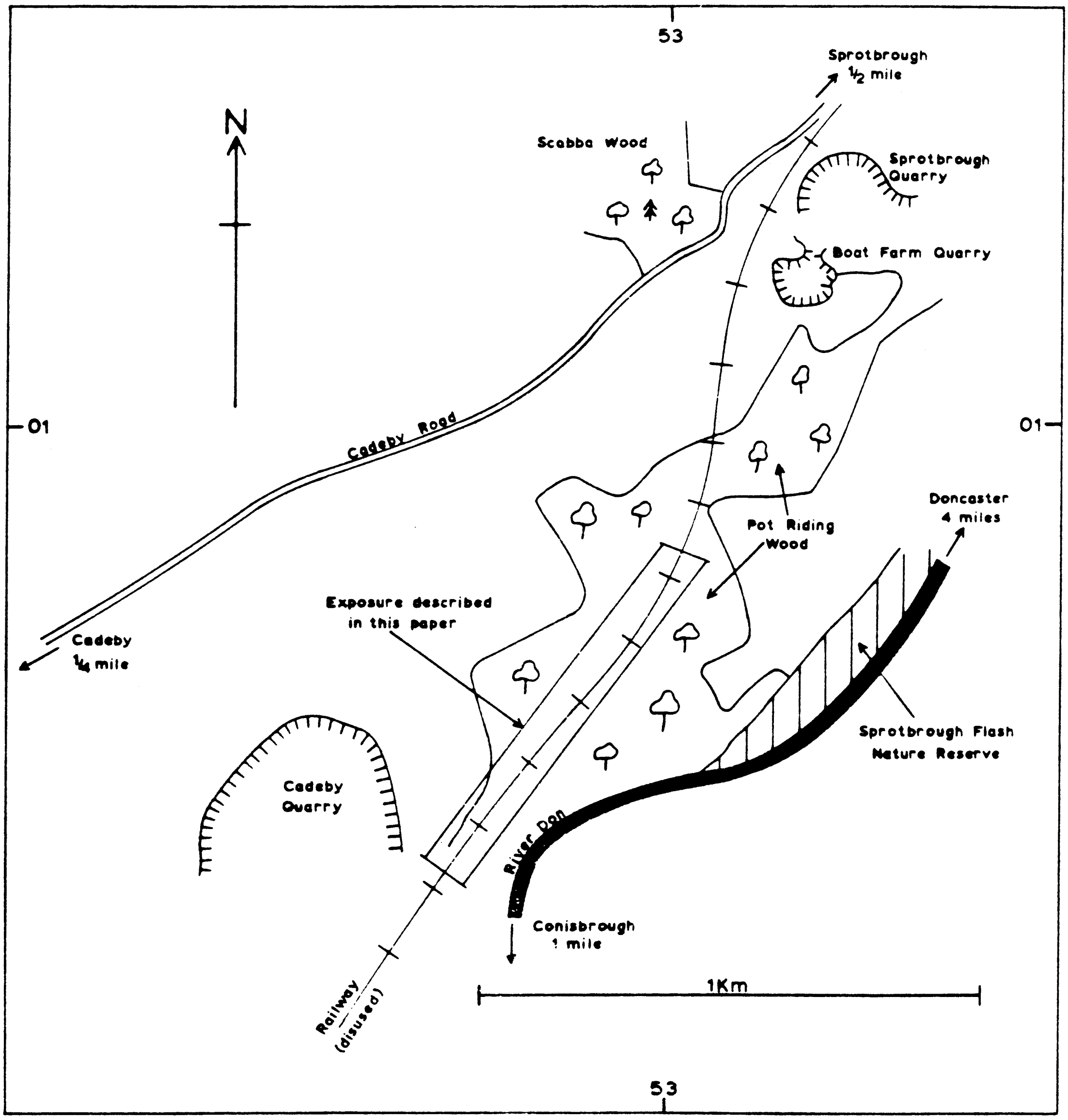

Fig. 1. Locality map.

2. The Hampole Beds

The Hampole Discontinuity is progressively overstepped by the Hampole Beds which vary in thickness from 1 to 4 m at this locality.

(i) *The Basal Dolomites* (0 to 2.5 m). These are absent at the type locality of the Hampole Beds at Hampole Limeworks Quarry (Smith 1968 p. 465) but occur on the west side of the Don Gorge, occupying the lowest parts of the discontinuity surface. They consist of a number of cyclic repetitions (three of which are exposed here the base being obscured) of cross-bedded oolitic or pelletal micrite dolomites in 30 to 50 cm beds (sample BD1 of Table 1). They are often reddened, dendritic (sample BD2) and with a dessication brecciated top. The micritic dolomite units are overlain by fissile soft, brick red, dolomicritic silts (sample BD3) from 5 to 20 cm in thickness and eroded at top.

(ii) *The Lower Mudstone*. This unit consists of a 1 to 5cm green silt, draped over a slightly undulating minor erosion surface overlying the Basal Dolomites. A sharp colour change from red to green marks its appearance over the Basal Dolomites. The top is locally stained brown.

(iii) *The Lower Dolomite* (0 to 5cm). This unit is locally bioturbated at base with scattered grooves, especially in the south. Parallel lamination and ripple marking on bedding planes is increasingly prominant upwards and the top is locally reddened. The lamination, picked out by streaks of green silt, is an alternation of calcitic and dolomitic laminae and is disturbed by scattered micrite filled domal structures (stomatolites of the LLH mode and S form of Logan *et al.* 1964). There are numerous shrinkage type birds-eye vugs (cf. Shinn, 1968 p. 215) and rare recrystallised brachiopods. The unit thins out north becoming a mass of interlocking breccia-like fragments and locally an algal boundstone of dolomite breccia.

(iv) *The Middle Mudstone* (3-30cm). This is a complex unit which overlies the Lower Dolomite northwards and is thickest in the cental part of the exposure infilling a palaeo-hollow which may have been 50cn deep by 8m wide. Green calcareous silts occur at the base (samples MM1, 2 and 4). These are reddened in the top 15 to 20cm (sample MM2t). This is overlain by 10cm of green silts identical to those below the reddened horizon. In central parts only the silts are overlain by fissile algal dolomite containing fenestral sheet cracks and birds-eye vugs. These are locally overlain by a number of channel fill dolomites (sample MM3t) varying in width from 30cm to 6m across, each eroded at top and overlain by a thin green silt.

(v) *The Upper Dolomite* (0.2-2m). This unit is thickest in the south (up to 2m) where it is divisible into 3 sub-units, the lowest of which is the most laterally persistent and is considered to be the lateral equivalent of the Upper Dolomite elsewhere.

The lower sub-unit (samples UD1, 2 and 3a) is 1m thick, locally bioturbated, oolitic dolomite. There is a transition from cross bedding at the base to parallel lamination at the top and the beds thin northwards. The topmost bed in the north contains numerous solution-enlarged vugs and may represent the lateral equivalent of the middle and upper sub-units in the south. The middle sub-unit is fissile, soft, green, calcareous silt (sample UD3b) up to 14cm thick. Locally small channels, up to 8cm deep, are cut into the top of the silts. These are filled with initially micro-cross bedded and then parallel laminated medium grained dolomite (sample UD3d) locally bioturbated and with dessication-cracked thin green silts draped over some of the bedding planes.

(vi) *The Upper Mudstone*. In the north this unit is a thin bed of coarse grained parallel-laminated dolomite with many solution-enlarged vugs. Southwards it consists of fissile dolomites with intervening thin green silt films, locally there are lenses (up to 3cm deep by 10cm long) of calcareous sandstone in the very south of the exposure.

3. The Sportbrough Member

1 to 5m exposed in the Pot Riding cutting. The lowest beds of the Sprotbrough Member overlap, to the north, a minor erosion surface at the top of the Upper Mudstone. They are parallel laminated at base and remain so for several metres in the north but become well cross-bedded within 20cm of the base in the south.

A diagrammatic summary of the Pot Riding exposure is given on Fig. 2.

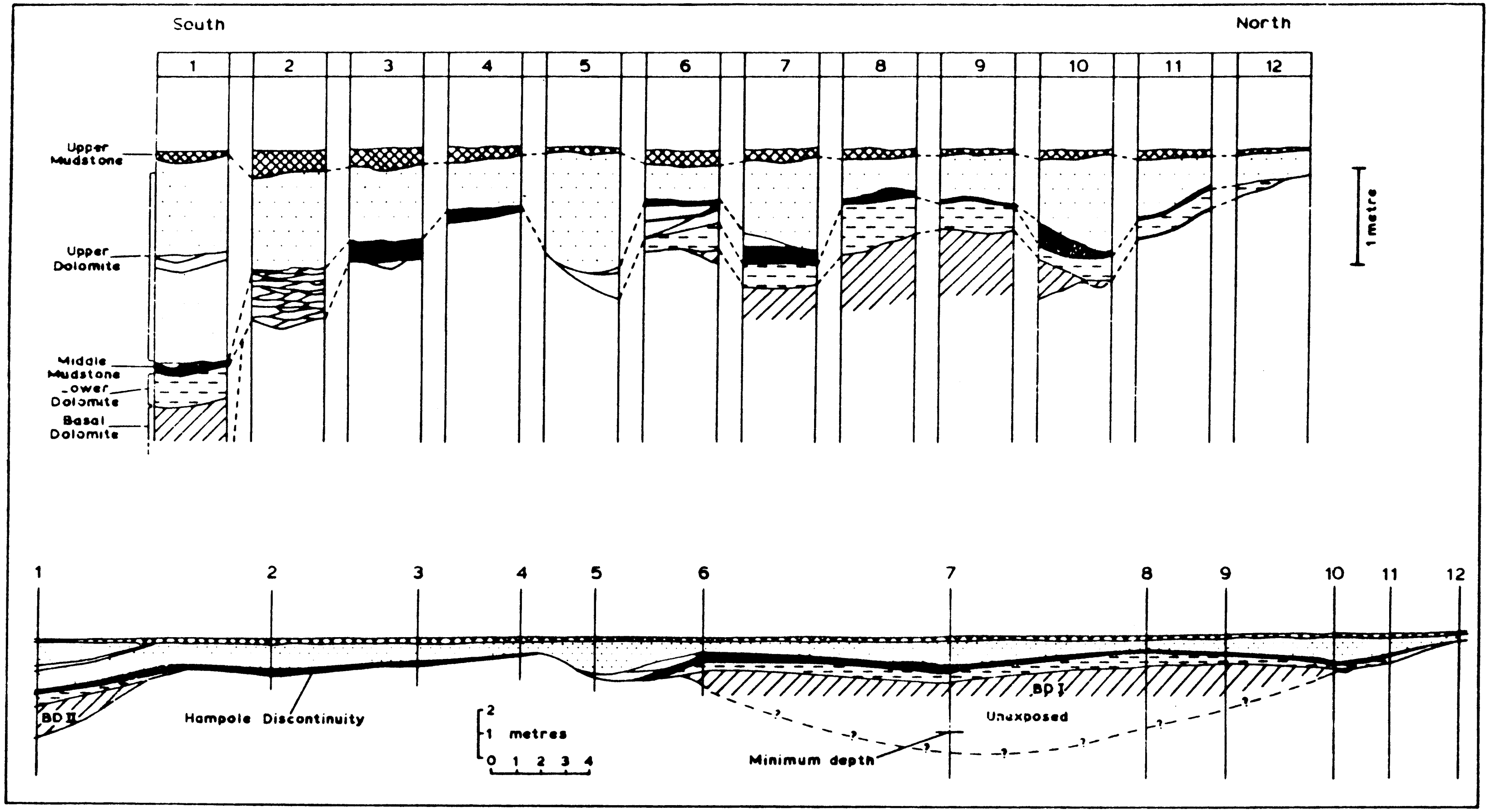

Fig. 2. Diagrammatic section and logs.

The cross-section is an accurate reconstruction of the Pot Riding exposure in which the top of the Upper Mudstone has been taken as datum horizontal. In reality it is folded. Vertical logs are also given for sequence detail and their positions are shown on the section by way of reference numbers 1, 2, 3, etc. The lateral thickness variations of the unit of the Hampole Beds is easily seen, as is the overlap relationship to the Hampole Discontinuity. Note also the general thickening of the sequence southwards.

Geochemical Techniques

Twenty one samples were taken from three sampling localites along the Pot Riding cutting. These were chemically analysed for those components shown on Table 1. In addition, hand specimens were examined under a microscope, along with crushed sample powders and the insoluble residues (e.g. quartz grains) left after treatment of the sample powders with 50% hydrochloric acid to destroy the carbonate component of the rock.

After crushing and drying, open acid (HF 48%) and acid leach (using conc HCl) digestions were performed and the resultant solutions were analysed by Atomic Absorption Spectrometry for all components on Table 1 except silicon and phosphorous. These were determined colourimetrically. The solutions for silicon were prepared by fusion with lithium metaborate.

The open acid results, with silicon included, represent a whole rock analysis and are given in Table 1 (part a). The acid leach analysis represents the carbonate fraction only (Table 1, part b). A third set of data calculated by substacting the acid leach from the open acid, represents the non-carbonate component and is given as Table 1 (part c). (Table 1 is on p. 116).

Environmental Interpretation

The character of the depositional environment is reflected by the syn-depositional mineral content, which comprises a marine derived carbonate component (originally aragonite and/or calcite) and a combined estuarine and aeolian derived clastic component including quartz, muscovite, clay minerals, small amounts of biotite, garnet, pyroxene, tourmaline, collophane and some grains of the haematite and plagioclase/K-feldspar).

The clastic component is considered to be either estuarine or aeolian or both because the insoluble residue from all beds is composed of a mixture of clay particles, mica flakes and silt to fine sand grade quartz grains, predominantly frosted. In addition, the silicate and carbonate components when plotted against each other reveal trends with negative correlations. This could be interpreted two ways, either the two components were derived from the estuarine (silicate) and marine environments (carbonate), or the silicate was deposited in the marine environment during periods when carbonate deposition was suppressed by unfavourable environmental conditions. The frosted grains and the association of the silt in beds exhibiting sedimentary structures is interpreted as being inter- or supra-tidal. The author favours a combined aeolian/estuarine origin for most of the silicate, although some may probably have been marine.

There is a continuous spectrum of environments between the aeolian/estuarine and marine environments and the sample represent various degrees of inter-mixing. If the acid leach CaO is taken to represent the marine component of the depositional environment and open acid $A1_2O_3$, SiO_2 to represent the estuarine/aeolian component then it possible to assign a relative value to the degree of intermixing by plotting one against the other. The trend obtained probably represents a continuous spectrum, but in Fig. 3 the samples fall into three distinct groups. These correspond with the estuarine, estuarine-lagoonal and inter- to supra-tidal environments.

The grouping of the plots could be a product of:–

A. Removal of intermediate strata by erosion to give apparent rapid change.

B. Rapid change in the depositional environment.

C. Sample bias, since the samples represent average compositions of a unit for each collecting locality.

The uniformity of unit composition along outcrop suggests the latter to be of little or no consequence. The erosion surfaces that frequently occur at the top of many units within the Hampole Beds are for most of their exposed extent, too small to be responsible for the rapid alternation of lithologies (the Hampole Discontinuity is excepted and not relevant in this case since it merely marks the base of the Hampole Beds). Units are frequently concordant with the underlying lithology. The author favours alternative B as an explanation for the grouping of plots and abrupt alternation of facies.

Phosphorous probably represents the remains of organisms. It correlates negatively with the carbonate and positively with the estuarine component suggesting that organisms were mostly estuarine derived possibly inferring the marine waters were hypersaline.

This is thought to have occurred primarily during periods of emergence when the sediment surface became exposed to the air for a period of time. The calcitic-dolomite inter-lamination of some beds probably records an early phase of dolomitisation, in accordance with the Gebelein and Hoffman (1971) model, where selective dolomitisation occurs in the algal rich laminae of interlaminated algal and sediment rich layers.

Most units are heavily dolomitised and the calcitic-dolomitic lamination has been partially obliterated. It is thought that a later phase of dolomitisation was responsible for this. There are two recent hypotheses that may be relevant to this phase. Firstly, the evaporite brine residue model, where dolomitisation and associated evaporite mineral emplacement occurs in a supra-tidal flat by sediment reaction with the concentrated marine derived pore waters supplied by capillary action, as confirmed by the experiments of Hsu and Siegenthaler (1971) and secondly the ground water mixing model, where dolomitisation occurs at the junction between the fresh phreatic and marine groundwater realms (see Leeder, 1982 for a review, pp. 297–301). The presence of relict traces of evaporite minerals in the samples, dramatic stratigraphic variation in degree of dolomitisation from unit to unit, and enrichment of clay minerals with alkali metals (see below) leads me to favour the former model. There is however, no evidence which excludes the latter and there is a possibility of both having operated at different times. Research by Margaritz and D.B. Smith (pers. comm) on carbon and oxygen isotopes apparently suggests a strong fresh water influx at about the level of the Hampole Beds, even when a mudstone film is their sole representative suggesting that some degree of dolomitisation according to the groundwater mixing model may have occurred. Coleman and Harwood (1980) give evidence of dolomitisation, due to the introduction of pore fluids, followed by calcitisation of nodular anhydrite by bacterial reduction of sulphate and de-dolomitization of nodule margins within the host rock, thus inferring dolomitisation prior to sulphate reduction. By analogy with sulphate reduction this dolomitisation is thought to be a near surface process which altered large volumes of rock, and probably acted as a third phase of dolomitisation in the Hampole Beds.

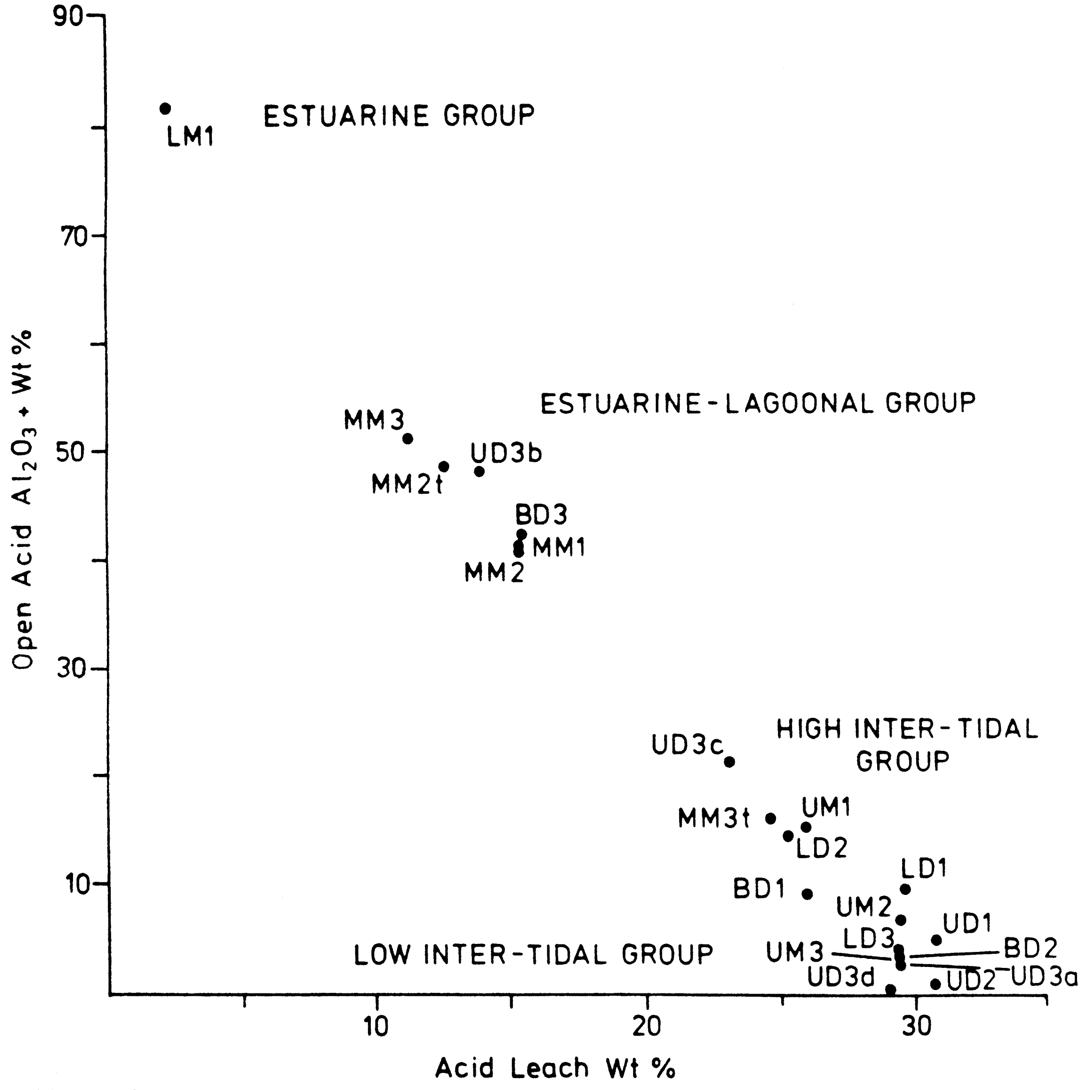

Fig. 3. Acid leach CaO versus open acid Al_2O_3 + SiO_2.

Note that a trend is revealed in which the sample plots fall into three distinct groups. These correspond to the estuarine, estuarine-lagoonal and supra-inter tidal environments as confirmed by lithologic evidence.

If dolomitsation did occur in the sabkha along the lines outlined by Shearman (1966) then a number of diagenetic minerals were emplaced. Since manganese normally correlates positively with both CaO and MgO the presence of non-carbonate calcium bearing phases is suggested by anamolies revealed when acid leach manganese is compared with acid leach CaO/MgO ratios (Fig. 5). This phase is probably gypsum since small gypsum crystals have been observed on hand specimens. Halite is thought to be the water soluble sodium phase and celestite is inferred from the presence of strontium in the whole rock analysis (Table 1). Halite (?), gypsum and celestite (?) are all thought to be diagenetic because of the lack of correlation between acid leach analyses and estimated carbonate and silicate contents. The source of strontium for celestite may have been either aragonite depletion during diagenesis or perhaps remnant strontium in carbonate minerals. In this latter case a weak correlation between Sr and the carbonate content might have been expected, however no such correlation has been observed. These minerals, along with dolomite, were probably emplaced as a result of precipitation from and/or reaction with concentrated marine derived pore waters in the sabkha. Iron and manganese oxides may have been produced by oxidation and precipitation after the reaction of slightly acidic meteoric water with the carbonate, liberating the iron and manganese components.

Metasomatising saline pore waters within the sabkha are also thought to have enriched the clay/mica fraction of the deposits with sodium and potassium. This is confirmed by the variation diagram obtained when the amount of these metals in the residual component (Table 1c) is plotted against the ratio of acid leach CaO/MgO (taken to represent the degree of dolomitisation suffered by each stratigraphic unit). As the degree of dolomitisation increases, so does the concentration of the metals, but the estuarine silts are anomalous due to the relatively low salinity of their depositional environment (see Fig. 4).

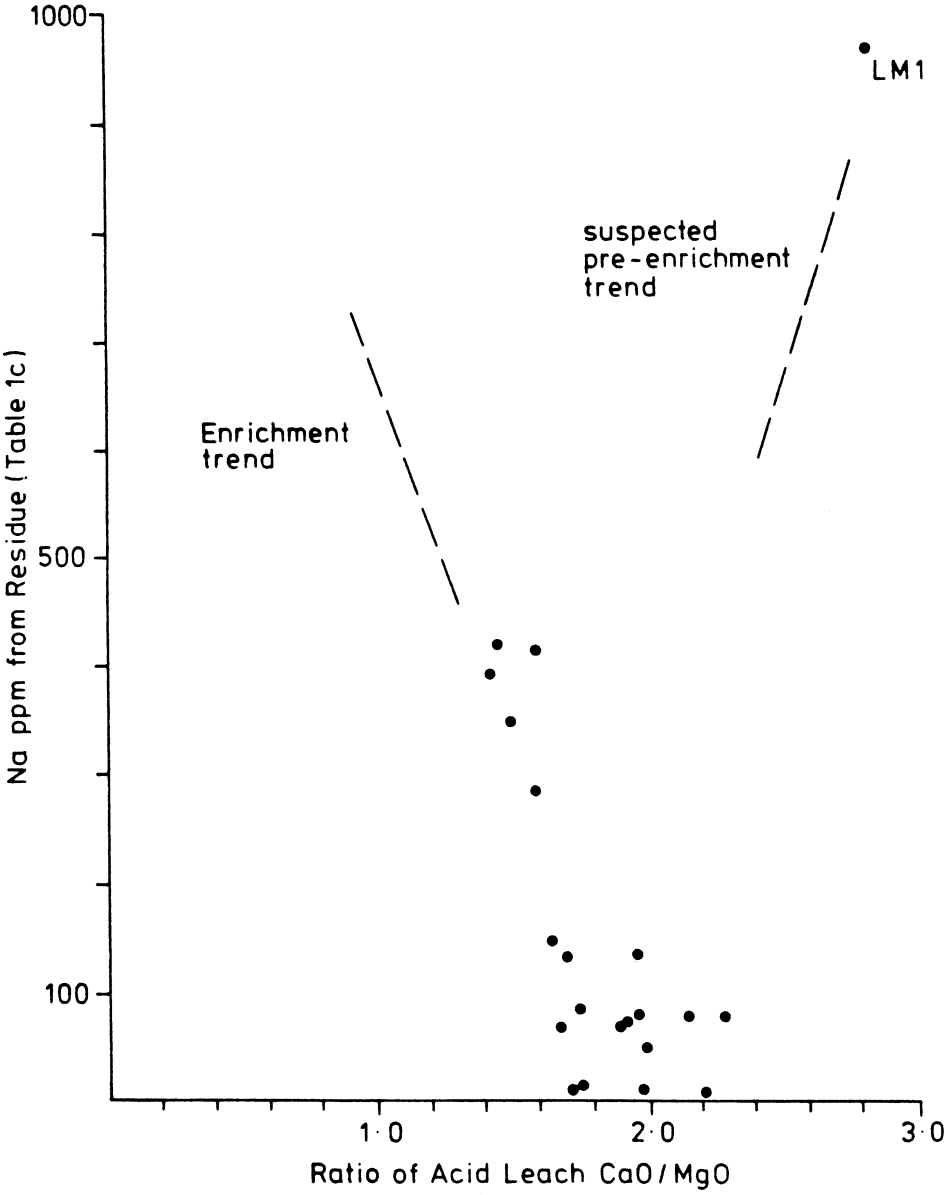

Fig. 4. Ratios of acid leach CaO/MgO versus Na in residues.

Highly saline ground waters within the sabkha during periods of dolomitisation enriched the clay/mica fractions of the samples in alkali metals. The ratio of CaO/MgO, which is assumed to represent the degree of dolomitisation suffered by each sample. As degree of dolomitisation increases (seen as a decrease in the CaO/MgO ratio) as does sodium (and potassium) concentration in the residue but the estuarine silt plots anomalously revealing the expected pre-enrichment trend showing decrease in alkali metal concentrations as the amount of clay/mica decreased.

Stratigraphical Geochemistry

The ratio of CaO to MgO represents the relative degree of dolomitisation experienced by each sample. When plotted stratigraphically the resultant curve closely resembles those curves obtained when the weight per cent HCl soluble iron and manganese are similarly plotted (Fig. 5a, b, c). A minimum for Figures 5b and c represents a period of intense oxide production and corresponds with periods of intense dolomitisation. The two processes were acting simultaneously during periods of emergence. The maxima and minima do not, however, correspond in magnitude in terms of prominence and relative position of points on the curve (see Fig. 3) possible reflecting the relative magnitude of meteoric water input for the stratigraphic units. If so the curves hint that input may generally have been greater at the base of the sequence than at the top.

According to Bathurst (1971) dolomitisation is more intense landward across a supra-tidal flat. The degree of dolomitisation represented by the ratio CaO/MgO (Fig. 5a) thus records the relative maximum remoteness from the marine environment attained by each unit during periods of emergence. Maximum remoteness was attained during the formation of the reddened horizon (sample MM2t) in the Middle Mudstone.

The stratigraphic curves for magnesium and lead are very similar. suggesting a common origin. Magnesium in dolomite is of known diagenetic origin and lead as galena is believed to be the same and probably marine derived. Copper, however, correlates with the estuarine input. Both lead and copper may occur as sulphide (galena has been found) possibly emplaced diagenetically from their respective sources by reaction with H_2S derived from decaying organic matter in the sediment.

The prominence of MM2t on the CaO/MgO curve provides a point of reference by which to view the sequence in terms of early regression followed by a transgressive phase. D.B. Smith (1968) favoured the base of the Middle Mudstone for the boundary between the two members of the Cadeby Formation. The evidence presented here suggests that the MM2t horizon within the middle mudstones would be a more appropriate level for the boundary since it marks the period when the area was most remote from the shoreline and just prior to the highest parts of the Hampole Discontinuity becoming covered for the first time as the crests of the discontinuity undulations became sediment covered. This horizon is however not recognisable at most exposures of these beds but has been observed by the author in Boat Farm Quarry (532 013).

Environmental Evolution

The beds of the Wetherby Member indicate a transition from sub-tidal to upper inter-tidal or supra-tidal conditions prior to complete emergence. This emergence is typically associated with intense erosion resulting in an unusually large degree of undulation along this part of the Hampole Discontinuity.

The basal dolomites developed in narrow hollows with bases of up to 2.5m below average ground level and record a number of cycles from sub/inter-tidal to estuarine-lagoonal conditions when estuarine waters introduced re-worked aeolian silts into the shallow saline lagoon. Emergence allowed diagenetic changes and the green to red colour change within a bed may record the lowest level of the palaeo-water table which appears to have been up to 50cm below palaeo-ground surface. The cycles were probably the result of sea level variations in the order of 1m in magnitude.

The Lower Mudstone represents an estuarine phase of re-worked silt deposition with a brief period of emergence prior to the development of the Lower Dolomites, the lower dolomite marine unit (more proximal in the south than the north) with generally inter-tidal base and supra-tidal top. Since the unit is absent over the top of small undulatiosn on the discontinuity the tidal range probably did not exceed 75cm. A thin veneer of lower dolomite might however have been removed by erosion.

The Middle Mudstone was mostly deposited in a broad depression at the centre of the locality. Initially saline shallow water lagoonal conditions existed before regression and the establishment of a supra-tidal flat when the water table fell to around 30cm below palaeo-ground surface producing the reddened horizon in this unit, which represents a palaeo-soil. A brief return to lagoonal conditions preceeded the establishment of an inter-tidal flat, traversed by tidal channels up to a metre in depth. From time to time estuarine incursions occurred depositing green silts prior to an increase in marine influence and deposition of the Upper Dolomite.

The Upper Dolomite is the most marine unit in the sequence, with the north again shallower than the south. The base is generally inter-tidal or perhaps shallow sub-tidal and bioturbation may indicate relatively "normal" salinities. These bioturbations are more common on the Upper Dolomite than any other unit in the Hampole Beds. Upwards and northwards the unit becomes steadily supra-tidal.

A relative sea level fall of about 1.5m facilitated the deposition of the upper two sub-units of the Upper Dolomite in the south of the locality only. Initially, periodically emergent lagoonal slits were deposited, succeeded by inter-dial carbonate punctuated by periods of estuarine insursion and the development of green silts.

A small relative sea level rise produced the Upper Mudstone. A low inter-tidal period (more supra-tidal in the north) with intermittent exposure, and what may have been "flash food" incursion, produced small sand filled channels.

A major transgression after this initiated the deposition of the Sprotbrough Member. Initially high inter-tidal in character, remaining so for several metres of sediment in the north but soon becoming sub-tidal in the south.

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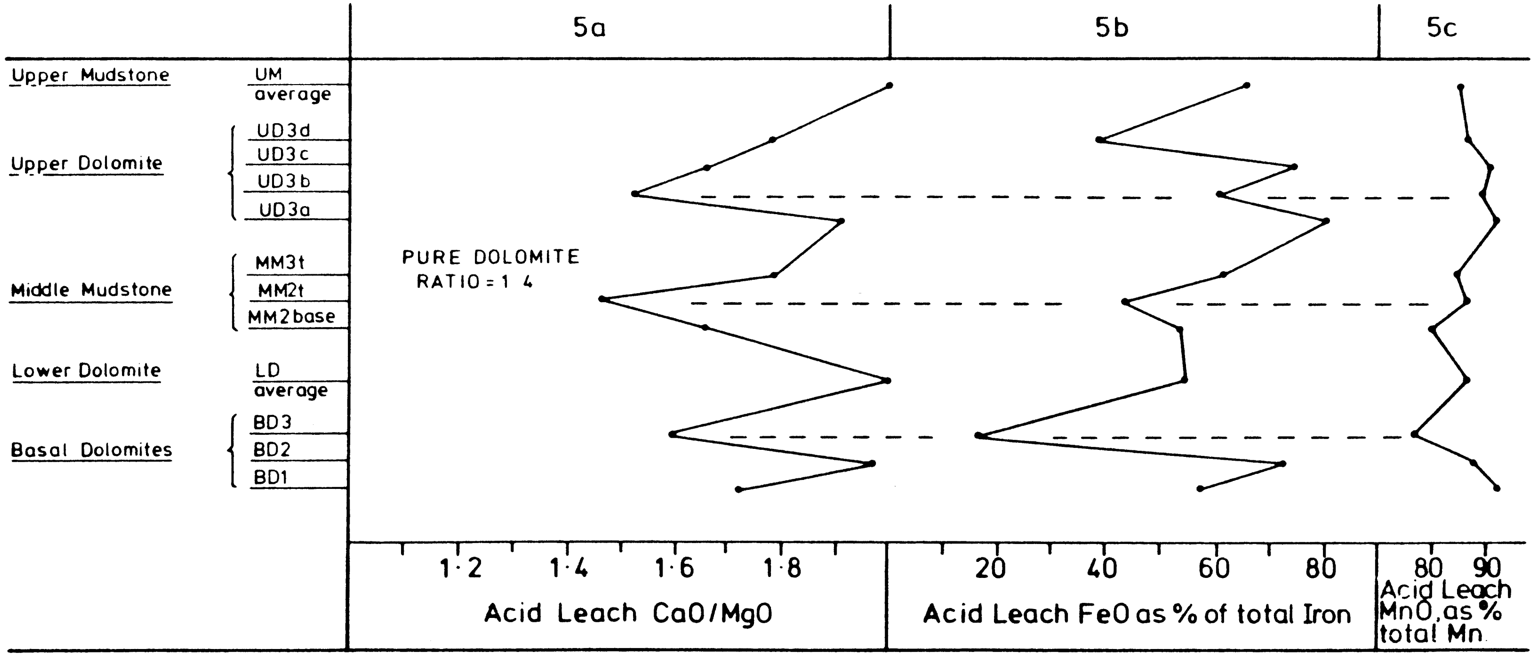

Fig. 5. Stratigraphical variations in acid leach values.

The periods of most intense dolomitisation and iron + manganese production occurred simultaneously producing a correlation between most of the maxima and minima of the curves. Maximum intensity of dolomitisation occurs at the MM2t horizon which is a significant peak to view the sequence in terms of regressive below and transgressive above. The minima and maxima do not correspond in relative magnitude possibly reflecting the size of meteoric water input. Generally input may have been greater after MM2t than before. The differences between the two curves for 3b and 3c are probably attributable to influxes of iron and/or manganese oxides by estuarine and/or aeolian introduction.

ERRATA

1. Due to an oversight which resulted in the author not receiving proofs, a number of printing errors crept into the letter to the editor entitled *Lithostratigraphy of the Peel Sandstones* in Vol. 10, No. 1, pp. 73–76 by S.F. Crowley (Dept. of Geology, University of Liverpool). The editor offers his apologies for these errors, the corrected versions of which, as supplied by the author, are given below.

Page 73. Line 24–29. This well developed inverted clast stratigraphy is most obviously defined by the restricted occurrence of Wenlock faunas to The Stack conglomerates (supported by the work of Lewis, 1934 and my own recent collection of approximately 70 fossiliferous clasts, a small number of which were examined by Dr. C.T. Scrutton) and Ashgillian faunas to the Whitestrand conglomerates (supported by Gill, 1903; Lewis, 1934 and the presence of Ordovician related crinoid ossicles identified in one derived limestone clast by Dr. S.K. Donovan).

Page 74. Line 7–8. 2. Prior to the uplift and erosion of the Cambro-Ordovician Manx Massif, as defined by the predominance of Manx Slate clasts in the Manx Carboniferous (Arundian) basal, red bed conglomerates exposed at Langness (south IOM) and their complete absence from the Peel Sandstone conglomerates.

Page 75. Line 18. Ford, T.D., 1984. Field excursion to the Isle of Man. *Mercian Geol.* 9. 243–244.

2. In Vol. 10, No. 2 Table 1, p. 116 in the paper by *M.A. Moss* the analyses for Acid Leach (1b) and Residue Calculations (1c) for BD2 and BD3 were inadvertently transposed by the author when preparing this table. The resulting descrepancy between Fig. 5 b and c and Table 1 was unfortunately not detected until after the journal had gone to press. The editor and author apologise to those readers who attempted to correlate Table 1 with Fig. 5.

In this same paper there are, in spite of proof reading by both the author and editor, different spellings of Sprotbrough. The spelling favoured by the Ordnance Survey and used by geologists for stratigraphical purposes is 'Sprotbrough'.