BRITISH RHAETIC BONE-BEDS

by

J. H. Sykes

Summary

An account is presented of the origins, occurence, and formations of British Rhaetian bone-beds from re-examination of present exposures and from a review of others published in literature.

Introduction

The British Rhaetic rocks (Penarth Group) is an easily distinguishable set of strata situated at the top of the Triassic System. The Group can be divided into Lower and Upper Rhaetic formations. Almost all the Rhaetic bone-beds are to be found in the Westbury Formation of the Lower Rhaetic and the paper is generally restricted to that part of the sequence. A further restriction is made in that only that part of the Westbury Formation which contains bone-beds is considered in detail.

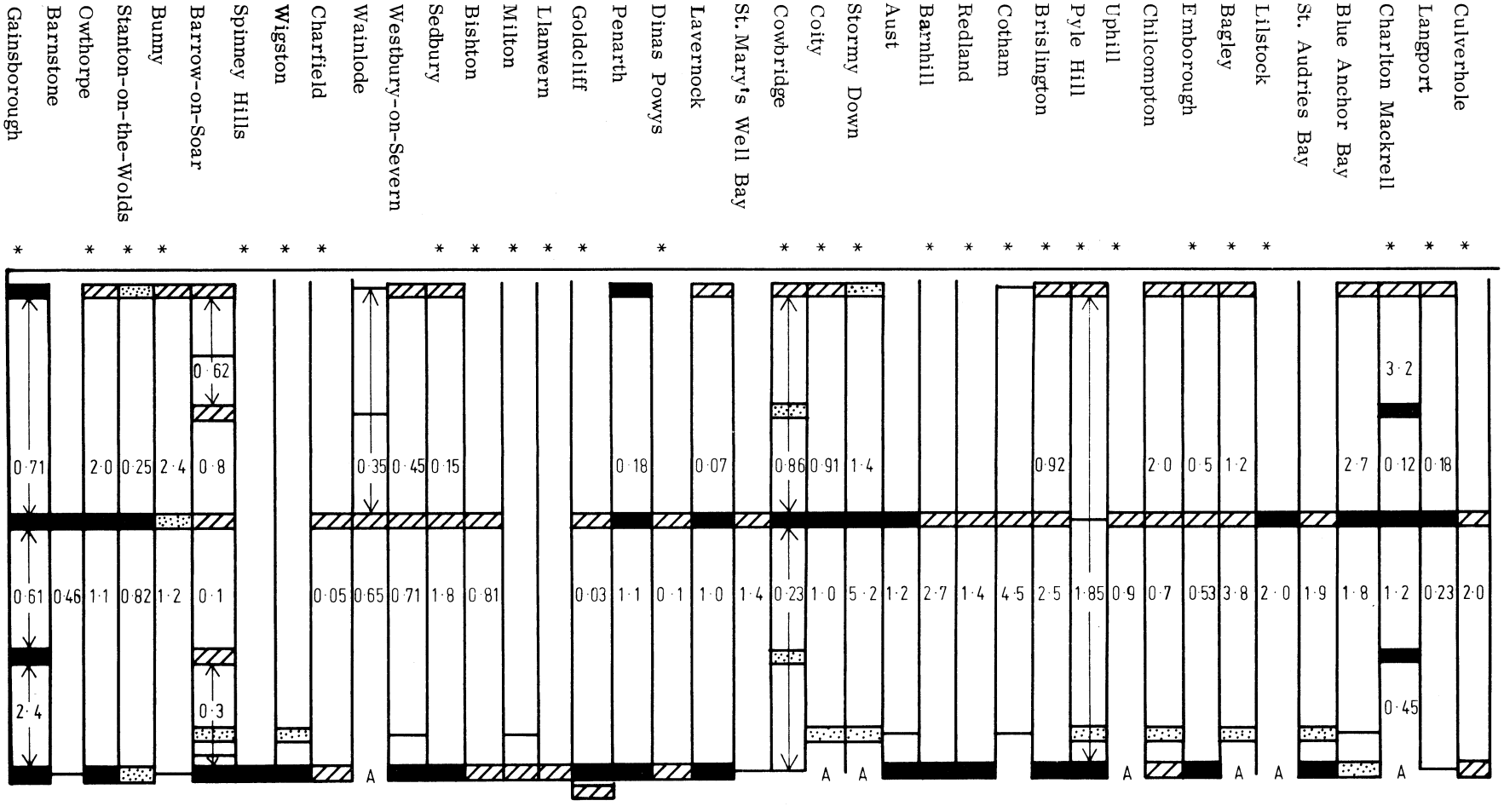
Eleven sections of Rhaetic rocks have been examined to determine all aspects of bone-bed deposition especially to observe the close relationship between the sandy content and the vertebrate fossils. Details of 31 other sections, now no longer readily available for examination, have been obtained from the literature. 39 localities are shown on text-fig. 1, those described by previous writers are marked by an asterisk and acknowledgements made in the text.

Attempts have been made to correlate individual bone-beds lithologically but because of the variation in thickness of the Westbury Formation and the discontinuous development of bone-beds, even over a short distance, correlation has proved to be difficult.

Method

Some of the bone-bed samples were well-cemented and these have been sectioned and their mineral contents determined. (Plates 14, 15, 16). Others, especially more friable ones, have been crushed to separate their constituents. 100 gm bulk samples were taken and, after crushing, the sample was washed in petroleum spirit to clean the grains and further aid the disintegration process. The grains were then passed through a sieve set, mesh sizes 850 to 63 microns (1000 microns = 1 mm). Particles less than 63 microns, mainly silt and clay minerals, were discarded. Those retained by the sieve screens were examined and the contents of each determined. Ten random portions of each sieve fraction were spread over a representitive area, 1 sq. cm. for particle sizes 250 and above and a 2 sq. mm. for the smaller sizes. An estimate number of grains was made by counting across the graticulate along several lines and squaring the mean. The grains of the least representitive materials were counted individually. The portions of the sieve fractions taken were weighed, each gram representing 1% of the original bulk sample. From this information the respective weights of each mineral could be determined in each sieve fraction and the percentage of the residue calculated (Tables 4-25). In naming the grade sizes, reference has been made to that part of the Wentworth (1922) scale reproduced overleaf.

Mercian Geol. Vol. 6, No. 3,
1977. pp. 197-239, 3 text-figs.
Plates 14, 15, 16.



Top of Tea Green Marl or Sully Beds.

Text-fig. 1. Sections of British Rhaetic Localities

Thickness of intervening beds are noted in metres but not drawn to scale. Trace and scatter bone-beds are not taken into account in the measurements. Localities taken from literature are indicated by an asterisk. Their classification is made arbitrarily from the information available.

Bone-beds are indicated thus: ■ = part primary, ▨ = secondary, ⁘ = scatter, —— = trace, A = absent

Table 1 Particle grade sizes and terms used

2 - 1	mm	very coarse sand
1 - 0.5	"	coarse sand
500 - 250	microns	medium sand
250 - 125	"	fine sand
125 - 63	"	very fine sand
63 - 32	"	coarse silt
32 - 16	"	medium silt

Criteria for primary and secondary depositional characters in beds

In order to comment on the origin of the bone-beds, criteria was required to decide if the bed resulted from original, primary deposition of the bone-bed sediment and fossils (referred to hereafter as the bone bed content) or if subsequent movement and transportation had taken place with redeposition (secondary) resulting in a natural concentration of bone-bed content.

Pettijohn (1957, p. 393) in dealing with limestones, states that the criteria for distinguishing between primary and secondary deposits are related to the sorting of grains, to current structure, to the state of articulation of the skeletal material (bivalves and etc.) and to the content and size of the non-carbonate detritus. A number of additional characteristics have been observed during field and laboratory examination and the following tables list features of primary and secondary deposition.

Table 2 Criteria for primary bone-bed deposits

1.	Unsorted material	- the current carrying the clast load, is checked and the load deposited before travelling far and before sorting takes place.
2.	Poor bedding	- the result of deposition of unsorted or rapidly deposited material.
3.	Shells with unbroken and articulate (joined) valves	- burial before erosion and transportation.
4.	Random orientation of shells	- lack of current action and quiet deposition *in situ*.
5.	Unbroken delicate fossils complete with fine surface detail	- burial takes place with little rolling or transportation.
6.	Coprolites, long, slender, unbroken	- lack of transport and abrasion.

The corresponding list for secondary deposition is given in Table 3.

Table 3 Criteria for secondary bone-bed deposition

1.	Well-sorted material	- a prevailing current of certain velocity will deposit a selected size of particles for a period, removing the smaller grades.
2.	Graded bedding	- velocity of the transporting current decreases and the finer particles are laid.

3.	Current bedding	- deposition by transporting currents, which may change direction producing 'cut and fill' structures.
4.	Fossil fragmentation	- movement of fossils for some distances.
5.	Fossil wear and abrasion	- transportation and rolling.
6.	Oolites and pisolites	- occurrence indicates current action.
7.	Ripple marks	- current action.
8.	Infilled fossil cavities	- tightly packed sand and finer fossils imply movement and compaction within the larger fossil.
9.	Mixed land and marine fossils	- implies lengthy transportation of the land fossils in a marine environment.
10.	Aligned fossils	- orientation on bedding planes in the direction of the current.

Classification of bone-beds

Application of the above criteria to the field examination of bone-beds has resulted in four different categories or types, which are described below:

1. Part primary bone-beds. All Rhaetic bone-beds have some features which suggest that they have been derived from a previously deposited source, although some primary depositional features may also be retained. These primary features are chiefly concerned with the condition and orientation of the fossils also the poorly bedded, unsorted deposits.

2. Secondary bone-beds. Well developed bone-bed layers, where all the depositional characters are secondary. The most common of these are concerned with the sorting and current bedding of the sediments and also the abrasion and fragmentation of the fossils.

3. Scatter bone-beds. Most sediments of the lower Rhaetic are devoid of coarse fragments although some layers of mudstone may contain a comparatively coarse bone-bed content (quartz and vertebrate remains) disseminated through the bed. A close inspection of these beds is necessary to observe their constituents. When the clay and silt elements are removed it is noticeable that the concentrations of sand and vertebrate fossils are definitely linked.

4. Trace bone-beds. Extremely thin layers, or pellets or patches of bone-bed, often only a single layer of grains, are designated 'trace bone-beds'. They are often found in association with the horizon of a major bone-bed such as at the base of the Westbury Formation. They can also be found isolated, when coarse grades of sand are present.

Descriptions of bone-beds at British localities

The localities of text-fig. 1 are described following the outcrop in a general north to south direction. Only that part of the sequence containing bone-beds is considered. Details of the bone-beds at the various localities are tabulated (tables 4 - 25, commencing on p. 204 reference to which is made in the text. The final synthesis of the evidence begins on p. 234. Previous authors measurements have been converted to metres and millimetres. National Grid References are given after each locality.

Thornton-le-Beans, Yorkshire, SE 397902. Tate and Blake, 1896, p. 32.

"A well sinking revealed black, pyritic shale with Rhaetic bivalve fossils and a 75 mm thick, granular, whiteish, pyritic, grey sandstone which contained fish remains."

	metres
Lea Cutting, Gainsborough Lincolnshire, Burton (1867, p.316)	
Shale, black	0.1
Hard, grey sandstone with pyrite, bivalves, fish, reptiles and coprolites.	0.43
Shale, black.	0.71
Sandstone, fine-grained, pyritic; with fish reptiles and coprolites.	0.15
Shale, black.	0.61
Second bone-bed, loose texture, coprolites.	0.012
Shale, black.	2.4
Bone-bed with upper part a loose micaceous sandstone; lower part with pebbles and pyrite matrix, fish reptiles and coprolites.	0.1
Tea Green Marl.	
Barnstone, Nottinghamshire, SK 739358 Sykes, Cargill and Fryer 1970.	
Sandy beds, black shales with layers of ferruginous siltstone, some very pyritic.	1.4
Shale, black, with thin layers of silt and, near the base, patches of fine and coarse sand with bone bed fossils.	1.8
Bone-bed, friable upper part with pebbles, coarse and fine sand, small and large vertebrate fossils in a mudstone matrix which also has patches of black shale. The lower part is of similar composition though cemented with pyrite. The fossil content is variable with worn, broken specimens also delicate fin spines and pieces of well preserved jawbones. There are numerous coprolites. The black shale parts are unfossiliferous.	0.076
Shale, black, containing varying amounts of sand and vertebrate fossils scattered through the rock. This course content is greatest near the base being transitionally rarer up to the bone bed. There is a thin, cemented bone-bed, up to 13 mm thick, near the base also traces of bone bed material in the basal layer.	0.5
Tea Green Marl.	

Remarks

A trace bone-bed is found at the base of the Rhaetic at Barnstone and a typically, gritty, thin, cemented, impersistent bone-bed a short way above. The whole of the black shales below the main bone-bed constitute a scatter bone-bed. If this is the redistribution of scattered previous bone-bed content (see discussion p.234), it is significant that the influence declines upwards and is rare in the upper part of these fairly well-bedded shales.

The main bone-bed is an example of a part primary bed. The evidence for primary deposition includes the presence of many coprolites, mostly unbroken and some elongate. There are fragile fossils such as fin spines and teeth with attached delicate roots also unworn fossils with their ornamentation intact. The deposits are unsorted, ranging from the very minute up to large fossils and pebbles. There are also thick patches of quietly deposited shale.

Criteria for secondary deposition include the many fragmented, rounded and worn fossils with all the surface ornamentation removed. The cavities of larger fossils are tightly packed with minute sand grains and fossils. There is a mixture of land and marine fauna also a few bivalves with phosphatised shells and calcareous interiors, on a horizon that does not generally contain bivalves and is non-calcareous.

In the first 25 mm of the black shales above the bone-bed there are thin, isolated patches of bone-bed material; sometimes only one layer of grains thick. In these trace bone-beds the fossils are always accompanied by sand. If they are laid independent of the main bone-bed, the minute fossils could have become incorporated with sporadic deposition of sand. Their confinement to the lowest 25 mm of shale above the bone-bed makes it more likely that they are small amounts of redistributed material from the main bone-bed elsewhere.

There is no further development of bone-bed above this horizon at Barnstone. The 'Sandy Beds' contain a few, minute, phosphatic fossils and the 'sandiness' is of silt grades.

	metres
Owthorpe, Nottinghamshire, SK 666336, Ivimey-Cook & Elliott (1969, p.147)	
Mudstone, greenish grey.	1.5
Mudstone, with a layer of fine sand and fish fragments.	2.7
Mudstone.	0.9
Mudstone.	1.1
Mudstone, coprolite layer and pyritised, sandy bone-bed layer.	0.8
Bone-bed, quartz granules, bones teeth, scales.	0.025
Shale, black, non-calcareous.	1.1
Bone-bed, black shale with large quartz grains and vertebrate remains infills burrows penetrating 25-30 mm into green marl below.	0.0
Tea Green Marl.	
Stanton-on-the-Wolds, Nottinghamshire, SK 637312, In Lamplugh, (1909, p.20.)	
Shale.	1.6
Pyritic sandstone.	0.06
Shale.	0.9
Pyritic limestone with fish scales.	0.025
Shale, black, fissile.	0.25
Bone-bed, white sand, pebbles, fish and reptile remains, coprolites.	0.025
Shale, black, fissile and earthy.	0.4
Coprolite seam, coprolites at wide intervals.	0.025
Shale, black, laminated, with occasional reptile bones.	0.4
Tea Green Marl.	
Bunny Cutting, Nottinghamshire, SK 578281, Kent (1953, p.134).	
Shale, black, crumbly.	1.5
Shale, sandy, micaceous, with many fish fragments.	0.075
Shale, crumbly and fissile, fish scales.	2.4
Shale, black with fish scales and probable coprolites.	1.8
Shale, black crumbly.	1.2
Sand bed, weathering brown, rare fish remains.	0.025
Tea Green Marl.	

East Leake, Nottinghamshire, SK 538281, Browne (1895, p. 688)

"There is no actual and massive bone-bed as at Aust and etc., although, most curiously, one piece - and one piece only, identical with Aust breccia - was picked up at the tip."

Barrow-on-Soar, Leicestershire, SK 573173, H. G. Fryer (in prep.)

	metres
Shale, fissile, black, with fine sandy layers and patches of coarser sand, some of which contain vertebrate remains.	1.0
Limestone, nodular, dark grey and unbedded.	0.15
Shale, black, fissile with fine sandy layers.	0.37
Limestone, nodular, embedded in black shale and overlain by grey clay. On the same horizon and surrounding the nodules there is a thin sandy bone-bed.	0.62
Fourth bone-bed, distinct sandy bone-bed layers interspersed with mixed sand and shale. Some cemented bone-bed is also present (table 4).	0.025
Shale, black fissile with occasional thin patches of bone-bed.	0.825
Third bone-bed, one part consists of quartz grains and vertebrate fossils in a mudstone matrix, one part is cemented quartz and fossils and a third is of unfossiliferous, bedded, siltstone.	0.025
Shale, black, fissile with occasional traces of bone-bed.	0.1
Second bone-bed, a thin typical bone-bed and a thin, bedded, pyritic siltstone.	0.3
Shale, black, lumpy poorly bedded, with some quartz grains and vertebrate fossils scattered throughout (table 5).	0.15
Shale, black, fissile with occasional bone-bed patches.	0.16
First bone-bed, a thin bed with three distinct parts. At the top is a pyritic, bedded, unfossiliferous siltstone, below is discontinuous, cemented layer of quartz and fossils and at the base is a mudstone with many scattered quartz grains and fossils (Plate 14, fig. 1; table 6).	0.050
Tea Green Marl.	

Remarks

A feature at Barrow-on-Soar is the rapid changes in the nature of a bone-bed from a crumbly mudstone scatter bone-bed with a low phosphatic content (table 6) to a cemented, clean quartz and fossil bed to a fine-grained rock minus fossils. This gradation to finer deposits shows how the bone-bed content is affected (Plate 14, fig. 1) the sequence also illustrates the rapid changes that can occur in the depositional environment of a single bed.

Within the black shales of the Lower Rhaetic there are occasional fin rays, scales and other fragments found at any horizon. However, in the 'lumpy' shale a short way above the base there is a sufficient concentration of bone-bed content to regard it as a 'scatter' bone-bed (table 5).

A 100 gram sample of the fine-grained part of the second bone-bed was crushed and examined. Only a few grains of fine sand were found with a few phosphatic grains, some of which were distinctly fossil. There was a small fraction of very fine sand which also yielded some phosphatic remains. The rest was of silt grade. This helps to show that the fine-grained rocks are only capable of retaining fossils of a comparable grade.

Explanation of the Tables 4 to 25

Each element of the bone-bed fragments are listed showing first their weight in each sieve, next their percentage of the sieve fraction and then the deviation for random sampling. In the next to the end column the weights from each sieve of each individual element are added together showing their percentages of the original 100 gm sample. The end column gives their percentage of the residue.

The bottom line gives the weights of each sieve fraction, which are added together in the next to the end column to give the weight of the total residue.

Barrow-on-Soar, Tables 4, 5 and 6

Table 4, fourth bone-bed

	850 microns +	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz				0.08	0.34	0.006	1.54	5.56	0.152	12.71	68.87	1.347	9.49	80.10	23.82	28.04
Phosphatic				20.15	74.32	0.214	1.54	5.64	0.069	4.71	25.50	0.540	0.33	2.82	26.73	31.47
Shale				6.76	25.34	0.041	24.56	88.80	3.436	1.04	5.63	0.036	2.03	17.08	34.39	40.49
Totals in gms.				26.99			27.64			18.46			11.85		84.94	

Table 5, lumpy shale

Quartz				0.02	0.94		0.07	1.16	0.009	.56	7.53		8.44	68.13	9.09	32.31
Phosphatic				0.02	1.25		0.06	0.90	0.004	.11	1.52		0.29	2.37	0.48	1.71
Pyrite				0.02	0.52		0.01	0.16	0.000	0.00	0.00		0.00	0.00	0.02	0.07
Shale				1.73	97.25		6.43	97.78	1.704	6.81	90.95		3.66	29.50	18.63	65.91
Totals in gms				1.78			6.48			7.48			12.39		28.22	

Table 6 lowest base

Quartz	0.95	4.15	0.020	0.57	3.24	0.020	4.13	22.53	4.004	3.42	34.3		0.96	36.09	10.02	13.98
Phosphatic	0.96	4.15	0.013	0.48	2.70	0.018	0.58	3.15	0.049	0.50	5.1		0.13	4.89	2.06	3.70
Tea Green Marl	0.82	3.56	0.025	0.96	5.41	0.049	1.03	5.62	0.159	0.71	7.0		0.11	4.13	3.65	5.09
Mudstone	20.30	88.14	1.731	15.68	88.65	1.493	12.66	68.70	12.94	5.32	53.6		1.46	54.89	55.35	77.23
Total in gms	23.03			17.69			18.34			9.95			2.66		71.67	

Only a part of the Rhaetic was exposed at Barrow-on-Soar but the whole of the section shows a development of thin and 'trace' bone-beds when there is a deposition of sediments coarser than silt. Table 4 illustrates the high content of sand and phosphatic content in the highest bone-bed.

	metres
Spinney Hills, Leicestershire, SK 406044, Harrison (1876, p.213)	
Shale, black.	0.6
Sandstone.	0.025
Shale, black.	0.75
Bone-bed, pebbly and sandy with fish, reptile remains and coprolites.	0.07
Tea Green Marl.	
Wigston, Leicestershire, SK 603991, Richardson, (1909, p.368)	
Limestone nodules.	0.08
Shale, black, somewhat sandy with fish scales.	1.2
Rust coloured layer.	0.025
Shale, black with fish scales and teeth.	0.75
Bone-bed, gritty sand with fish, reptiles and coprolites.	0.07
Charfield, Gloucestershire, ST 723924, Richardson (1904, p.532)	
Limestone, dark grey, arenaceous.	0.7
Shale, black.	0.33
Limestone.	0.7
Shale, black.	0.85
Sandstone, pyritic, fish and reptile remains.	0.025
Shale, black, sandy.	0.05
Sandstone, grey, calcareous and sometimes pyritic, bivalves and fish remains.	0.075
Tea Green Marl.	
Wainlode Cliff, Gloucestershire, SO 845257	
Marl, blocky with bivalves.	
Pectin limestone, grey to black with fibrous layers, shelly.	0.025
Shale, black and fissile with bivalves.	1.5
Mudstone, black, poorly bedded.	0.75
Sandstone, light grey, pyritic, calcareous, fine-grained with occasional vertebrate fossils.	0.05
Shale, black and fissile with some thin, calcareous siltstone lenses which have occasional, minute fossils.	0.35

	metres
Sandstone and siltstone, calcareous, divided into six groups 'a' to 'f' at the top.	0.17
f Black shales with thin, calcareous siltstones.	
e Fine, calcareous, pyritic sandstone with some medium sand concentrated in association with many boney fossils (Plate 14, fig. 2).	
d Fine, calcareous sandstone and siltstone with scattered fine bone-bed remains.	
c Fine, calcareous, micaceous, light grey sandstone pyritic in parts with occasional fossils (Plate 14, fig. 3).	
b Fine, calcareous light grey sandstone with much pyrite. There are some small vertebrate fossils with occasional larger specimens and coprolites (table 7).	
a Calcareous, micaceous, unfossiliferous, light-grey siltstone.	
Shale, black, fissile with occasional layers of silt.	0.5
Mudstone, black, poorly bedded with some clay and some silt layers. There is no sandiness at the base.	0.1
Tea Green Marl.	

Remarks

In the absence of sandy deposits, no vertebrate fossils are found at the base.

The series of hard beds which contains 'the bone-bed' show a variety of transitional forms of deposition. The lowest is a siltstone without fossils. The next above (table 7) has a very few coarse sand grains and some comparatively graded fossils though the rest of the phosphatic content is small with a high percentage of sand. The next two beds up (Plate 14, fig. 3) are secondary bone-beds with current bedded, well sorted sediments; the fossil fragments are typically larger than the quartz grains. These beds also demonstrate the critical limits of grade below which vertebrate fossils are not associated with quartz.

The bed next to the top is quite different being 'intermediate part primary' in origin, coarser and highly fossiliferous (Plate 14, fig. 2). Alternating unfossiliferous siltstone and black shales are trasitional back to a shale environment. There are trace bone-beds in the ensuing shales and, a sparsely fossiliferous sandstone ends the bone-bed influence.

Westbury-on-Severn, Gloucestershire, SO 717130

Shale, black, fissile, with some layers of white silt.	0.5
Pyrite, bedded, crystaline on upper surface, with layers of medium sand which contain vertebrate fossils.	0.025
Shale, black, fissile with grey, calcareous, thin siltstones and thin limestones.	0.45
Sandstone (upper '*Pullastra*' bed) medium and fine. The finer upper part contains rare minute phosphatic fragments (table 8) and the lower, medium sandstone has more and proportionally larger fossils (table 9).	0.3
Shale, black, fissile calcareous, with bivalves and some layers of siltstone.	0.6
Siltstone (lower '*Pullastra*' bed) calcareous with bivalves.	0.4

(Continued p. 209)

Wainlode Cliff, Table No. 7, Westbury on Severn, Tables 8, 9 & 10

Table 7, Sandstones & Siltstones (part b)

	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Fraction and % of 100 gms	Percentage of residue
Quartz	10.003	1.22	0.001	0.00	0.00	0.000	27.04	84.43	0.863	21.12	92.68		48.19	76.5
Phosphatic	0.17	5.39	0.005	0.32	6.25	0.010	0.33	1.02	0.165	0.07	0.30	0.001	0.89	1.5
Pyrite	2.87	93.39	0.513	4.72	93.75	0.809	4.66	14.65	0.165	1.60	7.02	0.140	13.85	22.0
Totals in gms	3.07			5.04			32.03			22.79			62.93	

Table 8, upper *Pullastra* bed, upper part. Small amounts of mica not taken into account

Quartz				0.101	13.44		1.04	27.24		40.14	93.13		41.28	86.6
Phosphatic				0.001	0.12		0.026	0.7		0.02	0.05		0.05	0.1
Pyrite				0.648	86.44		2.744	76.06		2.95	6.82		6.34	13.3
Totals in gms				0.75			3.81			43.11				

Table 9, upper *Pullastra* bed, lower part. Small amounts of mica not taken into account

Quartz	0.01	2.13		0.05	3.5	3.322	7.32	0.86		34.62	88.9		42.00	84.43
Phosphatic	0.07	14.89		0.25	17.5	0.029	0.17	0.2		0.79	0.2		1.28	2.58
Pyrite	0.39	82.98		1.11	79.0	0.782	1.02	0.12		3.94	10.9		6.46	12.99
Totals in gms	0.47			1.41			8.51			39.35			49.74	

Table 10, base. Minor amounts of pyrite and selenite not taken into account.

Quartz	4.79	17.5	0.126	4.09	14.0	1.080	4.25	65.50		2.27	69.63		15.40	23.21
Phosphatic	6.30	23.0	0.461	3.95	13.5	0.780	2.18	33.63		0.95	29.00		13.38	20.14
Tea Green Marl	0.69	2.5	0.010	0.44	1.5	0.011	0.06	0.87		0.04	1.37		1.23	1.85
Mudstone	15.61	57.0	1.110	20.73	71.0	8.856	0.00	0.00		0.00	0.00		36.34	54.80
Totals in gms	27.39			29.21			6.49			3.26			66.35	

(For explanation see pages 204, 205-209).

Explanation of Plate 14

Fig. 1. Barrow-on-Soar, 'Base'.

The lower part consists largely of very fine to medium sand with bone-bed fossils ranging from the minute up to 2 mm, in a calcareous, silicified matrix. It is not bedded but elongate fossils are laid horizontally. It is poorly sorted though the range of grades is narrow. Above, there is bedded siltstone with only a few minute fossil remains. This is an intermediate part primary bed.

Fig. 2. Wainlode Cliff, 'Sandstones and siltstones', part 'e'

The lower part consists of very fine sand with some fine sand in a calcareous matrix; there are also a few minute phosphatic fossil remains. In a similar matrix, the middle part contains sand ranging from very fine to medium; it has numerous bone-bed fossils from minute size up to 3 mm. It is poorly sorted within a fairly narrow size range and is poorly bedded but the platey fossils are well orientated horizontally. The upper part contains less medium sand and phosphatic fossils and is pyritised irrespective of the bedding. The bed is an intermediate part primary bone-bed.

Fig. 3. Wainlode Cliff, 'sandstones and siltstones', part 'c'

The lower part is a bedded siltstone which is truncated and overlain unconformably by a less bedded, very fine sandstone which contains pyritised shell fragments and minute bone-bed fossils. It illustrates the lower limits of sand grade for the presence of bone-bed fossils and also the relationship of sand and fossil sorting. This is a current bedded, secondary bone-bed.

Fig. 4. Lavernock, 'Bone-bed', part 'c'

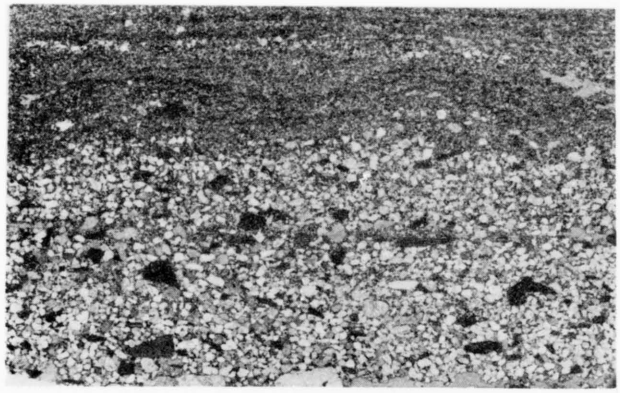
The lower part is made up of poorly bedded, compact, shelly fragments, some being pyritised. There are a few scattered quartz grains and phosphatic remains in this 'scatter' part of the bed. The upper part has a calcareous matrix with some whole and fragmented shells though its chief constituents are quartz and bone-bed fossils. The quartz varies between very fine and very coarse sand and the fossils are of corresponding sizes. Although the lower part is secondary, the upper part is unbedded, unsorted, with coprolites and unbroken shells; a part primary bone-bed.

Fig. 5. Lavernock, 'Limestone below bone-bed'

The rock has a mass of shells, quartz and bone-bed fossils in a lime mud matrix with patches of unfossiliferous, argillaceous limestone. Most of the shells are detached and unbroken. The quartz is unsorted between fine and coarse sand and the fossils also are unsorted, being distinctly associated with the sand; in parts both are absent. The lack of sorting along with randomly orientated, unbroken shells deposited in lime mud, show this as a part primary bone-bed.

Fig. 6. St. Audries Bay, 'sandstones and shales', part 'a'

This consists of fine to very fine sand and phosphatic fossils in a fine grained calcareous matrix. There is a large limestone inclusion with flow structure of the finer sediments around it. The matrix has many specks and strands of pyrite and some fragmented shells. A sorted, secondary bone-bed with an 'out of context' inclusion (see text).



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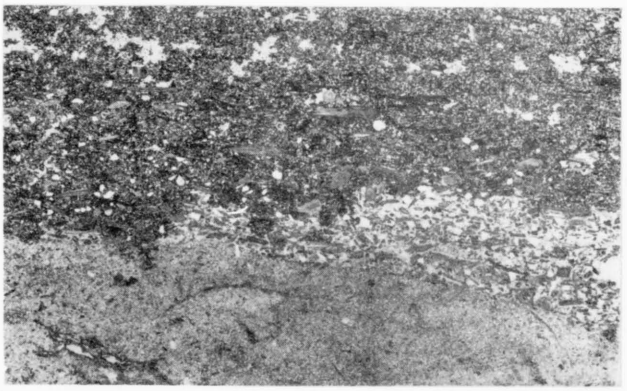

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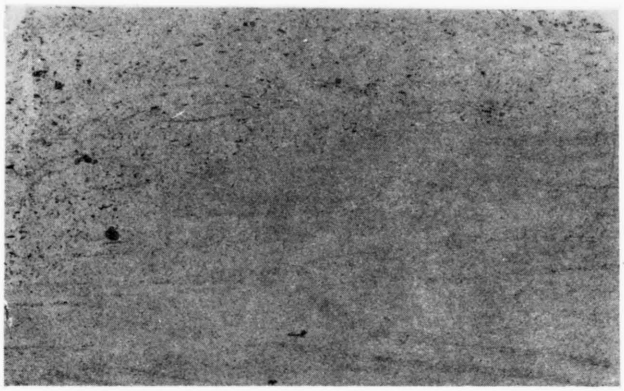

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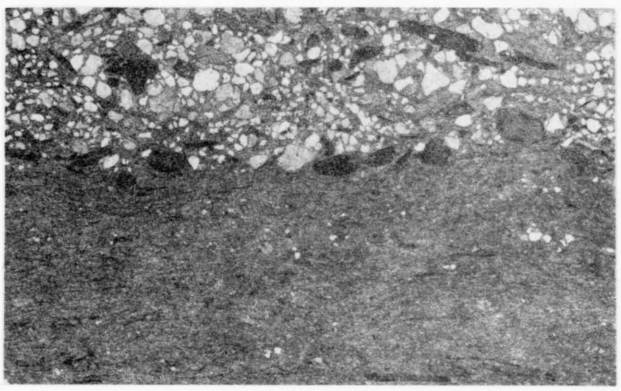

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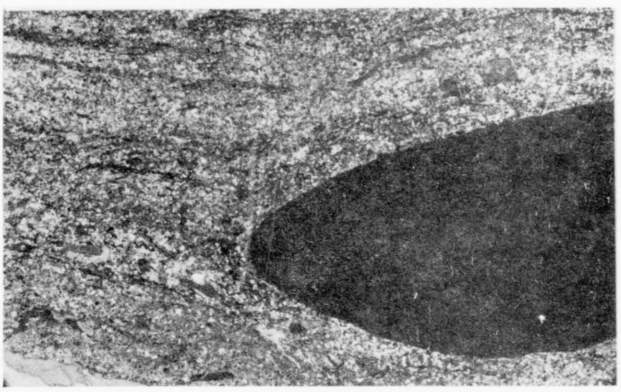


6

J. M. Sykes - British Rhaetian Bone-beds

	metres
Shale, black, fissile, three parts '*a*' to '*c*' at the top.	0.4
(100 mm) shale with bivalves and sandy patches, with some bone-bed constituents.	
(150 mm) shale with some fine sand patches.	
(150 mm) shale without sand, laid directly on Tea Green Marl. There are silt patches also flakes and pellets of the marl Tea Green Marl in the lowest 25 mm.	
Bone-bed, with coarse and fine sand, large and small fossils including bones and coprolites, there are also patches of Tea Green Marl. The bed is discontinuous over a short distance (table 10).	0.05

Remarks

The basal bed is part primary with an unsorted quartz content ranging between silt and pebbles (5 mm). Unsorted fossils of varying grades, including coprolites, are deposited with random orientation; some having surface details unworn. The bedding is slightly flexed in places but there is no current bedding. In table 10 the inclusion of 1.85% of Tea Green Marl shows the disturbance of the underlying bed. Where the basal bone-bed is absent there is no coarse sand but the current action along this horizon is shown by the inclusion of rolled Tea Green Marl clasts in the basal beds.

Higher in the sequence there is a comparatively large amount of quartz deposits but most of it is of siltstone grade and does not contain fossils. There is a varying amount of phosphatic content within the layers of the upper *pullastra* bone-bed. Tables 8 and 9 show how the fossil phosphatic content is smaller in relation to the finer-grade sandstone.

As at many other localities there is a third bone-bed on a higher horizon.

Sedbury, Gwent, ST 555930, Richardson (1903a, p.394)

	metres
Shales, black.	0.7
Limestone 75 mm to 200 mm, some fish remains and bivalves.	0.12
Shale, black, fissile.	0.15
Limestone, pyritic, fish remains and bivalves.	0.15
Shale, black, earthy and fissile.	1.83
Pebbly sandstones and shales alternating. Fish remains, coprolites.	0.2
Bone bed, conglomeratic, coarse sandstone with fish, reptile remains and coprolites.	0.1
Tea Green Marl.	

Bishton, Gwent, ST 390873, Richardson (1903b, p.378)

Sandstone, pyritic.	0.02
Shale, black, with much shell debris, fish scales and coprolites.	0.08
Shale, black.	0.66
Quartz sand, reddish brown.	0.05
Clay.	0.025
Quartz sand, black.	0.05

Continued p. 211

Explanation of Plate No. 15

Fig. 1. Penarth. Text-fig. 2, bone-bed sample locations 'a-g', sample 'a'

This has a dense bone-bed content in a calcareous matrix. It has sand from fine to coarse and boney fossils from minute to 5 mm. There are no shells present. The material is poorly sorted and contains coprolites; a part primary bone-bed.

Fig. 2. Penarth. Text-fig. 2, bone-bed sample locations 'a-g', sample 'b'

This has a similar content to as fig. 1, though the bone-bed content of 'b' is more diffuse and the matrix now contains some randomly orientated shells.

Fig. 3. Penarth. Text-fig. 2, bone-bed sample locations 'a-g', sample 'g'

This is a limestone with a bone-bed band in the middle consisting of many shells with some quartz and phosphatic fossils in a muddy-limestone matrix. The sand is medium to coarse-grained with corresponding fossil grades. This bone-bed content is poorly sorted and diffuse in a declining bone-bed which ends a short distance laterally. A 'part primary' bone-bed.

The upright division of the bone-bed is probably later a solution feature as 'ghost' shell remains may be seen in it.

Fig. 4. Penarth. Text-fig. 3, bone-bed sample locations 'a-r', sample 'a'

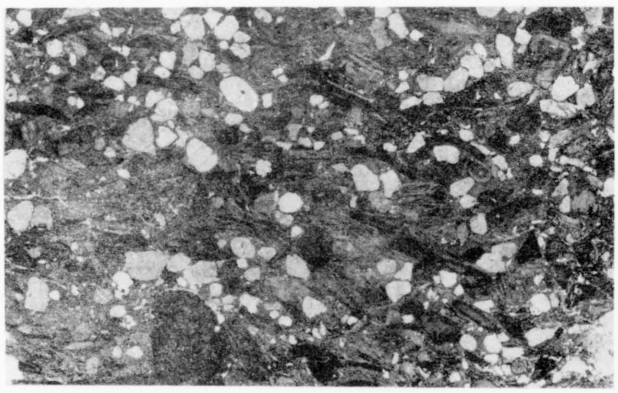
This is a limestone with shells scattered at random, many of them unbroken and some attached. At the top and the base it is an impure lime-mud which has a bone-bed content; the upper part being the coarser with quartz from very fine up to coarse sand and correspondingly sized fossils. There are occasional quartz grains and phosphatic fossils associated with the shelly middle part. A 'part primary' bone-bed.

Fig. 5. Penarth. Text-fig. 3, bone-bed sample locations 'a-r', sample 'b'

The rock has a similar composition to 'a' (fig. 4) but the bone-bed layers are thinner and generally of a finer grade. At the base there is a layer of limestone with some silt in its upper part. A thin layer of limestone also interupts the bone-bed near the top. The shelly middle part has fewer and more fragmented shells also occasional quartz grains and phosphatic fossils. A 'part primary' bone-bed.

Fig. 6. Penarth. Text-fig. 3, bone-bed sample locations 'a-r', sample 'i'

This consists of scattered quartz, phosphatic fossils and bivalve shells in a muddy-limestone matrix. The quartz and fossils are associated with one another though being generally rather diffuse. There are areas without quartz which are also devoid of phosphatic fossils. Both the 'bone-bed' and shell fossils are laid with random orientation, many of the latter being unbroken A 'part primary' bone-bed with a diffuse, declining bone-bed content.



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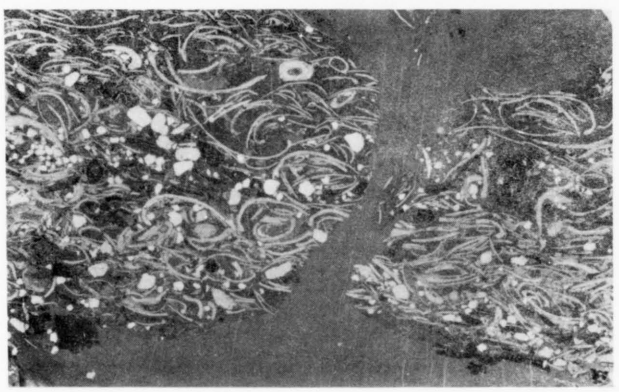

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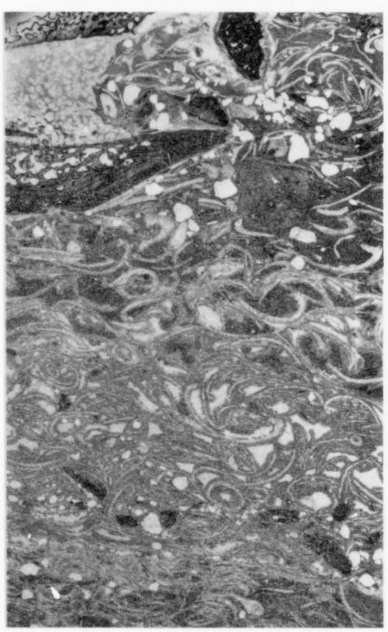

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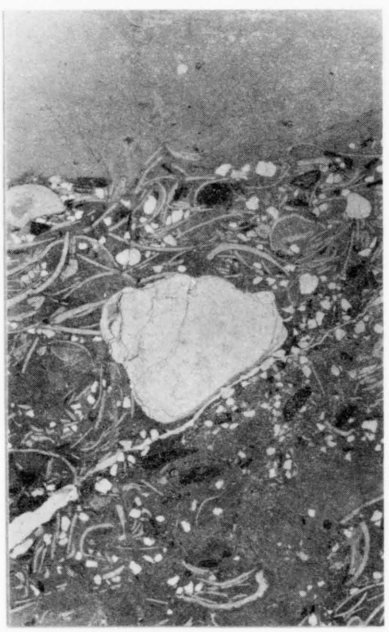


6

J. M. Sykes - British Rhaetian Bone-beds

	metres
Limestone, slightly arenaceous with fish remains and coprolites.	0.08
Tea Green Marl.	

Milton, Gwent, ST 367884, Richardson (1903b, p.381)

Shale, black.	
Shale, clayey with sandstone layers which contain fish scales.	0.38
Limestone, arenaceous with fish remains and bones.	0.075
Tea Green Marl.	

Llanwern, Gwent, ST 353878, Richardson (1903b, p.380)

Shale, black.	
Quartz sand with fish remains.	0.2
Grit, with fish scales.	0.13
Tea Green Marl.	

Goldcliff, Gwent, ST 366831, Richardson (1903b, p.374)

Shale, black.	0.61
Grit, very coarse, pyritic, calcareous, with fish remains.	0.15
Shale, black.	0.025
Pebbly sandstone with bones and fish remains.	0.15
Tea Green Marl.	1.52
Quartz sand with calcareous cement and bone-bed fossils.	0.15
Red Marl.	

Penarth, Glamorgan, ST 186697

General Section

Shale, black.	1.52
Third limestone, with fibrous calcite and black shale.	0.13
Shale, black, fissile.	0.45
Second limestone (*Pecten* bed) with bivalves.	0.18
Shale, black.	2.44
First limestone, gritty with shell fragments and vertebrate fossils.	0.13
Shale, black, unevenly bedded with some channel fillings which vary in size from 40 to 250 mm long and 8 to 20 mm deep. They contain quartz grains and bone-bed fossils.	0.18
Bone-bed, a discontinuous bed which varies laterally in its thickness and its nature. Two exposures are studied in detail.	0.025
Shale, black, fissile, on Sully beds at the base, where there are occasional, teeth, scales and coarse quartz grains also some small patches of cemented bone-bed.	1.07
Sully beds.	

Detail of bone-bed exposures 'a' to 'g' (text-fig. 2)

a. 20 mm thick and typical coarse-grain bone-bed with vertebrate fossils and coarse-sand in a matrix of fine sand and calcite (Plate 15, fig. 1).

b. 0.15 m north from 'a' 15 mm thick is similar to sample 'a' though there is some development of mudstone in the matrix and also some detached whole bivalves present (Plate 15, fig. 2).

c. 3 m north from 'a' 56 mm thick:

Calcareous mudstone	17 mm
Bone-bed	4 mm
Shale layer	2 mm
Bone-bed	5 mm
Muddy limestone	28 mm

A band of typical bone-bed is split by a thin layer of shale. There are no bivalves in the bone-bed which is less coarse than the previous samples. Above is a muddy limestone with some detached bivalves, scattered vertebrate fossils and occasional coarse grains of quartz. The lower muddy limestone is similar with less bivalves.

d. 0.53 m north from 'a' 82 mm thick:

Muddy limestone	25 mm
Shale layer	2 mm
Muddy limestone	13 mm
Bone-bed	30 mm
Muddy limestone	9 mm
Bone-bed	3 mm

The uppermost limestone contains shells which are almost absent from the two lower limestones. Near the middle there is bone-bed material with the same coarseness as at point 'c' though far more diffuse with fewer fossils and less sand. There is another thin layer of similar bone-bed at the base.

e. 0.8 m north from 'a' 26 mm thick. Muddy limestone with a diffuse bone-bed (6 mm) passing obliquely from top to base of the sample (85 mm long) this contains fossils and sand with a less muddy limestone matrix.

f. 1.1 m north from 'a', 25 mm thick is a shelly bone-bed with a muddy limestone matrix. Where there is a predominence of shells there are less fossils than in the parts containing quartz grains.

g. 1.35 m north from 'a' 25 mm thick; a muddy limestone with a thin (5 mm) sandy and shelly bone-bed near the middle (Plate 15, fig. 3). Here the bed passes laterally into black shale.

Bone bed exposure 'a' to 'r' (text-fig. 3)

a. 40 mm thick:

At the base there is a 4 mm layer of fibrous calcite. Above is a fairly coarse bone-bed then a brown, shelly layer with a coarse bone-bed layer at the top (Plate 15, fig. 5).

north

Muddy limestone with a sandy, shelly bone-bed in middle (pl. 15, fig. 3)

Muddy limestone with a diffuse, thin, shelly bone-bed

Muddy limestone with a diffuse bone-bed and black shale layer

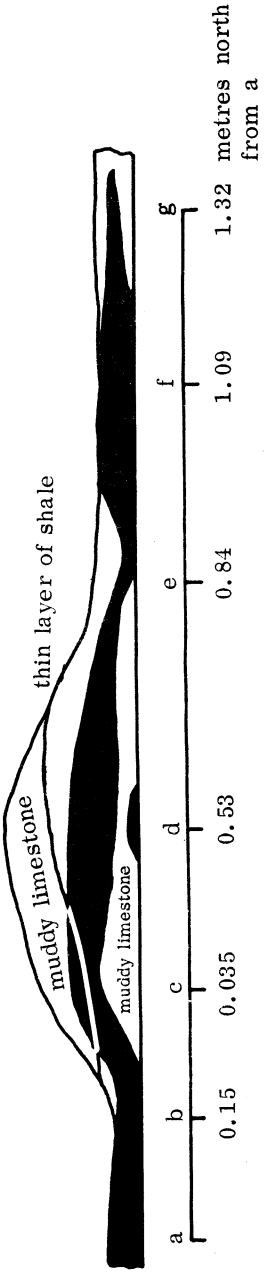
Muddy limestone with bone-bed split by layer of black shale

Muddy limestone with bone-bed split by layer of black shale

Coarse bone-bed with bivalves and some mudstone matrix (pl. 15, fig. 2)

Coarse bone-bed (pl. 15, fig. 1)

south



Text-fig. 2. Penarth bone-bed exposure 'a' to 'g'

b. 45.15 m north from 'a', 22 mm thick, is a bone-bed with a shelly middle part which contains fewer phosphatic fossils. It is fine-grained near the base and there is an unfossiliferous argillaceous layer at the top (Plate 15, fig. 4).

c. 54.9 m north from 'a', 6 mm thick is a hard, dark grey, non-calcareous, cemented mudstone in which there are embedded numerous, detached, unbroken bivalve shells laid convexly downwards.

d. 55.2 m north from 'a', 24 mm thick: Cemented, dark grey, noncalcareous mudstone, weathering reddish brown. It contains pyrite and whitish, speckled inclusions.

e. 55.5 m north from 'a', 6 mm thick: Dark grey, cemented, non-calcareous mudstone with a slightly calcareous, broken shelly content.

f. 55.815 m north from 'a', 25 mm thick: A bone-bed with vertebrate fossils and coarse sand in a calcareous matrix containing shell debris.

g. 56.42 m north from 'a', 25 mm thick: A bone-bed in a calcareous matrix with many fossils, including coprolites, also a small amount of coarse sand.

h. 56.88 m north from 'a', 20 mm thick is a bone-bed, a coarse-grained rock consisting of coarse sand and vertebrate fossils in a calcareous matrix with a small number of bivalves.

i. 57.65 m north from 'a', 22 m thick: Bone-bed with coarse and fine sand, unsorted vertebrate fossils also fragmented and unfragmented shells in a calcareous matrix. (Plate 15, fig. 6).

j. 58.1 m north from 'a', 20 mm thick: Fine, non-calcareous sandstone.

k. 58.5 m north from 'a', non-calcareous sandstone with pyrite.

l. 58.7 m north from 'a', 5 mm thick: Mudstone dark grey, cemented, non-calcareous with calcareous inclusions.

m. 58.85 m north from 'a' 3 mm thick: Mudstone, dark grey, calcareous.

n. 59.17 m north from 'a' 20 mm thick: Siltstone, fine grained with pyrite.

o. Between 59.2 and 61.3 m north from 'a', 25 mm to 25 cm thick: Limestone which bulges upwards to 25 cms and thins again over a distance of 2.1 metres.

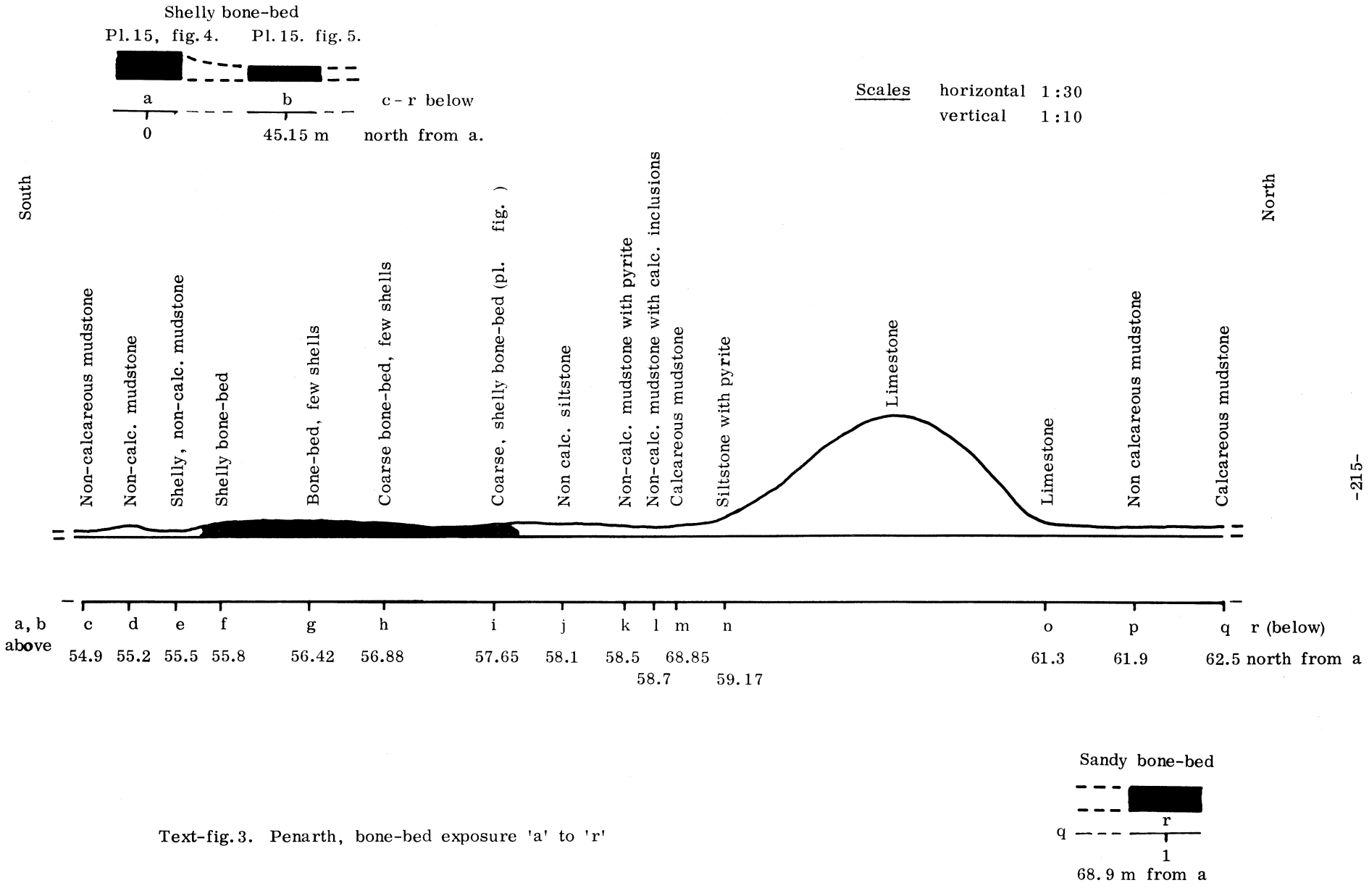
p. 61.9 m north from 'a', 8 mm thick: Mudstone, dark grey, cemented, non-calcareous. Near the base and at the top there are bands which are slightly calcareous and shelly though the shells have been replaced by pyrite, there is some pyrite and sand.

q. 62.5 m north from 'a', 8 mm thick: Mudstone, dark grey, cemented, calcareous, containing pyrite. The bed then passes laterally into black shale for a distance of 6.4 metres when the bone-bed reappears.

r. 68.9 m north from 'a', 38 m thick: Bone-bed with a predominance of medium grade sand and a scattering of small vertebrate fossils. The matrix is calcareous.

Remarks

No sample was found of the discontinuous bone-bed which has been noted by previous authors (Richardson, 1905, p.391) at the base of the Rhaetic at Penarth though its influence, in the deposition as a trace bone-bed is present.



Text-fig. 3. Penarth, bone-bed exposure 'a' to 'r'

The lengthy exposure of the main bone-bed provides an excellent opportunity for the study of its lateral development. It is discontinuous and many cm thick. It varies between being a sandy bone-bed, a sandy and shelly bone-bed, limestone, calcareous mudstone, non-calcareous mudstone and a siltstone. It also has combinations of these elements. The vertebrate fossils are directly related to the sandiness and also slightly to the shelly content. This may occur as a coarse horizon in a fine-grained rock or through the whole of the bed.

This is a part primary bone-bed, a striking feature being bivalves which are orientated at random, unbroken, attached and filled with lime mud showing that they were buried quietly, *in situ* before transport separated them or abraded them.

The isolated bone-bed channel fillings in the black shale above could indicate that currents bearing such material, swept past and left some of their load trapped in the hollows.

The first limestone above the bone-bed is a part primary bed with unsorted material and a deposition of bivalves in a calcareous matrix.

Dinas Powys, Glamorgan, ST 155712, Richardson, (1905, p.396).

	metres
Shale, black.	0.9
Limestone with quartz sand below containing fish remains.	0.12
Shale, black.	0.1
Sandy layer, chocolate colour with fish remains.	0.025
Sully beds.	

Lavernock, Glamorgan, ST 188682

Shale, grey near the top.	1.7
Limestone with fibrous calcite layers.	0.05
Shale, black.	0.5
Limestone with a fibrous calcite layer.	0.012
Shale, black.	app. 1.2
Limestone.	0.1
Shale, black.	1.3
Bone-bed, with shaley partings; Five parts 'a' to 'e' at the top.	0.165

e 25 mm thick

Shale, black with an impure limestone at the top.

d 20 mm thick

Shale, black with light scatter bone-bed and trace bone-bed in patches.

c 65 mm thick

Limestone, sandy. The upper part contains coarse and fine quartz, boney fossils and coprolites. The lower part has a compact shelly fauna with rare vertebrate fossils (Plate 14, fig. 4).

b 15 mm thick

Dark grey, impure limestone.

		metres
a	40 mm thick	
	Mudstone, cemented, pyritic, with scattered coarse grains and vertebrate fossils.	
	Shale, black.	0.075
	Limestone, arenaceous, intermittant up to 25 mm thick with quartz grains, vertebrate fossils and bivalves (Plate 14, fig. 5).	0.025
	Shale, black.	1.00
	In the lowest 100 m there are patches and scattered elements of trace bone-bed. Some of the black shale is laid directly upon, and filling cracks in the Sully Beds.	

Remarks

There is a well known pebble bone-bed, of patchy occurence, at the base of the Rhaetic at Lavernock. In the section examined this is reduced to a trace bone-bed and in places is completely absent.

The first bone-bed above the base is a part primary one and it may correlate with the main bone-bed at Penarth as they have similar features (Plate 14, fig. 5, Plate 15, fig. 4).

The bone-bed at the higher horizon has varying modes of deposition from limestone, arenaceous limestone to black shale and pyritic mudstone. There are also differing types of bone-bed though they are only associated with the sandy deposits. The lower part 'a' is a scatter bone-bed, part 'c' is a part primary bone-bed (Plate 14,fig. 4) part 'd' contains trace and scatter bone-bed material in the black shale and the argillaceous limestone is unfossiliferous.

It is interesting to compare this section with the one measured by Richardson (1905, p. 392).

Richardson	Metres	Present author		Metres
Limestone.	0.2	Limestone.		0.012
Shales, black, lower earthy.	1.0	Shale, black.		1.2
Limestone, lower part, shelly.	0.1			
Limestone, arenaceous bone-bed.	0.075	Shale, limestone at top.	(e)	0.025
Sandstone, hard, pyritic.	0.025			
Shale, parting.	0.025	Shale, black scattered bone-bed.	(d)	0.025
Sandstones, shale & 'beef'	0.1	Limestone, sandy bone-bed.	(c)	0.06
Black shales.	0.075	Shale parting, thin.		-
Limestone, dark, pyritic.	0.025	Limestone	(b)	.012
Shales, black.	0.1	Shale parting, thin.		-
Bone-bed.	0.025	Mudstone scatter bone-bed.	(a)	.025
Shales, black.	0.18	Shales, black.		0.075
Limestone bone-bed.	0.04	Limestone bone-bed.		0.025
Shales, black.	0.33	Shales, black.		1.00
Fish Bed, pebbly bone-bed.	0.025	Trace bone-bed.		
	2.325			2.464

Up to the second bone-bed above the base the beds correlate well though there are remarkable differences in their thicknesses. Hard beds of Richardson's section correlate with the parts 'a' to 'e' of the present section, though, over what must have been a short distance, the shale partings are equivalent of shale beds and the lithology differs. Both record two hard bone-bed horizons, though, in Richardson's section he finds one at the top on the same horizon as the unfossiliferous limestone in the present measurements. This comparison gives another instance of the striking lateral changes in a bone-bed.

Saint Mary's Well Bay, Glamorgan, ST 175676

	metres
Third limestone, muddy, black, with layers of fibrous calcite.	
Shale, black.	0.9
Second limestone with black mudstone and limestone shale.	0.1
Shale, black.	2.14
First limestone, dark grey, muddy.	0.12
Shale, black.	1.8
Bone-bed, three parts, 'a' to 'c' at the top.	0.04
c 8 mm thick A thin bed of pyritic limestone.	
b 6 mm thick A thin discontinuous layer which consists of cemented sand and vertebrate fossils.	
a 26 mm thick A discontinuous layer of limestone devoid of bone-bed content. It contains many bivalve shells detached and unbroken.	
Shale, black, the base being laid directly on Sully Beds. The lowest 25 mm contains a trace bone-bed in places.	1.4

Remarks

Saint Mary's Well Bay gives another example of a trace bone-bed occuring along the horizon of a major bone-bed at the base of the Rhaetic.

The bone-bed contains only a thin layer of fossiliferous material in the section measured. Specimens of a thicker, more developed bone-bed were found at the foot of the cliff, indicating its changing nature laterally.

Significantly, the thin bone-bed layer was coincident with the only coarse sand found. Richardson (1905, p.394) found the bone-bed in sandstones and limestone on the horizon of the third limestone in the present section.

Cowbridge, Glamorgan, SS 999745, Richardson (1905, p.400)

	metres
Shale, black	0.35
Limestone with mica and fish remains.	0.025
Shale, black.	0.10
Limestone, often arenaceous with coprolites.	0.025

	metres
Shale, black with gritty layers and conglomerate at the base, fish, reptile remains and coprolites.	0.74
Limestone, slightly sandy with few fish remains.	0.23
Marl with lumps of hard limestone and rare fish remains.	0.4
Sully Beds.	

Coity, Glamorgan, SS 925814, Francis (1959, p.167)

Sandstone, fine-grained with clay, shale and vertebrate remains	0.91
Shale and clay, green and black.	0.91
Pebble bed with vertebrates	0.075
Sandstone, white, medium-grained with vertebrate fragments.	1.00
Keuper grey marls.	

Stormy Down, Glamorgan, SS 846806, Francis (1959, p.163)

Sandstone, brown fine-grained, clay partings, vertebrate remains.	2.4
Shale, green and brown with fish remains.	1.47
Pebble bed with abundant fish remains.	0.1
Sandstone, hard, massive, white and yellow with vertebrate fragments and galena.	5.28
Keuper green marls.	

Aust, Avon, ST 564895

Second limestone (upper *Pectin*), dark grey, shelly.	0.12
Shale, black, fissile.	2.28
First limestone (lower *Pectin*), dark grey, shelly.	0.18
Shale, black, fissile.	1.22

A part of this bed, 0.6 m above the base contains pellets and patches of calcareous sandstone. These are up to 150 mm long and 6 mm thick and the coarser-grained ones have rare vertebrate fragments. At the base, fissile black shale is laid upon Tea Green Marl without a trace of sandiness or fossils. There are some rolled pellets of Tea Green Marl.

Remarks

The basal bone-bed at Aust Cliff is probably the best known in the country. *In situ* it is found high up in the cliff so it has been studied largely from pieces which have fallen on to the beach. The bed was excavated in July 1961 during the construction of the River Severn Suspension Bridge (M.4). It is a part primary bed being a well cemented, grey, calcareous matrix with many coarse clasts of quartzite and limestone; there is also an unsorted, well preserved, comprehensive vertebrate fauna.

Also from the beach, a second, highly fossiliferous bone-bed is described (Reynolds, 1945, p.32) as slabs of arenaceous limestone derived from the top and bottom of the lower *Pecten* bed. Short (1904, p.173) describes this bed as containing numerous quartz pebbles up to 12 mm across.

Over a distance of approximately 80 m to the South West the 150 mm bone-bed passes laterally into black shale with no bone-bed content. Similarly the highly fossiliferous lower *Pectin* bed passes into a shelly limestone. This shows that the currents which deposited the coarse breccia material must have had local effect only, probably scouring in the vicinity. It also shows that the absence of bone-bed is consistent with the lack of coarse deposits even when the presence of rolled Tea Green Marl indicates a certain amount of redistribution at the base.

Trace bone-beds are found with traces of the coarser-sand within the lower shales.

Barnhill Quarry, Avon, ST 725830, Macfayden (1970, p.204)	metres
Limestone, grey, argillaceous.	0.15
Shale, black with impersistent ferruginous layer full of vertebrate remains.	1.00
Limestone, *Pectin* bed with layers of fibrous calcium carbonate.	0.3
Shale, black.	2.43
Bone-bed with fish, reptiles and quartz pebbles.	0.3
Carboniferous limestone.	

Redland, Avon, ST 585753, Rendle-Short (1904, p.173)	
Limestone, dark, shelly.	0.15
Shale and clay, black. Siliceous band with bone-bed fossils.	0.6
Shale and clay, ferruginous.	0.92
Shale, black.	0.53
Sandstone, gritty, calcareous with vertebrates, coprolites and pebbles.	0.025
Carboniferous limestone.	0.025

Cotham Rd, Avon, ST 586739, Rendle-Short (1904, p.177)	
Marl, yellow.	0.45
Limestone, thin bands, very shelly containing fish remains and coprolites.	0.92
Limestone, shelly, black with fish scales.	0.12
Shale, black, siliceous bands with fish scales.	4.5
Bone-bed absent.	
Below base of Westbury beds not recorded.	

Brislington, Avon, ST 635704, Kelloway (1933, p.566)	
Upper Rhaetic marl, brown.	0.76
Limestone with fish remains.	0.23
Marl.	0.75
Limestone with bivalves and fish remains.	0.3
Shale, variable.	2.5
Arenaceous, calcareous layer with fish, reptiles, coprolites.	0.05

	metres
Pylle Hill, Avon, ST 598718, Wilson (1891, p.546)	
Limestone, light blue, bedded (Upper Rhaetic).	
Limestone with fish remains (Upper Rhaetic).	0.3
Lower Rhaetic	
Shales with fish scales.	0.25
Limestone.	0.075
Shale, black with pyritic seams having bone-bed fossils.	0.86
Shale, black.	0.7
Shale, black, firm with scattered coprolites and scales.	0.45
Shale, black with seams and pockets of pyritic grit with fish, reptiles, coprolites and pebbles.	0.12
Tea Green Marl.	
Uphill, Somerset, ST 317589, Kellaway & Oakley (1933, p.476)	
Shale, black.	2.00
Bone-bed, sandy shale and saccaroidal limestone.	0.15
Shale, grey and black.	0.9
Tea Green Marl.	
Chilcompton, Somerset, ST 652522	
Marl, light grey, weathering buff.	0.12
Marls and limestone, grey, clayey marl weathering buff with shelly layers and thin limestones.	0.5
The limestones show ripple marks and the under surface of the lowest one is covered with vertebrate fossils, associated with the shelly layer immediately below it.	
The shelly layers are in the lower part of the bed, they consist of numerous fragments of shells with vertebrate fossils, chamosite grains a little quartz and rolled fragments of shell, many of which have accumulated calcite and some become oolitic (table 11).	
Shale, black with thick layers of buff coloured material dominated by shelly remains.	0.075
The shale is crumbly and contains bivalves, many of which are unbroken; it is without bone-bed content.	
The shelly layers occur in the lower part of the bed and are similar to those in the bed above except that there is some finer-grained material that does not contain bone-bed fossils (table 12).	
Shale, black, fissile and crumbly, with many bivalves.	2.00
Limestone, a series of variable limestones with muddy partings:	
Five parts, 'a' to 'e' (top).	0.105
e 6 mm thick	
Limestone with occasional complete shell valves.	

Chilcompton Tables 11 to 14

Table 11, marls and limestone, lower part

	850-500 microns	Fraction percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz			0.00	0.0	0.000	0.02	0.12	0.000	0.05	0.49	0.001	0.00	0.00	0.07	0.44
Phosphatic			0.87	3.2	0.016	0.65	3.09	0.038	1.24	11.35	0.092	0.16	3.76	2.92	10.52
Calcite			1.02	3.8	0.028	0.00	0.00	0.006	0.00	0.00	0.000	0.00	0.00	1.02	1.60
Rest			25.16	93.0	0.606	20.23	96.79		9.63	88.16	0.707	3.96	96.24	58.98	87.44
Totals in gms			27.05			20.90			10.92			4.12		62.99	

Table 12, black shale with shelly layers

Quartz			0.004	0.08	0.000	0.02	5.24	0.001	0.10	2.8	0.011	0.03	1.5	0.154	0.85
Phosphatic			0.28	4.66	0.054	0.29	89.51	0.001	0.58	15.5	0.091	0.19	8.9	1.34	7.65
Calcite			0.166	3.01	0.028	0.31	4.91	0.083	0.50	13.5	0.130	0.25	11.6	1.226	6.91
Rest			5.430	92.25	11.887	5.29	0.34	1.915	2.55	68.2	0.939	1.66	78.0	14.93	84.59
Totals in gms			5.88			5.91			3.73			2.13		17.65	

Table 13, shelly mudstone

Quartz			0.01	0.08		0.01	0.05	0.000	0.00	0.00		0.00	0.00	0.02	0.05
Phosphatic			0.02	0.11		0.10	0.6	0.002	0.20	1.79		0.05	0.85	0.37	0.85
Rest			11.86	99.81		15.03	99.35	0.324	11.10	98.21		5.21	99.15	43.20	99.10
Totals in gms			11.89			15.14			11.30			5.26		43.59	

Table 14, basal bone-bed

Quartz	6.79	40.50	9.06	47.45		9.73	54.60		2.50	51.8		1.96	59.4	30.04	48.70
Phosphatic	4.65	27.75	5.99	31.37		7.48	40.02		1.55	35.9		1.12	34.1	20.79	33.70
Pyrite	4.42	26.38	3.40	18.81		0.98	5.38		0.27	6.3		0.22	6.5	9.29	15.06
Shale	0.92	5.37	0.64	2.37		0.00	0.00		0.00	0.0		0.00	0.0	1.56	2.54
Totals in gms	16.78		19.09			18.19			4.32			3.30			

For explanation see text. pp. 204, 221-225.

metres

d 17 mm thick

Below a mudstone parting is a limestone with a small amount of shell debris which has associated minute vertebrate fossils. The lower surface is ripple marked.

c 20 mm thick

Below another mudstone parting is a limestone with thinly scattered shell debris. It contains vertebrate fossils corresponding to the density of shell material. (Plate 16, fig.1).

b 18 mm thick

Another mudstone parting, then a limestone with disseminated shell fragments and vertebrate fossils in the upper and lower layers (Plate 16, fig. 2).

a 44 mm thick

Beneath the last mudstone parting is a limestone with masses of shelly fragments, vertebrate fossils and a little quartz. There is slight evidence of current bedding and, at the top, an abrupt change to a 5 mm layer of argillaceous limestone.

Shelly mudstone. 0.025

Similar to the shelly beds above the limestones though with less rolled fragments and fewer vertebrate fossils (table 13).

In the lower part, the fragmentation is finer and without vertebrate fossils.

Shale, black, part fissile and part crumbly. 0.7

Mudstone, black with thinly scattered vertebrate fossils and quartz grains, especially in the upper part. 0.3

Bone-bed.

At the base, discontinuous over distances of less than 1 m, leaving black shale resting directly upon Tea Green Marl. The bed is only a few mm thick and generally consists of cemented sand and vertebrate fossils though one specimen has a bone-bed layer 2 mm thick and on top a smooth limestone layer 4 mm thick.

Further along the cutting the bone-bed is still discontinuous though up to 25 mm thick. It is friable consisting of sand and fossils in a mudstone matrix (table 14).

Remarks

The basal bone-bed at Chilcompton illustrates its changing nature when traced laterally. At the section under review it is a few mm thick, cemented and associated with limestone. Approximately 80 metres to the north-east along the cutting it is up to 25 mm thick and is a friable mudstone with a large quartz and fossil content (table 14).

The higher bone-beds at Chilcompton are an exception which helps to prove the rule that vertebrate fossils are associated with coarse deposits laid in current action. There are only small amounts of fine sand present though there are masses of shell fragments, many of which have been rolled by current action and accumulated secondary calcite (tables 11, 12 & 13). Where this action is less evident and the deposits are of finer-grade the phosphatic remains are rare (table 13).

Within the bone-bed limestones the shell fragments do not have secondary calcite deposition. The vertebrate remains are minute and sorted in sizes comparable with the shell

Explanation of Plate 16

Fig.1. Chilcompton, 'limestones', part 'c'

This calcareous matrix contains silt, shell fragments, minute bone-bed fossils and some very fine sand. There are also extremely minute, pyritised shell fragments scattered through the rock. It is layered with bands having greater concentrations of shelly remains which contain the boney fossils. In the layers where sand and shell fragments are not concentrated the vertebrate remains are lacking; a well sorted and bedded secondary bone-bed.

Fig.2. Chilcompton, 'limestones', part 'b'

This bedded rock has a similar matrix to part c, fig.1. The shell fragments are scarce and phosphatic remains almost absent except for a thin, concentrated layer near the top which also contains some very fine sand. A well sorted, 'secondary' rock with the shell fragments orientated along the bedding and a thin trace bone-bed near the top.

Fig.3. Blue Anchor Bay. 'Main bone-bed' part 'b'

This is a trace bone-bed in a bed of fibrous calcite. It has a layer of silt with some grains of medium sand, pyrite and bone-bed fossile.

Fig.4. Blue Anchor Bay. 'Main bone-bed', part 'a'

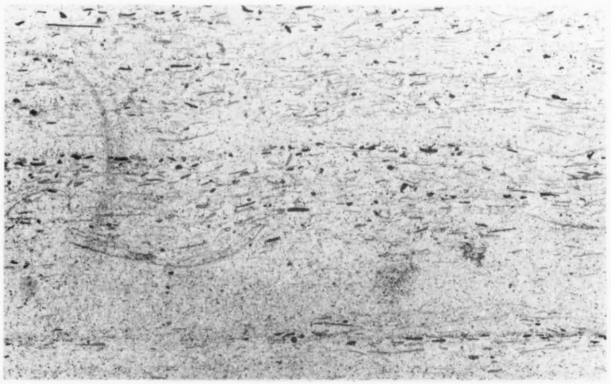
The lower part consists of quartz, phosphatic fossils and shells in a muddy limestone. The bone-bed content is poorly sorted within a fairly narrow range. It is not bedded but with the fossils generally orientated horizontally. Many of the shells are pyritised. There is an abrupt change to a fine-grained, well-sorted rock containing a mass of minute shell fragments, many of which are pyritised. There is some fine sand and occasional phosphatic fossils present. A well orientated, secondary bone-bed.

Fig.5. Blue Anchor Bay. 'Main bone-bed', part 'a'

Approximately 1 metre laterally from the locality for the sample shown as fig.4, this second sample from the same bed shows changes. There is a greater development of silty, shelly material which tends to lack bone bed content. The upper part is less shelly, more silty and better bedded; a secondary bone-bed.

Fig.6. Blue Anchor Bay. 'Richardson's Clough'

The rock contains a mass of quartz grains and phosphatic fossils with some shell remains, in a calcareous matrix. The material is not bedded or sorted; ranging from very fine to coarse sand with minute and large fossils. Coprolites are present and the shells are not very fragmented. At the base there is an abrupt break from a limestone without bone-bed content - a part primary bone-bed.



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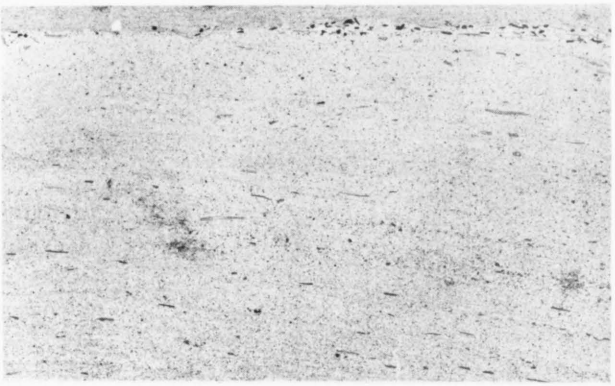

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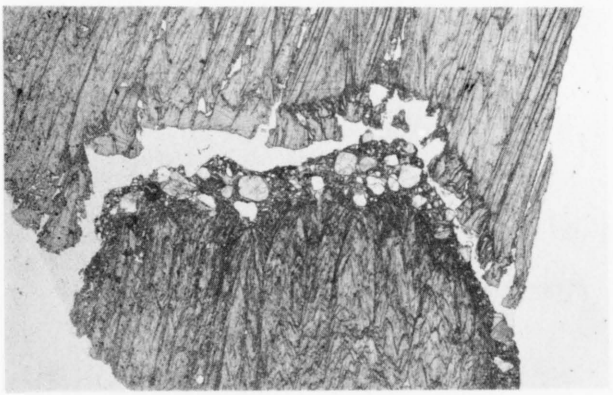

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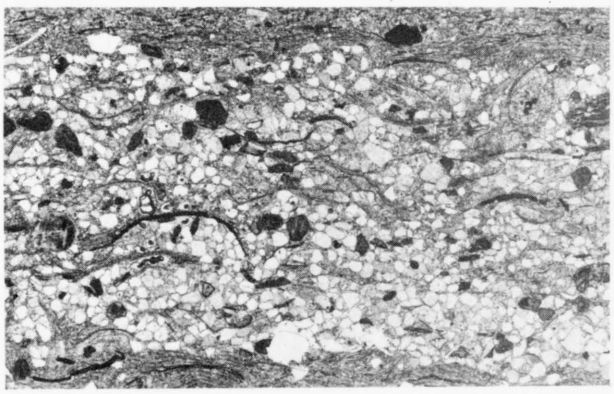

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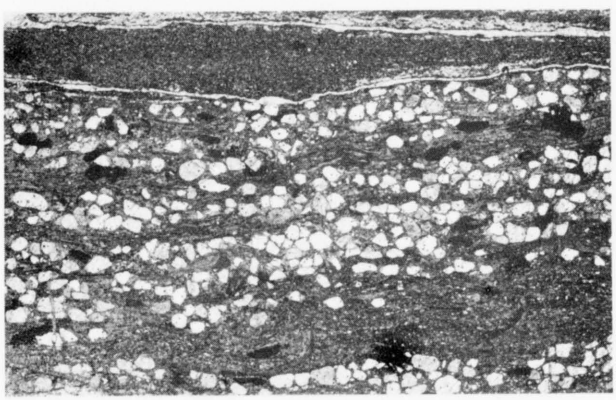

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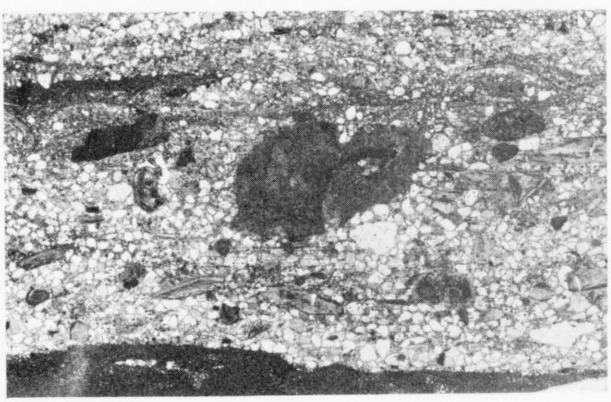

6

J. M. Sykes - British Rhaetian Bone-beds

fragments. They are chiefly associated with the denser shell fragments and with the quartz present (Plates 16, figs. 1 & 2).

All the bone-beds above the base are dominantly secondary.

The control of shells on vertebrate deposition is seen to play a minor role at Penarth (Plate 15, figs. 4 & 5) though at Chilcompton fragments of valves, rather than quartz grains, are found in association with well-sorted vertebrate fossils. (Lyell 1875, p. 558) in his pursuit of the principle that the processes of the present are the key to the past, made a search for bone-beds which are forming at the present time. He recorded two occurrences of recent bone-beds, one on the Rockall Bank, which extends for two miles along the bottom of the sea, and the other just east of the Faroe Islands which covers a distance of twenty miles at a depth of 45 fathoms. In both cases the bones are associated with an abundance of broken valves. It is therefore possible, given the right conditions, for shell fragments to play the same role as quartz in occurrence of and preserving bone-bed fossils.

Richardson reported a section examined earlier by H. B. Woodward (In Richardson, 1911, p. 66) at this railway cutting. It gives the following comparative description of the bone-beds.

Woodward	Metres	Present author	Metres
Marl, pale greenish yellow.	0.76	Marl, grey weathering buff.	0.12
Limestone, argillaceous with a thin, gritty bone-bed at the top.	0.1	Marl and limestone.	0.56
Shales, marly.	0.3	Shale with buff, shelly layers.	0.075
Shales, black.	0.6		
Sandstone, thin layers.	0.05	Shale, black.	1.98
Shale, black.	0.3		
Limestone, grey, arenaceous	0.075	Limestone, variable.	0.075
Shale, black. fissile.	0.6	Shale, black, shelly at the top.	0.6
Shale, black, unbedded.	0.3	Mudstone.	0.3
		Shale, black, fissile	0.3
Bone-bed, fish, coprolites, pebbles.	0.075	Bone-bed.	0.025
	3.16		4.035

Woodward found unbedded shale immediately above the basal bone-bed whereas there is 0.3 metres of fissile shale intervening in the present section. This contains pellets of Tea Green Marl which were gathered from the underlying beds elsewhere. Within the mudstone of the present section there is a thin scatter bone-bed which could still be derived from disturbed bone-bed material elsewhere and laid in a typical scatter bed medium.

The lowest limestone Woodward found to be arenaceous, which gives a lateral sandy association to this bone-bed (Plate 16, figs. 1 & 2).

In the argillaceous limestone near the top of the section, he found a bone-bed coincident with a gritty, arenaceous layer; this was not found in the present section. He places this horizon in the Upper Rhaetic though doubt has been thrown upon this conclusion (C. Duffin in personal correspondence). It is interesting to note that bone-beds may form high in the succession when the coarse deposits are present.

	metres
Emborough, Somerset, ST 612514, Richardson (1911, p.68)	
Shale, grey.	0.2
Sandstone, bone-bed with layers of 'beef' on top.	0.075
Shale, black with thin sandstones.	0.05
Sandstone, laminated and conglomeratic bone-bed.	0.3
Sandstone, false bedded.	0.43
Coarse, conglomeratic bone-bed.	0.12
Tea Green Marl.	

Wells, Somerset, ST 545455, Brodie (1886, p.95)

"One piece of bone-bed was found out of *situ*. — A mass of conglomeratic limestone and sandstone with bone-bed fossils."

Bagley, Somerset, ST 457462, Richardson (1911, p.53)	
Shales, black.	0.45
Sandstone bone-bed, pale grey, calcareous, 3-6 layers shell debris.	0.36
Shales, black.	1.2
Limestone passing into sandstone bone-bed.	0.025
Marl, yellowish, sandy.	0.12
Limestone passing into sandstone bone-bed.	0.025
Sandstone bone-bed and yellowish, sandy shale.	0.15
Limestone, massive, grey and shelly with occasional fish remains.	1.2
Shale, black, clayey with occasional fish remains.	1.2
Shale, black with thin, brown sandstones.	2.00
Lilstock, Somerset, ST 167456, Richardson 1911, p.28.	
Shale, black, fissile.	0.45
Sandstone bone-bed, hard, grey with pebbles, coprolites and fish remains; becoming a limestone upwards.	0.15
Shale, black.	0.75
Limestone and shale.	1.5
Shale, black with gritty layers.	0.5
Sully beds.	
Saint Audries Bay, Somerset, ST 101434 (Tables 15-22, pp.228-229).	
Shale, black.	0.075
Sandstones and shales, calcareous, divided into three parts, 'a' to 'c'.	0.53
c 230 mm thick	
Light grey, calcareous siltstones and thin, calcareous shales.	

metres

b 240 mm thick

Light grey, calcareous, fine sandstone and siltstone with some black shale. There are scattered grains of chamosite, pyrite and rolled shell fragments. Thinly bedded parts have ripple marks; thicker bedded parts have some vertebrate fossils and occasional coarse quartz grains.

a 60 mm thick

Light grey, fine sandstone with shell fragments, ostracods and some bone-bed fossils and quartz. There are inclusions of dark limestone. (Plate 14, fig. 6).

Limestone and shales; at the top there is a dark grey, shelly limestone, nodular in places. Below this are layers of hard, calcareous, shelly shale. At the base is a thin layer of limestone. 0.12

Shale, black, fissile and part crumbly. 1.45

Shale, black, bedded and lumpy, with variable coarse deposits. 0.36

They are divided into seven parts, 'a' to 'g' at the top.

g 25 mm thick

Mainly bedded with scattered quartz and vertebrate fossils also some thin layers and patches which are cemented and contain chamosite and crystaline quartz grains (table 15).

f 25 mm thick

This has a large amount of unbedded quartz grains and bone-bed fossils; the base shows channel fillings (table 16).

e 75 mm thick

Well bedded black shale with small patches of bone-bed material. There are scattered quartz and fossils also occasional grains of the underlying Sully marl (table 17).

d 75 mm thick

Layers of black shale and medium to fine sand, the coarser type containing fossils (table 18).

c 50 mm thick

Less well-bedded black shale with medium and coarse and also fossils spread throughout. There are some patches of bone-bed content and also some marl fragments as in 'e' (table 19).

b 75 mm thick

Black shale with layers and patches of quartz and fossils (table 20).

a 25 mm thick

Poorly bedded shale with concentrations of medium and coarse quartz. Bone-bed fossils are spread sparsely throughout. These lowest shales are laid directly upon Sully Beds where the basal bone-bed is not present. (table 21).

Bone-bed with quartz and fossils. 0.025

St. Audries Bay, Tables 15-22

Table 15, part 'g'

	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	205-125 microns	Fraction percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz	2.43	10.50		3.39	15.34		6.32	36.85	0.58	10.83	12.72	18.78
Phosphatic	0.54	2.33		0.48	2.16		0.34	1.98	0.12	2.17	1.48	2.19
Shale	20.19	87.17		18.21	82.50		10.49	61.17	4.64	87.00	53.53	79.03
Totals in gms	23.16			22.08			17.15		5.34		67.73	

Table 16, part 'f'

Quartz	7.29	70.37		17.61	66.13		1.74	70.03	6.44	63.00	33.08	66.55
Phosphatic	1.14	11.00		2.79	10.50		0.20	8.24	0.63	6.13	4.76	9.58
Shale	1.93	18.63		6.24	23.37		0.54	21.73	3.16	30.87	11.87	23.87
Totals in gms	10.36						2.48		10.23		49.71	

Table 17, part 'e'

Quartz	0.12	4	0.032	1.00	12.0	0.450	7.42	51.0	2.72	30.0	11.26	18.78
Phosphatic	0.06	2	0.009	0.13	1.5	0.017	0.51	3.5	0.18	2.5	0.88	2.19
Shale	2.76	94	0.975	7.21	86.5	3.466	6.63	45.5	2.46	67.5	19.06	79.03
Totals in gms	2.94			8.34			14.56		5.36		31.20	

Table 18, part 'd'

Quartz	0.51	60.0	0.606	1.14	47.17	0.568	11.22	74.12	6.43	78.00	19.30	35.96
Phosphatic	0.06	6.5	0.010	0.14	5.88	0.017	1.78	11.75	1.04	12.65	3.02	2.84
Shale	0.32	33.5	0.145	1.13	47.05	0.634	2.14	14.13	0.78	9.35	4.37	61.20
Totals in gms	0.95			2.41			15.14		8.25		26.69	

Table 19, part 'c'

Quartz	0.73	27	0.305	2.19	45	1.683	15.48	74.00	10.25	80.25	28.65	69.70
Phosphatic	0.10	4	0.010	0.28	6	0.035	2.22	10.62	1.18	9.25	3.78	9.20
Shale	1.82	69	1.013	2.31	49	0.738	3.26	15.38	1.28	10.50	8.67	21.10
Totals in gms	2.65			4.78			20.96		12.71		41.10	

Table 20, part 'b'

Quartz	0.78	6.0	0.067	5.37	25.2	1.574	17.06	66	6.68	65.5	29.88	43.0
Phosphatic	0.06	0.5	0.002	0.32	1.5	0.013	1.81	7	0.77	7.5	2.97	4.3
Shale	11.16	93.5	1.883	15.79	73.3	4.976	6.98	27	2.75	27.0	36.68	52.7
Totals in gms	12.00			21.48			25.85		10.20		69.53	

Table 21, part 'a'

Quartz	0.60	15.0	0.054	29.24	87.7	3.953	21.41	81.5	5.69	72.0	56.94	79.63
Phosphatic	0.26	6.5	0.008	1.23	3.7	0.080	1.90	7.25	1.21	15.5	4.60	6.43
Shale	3.14	78.5	0.452	2.87	8.6	0.274	2.96	11.25	1.06	12.5	9.97	13.94
Totals in gms	4.00			33.34			26.27		7.90		71.51	

Table 22, Comparative amount of quartz and phosphatic content in tables 15-20

Table number & horizon letter	21 a	20 b	19 c	18 d	17 e	16 f	15 g
Quartz	56.94	29.88	28.65	19.36	11.26	33.08	12.72
Phosphatic	4.00	2.97	3.78	3.02	.88	4.76	1.48
Totals in gms and percentage of 100 gms	6.094	32.85	32.43	22.38	12.14	37.84	14.20

For explanation see text. pp. 204, 226-230.

Remarks

At the base there is a thin, discontinuous bone-bed up to 20 mm thick. It is poorly cemented with a dominant, poorly sorted quartz content; an intermediate part primary bed.

The lowest 0.36 m of the deposits which appear as black shale are an excellent example of scatter and trace bone-beds with quartz and fossils scattered through the rock or in small patches and thin layers. The fluctuating fossil content is linked to the sandy content. This is shown in table no. 22 which is a compilation of tables nos. 15-21. The presence of Sully marl in these beds (tables 17 and 19) would help to indicate that they are a redeposition of disturbed basal bone-bed.

The lower part of the Westbury Beds at St Audries was first measured before 1871 by R. Etheridge (in Richardson, 1911, p. 21), before the publication of his paper in which he stated that the section was then obscured. Richardson also reported that the section was obscured but he gave Etheridge's measurements.

Etheridge (in Richardson)	metres	Present author	metres
Shale, black.	0.46	Shale, black	0.075+
Bone-bed, siliceous rock with rolled pieces of limestone, fossils, coprolites & quartz pebbles.	0.12	Sandstone and siltstone. Top Light grey calc. siltstone and	0.53
Shale, black.	0.38	black, calc. shale.	
Sandstone layers, greenish yellow, and black shale.	0.075	Middle Transitional from lower to upper.	
Shale, black.	0.46	Lower Bone-bed with quartz, shell fragments & limestone pieces.	
Limestone, hard, grey with fibrous calcite.	0.13	Limestone, partly nodular, shaley at the base.	0.12
Shale, black.	0.46	Shale, black, fissile.	1.45
Limestone.	0.025		
Shale, black.	0.46	Shale, bedded and lumpy with coarse deposits.	0.36
Earthy shale with lumps of marl and basal bone-bed.	0.075	Bone-bed.	0.020
	2.645		2.555+

These measurements must have been taken a short distance from each other and up to the bone-bed they compare fairly well. The sandstones which contain the bone-bed in the right-hand column above do not have the coarse, pebbly deposits or the thick bands of shale. The bone-bed is of much finer-grade and is found at the base rather than at the top as in the earlier measurements. The bone-bed in the present exposure is secondary being fairly well sorted and containing shell debris. It is possible that the limestone inclusions link it with Etheridges report of rolled pieces of limestone, coprolites and other part primary indications in the vicinity. (Plate 14, fig. 6).

metres

Blue Anchor Bay, Somerset, ST 042432

Limestone (*Pleurophorus*), medium grey, shelly with fibrous calcite. 0.23

Shale, black, fissile with bivalves 0.2

Bone-bed, a composite bed with five parts 'a' to 'e' at the top. 0.28

e Up to 120 mm thick

A massive, calcareous gritstone containing numerous vertebrate fossils which are generally small fish remains or fragments of larger fossils; coprolites are rare. Thin scrins of calcite pass through the bed which may cut across fossils. Many of the quartz grains have a unipyramidal crystaline development (table 23).

d 50 mm thick

This is transitional to the part below. It has layers of calcareous bone-bed sandstone, thin layers of black shale and some limestone. There is less quartz development. The bone-bed content grades smaller downwards.

c 70 mm thick

This part consists of alternating layers of non-calcareous, fissile black shale and thin layers of calcareous bone-bed sandstones. A feature, is distinct ripple formation throughout. The shale contains bivalves which may be laid immediately upon a sandstone. The thin sandstones vary from extremely thin wedges up to 11 mm thick. The grade is fine to medium sand and the fossils are scarce but scattered generally throughout the sandstone.

b Up to 30 mm thick

A fibrous calcite bed, variable in thickness. One sample (Plate 16, fig. 3), has a trace bone-bed layer of quartz fossils and pyrite.

a 18 mm thick

A calcareous, sandy bone-bed laid on black shale. It has a shelly lower part and is silty at the top (Plate 16, figs. 4 & 5). One sample contrasts in being packed with coprolites in a thin sandy bed.

Shale, black, fissile with many bivalves. 0.15

Limestone, grey, massive with limestone shales at the top. 0.6

Shale and limestone, black with limestone shale and limestone at the base. Thickness was not determinable.

Shale, black. 0.12

Limestone, fibrous calcite at the top and nodular at the base. 0.15

Shale, black. 0.6

Shales and limestones, poorly exposed though plentiful loose. 0.91

Richardson's Clough bone-bed must be from this horizon though not found *in situ*. In the samples on the beach, the bone-bed is found as part of a massive limestone. With the bone-bed there is an abrupt change to a coarse gritstone with a calcareous matrix. (Plate 16, fig. 6).

	metres
Limestone, limestone shale and shale.	0.9
The limestone is dark grey unbedded. The 1st shales are bedded and unfossiliferous. Part of the black shale is bedded and some unbedded. It has much silty deposit which can be seen as thin alternating layers with black shale. There are occasional bone-bed fossils.	
Limestone, dark grey with bivalves, thickness was not determinable.	
Shale, black, fissile.	0.9+
Limestone, thin, sandy with scattered, well preserved vertebrate fossils.	0.025
Shelly mudstone.	0.12
Numerous shelly fragments in a mudstone matrix. The upper part is much more shelly (table 24). Quartz and bone-bed fossils are present scattered through the rock. There are fragments of Sully marl, especially near the base (table 25).	

Remarks

The bone-beds illustrate the varying kinds of bone-bed deposition. The lowest beds are examples of scatter bone-beds. The upper part has a greater amount of broken shells and rather more quartz and fossils though the proportions are similar in both samples (tables 24 & 25). On top of these beds the lithology changes to a sandy limestone though the scatter bone-bed content is retained.

In the shales above the second limestone there are thin trace bone-beds. A random 100 gms sample was broken down which proved to contain approximately 50% black shale, a substantial fraction of very fine sand and the rest silt. No fossils were noted.

The horizon known as 'The Clough' (Richardson, 1911, p.18) is an example of a part primary bone-bed (Plate 16, fig. 6).

Part 'a' of the main bone-bed, which is near the top of the exposure, shows changing conditions both vertically and laterally. In the lower typical bone-bed part of two adjacent samples (Plate 16, figs. 4 & 5), one (fig. 5) is thinner and has a much stronger development of fine-grained, unfossiliferous matrix. In the upper part there is a change from an almost unfossiliferous siltstone (Plate 16, fig. 5) to a shelly, calcareous matrix with some scattered quartz and fossils (Plate 16, fig. 4). Traced laterally a short way, it is dominated by coprolites, a part-primary feature.

Part 'b' provides an example of a trace bone-bed (Plate 16, fig. 3) in a generally unfossiliferous calcium carbonate rock which has become fibrous, presumably by subsequent diagenetic pressure.

Part 'c', by its rippled nature, shows that current action was affecting the deposition. It again demonstrates that the bone-bed fossils are only found associated with the coarser deposits. The distinct break from bone-bed sand to black shale with bivalves and vice versa, occurs several times in this part of the bed.

Part 'e' has a mixture of primary and secondary features. It is unbedded, poorly sorted with a mixture of worn and unworn fossils deposited with random orientation. The minute fossils are well integrated with the larger ones and there are very few coprolites. Table no. 23 shows the high proportion of coarse sand present. With such a coarse and originally porous rock it is probable that the crystaline development was caused by silica rich fluid passing through the rock laterally or being squeezed upwards during compaction. The pyrite could be of similar origin. Scrins of calcite which cut across the consolidated rock must have been a later development.

Blue Anchor Bay, Tables 23, 24 and 25

Table 23, 'Massive grit'

	850+ microns	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Totals in gms and percentage of 100 gms.	Percentage of residue
Quartz	19.00	77.30	0.943	28.29	88	1.171	29.05	88.0	3.353	3.87	70.13		1.84	74.12		82.03	83.96
Phosphatic	4.35	17.70	0.078	3.21	10	0.103	3.46	10.5	0.382	1.39	25.25		0.49	19.75		12.90	13.20
Pyrite	1.24	5.00	0.014	0.64	2	0.015	0.49	1.5	0.007	0.25	4.62		0.15	6.13		2.77	2.84
Totals in gms	24.59									5.51			2.46				

Table 24, Shelly base

Quartz				0.10	0.7	0.023	0.76	5.1	0.044	10.34	45.5	2.901	0.86	12.9	0.364	12.06	20.6
Phosphatic				0.46	2.9	0.016	1.18	7.9	0.060	1.45	6.4	0.087	0.42	6.4	0.065	3.47	5.9
Rest				14.05	96.4	0.674	12.98	87.0	3.361	10.93	48.1	3.682	5.33	80.7	2.279	43.29	73.5
Totals in gms				14.57			14.92			22.72			6.61			58.82	

Table 25, Lowest base

Quartz	0.15	0.93		0.02	1.12	0.004	0.39	9.16	0.454	5.22	83.28	3.481	0.12	8.48	0.071	5.95	19.46
Phosphatic	0.48	2.98		0.12	4.89	0.028	0.28	6.57	0.101	0.42	6.73	0.108	0.12	8.88	0.086	1.45	4.74
Rest	15.47	96.09		2.30	94.38	0.612	3.59	84.27	5.042	0.63	9.99	0.441	1.16	82.64	2.388	23.09	75.78
Totals in gms	16.10			2.44			4.26			6.27			1.40			30.47	

For explanation see text pp. 204, 231-2.

Charlton Mackrell, Somerset, ST 417212, Richardson (1911, p.42)

	metres
Shale, black.	0.1
Limestone, black, earthy, mixed with shale, slightly arenaceous with bivalves and fish remains.	0.1
Shale and similar limestone.	0.1
Limestone, dark grey, very shelly with fish remains.	0.075
Shale, black, fissile.	0.9
Limestone.	0.18
Shale, black.	2.1
Shale, black, arenaceous, micaceous, with numerous coprolites and fish remains.	0.2
Limestone, sandy, micaceous.	0.12
Sandstone bone-bed, hard, grey with fish, reptiles, coprolites and pebbles.	0.15
Shale, black and greenish with a nodular limestone.	1.2
Shale, sandy with pebbles and many fish remains.	0.075
Shale, black, non-laminated, streaked with white, sandstone layers.	0.45
Tea Green Marl.	

Langport, Somerset, SY 417272, Richardson (1911, p.50)

Shale, black with a few gritty seams.	3.0
Sandstone, earthy with fish remains.	0.075
Shale, black and yellow.	0.18
Sandstone, grey, fine-grained with pebbles, coprolites and fish remains.	0.6
Shale, black.	0.012
Shale, black, fissile.	0.22
Shale, black with green marl and fish remains.	0.012
Tea Green Marl.	

Culverhole Point, Devon, SY 275893, Richardson (1906, p.40)

Shale, black, earthy.	0.33
Limestone, dark grey, pyritic with bivalves and fish remains.	0.2
Bone-bed black shales, indurated, gritty, fills cracks in the Tea Green Marl. It contains fish remains and coprolites.	0.05

Discussion

The commonly held opinion on the origin of the Rhaetic throughout England and Wales is that the sea encroached rapidly across a low lying plain of continental deposits and salt lakes; and that the Rhaetian deposits were laid generally in shallow waters (Wells and Kirkaldy, 1956, p.332, Wills, 1950, p.92).

Black shale is the dominant deposit of the lower Rhaetic beds. It is accompanied by sand and siltstone and especially in the south-west by more calcareous deposits and limestones.

After the deposition of the black shales there was a general shallowing of the sea for the Upper Rhaetic deposits, accompanied by a decline in the marine fauna, its absence in many places, and elsewhere a reversion to the Keuper type of deposition (Kent, 1970, p.361).

During the period of the Lower Rhaetic a number of bone-beds and incipient bone-beds formed at certain horizons. In the sections examined it has been found that bone-bed formation coincides with the presence of sandy deposits. This fact has been generally confirmed by descriptions in the relevent literature.

There appears to be a direct comparison between the grade of the coarse sediment and the size of the bone-bed fossils. The fossils range from many cm long, down to the extremely minute. The largest are nearly always found in the pebbly part primary bone-beds.

In the secondary beds the range of fossil sizes is usually larger than the quartz grains present but finer particles contain finer fossils eventually down to the silt grade which, as a rule, is unfossiliferous. The conclusion is made that in the secondary beds the fossils are graded along with the rest of sediments.

Scales, fin rays and larger fossils are occasionally found in the black shales though their occurrence is rare and isolated. It is necessary to explain why the fossils should be preserved only in the coarser deposits. Ager (1963, p.197) pointed out that the number of organic remains found within a bone-bed is not the significant factor that it was once considered to be by theories based on catastrophic events, because, at any given interval, a whole generation has time to die before an appreciable amount of sediment has been deposited. This is also true during the deposition of the black mud, but in those conditions the vertebrate fossils were only rarely preserved. It is likely that the coarse sediments were not only coincidental with the gathering and sorting of the fossils but they also provided a medium for their protection after deposition. This has been previously suggested by Swinnerton and Kent (1949, p.36).

Denison (1956, p.389) describes the formation of a bone-bed by a process of the winnowing away of the finer material and the slow accumulation of a residual material over a lengthy period of time. This leaves the problem that some of the thickest bone-beds are found in the areas of greatest deposition such as at Blue Anchor Bay. If we can accept that it was possible for a supply of boney material to be available and incorporated contemparaneously, and preserved with the coarse content; then the problem of slow, condensed deposition does not necessarily arise. We can then explain the puzzling mixture of worn and unworn fossils in the part primary bed and the presence of both these primary and secondary features within the same bed.

Bennison and Wright (1970, p.282) outline the possible land areas at the time of the Rhaetic. They extended over the greater part of Wales and the London Brabant Massif in the east, with a few small islands in the Mendips and Bristol Channel districts. There are exceptional thick deposits of sandstone in the Bridgend district of South Wales (Francis, 1959, p.163) and some littoral, basal deposition around that region. However, the land areas are considered by Audley-Charles (1970, p.65) to have been only gentle uplands and he remarks on the absence of important sources of arenaceous deposits in the Bristol region and the diminished source of clastic element from the east. With the incoming of the sea over a peneplaned area there would be little deposition from the surrounding upland areas. It is likely that the Lower Rhaetic deposits will have been derived largely from the thick strata of previously deposited Keuper Marls. The change of colour from grey-green to black is considered to be due to the prescence of carbonaceous matter, anaerobic bacterial activity and reducing conditions leading to the formation of iron sulphides.

Samples of Tea Green Marl from immediately below the base of the Westbury Beds consist of clay grade material with small fractions of silt and sand. Rhaetic deposition, which is predominantly composed of fine sediments, could well be a resorting of the Keuper Marls into fine paper shales with layers of silt and some sandstones. Undisturbed black shales infer quiet depositional conditions but with the occurrence of bone-beds there are signs of current activity. The current caused by the incoming sea could remove the low lying areas of marl (Kent, 1970, p.361) and in doing so sort out the finer material leaving concentrations of coarser material including fossils. Thus the incursion of the Rhaetic sea could provide the

current action responsible for the creation of a widespread bone-bed. Whilst erosion was occurring in some places, there is evidence in others, that small amounts of coarse sediment were being left in hollows and dried out cracks in the underlying marl. In some areas bone-bed sediments would be banked up comparatively thickly thus creating a widespread, but discontinuous bed.

Considering that there are bone-beds above the base, of the Rhaetic with a suggestion that there are two other peaks of bone-bed forming activity (text-fig. 1); it is possible that there will have been two other periods of disturbance and current activity, though not necessarily simultaneously, over the whole area. These may have been due to eustatic movements or crustal warping causing changing in sea level before the return to the shallower conditions of the Upper Rhaetic. The increased number of secondary bone-beds at these higher levels (text-fig. 1) indicates a greater tendency for the sorting and reworking of the deposits than at the initial marine invasion.

Hecker (1965, p.38) states that 'in shallow, agitated waters, changes in local conditions of life and concomitant sedimentation may occur very quickly and as a result strata formed under these changing conditions may be very thin.' A striking feature of many bone-bed exposures is that, in spite of their being thin, they display abrupt changes in their type of deposition. This can occur vertically as for example in the basal bed at Barrow-on-Soar or horizontally as is strikingly displayed at Penarth.

Part Primary bone-beds

The mixing of primary and secondary depositional features creates wide variation in the nature of bone-beds. One type are extremely fossiliferous, having very coarse deposits and large well-preserved vertebrate remains. Perhaps the best example being the well known bone-bed at Aust Cliff.

In others, the primary aspects of deposition are more concerned with the nature of limestones and their invertebrate faunas such as at Penarth (Plate 15, figs.4 & 5).

The boundaries between the different bone-bed categories are not clearly drawn and in some cases the secondary influences are stronger and the primary features less determinate. These, such as at Blue Anchor Bay (Plate 16, fig.5) and Barrow-on-Soar (Plate 14, fig.1) can only be classed intermediate part primary bone-beds.

Secondary bone-beds

All the bone-beds observed have shown some aspects of secondary deposition in the forms of fragmentation, abrasion and integration of the contents. In many of them, secondary features are almost excusively present and in examples from Wainlode Cliff (Plate 14, fig.3) and Chilcompton (Plate 16, fig.1) they are completely dominant.

Amongst the bone-beds noted (text-fig.1), in the three major bone-bed horizons the number of part primary beds declines upwards from 17 to 14 to 2 whereas the secondary bone-beds have the opposite trend upwards from 6 to 19 to 16. This shows that secondary features are more apt to occur at higher horizons which reflects the changing nature of subsequent current activity after the first marine invasion.

Scatter bone-beds

These could be aptly named fossiliferous shale. They are not obvious as such until a close inspection is made of the rock when the isolated fossils and sand grains are found scattered widely within them. At St Audrie's Bay there is thick scatter bone-bed of varied concentration though the amounts of quartz and boney fossils, which constitues the bone-bed content, are linked together as is shown in table no. 22.

In considering their origins it is significant that these scatter bone-beds are always found near above a part primary or secondary bone-bed horizon, especially where the bone-bed is thin or missing at that locality. Scatter bone beds are typically unbedded or poorly bedded which would suggest that they have not travelled far or that they have been rapidly deposited, preventing the grains from settling and orientating to develop fissility. In part primary and secondary bone-beds the quartz and vertebrate fossils are found in close association in a thick layer and if scatter bone-beds are a diseminated redistribution of this material before its cementation, it is likely that the current action also swept away a considerable amount of finer material which was re-deposited before there could be a resorting of the sediments.

Pellets and flakes of marl can often be found in the basal bond-bed, showing the association of these beds with the basal shales and underlying marls. An example occurs 3 cms above the base in the scatter beds at St. Audries Bay.

Trace bone-beds

These are confined to the finer grades of material. Much of the black shale contains layers of clean silt and, associated with them are thin layers and patches, even pellets of fine of medium grade sand. In most cases when the latter deposits are present, minute bone-bed fossils can be found with them. At Barnstone they occur only below and immediately above the bone-bed. The restriction of the trace bone-bed to the 25 mm above the bone-bed suggests that the fragments in the 25 mm have been derived from the underlying bone-bed, being resorted and redeposited. Traces of bone-bed which are found at the base of the Rhaetic could be directly associated with the wide-spread basal bone-bed as incidental material trapped in mudcracks, or left by currents which were piling up thicker bone-beds elsewhere. At other localities their presence is much more at random and not distinctly associated with a major bone-bed, an example is at Barrow-on-Soar. If these trace beds developed independently of a major bone-bed it is feasible that the current action which sorted the sand also sorted the fossils and these are incipient secondary bone-beds.

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