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THE PORTLAND BEDS OF THE DORSET MAINLAND.

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CONTENTS.

I. INTRODUCTORY AND HISTORICAL.

ON the mainland of Dorset the outcrop of the Portland Beds is 27 miles in length, extending from Durlston Head near Swanage to Portisham near Abbotsbury.[1] The strata being for the most part steeply tilted in the northern limb of the Weymouth-Purbeck anticline and intricately dissected by the sea-coast, the outcrop provides in a series of unrivalled sections all that the geologist could wish for. Since the thickness is greater (about 240 ft. in the east), the outcrop immensely longer, the sections more numerous than in the Isle of Portland, and since important changes take place in the rocks as they are traced from one end of the outcrop to the other, it is regrettable that in geological literature the mainland has been relatively neglected.

The reason is the commercial fame of Portland. Although the island is less than four miles long by a mile and a half wide, it has been frequently visited and studied by those interested in the stone industry as well as by geologists. Within the last three years a paper has been published by this Association dealing fully with the lithological aspects of the stone and the history and methods of working of the quarries (Edmunds and Schaffer, 1932), and Mr. L. R. Cox has dealt exhaustively with the fauna of the Basal Shell Bed (Cox, 1925).

[1] Readers should consult the Geological Survey's 1-inch colour-printed maps, Sheets 343 (Swanage) and 342 (Weymouth).

Disconnected references to the Portland Beds of the mainland were made by Fitton (1836), Buckland and De la Beche (1836), and Damon (1860), but the first stratigraphical work devoted to the Portland Beds alone was J. F. Blake's "Portland Rocks of England" (1880, pp. 193-9). Even in this work, however, the whole of Purbeck is dealt with in two 8vo pages, and the terminology is so archaic and the measurements are so erratic that the account conveys little to the present-day reader and is difficult to follow in the field.[1] The treatises of Woodward (1895) and Strahan (1898), usually so exhaustive and rich in information, seldom provide descriptions of anything but the Portland Freestones, merely the highest 40-50 ft., or one fifth part of the formation. The thick and highly fossiliferous Cherty Series and Portland Sand are dismissed with a bare mention, and careful records of fossils are lacking. Two of the five complete sections of the whole formation on the Dorset mainland, Gad Cliff and Dungy Head, are omitted altogether.

In spite of these palpable deficiencies (to modern eyes), Strahan's classic memoir of 1898 is still the last word on the subject, in no sense superseded by such works as have been subsequently published. Of these only three call for notice: some isolated observations at Hounstout by Buckman (1926); a petrographical investigation of the Portland Sand by Latter (1926), whose observations, however, are of no help to the stratigrapher since he does not record a single fossil; and lastly an outline account of the stratigraphy published by the present writer in a book of too wide a scope for details to be given (Arkell, 1933).

In consequence, the greater part of the Portland Beds has remained to the present day virtually a *terra incognita*. One can clamber along the foot of the splendid sections in Purbeck and expect to pick up something new at any moment. As late as 1914 Salfeld, after a visit from Germany, was still able to affirm that the peculiarly-ribbed ("virgatotome") ammonites of the genus *Virgatites* Pavlow, characteristic of Russia, would be found below the Blackstone, in the middle of the Kimeridge Clay. But in 1926 Buckman found them in the Portland Sand, from 300 ft. to 350 ft. higher up. Further discoveries, described below, substantiate Buckman's correlation and seem to settle the question of what level yields the nearest approach to these virgatotome ammonites represented in England. Unfortunately Lewinski, in an important monograph on the *Virgatites* beds of Poland (1923), and other recent writers, have repeated Salfeld's faulty zonal classification in this and other respects and so perpetuate a distorted correlation.

It is significant of the little heed taken of the Portland

[1] As for the ten miles of outcrop north of Weymouth, Blake, in spite of the imposing title of his paper, was content to mention Ringstead and Upwey and then say, "I have not been able to visit Corton, where the Portland Sand is said to be exposed." (1880, p. 199.)

Beds of the type-locality by foreign writers that Lewinski attempts to abolish the Portlandian Stage altogether, alleging ambiguity, and uses instead the term Bononian, introduced by Pavlow in 1896.[1] But apart from the fact that the ancient term Portlandian (Brongniart, 1829) cannot be thus peremptorily set aside, it is true to say that there is hardly any stage term so deeply involved in confusion and ambiguity as Bononian. It was first introduced by Blake in 1880 (p. 196) in the form Boulognian, which he changed to Bolonian in 1881 (p. 581), and which Pavlow first adopted in 1891 (p. 550) in the form Boulonian, changing it to Bononian in 1896. Nor do these metamorphoses alter the fact that Blake proposed the term expressly for strata *below* the Portland Beds.

It is surely time that the accepted definitions of stratal terms should be based on the previously established scope of the formations in the type localities from which they take their names. It is typical of what occurs at present that Salfeld in his paper "On Certain Upper Jurassic Strata of England" (1913, p. 424) determines the zones that are proper to "The Portland or Portlandian in the German and French sense" (i.e., *apud* d'Orbigny), but not to the Portlandian of Dorset. He does not attempt to show in what respects d'Orbigny was wrong in his interpretation of the English formations, and there is no acknowledgment that the French and German authors have been led astray. Rather it seems that it must have been William Smith[2] and Fitton[2] who were in error in not correctly anticipating the judgments of d'Orbigny and his followers; for we read "The bulk of the Kimeridge Clay of Kimeridge, all the clays that lie above the Maple Ledge Stone Band, belong to the Portlandian, because the clays between the Maple and Yellow Ledges yield *Gravesiæ* of the groups of *G. gravesi* and *G. irius* . . . and are therefore the equivalents of our Gigas Beds" (Salfeld, 1914, p. 192). De Loriol (1875, p. 240) also remarks artlessly, "It must be noted that in England the Portlandien moyen has generally been confused with the upper beds of the Kimeridge Clay"! D'Orbigny was not so great a palæontologist that because he standardised the misidentification of the genus *Gravesia* with the not very similar *Titanites*, the Kimeridge Clay of England, named decades before he wrote, must be dismembered and three quarters of it handed over to the Portland Beds.[3]

The present paper, therefore, is intended as a contribution towards an understanding of the Portlandian Stage in its type-locality. It does not aspire to an exhaustive treatment of the

[1] Bononia = Boulogne-sur-Mer.

[2] William Smith in 1815-16 named the "Portland Rock." and "Sand." Fitton in 1836 added more precisely "Portland Sand" (see Arkell, 1933, pp. 4, 7).

[3] I am glad to see, in a publication received since the above was written, that Dr. Spath has begun to make a stand against the distortion of English Stratal terminology [Spath, 1914, p. 869, and table on p. 864]. It is to be hoped his recommendations will be adopted.

ammonites, which would require a monograph with folio-sized plates. Before such a study could be made, extensive blasting or quarrying would be needed to procure a properly representative collection from all parts of the formation; for the ammonites in existing collections nearly all come from the Freestone Series, one fifth part of the formation. Abundant giant specimens can be seen along the cliffs embedded in the Cherty Series and the hard bands of the Portland Sand, and they can sometimes be identified generically, but the rock is nearly as hard as iron and they cannot be detached by ordinary methods. Field-records therefore often have to suffice.

II. THE EAST PURBECK SECTIONS.

The Cliffs of Seacombe and Winspit; St. Alban's Head; Worth Quarry; Emmit Hill and Hounstout.

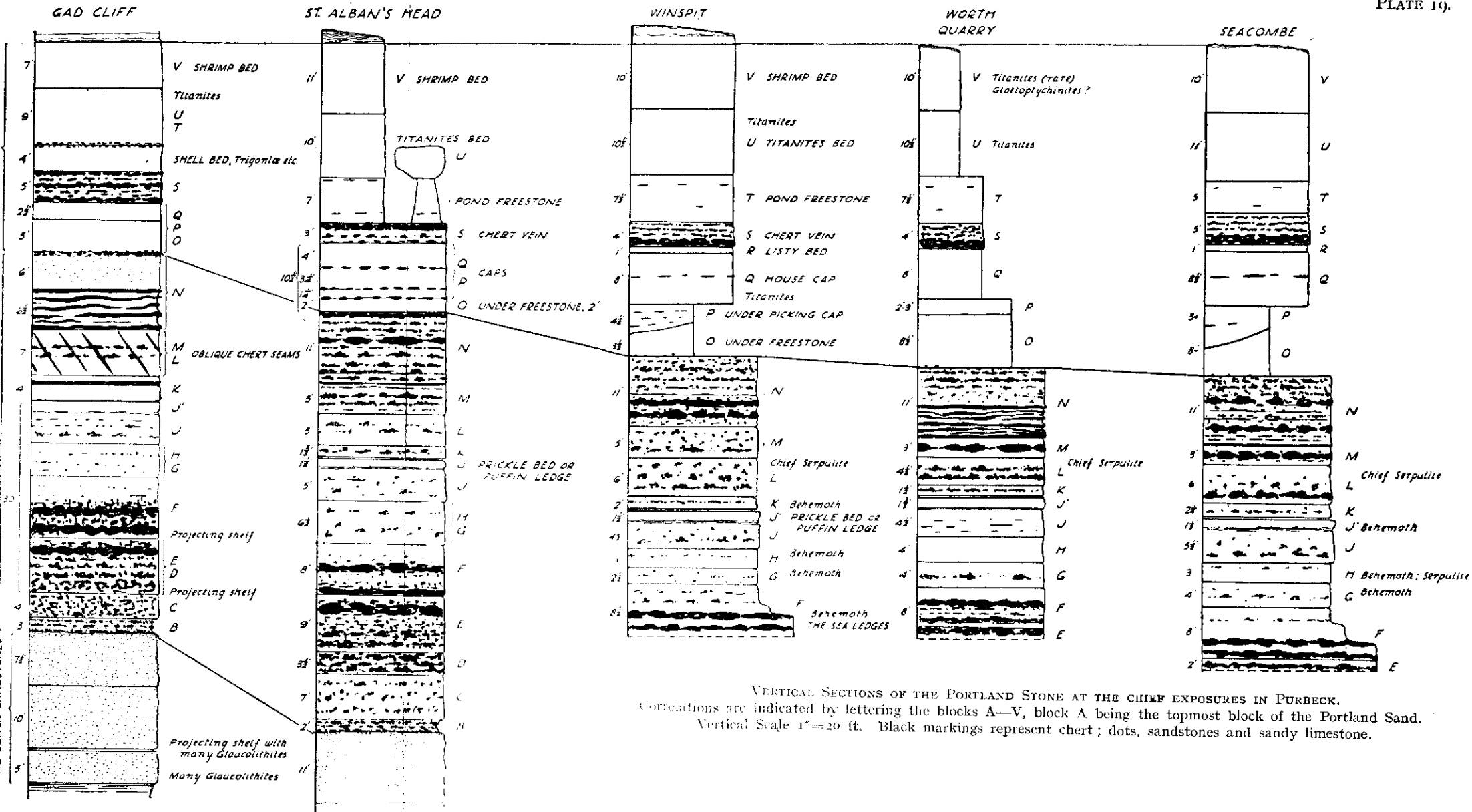
The Portland Stone forms a vertical wall rising from one to two hundred feet straight from the sea for a distance of 4½ miles, from Durlston Head to St. Alban's Head. Throughout this distance there is a continuous perfect section, often with the basal Purbeck Beds in the brow of the cliff above; but it is inaccessible at all tides, deep water nearly everywhere approaching to the foot of the cliffs. Although the strata are nearly horizontal, there is a gentle seaward dip and they undulate slightly and are faulted. Consequently in some places the top of the Portland Sand is brought up not far below sea-level, and at these places the talus of lodged blocks may protrude through the water (as at the Ragged Rocks). Nowhere, however, is the base of the Cherty Series visible until St. Alban's Head is reached.

The east side of St. Alban's Head presents a magnificent precipice of Portland Stone, at the foot of which fallen blocks and disintegrating landslips spread out as a wild undercliff, lodged upon the Kimeridge Clay (Plate 20). On the west side of the Head (Pl. 21, B), and its continuation, Emmit Hill, the Portland Stone begins to run out. The accessible part of the cliff there shows a section of the Portland Sand nearly a mile in length.

Beyond the gap of Chapman's Pool, Hounstout Cliff rises 501 ft. above the sea, presenting probably the finest single section of Upper Kimeridge Clay and Lower Portland Beds in existence.[1] Here the Portland Stone has risen so that it forms only a capping, occupying the highest 50 ft. This is the only inaccessible part. On the east side the section extends down to the zone of *Pavlovia rotunda*, and on the west side, owing to the easterly dip of the beds, 100 ft. lower, to clays covered with crushed *Pectinatites*.

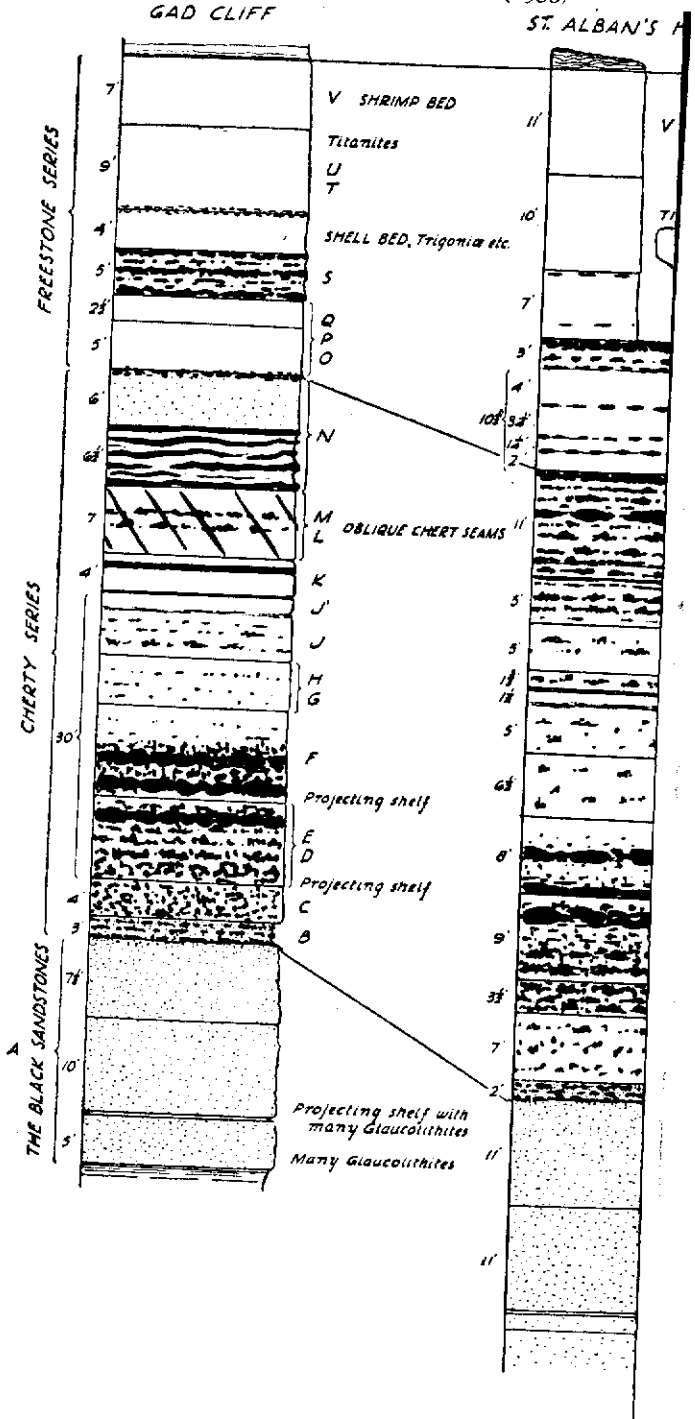
West of Hounstout the outcrop of the Portland Beds passes

[1] See Arkell, 1933, plates XIX. and XXIV.



VERTICAL SECTIONS OF THE PORTLAND STONE AT THE CHIEF EXPOSURES IN PURBECK.
Correlations are indicated by lettering the blocks A—V, block A being the topmost block of the Portland Sand.
Vertical Scale 1"=20 ft. Black markings represent chert; dots, sandstones and sandy limestone.

[To face p. 305.



inland, but where it strikes the sea again, four miles farther west, another splendid cross-section is displayed in Gad Cliff (Pl. 23 and 24.).

Points of Access. The Freestone Series is the most easily accessible part of the formation. It has been (and sporadically still is) worked in open quarries and galleries at numerous points in the upper part of the cliff between Durlston Head and St. Alban's Head. The best points for studying it are the ancient quarries at Tilly Whim,[1] Dancing Ledge,[2] Seacombe, Winspit[2] and the east side of St. Alban's Head. After space has been cleared down to the top of the Cherty Series, galleries are driven into the Under Freestone and Under Picking Cap; the House Cap forming the roof and the top of the Cherty Series the floor. At Worth Quarry, inland, one mile north-west of Worth Matravers, the method of working is entirely open.[3]

The Cherty Series has not been quarried in the cliffs, but the upper part may be examined at the four points where dry valleys or coombs descend to the sea making a partial break in the cliffs: Tilly Whim, Dancing Ledge, Seacombe and Winspit. At none of these places does the section continue below Blocks E or F, or just below the middle of the series. Worth Quarry, the only place where the Cherty Series has been quarried, stops short at the same level. The basal portions can only be studied at the point of St. Alban's Head, where two steep footpaths descend the cliff. It is also possible to work more than half-way up from the bottom at the edges of the scree tuns (see Plate 20).

The coastguards' gardens, under the brow of the south face of the upper headland, are situated upon a detached slice, which has slipped or been faulted down. Consequently much of the section is here repeated.

The Portland Sand can be studied *in extenso* in Emmit Hill[4] and the west face of St. Alban's Head (Pl. 24, B) and again in Hounstout. The whole of it up to the Parallel Bands is most conveniently accessible for collecting in Emmit Hill, especially on either side of the debris fan of a recent rock fall about the middle of the cliff.[5] Hounstout is also climbable west of the central arête. The best section of the Parallel Bands and the Black Sandstones, however, is afforded by a large slipped mass close to the sea in the undercliff on the east side of the extremity of St. Alban's Head.

[1] Photographs published by the Association in Hudleston and others, 1896, pl. xi., p. 310, and Monckton, 1910, pl. xii.

[2] Photographs published by the Association in Hoveden, Monckton and others, 1910, pl. xxxviii., p. 518., and in Arkell, 1933, pl. xxiii.

[3] After a change of ownership this quarry now bears the name Swanworth Quarries (Summer, 1935).

[4] Photographs published by the Association in Latter, 1910, pl. iii, p. 78; see also Arkell, 1933, pl. xxiv.

[5] It should be noted that the luxuriant undergrowth and grass here and under St. Albans and Gad Cliffs harbour abundant adders. They are common enough to be dangerous unless gaiters are worn.

In the following description, in which the grouping differs somewhat from that adopted in previous accounts, the Stone Series is lettered in blocks from A to V, beginning with the 30 ft. block of black sandstones now assigned to the Portland Sand on palæontological as well as on lithological grounds (see p. 311). The Portland Sands are numbered in beds from 1 to 28.

FREESTONE SERIES.

The normal development of the Freestone Series is too well known to need lengthy description here. In the following tabulated section, measured at Seacombe, the terminology used in the author's earlier account is adopted (Arkell, 1933, pp. 485-9), without repeating all the reasons.

		Feet.
V.	SHRIMP BED[1]. White, fine-grained sublithographic limestone, very constant in appearance from Durlston Head to Lulworth. The 'Shrimp' is a small Crustacean identified by Mr. H. Woods as probably *Calianassa*. Bivalves abound, especially *Trigonia gibbosa*, mainly var. *damoniana* de Lor., *Protocardia dissimilis* (Sow.), *Chlamys* (*Camptochlamys*) *lamellosa* (Sow.), *Isognomon* [*Perna*] *listeri* (Brown) [= *bouchardi* Oppel][2], *Pleuromya tellina* (Ag.), with *Trigonia incurva* Benett, *Isocyprina* sp., etc. Since the publication of the author's last account Worth Quarry has yielded from this bed a fairly complete specimen of *Titanites*. There are also fragments of coarsely-ribbed triplicate ammonites suggestive of Buckman's *Glottoptychinites* ..	10
U.	TITANITES BED. Hard, greyish, shelly limestone ('spangle'), as at Worth Quarry, especially shelly in the basal 2 ft. Innumerable *Trigonia gibbosa*, *T. incurva*, *I. listeri*, *Chl. lamellosa*, *P. dissimilis*, *Ostrea expansa*, etc. This bed is the source of nearly all the giant ammonites of various species of *Titanites* (though at Winspit some occur in the House Cap). At Tilly Whim a lenticular oyster bed develops on this horizon. Locally about 8 ft. of the rock is almost entirely composed of *Exogyra nana* (Sow.), *E. thurmanni* Étall., *Ostrea expansa* Sow. and *Isognomon listeri* (Brown), with a smaller proportion of *Lima rustica* (Sow.) and *Plicatula boisdini* de Lor. Sometimes the fossils are dissolved away, leaving patches of rock like the Roach of Portland	10–11
T.	POND FREESTONE. Good oolitic freestone. Fossils nearly all comminuted. Occasionally spoilt by lenticles of white silicified oolite. At Worth 7–7½ ft. Here only	5
S.	CHERT VEIN. Limestone with dense nodular chert in the lower 2 ft. and sparser chert in the upper 3 ft.	5
R.	LISTY BED. Grey limestone with a ready vertical and horizontal fracture, strongly marked off above and below. So called, according to the foreman of Worth Quarry, " because	

[1] The thickness was stated by Hudleston to be 16 ft. at St. Alban's Head, but I have searched at all available sections on the head, and find that the thickness does not exceed 11 ft. at any accessible or visible point.

[2] The *Isognomon* usually known as *Perna bouchardi* Oppel, and one of the commonest fossils in the Portland Beds, was first named *Crenatula listeri* by Brown (1845–9, Illustr. Fossil Conchology, p. 165), the type being the typical cast from the doggers of the Shotover Grit Sands of Shotover Hill, Oxford, figured in Parkinson's Organic Remains, 1811, vol. iii., pl. xv., fig. 5. This commemoration of Martin Lister antedates Oppel's name by ten years.

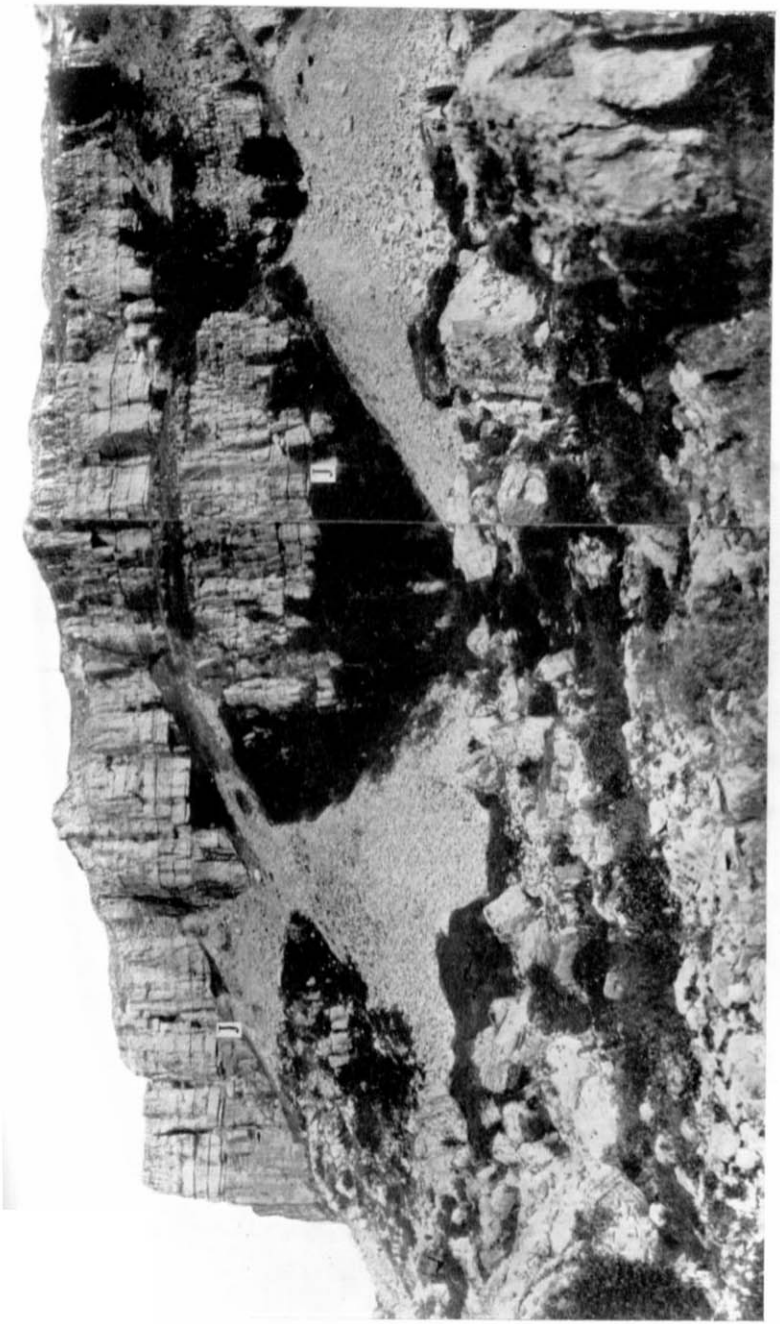


Photo: W.J.A.

ST. ALBAN'S HEAD, EAST SIDE: PORTLAND STONE, CHERTY SERIES.

[To face p. 306.

Feet.

it breaks easily." Not present at Worth. The 'Lisky' Bed of Buckman (1926, p. 35) and the "Nist" Bed of H. B. Woodward (1895, p. 190) .. .. .. 6 inches to 1

Q. HOUSE CAP. Hard grey shelly limestone ('spangle'), resembling the *Titanites* Bed, and like it especially shelly in the basal portion. The under surface, which forms the roof of the galleries at all the cliff quarries, is covered with large shells of *O. expansa, I. listeri, L. rustica, C. lamellosa*, etc. At Winspit several giant specimens of *Titanites* can be seen embedded in the basal 1–2 ft.[1] About 5 ft. from the bottom of the bed is a band of thin lenticles of white chert and silicified oolite 8½

P. UNDER PICKING CAP. Hard freestone, locally called spangle. It is cut to waste in order to get at the Under Freestone .. 3

O. UNDER OR BOTTOM FREESTONE. Fine cream-coloured oolite, an excellent quality freestone, the shells nearly all comminuted. This was the stone for which all the old cliff quarries were principally worked. Partly false-bedded .. 8

Total 50 ft.

CHERTY SERIES.

From measurements and correlations made at Seacombe, Winspit, Worth and St. Alban's Head (see Pl. 19).

Feet.

N. Cherty Limestones, often sandy, white-weathering; small chert nodules more or less disseminated throughout as well as segregated in bands, and one or two bands of large semi confluent nodules. At St. Alban's Head one such is conspicuous about the middle. At Worth Quarry the lowest 5 ft. contains some eight 2in–3 in. veins of tabular undulating but mainly horizontal chert, and at Seacombe one vein, of the same thickness, defines the base of the block. The block weathers into different numbers of beds in different places. Total always 11

M. Cherty and Serpulitic Limestone. At Worth Quarry and Seacombe 3 ft. thick with a median band of very large chert nodules up to 1 ft. thick. At Winspit and St. Alban's Head 5 ft. and the nodules smaller. *Isognomon listeri, Chlamys lamellosa, Exogyra nana, Trigonia gibbosa, Serpula gordialis* (Schloth.), etc. 3–5

L. Highly Serpulitic Cherty Limestone. Often partly a pure Serpulite (*S. gordialis* Schloth. sp.). The upper surface shelly. At Winspit the under surface shows large *Behemoth*.[2] 4½ ft. at Worth, 5 ft. at St. Alban's Head, 6 ft. at Seacombe and Winspit. *I. listeri, C. lamellosa*, etc. (see Pl. 22) .. 4½—6

K. Persistent band of cherty limestone, sometimes weathering with algal structure. *Behemoth* at Winspit 1½–2¼
Soft parting forming a deep recess in the cliffs.

J.' Prickle Bed or Puffin Ledge.[3] The most conspicuous, easily recognised datum in the Cherty Series all along the cliffs. A comparatively soft chertless bed; weathering reveals a peculiar ropy structure reminiscent of lava and in places

[1] Woodward records '*Ammonites giganteus*' in this bed (at Winspit only).

[2] For interpretation of these records see notes on p. 336.

[3] Quarrymen's names supplied by W. J. Bower of Winspit Cottage. The puffins nest in the recess above it.

		Feet.
	of pillow-lava ; and a mass of ramifying forms probably due to algæ. *Behemoth* at Seacombe and Winspit ..	1½
J.	Limestone, sparsely cherty, cemented on to J′ with an indistinct parting. The two together form the most noticeable and easily-recognised block (6–7 ft. thick) in every section	4½–5½
H.	Limestone, little chert, locally Serpulitic (*S. gordialis*). Large *Behemoth* at Winspit	3–4
G.	Limestones with one or more bands of chert nodules. At Seacombe *Behemoth* and many *Lima rustica, Isognomon bouchardi, Ostrea expansa*. At St. Alban's Head and elsewhere locally in the cliffs G. and H. are fused together or split into three. At Winspit G is 2½ ft. thick ,at Worth Quarry and Seacombe 4 ft.	2½–4
E. and F.	The Sea Ledges. Limestones with massive bands of confluent nodular chert (up to 1 ft. thick), usually weathering into two principal blocks, each 6 ft. to 9 ft. thick. These form the ledges at sea-level (Seacombe, Winspit, etc.), and the bottom of Worth Quarry. A few very large *Behemoth*. Total thickness at St. Alban's Head	17
	From the middle of these beds downwards the rest of the Cherty Series is accessible only at St. Alban's Head.	
D.	Cherty limestone. Much chert in large nodules	3½
C.	Cherty limestone	7
B.	Soft sandstone weathering to a sand, with bands of chert ..	2
	Total thickness of Cherty Series	65 ft.

PORTLAND SAND.

THE BLACK SANDSTONES (BLOCK A) AND PARALLEL BANDS.

A. 28.	Hard black sandstone, weathering grey-brown, cavernous, with many of the cavities in the shapes of chert nodules partly filled with black calcite. Honeycombing ..	11
A. 27.	Hard black sandstone, weathering grey-brown, cavernous, with black calcite, as above ; honeycombing, abundant *Glaucolithites*	11
A. 26.	Upper Parallel Band ; hard black sandstones, as above, with black calcite, and a 9 in–12 in. band of homogeneous cementstone at the top, separated by 3 inches of dark sandy shale. Many *Glaucolithites*	7
25.	Shales, light grey, chalky, papery, with two white bands ..	3
24.	Middle Parallel Band : persistent sandy cementstone ; can be followed by the eye from St. Alban's Head to Hounstout	1½
23.	Shales, as above (25)	1
22.	Lower Parallel Band ; hard, grey, sandy cementstone or sandstone, with some cavities containing black calcite (fewer than in Block A)	10
	Total	45 ft.

ST. ALBAN'S HEAD MARLS.[1]

21. Light grey marls with seven rows of white cementstone nodules, six rows in the highest 7 ft., the two lowest rows larger than the rest. Some nodules full of lamellibranch

[1] Blake's Bed 12, 1880, p. 195.

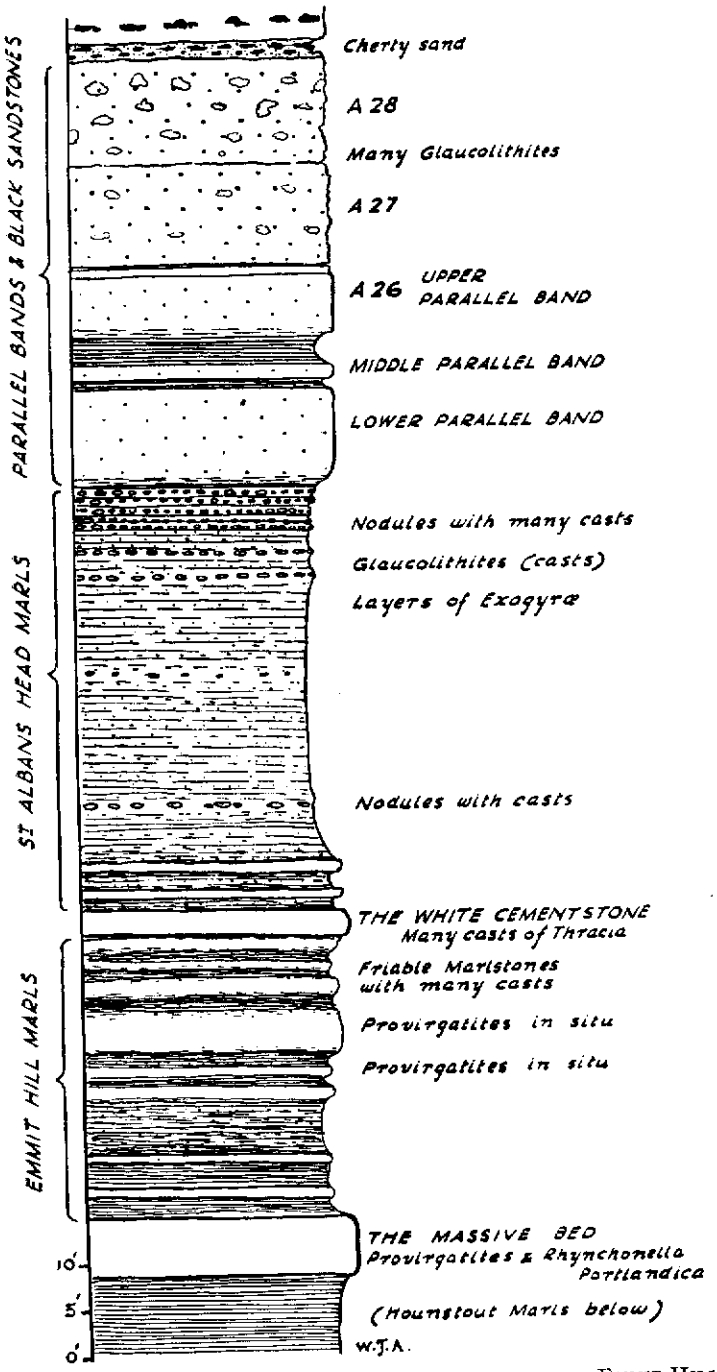


FIG. 42.—SECTION OF THE PORTLAND SAND MEASURED AT EMMIT HILL.
Vertical Scale 1″=20 ft.

		Feet.
	casts—*Eocallista implicata* (de Lor), *E. pulchella* (de Lor), *Isocyprina* spp., etc. *Glaucolithites* (fragments)	10
20.	Dark grey bituminous shales and marls, with two indistinct rows of nodules. Layers of *Exogyra nana*, with some *Camptonectes* and *Isognomon* (broken)	24
19.	White cementstone nodules with *Thracia depressa* (Sow.), *Buchia mosquensis* (von Buch), *Camptonectes*, *Isocyprina*, etc. .. .. 6 in.	11
18.	Grey shaly marl .. .. 6 ft. 0 in.	
17.	Band of hard white cementstone .. .. 8 in.	
16.	Grey shaly marl .. .. 2 ft. 0 in.	
15.	Band of hard white cementstone .. .. 8 in.	
14.	Grey shaly marl .. .. 2 ft. 0 in.	
	Total	45 ft.

THE WHITE CEMENTSTONE.[1]

		Feet.
13.	Conspicuous band of light grey to white cementstone, breaking with a conchoidal fracture and the surfaces often showing red staining. *Glaucolithites* (*'Leucopetrites'*) *cæmentarius* S. Buckman (T.A., p. 35, pl. DCLXXVII) said to come from this band. Abundant *Thracia depressa* (Sow.), *Pleuromya tellina* (Ag.), *Parallelodon* (*Beushausenia*) *foetidum* (Cox), *Ostrea expansa* Sow., *Modiola* (*Musculus*) *autissiodorensis* Cotteau, *Protocardia calcarea* (Blake), *Eocallista*, *Isocyprina*. This bed is conspicuous on the west side of St. Alban's Head at Emmit Hill, and at Hounstout. It is Blake's Bed 13, 'cementstone with abundant *Thracia*, 2 ft.' (1880, p. 195), and Latter's Bed 6 at St. Alban's Head and Emmit Hill and Bed 4 at Hounstout (1926, pp. 76-8)	2-2½

EMMIT HILL MARLS.[2]

12.	Dark grey to black shaly marl or sandy shale, with two or three partly indurated bands, forming a friable marlstone	8
11.	Friable black marlstone, as above, with bituminous smell. Perfect *Provirgatites* (*in situ*) and biplex ammonites. *Thracia depressa*, *Modiola* (*Musculus*) *autissiodorensis*, *Parallelodon* (*Beushausenia*) *foetidum* and another more elongate species, *Pleuromya uniformis* (Sow.) [= *tellina* Ag.], *Pl. sinuosa* Roemer, *Protocardia calcarea*	4
10.	Dark grey shaly marl or sandy shale, bituminous, 1½ in ..	5
9.	Friable black marlstone, as above. *Provirgatites* (*in situ*), and biplex ammonites, *Thracia depressa* and *Exogyra nana* .. .. 8 in.–10 in.	
8.	Dark grey shaly marl or sandy shale, bituminous, 1 ft.–1½ ft.	
7.	Friable black marlstone, as above, bituminous *Exogyra nana* .. .. 8 in.–10 in.	
6.	Dark grey shaly marl or sandy shale	6
5.	Marlstone, grey-brown, bituminous. *Exogyra nana*	½
4.	Grey marl	3
3.	Marlstone, brown, sandy, like the Massive Bed	½
2.	Grey and brown marl	2½
	Total	30 ft.

[1] Blake's Bed 13. [2] Blake's Bed 14.

A.—WORBARROW TOUT AND PONDFIELD FROM BELOW GAD CLIFF.

Photos: W.J.A.

B. ST. ALBAN'S HEAD, WEST SIDE. PORTLAND STONE (CHERTY SERIES) AND TOP OF PORTLAND SAND.

(*To face p.* 310.

THE MASSIVE BED.[1]

		Feet.
1.	Prominent band of hard, blue-centred, brown-weathering, shaly to rubbly, calcareous sandstone, forming the most easily-recognized feature in Hounstout Cliff and well exposed also at Emmit Hill and on the west side of St. Alban's Head, close to Pier Bottom. *Exogyra nana, Oxytoma octavia* (d'Orb.), and locally crushed *Rhynchonella portlandica* Blake. Fragments of *Provirgatites* cf. *scythicus* (Vischniakoff) found by Buckman (T.A., 1926, pp. 323, pls. DCLXXV, DCXCIII); 'biplex' ammonites	6
	Total thickness of Portland Sand	128 ft.

[Hounstout Marls below, best exposed at Hounstout, 50 ft.[2]]

In his former account, the author drew the line of division between the Portland Sands and Portland Stone at the top of the Upper Parallel Band; for, while this was obviously arbitrary, it seemed to agree best with the grouping adopted implicitly if not explicitly by Hudleston and Strahan (Arkell, 1933, pp. 489-90). At the same time he remarked (*loc. cit.*, p. 492) "It seems likely that Fitton included in the Sands the 24 ft. of sandstone above the Parallel Bands," which would make up the thickness to more like the 120-140 ft. estimated by Fitton. Further study has shown that there are good palæontological and lithological grounds, as well as historical, for following Fitton, and that to draw the line of division in Block A, the Black Sandstones of the above description, is more arbitrary than to choose the top of them. In the first place an examination of the ammonites has shown that those in the Upper Parallel Band (A, 26) are identical with those in the bed above (A, 27), and they all belong to the Upper Portland Sand group typified by *Glaucolithites gorei* auct., with which they are probably congeneric. In the second place the nodular black masses in the top block of these sandstones (A, 28) which have been hitherto mistaken for chert nodules like those in the beds above, have proved to be not chert, but in nearly all cases nests of black calcite.[3] Consequently there seems every reason for drawing the upper limit of the Portland Sand above the 29 ft. mass of the Black Sandstones (Block A). This block may safely be identified with the top bed of Fitton's original Portland Sand, his Bed 2, which he stated was 25 to 30 ft. thick (Fitton, 1836, p. 211). His Bed 3 ("about 60 ft.") then corresponds with the Middle and Lower Parallel Bands and the St. Alban's Head Marls (together 60 ft. thick) and his Bed 4 ("about 40-50 ft.") falls into line with the

[1] Blake's Bed 15.

[2] It is quite possible that in the west, as at Coryates (p. 331), where the Portland Sand becomes more sandy and does not seem to thin out to anything like the same extent as the Portland Stone, the Hounstout Marls may become more sandy and augment the Portland Sand. The historical reasons for excluding it here are given in Arkell, 1933, pp. 445-6. Detailed search for fossils in the marls and clays below the Massive Bed, down to the Rotunda Nodules, still remains to be undertaken.

[3] Some are of a black muddy sandstone, softer than the surrounding stone.

Emmit Hill Marls, Massive Bed, and White Cementstone (together about 40 ft. thick); the last is his "band of firmer consistence, which contains casts of *Panopæa depressa* and other bivalves".

III. THE WEST PURBECK SECTIONS; GAD CLIFF AND WORBARROW.

Gad Cliff constitutes perhaps the grandest stretch of cliff scenery on the English coast (Pl. 23 and 24). For over a mile the Portland Stone and up to 40 ft. of Purbeck Beds form vertical and in places overhanging precipices, carved by the weather into jagged bastions, which tower above a steep slope of Portland Sand and Kimeridge Clay. The cliff owes its grandeur to the fact that, whereas at St. Alban's Head the beds lie almost horizontally, at Gad Cliff they dip inland at a steep angle (25°-35°). Thus in the stretch of half a mile all the strata from the Purbeck Beds to an horizon several hundred feet down in the Kimeridge Clay descend to the foreshore in turn.[1]

The Freestone Series and the top part of the Cherty Series may be conveniently examined in the west side of Pondfield Cove (Pl. 21, A). About 20 ft. of the middle of the Cherty Series runs into the sea precipitously at the eastern horn of Pondfield Cove and can only be examined from a boat; but all the rest of the Cherty Series and the whole of the Portland Sand with the block of Black Sandstones at the top are well exposed below the western end of Gad Cliff. The exposures are somewhat difficult of access, but once the preliminary difficulties have been surmounted there is nothing to prevent a detailed examination of the whole of the Portland Sand and the lower part of the Portland Stone. Since this is one of the only five complete sections of the Portland Sand on the Dorset mainland, it is surprising that hitherto it has been virtually ignored (see, e.g., Strahan, 1898, p. 62). Lying as it does five miles north-west of St. Alban's Head, the section provides a link with the area north of Weymouth which cannot be neglected.

High up in Gad Cliff two conspicuous white bands can be seen (Pl. 23 and 24). The higher of these is the Shrimp Bed and marks the top of the Portland Stone; the lower is about on the horizon of Block M of the Cherty Series.[2] These uppermost beds, however, are best examined at close quarters in Pondfield Cove, where they sink to sea-level. In the following description, the measurements and particulars are taken in Pondfield and Worbarrow Tout down to the 4 ft. block with a constant band of black chert (Block K) and thence downwards are continued under Gad Cliff.

[1] About 100 yds. east of the Wagon Rock the Basalt Stone Band may be recognized in the foreshore, and the White Septarian Band of Strahan's three stone bands is conspicuous in the small cliff near the sea.

[2] Woodward (1895, p. 193) wrongly states that they are both in the Cherty Series.

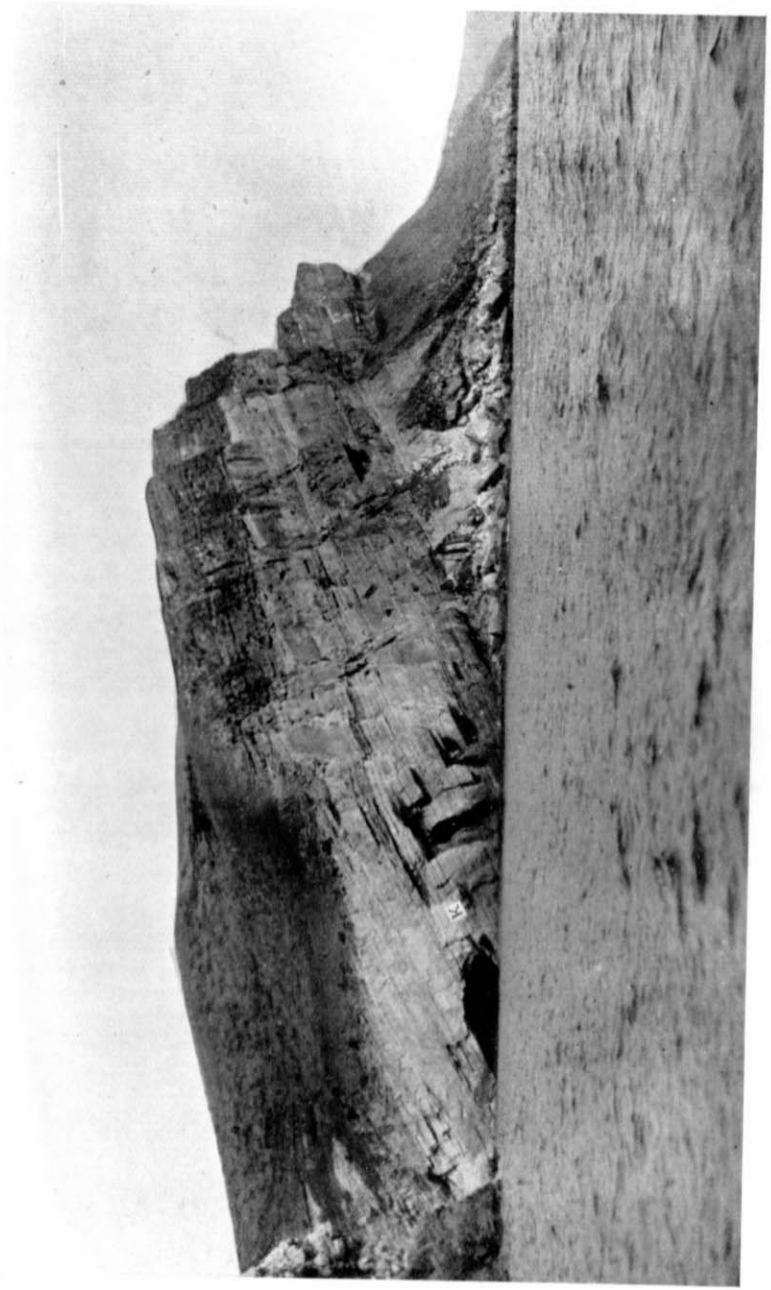


Photo: W.J.A.

GAD CLIFF FROM THE SEA.

To face p. 312.

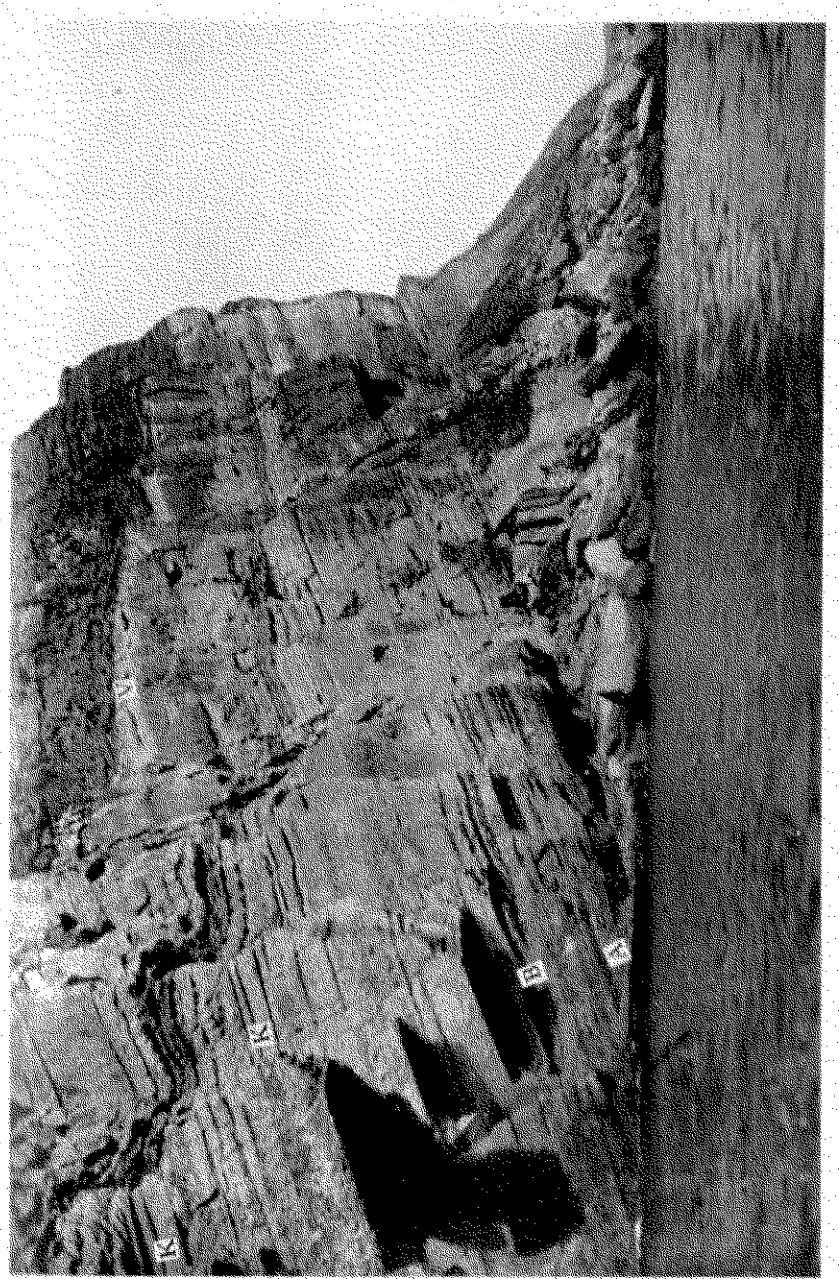


PHOTO: W. J. A.

GAD CLIFF FROM THE SEA.

(To face p. 313)

The lettering of the blocks B to V of the Stone Series is intended to correlate with the St. Alban's Head section, but the beds of the Portland Sand are numbered independently, precise correlation being impossible.

FREESTONE SERIES

Beneath the Purbeck Broken Beds, the most easily recognized datum, the following section extends to the base of the Purbeck Beds in Pondfield Cove :—

		Feet.
PURBECK BEDS	Tufaceous Burr	2
	Dirt Bed, pebbly	½ – 1
	Tufaceous Burr	½ – 1
	White laminated limestone ..	8
	Dirt Bed, with breccia ..	½ – 1

		Feet.
V.	SHRIMP BED. The usual white, sublithographic limestone, with the usual fossils. In two blocks	7
U.	TITANITES BED. Fossiliferous limestone, with giant *Titanites* 1 ft. from the top, and many lamellibranchs (usual) ..	9
T.	Band of small chert nodules	1
	POND FREESTONE; a rich shell bed in the middle; *Trigoniæ*, etc.	4
S.	CHERT VEIN. Three thick and several thinner bands of chert in limestone	5
O–R.	UNDER FREESTONE AND CAPS. White, oolitic freestone, in two blocks	7½
	Total of Freestone Series ..	33 ft.

CHERTY SERIES.

N	Band of small chert nodules	1 ft.	12½
	Buff sandy limestone or calcareous sandstone	5 ft.	
	Buff sandy limestone, with undulating but mainly horizontal veins of thick tabular chert, as in the lower half of N. at Worth	6½ ft.	
M & L.	White limestone with two bands of chert nodules, and crossed by numerous parallel oblique veins of black secondary chert which cut the bedding at an angle of about 45°		7
K.	Limestone with, in the upper part, a very conspicuous and persistent vein of tabular black chert, 6″ to 10″ thick. Forms a convenient and unmistakable datum for correlating Gad Cliff with Worbarrow Tout		4
Cherty Limestones, an almost indivisible and inaccessible mass, which forms the chief feature of the precipices of Gad Cliff ..			30
The main bedding planes divide the mass approximately as follows :—			
J & J¹	Limestone, little chert	6 ft. 7 ft.	
H & G	Limestone, very little chert ..	5 ft. 6 ft.	
F.	Limestone, the upper part almost chertless, the middle and lower part very cherty, with two thick bands of nodular chert (Evidently the sea ledges)	9 ft.–10 ft.	

		Feet.
? D & E	Limestone with much chert, and a thick band of nodular chert near the top .. 8 ft.–9 ft.	
? C	Limestone with much chert, a well-marked block ..	4
B.	Soft sandstone, weathering to a sand, with two or three rows of chert nodules	3
	Total thickness of the Cherty Series ..	60 ft.

PORTLAND SAND.

THE BLACK SANDSTONES (BLOCK A) AND PARALLEL BANDS.

A. 17.	Intensely hard black sandstone, riddled by cavities with shapes like chert nodules, but filled with black calcite; showing fucoidal structure. Honeycomb weathering..	7½
A. 16.	Intensely hard black sandstone as above, with fucoidal structure, cavities containing black calcite, and honeycomb weathering. The base projects as a prominent ledge, on which are numerous specimens of *Glaucolithites* (see Pl. 21, A, and Pl. 22, A)	10
A. 15.	Upper Parallel Band: Intensely hard black sandstone, as above, with numerous cavities filled with black calcite and abundant *Glaucolithites*	5
14.	Soft grey marl and mudstone, chalky and papery in the cliff, but hardens on contact with the sea	3
13.	Middle Parallel Band: Cementstone	1
12.	Lower Parallel Band (equivalent of): Grey marl with a thin, soft cementstone band in the middle, and a 1 ft. cementstone band at the base	4
		30 ft.

ST. ALBAN'S HEAD MARLS.

11.	Grey-blue shaly marls and shales with rows of cementstone nodules, especially in the upper part	22
10.	*Exogyra* Bed. Tough pale grey marl full of light flattened pellets of similar but whiter marl, and crowded with small valves of *Exogyra nana*, with abundant *Plicatula boisdini* de Lor., and *Ostrea expansa, Chlamys lamellosa, Isognomon* (fragments)	2
9.	Brachiopod and *Exogyra* Beds. Tough grey sandy marls (hardening on contact with the sea-water) with rows of cementstone nodules and in the bedding-planes impersistent layers of larger *Exogyra nana* crowded together, with abundant *Oxytoma octavia* (d'Orb.), *Ostrea expansa, Plicatula boisdini* de Lor. and locally (in one seam, 6 ft. from top) numerous *Rhynchonella* n. sp.[1] and *Terebratula bononiensis* Sauvage and Rigaux..	10
8.	Tough grey sandy marl	5
7.	Two bands of tough grey marlstone; softer between ..	2
6.	Yellow sandy marl (4 in.) overlying grey marl (8 in.) full of *Exogyra*; also *Oxytoma octavia* (d'Orb.), *Serpulæ*, minute Terebratulid	1
		42 ft.

THE WHITE CEMENTSTONE AND EMMIT HILL MARLS.

5.	Tough, grey-centred, brown-weathering, marly, sandy cementstone, tougher and nodular in upper 2 ft. (repre-	

[1] To be described in a Supplement.

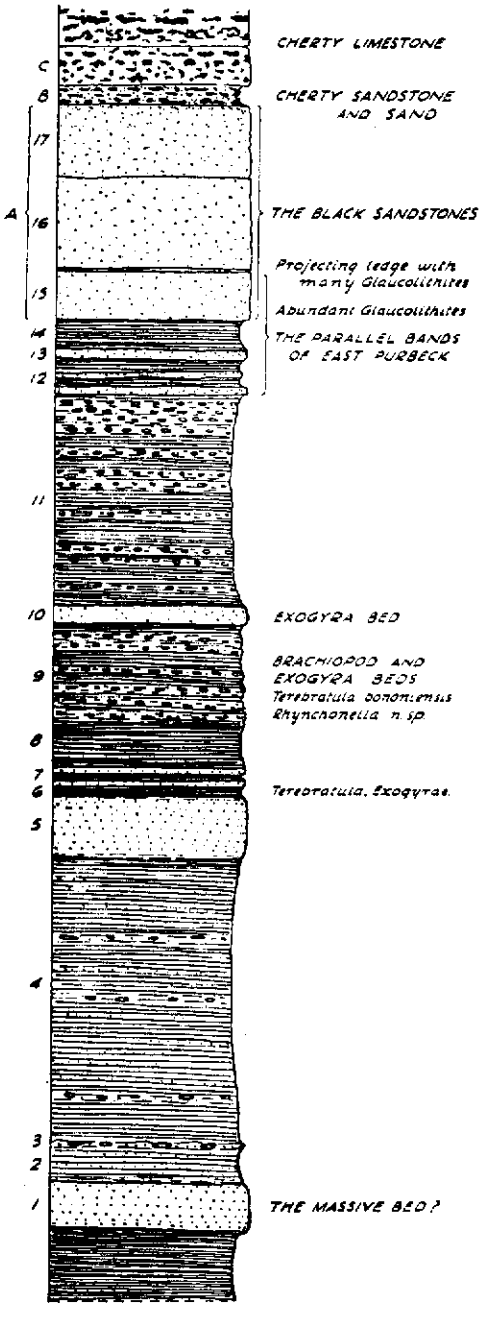


FIG. 43.—PROFILE OF THE PORTLAND SAND OF GAD CLIFF, Showing the junction with the Cherty Series of the Portland Stone (B.,C.) and the position of the Brachiopod and Exogyra Beds. Vertical Scale 1″=20 ft.

	Feet.
senting the White Cementstone ?) ; the rest weathering to yellow marly sand	6
4. Grey sandy marls, some bituminous, with three rows of cementstone nodules (0-6 in.)	30
3. Marly cementstone band, breaking into nodules (6in-9in.)	4
2. Grey sandy marls, as above (3 ft. 6 in.)	
	40 ft.

? THE MASSIVE BED.

1. Tough grey, cream-weathering sandy marl and marlstone, with obscure nodular structure. Stands out as a hard band, but not so conspicuously as the Massive Bed farther east	5
Total thickness of Portland Sand ..	117 ft.

[Top of Hounstout Marls : Dark grey-blue marly clay, seen to 15 ft.]

From the Cherty Series (horizon unknown) of this locality the Tisbury star-coral, *Isastræa oblonga* Flem., has been recorded, but very rarely (Woodward, 1895, p. 193). In the chert nodules of various places sponge-spicules of the genus *Pachastrella* have been identified (*ibid.*, p. 187). At least some of the chert, such as that which crosses the bedding as described above, is obviously of secondary origin, as is also the white silicified oolite found in the Freestone Series; and the conclusion is probably justifiable that the whole of the chert is secondary. It is noteworthy that in the intensely hard sandstones at the base of the Cherty Series and in the Parallel Bands there are many cavities having the shapes of chert nodules but instead filled (only partly) with calcite. It is difficult to explain these except as secondary after chert, unless it be supposed that all the chert is secondary after calcite.

IV. CORRELATION OF THE FREESTONE SERIES OF EAST AND WEST PURBECK.

The outstanding difference between the Portland Stone to the east and that to the west of St. Alban's Head is the disappearance in the west of the commercially valuable freestones.

W. H. Hudleston (1896, p. 319) stated that in Gad Cliff and Worbarrow Tout the Shrimp Bed and *Titanites* (*Perna*) Bed (together only 16 ft. thick) rest directly upon the Cherty Series. I commented in 1931 (1933, p. 488) "it remains to be proved whether the Pond and Under Freestones and intervening Cap disappear or merely lose their character and become cherty." The solution of the problem obviously lay in a detailed examination and correlation of the individual beds of the Cherty Series all along the cliffs of Purbeck, with especial attention to their behaviour in the critical area of St. Alban's Head. The required

investigation was consequently undertaken in August, 1933, and the results were demonstrated to the Association at the Whitsun Field Meeting in 1934 (Arkell, 1934).

It may be presumed that the tendency of limestones such as these to split up horizontally into blocks or courses along thin partings of softer material is an original feature, due to periodical changes in the sediment or the rate of sedimentation. It is therefore not surprising to find that the principal courses (with local variations and aberrations) are traceable for several miles along the cliffs, from Tilly Whim to St. Alban's Head. But it is more surprising to find that the concentration of the chert nodules, which have usually been assumed to be a secondary feature, also remains very much the same for so long a distance. As will be seen by a reference to the drawings of measured sections (Plate 19), the same courses of stone with approximately the same concentrations of chert nodules can be traced with safety at least from Seacombe round the point of St. Alban's Head. If the chert is not of primary origin, the explanation is probably that the concentration of chert is dependent on original constitutional differences in the limestone courses; consequently that it reveals differences which were original but would not otherwise have been detected.

However this may be, it is certain that at St. Alban's Head and westward there are additional cherty strata at the top of the section not present in the easterly localities where the Freestones are typically developed. The inference is that the lower (and economically most valuable) part of the Freestone Series does not thin right away in a westerly direction as Hudleston thought, but deteriorates and becomes cherty.

The proof of this change can be demonstrated at Seacombe and Winspit. The first indication of what occurs is to be seen at Seacombe. The measurements on p. 307 were taken in the north part of the large quarry. If the beds below the House Cap be followed seawards (to the south-west), the Under Picking Cap will be seen to thicken at the expense of the Under Freestone until their relative thicknesses are reversed. At the cliff edge there is only 5 ft. of Freestone and 7 ft. of Under Picking Cap.

At Winspit the process goes further. In the quarries on the western side of the valley, and at the western end, the Under Freestone, strongly false-bedded, is only 3 ft. 6 ins. thick, but it is surmounted by as much as 5 ft. of Under Picking Cap, containing at least three rows of cherty lenticles (largely silicified oolite). The roof of the galleries is as usual formed by the House Cap (here containing *Titanites*), and the immediately subjacent topmost block of the Cherty Series (Block N) is the same thickness as at Seacombe (11 ft.).

Three quarters of a mile to the south-west are the recently worked quarries on St. Alban's Head. An inspection of these at

once reveals that only the Pond Freestone (with its overburden of *Titanites* and Shrimp Beds) has been worked. No attempt has been made to reach the Under Freestone. In fact, the Pond Freestone seems at first sight to rest directly on the Cherty Series. Closer investigation shows, however, that the floor of the quarry is not made of the true Cherty Series but of the Chert Vein in the middle of the Freestone Series. By climbing down the steep cliff-path it can be seen that from the bottom of the Pond Freestone to the top of Block N of the Cherty Series (here still 11 ft. thick, with the same recognizable sequence of courses below it) are 13½ ft. of limestones with six bands of chert nodules. These must represent the Chert Vein, Listy Bed, Caps and Under Freestone, in all 25½ ft. of strata at Seacombe, but only 18½ ft. at the west end of Winspit.

By combining the sections seen in the quarry, and at the top of the cliff-path, and as revealed by the mushroom-shaped stone monolith conveniently left on the edge of the cliff by the quarrymen, the following succession can be made out (Pl. 19) :—

SECTION AT ST. ALBAN'S HEAD.

		Feet.	
	Purbeck Beds. Grey tufaceous limestone	2	
Freestone Series.	Shrimp Bed	11	
	Titanites Bed, in 3 or 4 blocks, very shelly	10	
	Pond Freestone, with some white chert lenticles at top and near base	7	
	Chert Vein. Limestone with three bands of chert lenticles, one at the top 1 ft. thick	3	
	Caps and Under Freestone: Limestone 4 ft.		
	Band of chert nodules		
	Limestone 3 ft. 3 in.		
	Band of chert nodules		
	Limestone 1 ft. 3 in.		
	Band of chert nodules		
	Limestone 2 ft.		10 ft. 6 in.
	Block N of the Cherty Series below (11 ft.).		

The deterioration of the Under Freestone here revealed does not take place directly towards the west, but towards the south-west. At Worth Quarry, two miles inland, which is almost as far west as St. Alban's Head Quarry and half a mile farther west than Winspit, the development of the beds is the same as at Seacombe (north end). At Seacombe, moreover, the diminution in the thickness of the Under Freestone is seaward, as much south as west.

By the time Gad Cliff and Pondfield are reached we are prepared for what to expect. Instead of the Freestone Series being there only 16 ft. thick as Hudleston thought, it is more likely to be 33½ ft. thick. The precise baseline chosen (p. 313) is favoured on two grounds: (1) At this level there is a marked change downwards from white oolitic limestone to buff sandy

limestone, and the next block below, with the horizontal undulating veins of tabular chert, is identical with the lower half of Block N at Worth Quarry. (2) In all the easterly sections Block N maintains a constant thickness, and since the total for the Cherty Series at Gad Cliff is only some 9 ft. less than at St. Alban's Head, it is reasonable to assume that Block N has not much diminished.

V. LULWORTH: BACON HOLE TO DUNGY HEAD.

The development in the two miles of outcrop on either side of Lulworth Cove is best illustrated by sections at the two extremities: the Freestone Series at Bacon Hole near the Mupe Rocks, and the Cherty Series and Portland Sand at Dungy Head. In Bacon Hole the Freestone Series is well exposed, but the Cherty Series falls precipitously into the sea all the way along the outer side of the outcrop until Dungy Head is approached, where it becomes accessible and the Portland Sand rises from beneath. The Bacon Hole section is repeated in the horns of Lulworth Cove, but the rock is too sea-etched to favour examination.

SECTION IN BACON HOLE.

PURBECK BEDS (Complete Section).

		ft.	ins.
	Thick bands of hard white slatt[1]		
	Black and white laminated shale	4	
	Laminated limestone	6	
	Dirt Bed	3 in. to	6

FREESTONE SERIES.

8.	Shrimp Bed. White sublithographic limestone, full of *Trigonia gibbosa* var. *damoniana*, *Chl. lamellosa*, *Prot. dissimilis*, etc.; a large surface of the top of the bed is exposed, and is covered with ripple-marks[2]	2	0
7.	White limestone, coarsely oolitic, shelly (part of Shrimp Bed ?)	4	6
6.	Band of chert nodules	6in. to	9
5.	White oolite	3	6
4.	Shelly limestone, full of *Chl. lamellosa*, *I. listeri*, *O. expansa*, *Plicatula boisdini*; *Titanites* 2 ft. in diameter, *Pleurotomaria rugata*		6
3.	Band of chert nodules, fused into the bottom of Bed 4		6
2.	Limestone and freestone, the lower part false-bedded	10	0
	Total	21	9

CHERTY SERIES.

1.	Cherty limestones, inaccessible, seen to about	30 ft.

[1] Slatt is the convenient quarrymen's term used in the Isle of Portland for the peculiar fissile, laminated, white chalky-weathering limestones of the Purbecks. It saves much circumlocution.

[2] These were pointed out to the Association on the Whitsun Excursion, 1910. [Hovendon, 1910, p. 511.]

Presumably Bed 2 represents the Under Freestone and Caps (2 ft. less than at Pondfield), Bed 3 the Chert Vein, and Beds 4, 5, 6 the *Titanites* Bed. Only 4 ft. of the Pond Freestone remained at Pondfield, and here it is apparently absent. Beds 7 and 8 have been quarried.

At Dungy Head there is a complete exposure of the Portland Beds (see Fig. 44). Unfortunately, however, the Freestone Series, although evidently well-developed and easily recognisable, does not lend itself to detailed examination and measurement because the exposed surface where accessible is a fault plane. The section begins to be good just about the junction of the Freestone and Cherty Series, thus forming a continuation of that at Bacon Hole. Probably the whole of the Portland Sands, as defined in Purbeck, are exposed, though much of the section is dangerously steep and consequently yields little information.[1]

SECTION AT DUNGY HEAD.

Freestone Series—oolitic and shelly limestones with roach bands—above.

CHERTY SERIES.

		ft.	ins.
N	Limestone, with large masses of chert 3 ft. Ditto, a band of chert at top .. .. 2 ft. Enormous band of solid chert (connected with disturbance) .. .. .. 1 ft. 6 in. Limestone, nodular, full of irregular small and large chert nodules .. .. .. 5 ft.	11	6
	Deeply-weathered parting.		
M & L	White limestone with black chert nodules, forming a conspicuous white band, as at Gad Cliff	3	0
? K	Shelly limestone, no chert. *Behemoth*	2	0
J'	Relatively soft, easily weathered chertless sandy limestone with the characteristic and peculiar 'ropy', pillowy, fucoidal structure of the Puffin Ledge in Purbeck; irregular surface	1	9
J	Ditto, shelly, honeycombed, very irregular surface ..	2	3
	Broken-shell limestone with a few cherts; forming one block with bed below	2	0
H & G	Limestone; scattered large nodules of chert	2	6
F, E, D, C, B.	Main mass of the Cherty Series: hard limestones, becoming sandy downwards, full of large nodules and bands of chert, especially three thick bands in the upper half, like the Sea Ledges	10	0
	Total thickness of Cherty Series ..	35	0

PORTLAND SAND.

A. 10.	The Black Sandstones: Hard black sandstone as at Gad Cliff, the lower part slightly softer, weathering cavernous and honeycombed; the highest 15 inches intensely hard. *Glaucolithites* in the lower half (4 specimens seen *in situ*)	13	6

[1] This complete section is omitted altogether from Strahan's memoir [1898] and Latter [1926, p. 79] seems to include the Cherty Series in the Portland Sand.

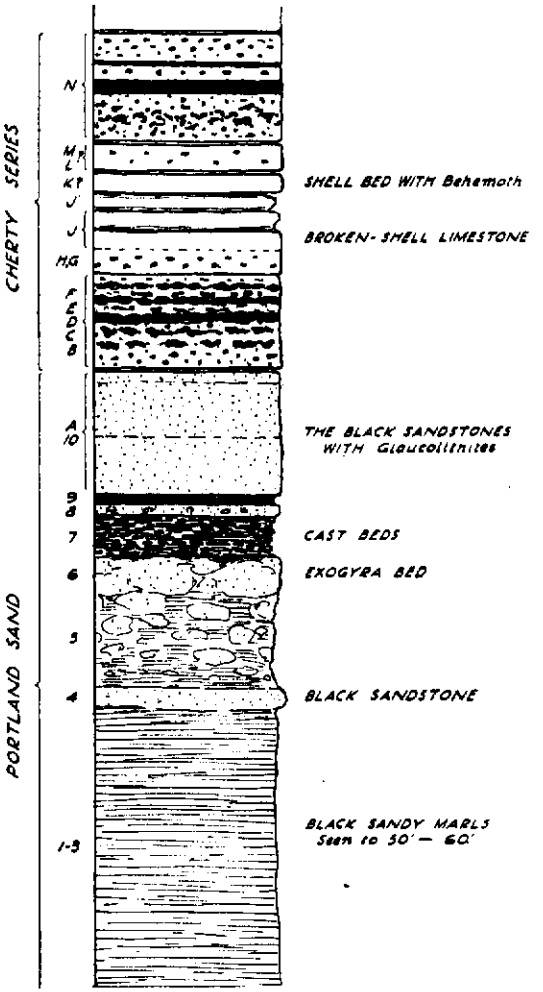


FIG. 44.—SECTION OF THE CHERTY SERIES AND THE UPPER PART OF THE PORTLAND SAND, DUNGY HEAD, LULWORTH. Vertical Scale 1"=20 ft.

		ft.	ins.
9.	Clay, black sandy, with some light grey patches	1	0
8.	Black sandy cementstone with intensely hard nodules	1	0
7.	CAST BEDS : Black shales with about 10 layers of highly fossiliferous soft cementstone nodules packed with lamellibranch casts. *Glaucolithites* common ; also *Modiola autissiodorensis, Pleuromya, Trigonia* sp. and many others too badly preserved for identification	4	6
6	*Exogyra* BED : Cementstone, hard, grey, sandy, in large irregular, lumpy, semi-coherent masses among marl ; crowded with *Exogyra nana* ; also *Serpula gordialis* and *Plicatula boisdini*	4	0
5.	Black sandy marls with much nodular, irregular, grey, sandy cementstone like that above but lacking the profusion of oysters	10	0
4.	Grey-black sandstone	2	0
3.	Black sandy marls and sands with occasional more or less indurated bands and a few rows of cementstone nodules	c.50	0
2.	Black sandstone	2	0
1.	Black sandy marls, seen to	6	0
	Total Portland Sand seen, c.	95	0

The remarkable feature of this section is the fact that although it is midway between Gad Cliff and Ringstead (3½ miles from each), the Cherty Series, which is almost identical in thickness with that at Ringstead, yet shows many more points of resemblance to that at Gad Cliff. Seeing that the total thickness of the Cherty Series has decreased from 60 ft. to 35 ft., the degree of resemblance is surprising. The conspicuous white band near the top (correlated with Blocks M and L of East Purbeck) is still present, and the rest of the cherty beds above (Block N) are still 11½ ft. thick. The scarcity of chert about Blocks G to K and its abundance about the level of the Sea Ledges (Blocks C to F) are still striking, and the peculiar lithological appearance of J and J', the Prickle Bed or Puffin Ledge, is at once recognised by any observer familiar with East Purbeck. Finally, the hard Black Sandstones at the top of the Portland Sand, still with the same ammonites, complete the comparison with Purbeck. Here, however, in conformity with the general attenuation, there are only two blocks of this black sandstone, and the Parallel Bands are no longer recognisable. The upper part of the Portland Sand is also apparently much condensed. Bed 6 is apparently Bed 20, and Bed 7 is Bed 21.

VI. THE OUTCROP NORTH OF WEYMOUTH : RINGSTEAD, POXWELL, PRESTON AND UPWEY TO PORTISHAM.

(a) Ringstead.

On the threshold of the western area north of Weymouth, and 3½ miles west by north of Dungy Head, there is a complete

key section in the east corner of Ringstead Bay, below Holworth House. The rocks here are lowered by pre-Albian (and perhaps pre-Aptian) faulting, and dip at a high angle into the cliff. The Purbeck and Portland Beds and the Kimeridge Clay are planed off and directly overlain by the Gault. There are two sections, one immediately below the house, showing Gault at the top, which is difficult of access and guarded by dense undergrowth ; the other a short distance farther west. The latter, which has been kept clear by quarrying, shows the following section (Fig. 45). Previous published accounts contain some curious incompatibilities [see Arkell, 1933, p. 499] ; but the whole section is easily accessible.[1]

SECTION AT HOLWORTH HOUSE, RINGSTEAD.

PURBECK BEDS.

	ft.	ins.
Clay and slatt, with some *Cyrena* bands, obscured, about	25	0
Hard slatt	3	6
Slatt and shaly clay	10	6
Cypris freestone	2	0
Slatt	4	0
Cypris freestone and hard slatt, irregular base and marl parting	3	6
Chert seam (2 in.) in white limestone	1	0
Slatt, with a 3 in. dark clay seam 1 ft. 3 in. down	6	3
Tufa	2	6
Dirt Bed, black and white seams	1 in. to	2
Tufa	1	6
Dirt Bed, black and white seams	1 in. to	2
Tufaceous, ostracodal limestone		6
White, splintery limestone, full of hollow moulds of tiny freshwater gastropods and "Cyrenas" ; cemented tightly on to the beds above and below	½ in. to	9 in.

PORTLAND BEDS.

FREESTONE SERIES.

		ft.	ins.
27.	Roach : White limestone, a mass of casts of *Trigonia gibbosa, Protocardia dissimilis, Pleuromya*, etc., and shells of *Ditrupa rustica* and *Chlamys lamellosa*	1	2
26.	Limestone ; a white, soft freestone, with broken shells, passing down into roach in the lower two-thirds, full of casts as above	3	6
25.	Limestone ; a white freestone passing down into roach as above ; *Isognomon listeri* common	4	6
24.	Gap in section where limestone has been quarried, the place now totally concealed by debris ; about	12	0
	Total about	21	0

CHERTY SERIES.

23.	Limestone, oolitic, with a few thin seams of chert	5	0
22.	Ditto, more cherty	2	0

[1] Latter's description [1926, pp. 79, 80] is almost totally irreconcilable with the section here given. He includes in his "Portland Sand" the greater part of the Cherty Series of the Portland Stone, and fails to mention the Serpulite, the Basal Shell Bed, or the *Exogyra* Bed. Buckman's [1926, p. 37] is still less intelligible.

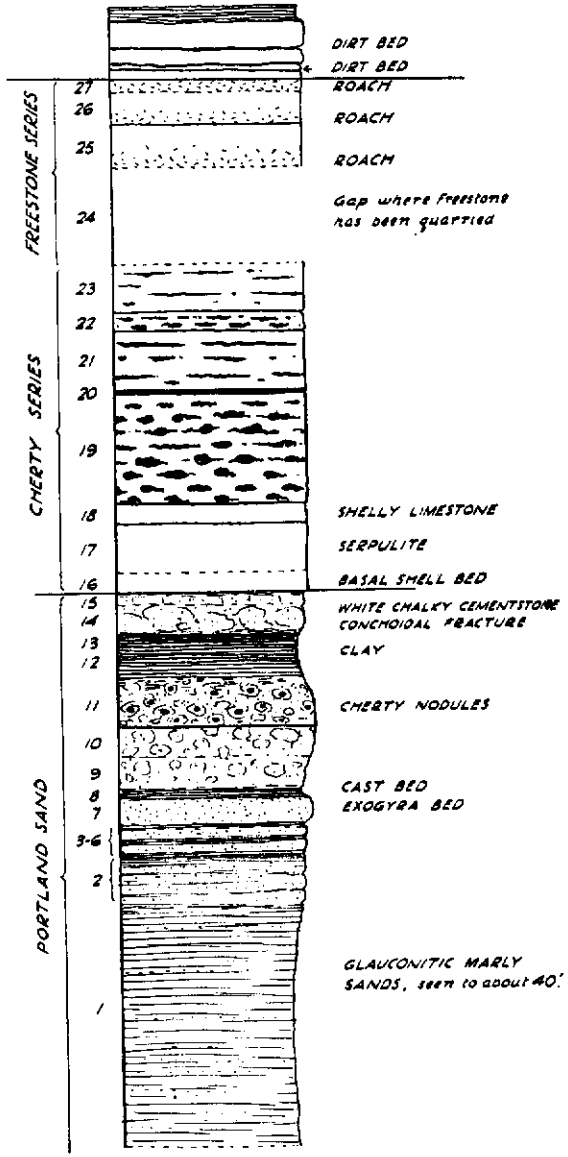


FIG. 45.—SECTION OF THE PORTLAND BEDS WEST OF HOLWORTH HOUSE, RINGSTEAD BAY. Vertical Scale 1"=20 ft.

		ft.	ins.
21.	Limestone, white, with chert bands	6	0
20.	Chert band, continuous .. .. 3in. to	1	0
19.	Chalky white limestone with large black chert nodules and broken shells, the lower part with *Serpula gordialis*	11	6
18	Shelly limestone, with large *Isognomons*; no chert	2	0
17.	SERPULITE : white chalky limestone, full of *Serpula gordialis*	5	0
16.	BASAL SHELL BED. Limestone full of calcitic shells, *Trigoniæ*, etc., etc.[1]	2	0
	Total ..	34	6

PORTLAND SAND.

15.	Cementstone with vertical fracture	1	0
14.	Whitish cementstone with irregular splintery fracture, often conchoidal, weathering red in places. (This and bed 15 = Latter's Bed 9, 1926, p. 79 ?)	3	0
13.	Black clay (Latter's Bed 8)	1	6
12.	Marly clay and marl, more or less hardened towards base	2	6
11.	Cementstone, sandy, nodular, the nodules with cherty centres; the lower part very hard, projecting .. .. Even bedding-plane	5	0
10.	Cementstone, sandy, very hard, less nodular and cherty; forms prominent bluff with the lower part of bed above. *Glaucolithites* (typical), *Ostrea expansa*, *Isognomon*, *Lima* casts, patches of *Serpula gordialis* and *Exogyra nana*	2	6
9.	Cementstone, sandy, a strong stinkstone, rubbly, less hard. *Glaucolithites*, *Trigonia incurva* casts, *Modiola aulissiodorensis*, *Protocardia calcarea*, *Plicatula*	3	6
8.	Soft rubbly sandstone full of casts of *Trigoniæ*	1	0
7.	*Exogyra nana* BED : Rubbly, sandy cemenstone, packed with *Exogyra nana*, also small *Glaucolithites* and clavellate *Trigoniæ*	2	6
	Total to base of *Exogyra* Bed ..	22	6
6.	Sandy marl, soft, greenish-brown (Top of Latter's Bed 4 ?)		6
5.	Sandstone or sandy cementstone	1	0
4.	Sandy marl, as above		6
3.	Sandstone, as above	1	3
2.	Sandy marls with some irregular bands of soft, crumbly, sandstone	5	0
1.	Sands, marly, greenish and mustard-coloured, with a few semi-indurated bands, well exposed for about	25	0
	Ditto, semi-overgrown, seen sporadically for about	15	0
	Total seen below *Exogyra* Bed, c. ..	50	0

It will be seen that here already the Purbeck subdivisions in both the Stone and the Sands are lost sight of, and affinities are all with the country to the west. For instance the Freestone Series begins with Roach at the top instead of Shrimp Bed (though the Portland Screw is absent, as noted by Hudleston [1898, p. 302]); this rests on freestone (cf. Whit Bed of Port-

[1] The Basal Shell Bed can also be seen, with some of the Cherty Series and a considerable portion of the Portland Sand, dipping north at a high angle, in an old quarry at the back of South Down Farm, half a mile to the N.W.

land); and finally freestone has returned at the bottom and has been quarried (cf. the Base Bed Freestone of Portland).

The Cherty Series has become chalky, and the lowest 9 ft. are without chert, as in Portland; and, most characteristic of all for the Portland section, the Basal Shell Bed has appeared.[1]

In spite of these affinities with Portland and differences from Lulworth, the thicknesses of both the Freestone and the Cherty Series are the same as at Lulworth, as shown by the sections at Bacon Hole and Dungy Head. The curious fact thus emerges that the stratigraphical changes do not take place *pari passu* with the diminution in thickness from east to west, but independently of it and later. The diminution in thickness occurs in the three miles between Gad Cliff and Dungy Head; the stratigraphical changes occur in the next three and a half miles, between Dungy Head and Ringstead.

The likeness to Portland Island does not end with the Portland Stone. In the Sand comparable changes have occurred. There is no sign of the massive block of Black Sandstones at the top, so conspicuous from St. Alban's Head to Dungy Head; and instead we find a few feet of whitish cementstones and clays. The latter (Beds 12 and 13) give a suggestion of the Portland Clay. The *Exogyra* Bed is a typical Portland feature, although it has already begun to be developed at Gad Cliff and Dungy Head. Above it at Ringstead come mainly very hard sandy cementstones, like the block of hard strata at Portland which have been called the West Weare Sandstones; below it are mainly soft sands, greenish or mustard-coloured (glauconitic) and marly, with subordinate cementstones (= the softer Black Nore Beds). [For explanation of these stratal terms at Portland see Arkell, 1933.]

(b) Poxwell, Preston and Upwey.

A quarter of a mile south of Poxwell Church, on the southern border of Poxwell Circus and on the east side of the main road, a quarry in work shows the following section:—

QUARRY SOUTH OF POXWELL.

		ft.	ins.
	PURBECK BEDS.		
8.	Slatt and shale, about	6	0
7.	Tufa ("burr"), lenticular, forming great pillow-like masses, with silicified tree-trunks, one over 6 ft. long, and locally thin Dirt Beds	4	0
6.	Dirt Bed; black and white seams	2in. to	4
5.	Finely laminated white limestone full of moulds of tiny fresh-water gastropods, as at Holworth House	1	3

[1] For the wonderful fauna of the Basal Shell Bed of Portland see Cox, 1925. The identifications of lamellibranchs throughout this paper are based on Mr. Cox's two papers, 1925 and 1929.

		ft.	ins.
	PORTLAND FREESTONE SERIES.		
4.	Shelly limestone, white, chalky, full of *Trigoniæ, Chlamys lamellosa, Isognomon listeri, Protocardia dissimilis, Mytilus,* etc.	1 ft. 3in. to	1 6
3.	Ditto, same fossils but scarcer; *Titanites in situ*		3 6
2.	Chert vein	1 in to	3
1.	White freestone in two courses, few fossils; seen to	7	0

A similar section, but less clear, may be seen in a quarry south of the main road three quarters of a mile west of Osmington Church. This brings us to the interesting district around Preston and Bincombe.

In dealing with the Portland Stone of this district Strahan remarks [1898, p. 69]: "*Ammonites giganteus* occurs abundantly along these outcrops, and at Greenhill Barton there is an oyster-bed like that at Tilly Whim."

This stimulating passage led the author to make a close investigation of the hills at the back of Preston and on by Green Hill and Bincombe to Upwey, with rather surprising results.

By Green Hill Barton and round the north side of Chalbury Camp, and in the dry valley followed by the road between Chalbury Hill and the next hill to the west, two hard limestone bands crop out as natural scars in the turf, forming conspicuous features reminiscent of Yorkshire (see Pl. 25, C). The higher scar, running along the west side of the valley, is formed by the hard pillowy tufa at the base of the Purbeck Beds, as just described in the quarry at Poxwell. The other scar consists of a still harder limestone which, when broken, turns out to be more in the nature of a sandy cementstone. In this "scar limestone" there is a softer band, usually about 2 ft. thick, which is the oyster bed referred to by Strahan.

The oyster bed proves on closer examination to differ from that at Tilly Whim [*supra*, p. 306] by being composed almost exclusively of masses of small shells of *Exogyra nana* [*bruntrutana*], assisted locally by *Serpula gordialis*, whereas that at Tilly Whim contains in addition a high proportion of the larger *Exogyra thurmanni* with numerous *Ostrea expansa, Isognomon, Plicatula boisdini* and *Lima rustica*. Palæontological impressions are vindicated by an excellent section in a road-cutting at Green Hill, close to the great fault, which shows that on stratigraphical grounds this cannot be the oyster bed of Tilly Whim.

GREEN HILL ROAD-CUTTING.

		ft.	ins.
5.	Cementstone bands and hard marl, largely obscured	4 ft. or	5 0
4.	Cementstone, very hard, about		4 6
3.	Marl		2 6
2.	Cementstone, very hard, forming a projecting bluff, the lower and middle parts an oyster bed—a solid mass of *Exogyra*		

		ft.	ins.
	nana, with *Serpulae*. Occasional *Ostrea expansa* and *Isognomon*	6	0
1.	Sand and marls, greenish, with many irregular rubbly bands of sandy cementstone nodules, seen to	18	0

This section shows unquestionably that the oyster bed is the *Exogyra* Bed in the Portland Sands. The old workings on the north-east side of Chalbury Camp, which expose the "scar limestone" with the *Exogyra* Bed in the middle, likewise give clear indications of marly strata above and of sandy below. The same bed can be traced nearly all round Poxwell Circus, from as far east as Moigns Down.

The only other possibility that suggests itself, that the oyster bed may represent the Basal Shell Bed of the Portland Stone, is exploded by a complete section of the Portland Stone in two large quarries only a quarter of a mile away, on the south side of Chalbury Camp. These quarries have been extended since they were described briefly by Strahan [1898, p. 69], and they now show the Basal Shell Bed in normal mixed-shell facies resting upon the Portland Clay as at the north end of Portland Island. This is, indeed, the nearest exposure on the mainland to Portland, which is only 5½ miles away.

QUARRIES SOUTH OF CHALBURY CAMP.

PURBECK BEDS.

		ft.	ins.
16.	Shale and slatt, about	4	0
15.	Tufa, as at Poxwell, with large trees *in situ*, up to	6	0
14.	Dirt Bed, black .. .. 1 in. to		2
13.	Tufa .. .. 6 in. to	1	6
12.	Dirt Bed, black .. .. 1 in. to		2
11.	Laminated white limestone	1	4

PORTLAND STONE.

FREESTONE SERIES.

		ft.	ins.
10.	Shelly limestone, hard, white, full of *Chlamys lamellosa*, *Isognomon*, etc., etc.	3	0
9.	Band of large chert nodules		6
8.	White limestone	10	6
7.	Band of continuous black chert nodules, average about ..	1	0
6.	White limestone in four courses	9	0
	Total ..	24	0

CHERTY SERIES.

		ft.	ins.
5.	Hard white limestone with scattered cherts	4	0
4.	Hard white limestone full of big black chert nodules.. ..	12	0
3.	Hard limestone, a little chert in upper part : large ammonites (*Behemoth* ?), *Isognomon*, casts of *Protocardia dissimilis*, *Serpulae*..	8	6

		ft.	in.
2.	Basal Shell Bed, packed with calcitic fossils : *Trigoniæ*, *Protocardia*, *Isognomon*, *Mytilus*, *Ch. lamellosa*, *Lima*, large ammonite (*Behemoth* ?), *Serpula gordialis*, etc.	2	6
	Total ..	27	0

PORTLAND SAND.

		ft.	in.
1.	Greenish clay, becoming sandy downwards (Portland Clay) seen to ..	6	0

In the next valley westward, that in which Bincombe lies, Strahan states "We pick up the Portland Stone outcrop 160 yards west of the Church. The rock dips northwards at 40° to 70°, but flattens in The Knoll, as at Chalbury, into a nearly level plateau" [1898, p. 70]. This plateau is all coloured as Portland Stone on the Geological Survey map (sheet 342, 1904 edition). When we come to examine it, however, we find that only the northern end is occupied by a tongue of Portland Stone (Cherty Series), and that the *Exogyra* Bed in its thick band of hard cementstone crops out again as a scar near the top of the escarpment all round the head of the coomb on the east side of the "neck" of The Knoll. It was apparently this that was mistaken for Portland Stone over the rest of the plateau, as at Green Hill. On the south face of The Knoll there are large masses of the same bed at different levels, all apparently more or less slipped, and a small quarry on the east side shows greatly disturbed beds, a jumble from all levels, but mostly sandy, probably the debris of an ancient landslip.

At Upwey the great quarry in the Portland Stone has deteriorated since it was described by Woodward [1895, p. 195] and Strahan [1898, p. 108] and there is nothing to add to their descriptions. Beneath thick Purbeck Beds, 19 ft. of Portland Stone can still be seen, the whole of it belonging to the Freestone Series, although there are more bands of chert than usual. Two thick bands of nodular and tabular chert 15½ ft. from the top, together 1 ft. 9 ins. thick with the thin separating limestone, probably represent the thick chert band 14 ft. from the top of the Freestone Series at Chalbury Camp. On this hypothesis the junction of the Freestone Series and Cherty Series should fall about 9 ft. lower; that is, in the "beds not seen, about 13 ft." of Strahan's section [1898, p. 108].

(c) Upwey to Corton and Portisham.

The most westerly stretch of the outcrop forms a straight, narrow ridge four miles in length, from the defile at Upwey to Portisham. The dip is steeply to the north in the northern limb of the Weymouth Anticline. At Portisham the outcrop disappears finally under the Upper Greensand. These four miles of outcrop constitute one of the most attractive stretches

of country in Dorset, and they are of great geological interest.

Beginning at the east end, we first meet with the same thick band of hard cementstone, which we have now learnt marks about the upper-middle part of the Portland Sands, cropping out intermittently as a scar low down along the escarpment on the south side of Friar Waddon Hill. It can be followed all the way to Portisham, and the scar formed by it is an easily recognized feature when the ridge is viewed from the south at a distance, from the road or the railway to Abbotsbury. A considerable way above it follows the Portland Stone, which, however, does not show. It here gives rise only to rounded grassy slopes, being apparently more readily soluble, in spite of its massive Cherty Beds and its property of forming angular precipices where cut by the sea. Beside the track over the hill above Friar Waddon Dairy House a limekiln quarry exposes about 8 ft. of white chalky limestone (Freestone Series) overlying 12 ft. of the Cherty Series, white chalky limestone with some calcitic shells and many enormous nodules of black chert, many of them two and three feet long. Better sections, however, can be seen farther on.

West of the tumuli on this hill the ridge becomes lower and narrower, and at Corton the road to Corton Farm and Church traverses it by a deep cutting with vertical sides of solid rock (Pl. 25, B). At first sight this section would be taken for Portland Stone; but, as Damon recognised [1860, p. 75; 1884, p. 83], it lies entirely in Portland Sand.[1] The "scar" cementstone can be traced into the cutting from both sides, but it has here become very much thicker. There is no definite *Exogyra* Bed, but *Exogyræ* are scattered through about 25 ft. of rock, most of which is very hard and much of it strongly serpulitic, like the Cherty Series above; but there is no chert. An interesting feature here and along the adjoining scars is the abundance of large ammonites, which exhibit the round whorl-sections and regular bifurcating ribbing of *Glaucolithites*.

The sides of the cutting and a small quarry above show the following section.

CORTON ROAD-CUTTING.

	PORTLAND SANDS.	ft.	ins.
10.	Dark grey sandstone, broken up by weathering	2	6
9.	CAST BEDS: Blue-grey marls and thin bands of nodular sandy cementstones, full of casts of *Thracia depressa, Pleuromya uniformis, Protocardia calcarea, Unicardium verioti, Trigonia incurva, T. gibbosa, Eocallista, Isocyprina*; also typical *Glaucolithites*. Some of the marly layers towards the base are full of *Exogyra nana*	6	0

[1] Buckland and De la Beche [1836, p. 20] gave a list of fossils as from the Portland Sand of Corton; but from their coloured folding map [Pl. I.] it is evident that they mistook the hard rock in the higher part of the cutting, and at the Knoll, for Portland Stone. Strahan's 6-inch maps show that he interpreted it correctly between Portisham and Upwey, but not farther east. (See also Strahan, 1898, p. 62.)

Photos: W.J.A.

PORTLAND SANDS WITH SCAR LIMESTONES AT CORYATES, CORTON AND CHALBURY.

To face p. 330.

		ft.	ins.
8.	CAST BED : Rubbly sandstone, a mass of casts as above, especially *Trigonia gibbosa* and *T. incurva*	3	0
7.	Sandy cementstone, very hard, drab greenish-grey, much of it a serpulite full of *S. gordialis*. *Exogyra nana* common. Several large typical *Glaucolithites* (one 1 ft. 1 in. in diameter)	6	6
6.	Sandy shales and bands of light laminated cementstone nodules	4	6
5.	Cementstone, very hard, a solid block forming most of the vertical walls of the cutting ; seams of *Serpula gordialis* and *Exogyra nana*. Large *Glaucolithites* (several) ; locally a serpulite	11	6
4.	Marl parting ; small crushed biplicate ammonite		6
3.	Hard grey sandy cementstone or sandstone	1	9
2.	Sandy marl parting ; casts of *Pleuromya* and *Trigonia* ..		6
1.	Sandstones, mustard-coloured, rubbly, on the whole soft, with many small harder nodules of diverse shapes ; seen to	40	0
	The same apparently continues down the road for at least another	15	0

The round-whorled ammonites are here more abundant than at any locality in Dorset, and they attain large sizes. They occur through at least 30 ft. of rock and the harvest must have been a rich one for any collector who could have been on the spot when the cutting was made (well over a century ago). They serve to correlate the rocks with the St. Alban's Head Marls and the West Weare Sandstones.

Less than half a mile farther west a second road-cutting traverses the ridge, above Coryates, but here the road follows an older stream-course and the section is not so good (Pl. 25, A). A sand-pit east of the road in the short defile exposes about 12 ft. of mustard-coloured glauconitic sands, and discontinuous sections in the bluff on the opposite side show that the sands must be at least 60-70 ft. thick. There are two or three thin bands of sandstone, in one of which (high up) was part of a small biplicate ammonite such as are found abundantly in the Emmit Hill Marls of Emmit Hill. The whole of these sands lie below the massive cementstones of the Corton cutting, which here form the crest of the ridge ; the upper part probably represents the softer rubbly sandstones (Bed 1) at Corton, here more decalcified or more sandy. At Friar Waddon boring, a short distance to the north-east, the Survey assigned 80½ ft. of the core to Portland Sands, and I suspect that about 10 ft. of their basal bed of the Portland Stone should be transferred to the sands also. (See Edwards and Pringle, 1926, pp. 75-6.)

As remarked above (p. 311) it is possible that the Sands are hereabouts augmented by the Hounstout Marls becoming sandy.[1]

[1] The sands show signs of becoming clayey where very poorly exposed at the bottom, but there is nothing to show at what horizon this change takes place, and it is misleading to say " the junction with the Kimeridge Clay is exposed " [Latter, 1926, p. 81], at any rate in the present state of the section. No definite Kimeridge Clay (lithological or palæontological) was reached in the Friar Waddon boring, and so the lithological Portland Sands may be thicker than 90 ft. ; but it seems probable that the boring just reached the bottom.

Between Corton and Coryates there seems to be a gentle roll in the strata, for the Portland Stone retreats off the main ridge for a distance of three-quarters of a mile and forms a lower, subsidiary scarp north of the road, marked by a line of overgrown quarries in the Lower Purbeck Beds. The profile of the main ridge, capped by the resistant cementstones, is remarkably sharp (see Pl. 25, A).

Between the Coryates cutting and Waddon the cementstone shows again as scars, and in one small section, 4 ft. deep and a few yards wide, a very large specimen of *Glaucolithites* (?) protrudes, 18 inches in diameter, and there is the impression of another. The base of the Cast Beds can be seen above (1 ft.), packed with *Trigoniæ*, *Exogyra nana*, etc. They correspond with Bed 7 at Dungy Head and Bed 21 at Emmit Hill (pp. 322, 308).

Above this the Portland Stone comes up to the crest of the ridge again, soon followed by Lower Purbeck Beds, and these continue to Portisham. Beside the track over the hill above Waddon a quarry and an old lime-kiln close together provide a nearly complete section of the Portland Stone. The larger quarry shows Beds 1 to 8 and the smaller Beds 6 to 10.

WADDON QUARRY AND LIMEKILN.

PURBECK BEDS.

11. Tufa, in pillowy masses, has been worked two or three feet above the old limekiln, and still protrudes.

PORTLAND BEDS.

FREESTONE SERIES.

		ft.	ins.
10.	Gap .. ..About	2	6
	White chalky limestone	1	0
9.	Line of chert nodules		4
8.	White chalky limestone with *Titanites*	3	0
7.	Line of chert nodules		6
6.	White chalky limestone, few fossils; some casts of *Protocardia*, *Natica*, etc.	7	0
	Total about ..	15	0

CHERTY SERIES.

5.	Hard white cherty limestone full of enormous black chert nodules 2 and 3 ft. long and more. Some shells	10	0
4.	Marly parting (chalky)		3
3.	Hard white chalky limestone with scattered chert nodules (common), some fairly large	8	6
2.	Yellow marly limestone and marl		9
1.	Serpulite: hard white limestone full of *S. gordialis*, and a few chert nodules; *Kerberites* (?). Seen to	4	0
	Total seen ..	23	6

This section affords definite evidence that the whole Portland Stone is still thinning westwards. The correspondence, bed for bed, with Chalbury Camp and Holworth House is still close, but both divisions are thinner. The Freestone Series has shrunk from about 21 ft. at Holworth and 24 ft. at Chalbury to 15 ft.; the Cherty Series is very little thinner than at Chalbury, but about 9 ft. thinner than at Holworth. (Since the Serpulite in the base of Waddon Quarry is evidently that in the same position at Holworth, where it is 5 ft. thick, and the equivalent of Bed 3 at Chalbury which is 8 ft. 6 ins. thick, the base of the Portland Stone may be assumed to lie from two to five feet below the floor of the quarry).

This section shows far more than the extensive but derelict quarries at the end of the ridge above Portisham, described by H. B. Woodward [1895, pp. 196, 261; and the description repeated in Strahan, 1898, pp. 71, 110], which extended only to the base of the Freestone Series. At present they show only the highest 12 ft. of the Freestone Series, corresponding bed for bed with the section at Waddon.

PORTISHAM QUARRIES.

PURBECK BEDS above, with at the base, below the tufa, 1 ft. 6 ins. of laminated limestone full of tiny gastropod casts, as at Holworth, Poxwell, etc.[1]

PORTLAND BEDS.

FREESTONE SERIES.

		ft.	ins.
10.	Shelly white limestone	4	0
9.	Line of chert nodules	1	0
8.	White chalky limestone with a line of chert nodules	3	0
7.	Line of chert nodules	1	0
6.	White chalky limestone, seen to	3	0

(The numbering of the beds as at Waddon).

The Waddon quarry provides reason to suspect that in his "general section at Portisham," Woodward somewhat underestimated the total thickness of the Portland Stone when he put it at 34 ft. [1895, p. 196]. The thickness at Waddon is at least 40 ft. and at Friar Waddon perhaps 50 ft.[2] Likewise the thickness of 40 ft. given for the Portland Sand is more like half the true thickness, as appears from an examination of the steep scarp overlooking the town, which shows 60 ft. of Portland Sand capped by 14 ft. of gravel, above which the slope rises more gently. Moreover, the Friar Waddon boring is only 2 miles

[1] The large silicified tree-trunk ("fossil elephant") encased in a sheath of tufa, and measuring 14 x 4½ ft., figured in Strahan's Memoir (p. 111), can still be seen in the floor of the western extension of the quarry. The tufa sheath has curious annular ribs, difficult to explain.

[2] Edwards and Pringle, 1926, p. 75 (Friar Waddon boring; I think not 60 ft. as there stated).

		Ammonite Zones.	Isle of Portland.	Purbeck.	Ringstead-Portisham.	Vale of Wardour.	Swindon-Aylesbury.	Boulogne and Wimereux.*	
Portlandian.	Portland Stone.	*Titanites titan* and *T. giganteus*	Freestone Series (25 ft.)	Freestone Series (50 ft.)	Freestone Series (15–24 ft.)	Upper Building Stones (0–16 ft.)	Roach and Creamy Limestones (10 ft.)	Sables et grès calc. à *Card. dissimile* et *Trig. gibbosa* (12 ft.) Sables et grès calc. à *Ampullina ceres* et *Trig. gibbosa*, with *Titanites* (12 ft.)	" Portlandien Supérieur."
		Behemoth spp, with *Kerberites kerberus* and *K. okusensis*	Cherty Series (with Serpulite) (50–60 ft.) Basal Shell Bed	Cherty Series (with Serpulite) (65 ft.)	Cherty Series (with Serpulite) (25–35 ft.) Basal Shell Bed	Chalky or Cherty Series (24 ft.) Ragstone Shell Beds (8 ft.)	Swindon and Crendon Sands and Stone (25 ft.) Cockly Bed (4 ft.)	Sables et grès calc. à *Cardium pellati*, with *Behemoth* (6 ft.) Calcaires grav. et glauconieux et argiles sableuses à *Astarte saemanni*, with *Kerberites* (6 ft.)	
	Portland Sand.	*Glaucolithites glaucolithus* and *G. gorei*	Portland Clay (0–14 ft.) West Weare Sandstones and *Exogyra* Bed (30–40 ft.)	Black Sandstones and Parallel Bands (45 ft.) St. Alban's Head Marls with *Exogyra* Beds (45 ft.)	West Weare Sandstones (and cement-stones) with *Serpulæ* and *Exogyra* Beds (25–40 ft.)	Main Building Stones (18 ft.) Basement Beds (pars) (7 ft.) Phosphatic Lydite Bed	Glauconitic Beds (3–10 ft.) Phosphatic Lydite Bed	Calcaires noduleux et argiles sableuses à *Perna bouchardi* et *O. expansa*. " *Per. pseudobiplex* " (33 ft.) Phosphatic Lydite Bed of Tour de Croï	" Portlandien Moyen " (Upper part of)
		Provirgatites scythicus	Upper Black Nore Beds (35 ft.) Black Nore Sandstone	Emmit Hill Marls (30 ft.) Massive Bed (6)	Sands of Ringstead and Coryates (c. 50 ft.)	Gap ? Basement Beds (20–30 ft.)	Absent	Absent ?	

* See the works of Messrs. Pruvost, Pruvost and Pringle, and Dutertre in the List of References.

away (see p. 331). The massive cementstones form scars as usual, and rabbits and sheep have contributed to make a passable section ; and here, at the extremity of the outcrop, the *Exogyra* Bed has returned.

VII. NOTES ON THE AMMONITE SUCCESSION AND THE CORRELATION TABLE.

The following notes have no pretentions to exhaustiveness. They are but the first attempt to bring together the relevant facts from the scattered literature of English Portlandian ammonites and those bearing on the zonal succession observed during the examination of the outcrop.

(a) The Freestone Series.

The Freestone Series is the source of nearly all the giants from the quarries of Portland Island and the mainland. Until recently only two species appeared in the literature, *P. giganteus* (Sow.) and *P. bononiensis* de Loriol, and these were used as zone-fossils for the Freestone Series by Salfeld [1914, p. 130]. But on the restriction of the genus *Perisphinctes*, Buckman proposed four new genera : *Titanites*, *Briareites*, *Gigantites* (all 1921), and *Galbanites* (probably a nucleus) (1922). The earliest is *Titanites*, and the others can for the present only be regarded as synonyms [see Spath, 1931, p. 472 ; and Arkell, 1933, p. 481].

In the field it is usually out of the question to distinguish between species, when all that is seen is fragments or partial sections in the rock face. The generic characters are, however, usually unmistakable. In cross-section the whorl is distinctly compressed (high) ; the coiling is rather involute ; and the ribbing is of a characteristic type, not very strong, with a more or less marked forward sweep on the lateral areas.

Specimens are common in the *Titanites* Bed wherever it is worked in Purbeck. At Winspit they are also not uncommon in the House Cap (p. 307). Here the quarries are derelict and whole specimens have not been seen by the author. So far as can be learned from cross-sections and fragments they differ in no way from those in the *Titanites* Bed. At Worth Quarry and Seacombe typical *Titanites* (but not full sized) are also found in the Shrimp Bed (p. 306).

In the country north of Weymouth they have been noted by the author near the top of the Freestone Series at Poxwell and in the upper half at Waddon (pp. 327, 332).

The Shrimp Bed of Seacombe, St. Alban's and Worth Quarry contains in addition a strongly ribbed triplicate type of ammonite, of which only fragmentary remains and impressions have so far been found. Buckman (1927, Pl. dccxvii., A, B) recorded a somewhat similar form from the very highest levels near Aylesbury

under the name *Glottoptychinites*, with which I identified the Dorset form with a query in 1933 (*op. cit.*, p. 485). Such fragments as have so far been found might be identified equally well with this genus or with *Kerberites* of the Cherty Series; but more material is needed.

(b) Cherty Series.

Ammonites of giant size, though never so large as the largest *Titanites*, are just as common in the Cherty Series as in the Freestones, and they range through a thicker series of strata. They are far less well known, however, because the Cherty Series is rarely worked and so whole specimens are not often procured. In the cliffs accurate identifications are seldom possible, but since most of the forms will probably be found to belong to Buckman's genus *Behemoth*,[1] they have been recorded under that name. They differ from *Titanites* in being more inflated and more evolute, and many of them show stronger ribbing. That there is a difference was realised by Blake [1880, pp. 192, 228], who gave them a new name, *A. pseudo-gigas*; but unfortunately Blake designated no type and Buckman has since designated a neotype from the Freestone Series of the Aylesbury district,[2] thus alienating the name from the forms for which it was certainly intended. These forms have also been distinguished from "*A. giganteus*" by being recorded by some writers as *Perisphinctes bononiensis* de Loriol [1874, Pl. iii.], which appears from the original figure to be a *Behemoth*.

Salfeld [1914, p. 130] in his zonal scheme placed the Cherty Series in his zone of *Perisphinctes pseudo-gigas* Blake and *P. okusensis* Salfeld. The latter is a coarsely-ribbed triplicate form common in the Cockly Bed of Okus Quarry, Swindon, and Buckman made it the genotype of a new genus *Kerberites* [1924, Pl. dxx.]. In order to retain Salfeld's zones so far as possible, the index-fossil should be *Kerberites okusensis* (Salfeld), with which Buckman [1926, p. 26] coupled, as alternative index-species, *Kerberites kerberus* Buckman, from the Vale of Wardour. It was a typical example of *Kerberites* that Blake figured as *Ammonites triplicatus* Sow. from the Cherty Series of the Isle of Portland [1880, Pl. x., fig. 7.]

In the Boulonnais, according to published records, *Kerberites* occurs in a lower bed than *Behemoth*, immediately below it. The former is recorded (sub "*Per. triplicatus*") in the "Calcaires graveleux et glauconieux à *Astarte saemanni*" (6 ft.) and the latter in the superjacent "Sables et grès calcareux à *Cardium pellati*" (6 ft.) [Pruvost, 1925, p. 193]. At Swindon likewise, the Cockly Bed, in which *Kerberites* abounds, represents only the lower part of the Cherty Series. The rest is developed as the

[1] Buckman, 1922, Pl. cccv. a, b.

[2] "*Trophonites*" *pseudogigas* (Blake). [Buckman, 1926, p. 26.]

Swindon Sands and Stone, which are unfossiliferous; but the Cockly Bed there also yields abundant *Behemoth*.

(c) Portland Sand, upper half. (St. Alban's Head Marls and Black Sandstones in Purbeck; West Weare Sandstones and *Exogyra* Beds in the west.)

The upper half of the Portland Sand contains a distinct fauna of ammonites, also often large, most of them characterised by almost perfectly round whorl-section, evolute coiling and strong, regular, biplicate ribbing, which passes strongly over the venter. Salfeld first distinguished these by a special specific name, *Perisphinctes gorei* Salf[1]., and he recorded specimens that he was satisfied were typical in the upper part of the Portland Sand of Portland Island (where fragments are not uncommon among the fallen blocks at the foot of West Weare Cliffs) and in the equivalent Glauconitic Beds at Swindon. For these strata he therefore created the zone of *P. gorei* [Salfeld, 1914, pp. 130, 191, 198].

Unfortunately complications arise over the type of Salfeld's species, for he designated as type, not one of the English examples, but the French specimen figured as *Ammonites biplex* by de Loriol (1874, Pl. ii., Fig. 1), which is distorted by compression. The original of this figure was said by de Loriol to come from the quarries at Wimille near Wimereux, which according to Pruvost [1925, p. 193] precludes its belonging to strata lower than the "Couches à *Astarte saemanni*" (see above, p. 334). Salfeld himself [1914, p. 222] placed it even a little higher, in the "Couches à *Cardium pellati*." These two sets of beds are together only about 12 ft. thick; but they yield specimens of *Behemoth* (in the higher part) and *Kerberites* (in the lower), and but for this matter of *P. gorei* they therefore correlate with the Cherty Series of the Portland Stone.[2] On the other hand, *P. gorei* is said to be very rare in the Boulonnais, and Pruvost [1925, p. 193] states, "truth to tell, its precise horizon is unknown."

It is the opinion of all those who have investigated the two coasts (including the author) that the fauna of the upper part of the Portland Sand correlates, not with these strata just mentioned, but with the group next below them, about 33 ft. thick, called the "Calcaires noduleux et argiles sableuses et glauconieuses, noir-verdâtre, à *Perna bouchardi, Ostrea expansa, Oxytoma octavia*, etc." [See Pellat, 1878 and 1879; Pringle in Pruvost and Pringle, 1923, p. 17; in Pringle and Pruvost, 1924, p. 398; and in Pruvost, 1925, p. 196]. The beds, which are well exposed in the cliffs between Wimereux and Boulogne, recall the

[1] After Mr. C. H. Gore, Freeman of Swindon, who procured many fine fossils from the Portland Beds of that town.

[2] It should be noted, however, that a specimen of *P. gorei* is recorded by Cox [1925, p. 123] from the Basal Shell Bed of the Portland Stone at Portland, associated with *Kerberites* and *Behemoth*.

nodular parts of the Portland Sand very forcibly, and they rest, like the *gorei* zone in Wiltshire, Oxfordshire and Buckinghamshire, upon a phosphatic nodule bed with derived Pavlovids (Niveau phosphaté du Tour de Croï, Ph. 3). It was long ago pointed out by Hudleston that the Boulonnais succession is more like that at Swindon than that in Dorset.

In these supposed equivalents of the Upper Portland Sands in the Boulonnais, immediately overlying the Tour de Croï phosphate bed and for about 30 ft. upwards, there is a rich fauna of Perisphinctids, some of large size, as yet practically unstudied. They have usually been referred to, like those in our Upper Portland Sand, as *P. biplex*; but Prof. Pruvost has named some especially large ones ("encore mal connus, qui atteignent une taille énorme"), *P. pseudo-biplex* [Pruvost, 1925, p. 194]. It is these that one recalls when confronted with the huge ammonites in the cementstones of the Upper Portland Sand at Corton and Waddon.

The generic designation of these forms, when so little is known of their detailed characters, presents considerable difficulty. Buckman named one typical round-whorled form from the White Cementstone of Hounstout *Leucopetrites caementarius* [1926, Pl. dclxxvii.]; but this name was anticipated by several of his own generic names for specimens from the Glauconitic Beds inland: *Glaucolithites*, *Crendonites*, *Crendonina*, *Polymegalites*, and *Gyromegalites*. The earliest is *Glaucolithites* (1922, Pl. cccvi, A, B), and since there seems no doubt that *gorei* (auct.; including Salfeld himself) is congeneric with the genotype species *G. glaucolithus* Buckman, this name must be adopted for the zone fossil.

Specimens of *Glaucolithites* (probably embracing numerous species) are abundant all along the outcrop. In the cliffs of Emmit Hill and Hounstout they abound in the Black Sandstones (Block A), and in the upper part of the St. Alban's Head Marls, a range of about 80 ft. above the White Cementstone. At Gad Cliff the Black Sandstones are again their chief repository.

At Ringstead they begin to be abundant in the hard cementstones on the level of and above the *Exogyra* Bed, and range upwards for 10 ft. At Corton their vertical range is at least 30 ft., and they excel in numbers and in size, the rock being similar to that at Ringstead and in the Isle of Portland (West Weare Sandstones and *Exogyra* Bed).

(d) Portland Sand, lower half. (Emmit Hill Marls and Upper Black Nore Beds.)

In the lower half of the Portland Sand, a smaller type of ammonite abounds, in the form of crushed and usually crumbling internal casts, which give no idea of the whorl-section or the suture-line. A typical example from the Emmit Hill Marls of

Emmit Hill is figured on Pl. 26, Fig. 3, to show the style of ribbing, which is very irregular, alternating rapidly from simple to biplicate and triplicate. Accurate identification of such material is impossible, but there is a distinct resemblance to the ammonites found in the "Argiles grises, etc." of the Boulonnais, *below* the Tour de Croï phosphate bed,—the group of "*Perisphinctes*" *boidini* (de Loriol) [1874, Pl. iv., Fig. 3].[1]

In the same beds at Emmit Hill and Hounstout (Beds 1, 9, 11, p. 310) have been found some ammonites of great interest. These are likewise crushed casts showing no whorl-section or suture-line, but they are decidedly high-whorled and involute and bear the remarkable virgatotome style of ribbing characteristic of the Russian (Volgian) genus *Virgatites* Pavlow. Their peculiarity is that bundles of three, four and five parallel secondaries branch off from the anterior side of each primary rib.

The first to call attention to the presence of these forms in the Portland Sand was Buckman, who figured two fragments from the Massive Bed of Hounstout, identifying them as *Virgatites scythicus* Michalski and *V. pallasi* Michalski [Buckman, 1926, Pl. dclxxv. and Pl. dcxciii.]. Subsequent search by the author proved that similar fragments are not uncommon in Beds 9 and 11 at Emmit Hill, and in September 1933 the perfect specimen illustrated on Pl. 26, Fig. 2, was found *in situ*. It too is crushed flat, but it shows the true virgatotome ribbing admirably, and is sufficiently complete to admit of the Dorset species being for the first time described and named:—

PROVIRGATITES ALBANI sp. nov. Holotype figured on Pl. 26, Fig. 2, in the author's collection, from Bed 11 of the Emmit Hill Marls at Emmit Hill, St. Alban's Head.

The specimen measures 55 mm. in diameter, the height of the (crushed) whorl being 37%, and the width of the umbilicus 28%. The primary ribs at that diameter number 22, and it can be seen in the umbilicus that the number on the penultimate whorl is about the same. From supplementary material, too fragmentary to figure, it is known that the ribs on the inner whorls bifurcate. Where they first appear on the holotype they bifurcate about the middle of the lateral area. Of the visible ribs on the last whorl, three are oblique simple ribs, three have three branches, eight have four branches, and two have five. The furcation is typically virgatotome ("polyschizotomous"), the secondaries parallel and the posterior sides of the sheaves curved gently, concave backwards, on the middle of the lateral area. The secondaries are strongly prorsiradiate, the primaries recti- and flexi-radiate.

The nearest species among published figures is *Perisphinctes scythicus* (Vischniakoff) Michalski (1894). As lectotype is chosen

[1] Nowaïsky, however, considered *P. boidini* a *Pavlovia*, and the Argiles grises are usually correlated with the *Pavlovia* zones (= Swindon Clay).

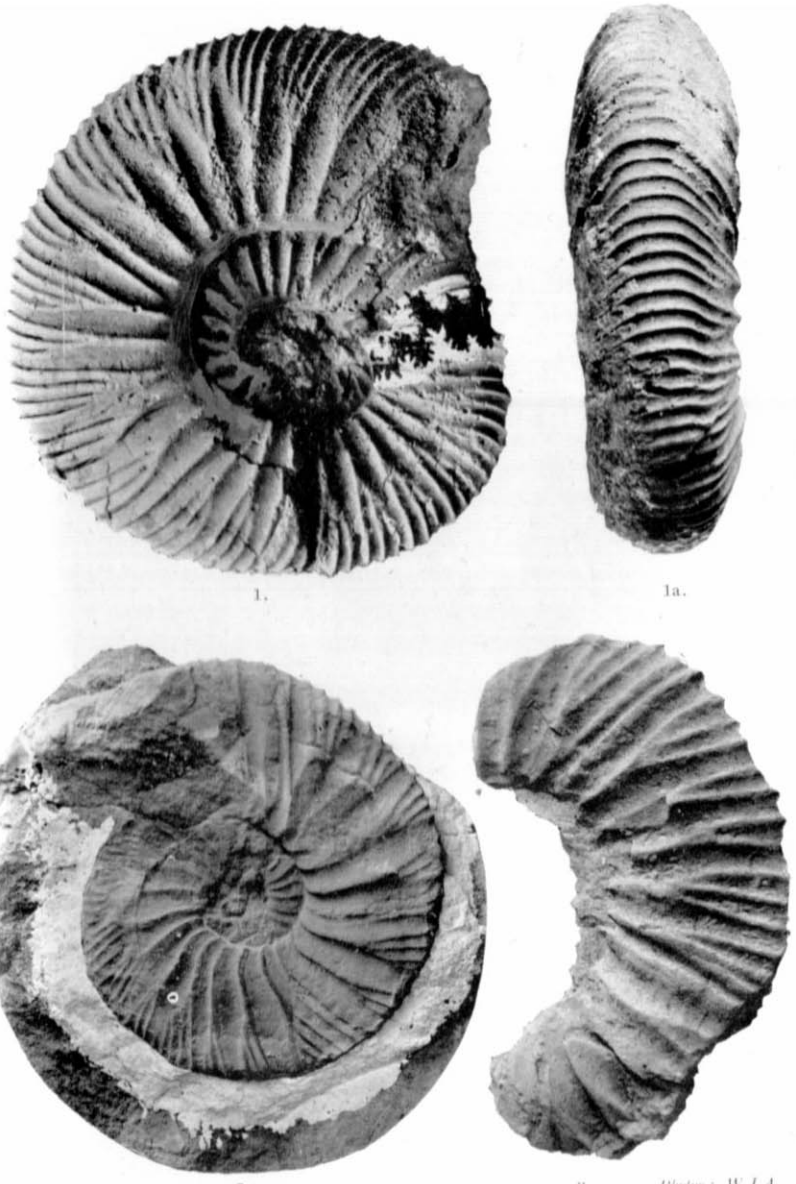
the "Normaltypus" figured on Michalski's Pl. vii., Figs. 1a-d.[1] But neither this nor any of the other Moscow specimens figured under the same name can be regarded as conspecific with the Dorset ammonite. The lectotype of *scythicus* at a corresponding stage of growth is much finer ribbed (twice as many ribs). The "mutations variety" in Michalski's Pl. vii., fig. 7, is closer, but in that the ribs are too flexuous and the umbilicus is too wide. The ribbing of *P. stschukinensis* Michalski (1894, Pl. vi., fig. 8) is also similar, but more regular and finer, and the ribs are more numerous.

A closer comparison with our Dorset ammonite is to be found in the Portlandian of Pomerania. At Schwanteshagen, near the Baltic coast, Richter (1931) has described an extremely important quarry section which, with that nearby at Zarnglaff, exposes almost the complete succession from the uppermost Oxfordian (*Ringsteadia* zone) into the Wealden. Dohm (1925, p. 36, Pl. v., fig. 4, and Pl. ii., fig. 3) had already drawn attention to the presence here, towards the top of the succession, of Virgatitids, which he identified with *V. scythicus* (Vischn.) and *V.* cf. *quenstedti* (Rouill.). Since his figures are unsatisfactory, I figure here (Pl. 26, Figs. 1, 1a) a better specimen from Schwanteshagen, which I was allowed by the kindness of Dr. O. H. Schindewolf to select for the purpose from the collection of the Prussian Survey Museum in Berlin. I propose for it the name PROVIRGATITES POMMERANIA sp. nov. The dimensions are 73 mm., .385, .30, .315. The ribs number 28 to the whorl at 70 mm., and 26 at 55 mm., not counting oblique simple ribs, of which there are 3 or 4 per whorl. The ribbing is more regular as well as denser than in *P. albani*, being mainly trichotomous on the first half of the outer whorl and on the second half becoming regularly four-branched. The curvature of the ribs, however, the mode of furcation, and the relative lengths of the secondaries, are all much as in *P. albani*.

P. albani and *P. pommerania* belong to the group of *P. scythicus*, distinguished by Michalski as *Perisphinctes* as opposed to his *Olcostephanus*, and Lewinski (1923) has proposed for the group the name *Provirgatites* as distinct from the true *Virgatites* (=*Euvirgatites* of Lewinski), which embraces Michalski's "*Olcostephani*." *Provirgatites* differs from *Virgatites* in having only biplicate ribbing on the inner whorls, and in the fact that the ribbing is always somewhat raised at the point of furcation and fades on reaching the umbilical area, which is smooth and undercut. There are also differences in the septal sutures.

Michalski was under the impression that all the species figured by him occurred together, but Russian authors have since shown that *Provirgatites* occurs on a lower horizon than *Virga-*

[1] Vischniakoff's memoir having been privately printed for private circulation, his names have been held to rank only as MS. names never published.



1. 1a. 2. 3. Photos: W.J.A.

PROVIRGATITES OF THE SCYTHICUS ZONE.

[To face p. 340.

ites and moreover has a wider extension, having been found also beyond the Moscow Basin, in south-east Russia and Poland (refs. in Lewinski, 1923, pp. 90-94, and since then Passendorfer, 1928). The forms here described prove beyond doubt that the *Provirgatites scythicus* zone extends beyond Poland through Pomerania into Dorset, and they provide the first significant link in correlating the Moscow Basin Portlandian with the type sections in Dorset.

Nothing comparable with *Provirgatites albani* or *pommerania* has been figured in the numerous works by various authors on the Portlandian of the Boulonnais. There, as in England, Perisphinctids with a more or less virgatotome style of bifurcation have been recorded from the middle part of the Kimeridge Clay (*Subplanites* = "*Pseudovirgatites*" = "*Virgatosphinctes*" zones), like those described from the borings in Kent and at Corton, Dorset [Lamplugh, Kitchin and Pringle, 1923].[1] But these do not really bear a very close resemblance to the forms now in question. The various ammonites from the Portlandian figured as *Virgatites* by Sauvage [1911, Pl. ix.] have all proved to be quite different—in most cases they are young of *Kerberites* and perhaps *Behemoth* [as recognised by Pringle and Pruvost, 1924, p. 2, footnote, and agreed by Dutertre, 1926, p. 16].

The significance of the recognition of the true *Provirgatites* fauna in Dorset is that it provides an accurate date for the final closing of the strait which linked together the Upper Jurassic seas of the Moscow and Anglo-French basins via Poland and northern Germany. The *Provirgatites* fauna is the last marine Jurassic fauna common to the four areas. Richter's work at Schwanteshagen shows that in Pomerania the next fossiliferous rocks overlying the *Provirgatites* beds, and only 10 ft. above them, are brackish sediments of Wealden facies. He concludes that the strait was closed between Pomerania and Poland immediately after the *Provirgatites* hemera. The Hanover area appears to have been cut off still earlier, presumably by a retreat of the sea to the northward, for there nothing but the Plattenkalk of Eimbeckhausen (devoid of ammonites) is present to represent all or any of the Upper Kimeridgian and Portland Beds. Above it follow the Marls of Mund, which are undoubtedly Lower Purbeck (see Arkell, 1933, pp. 549-52).

Thenceforth the ammonite faunas in the Moscow and Anglo-French basins evolved along independent lines, giving rise to the wonderful Virgatitids in Russia and the equally remarkable, but very different, Titanitids in England and northern France. *Virgatites* may be supposed to have evolved directly from ancestors already in Russia during the formation of the *Provirgatites* zone; but in the western basin the fauna was more varied and

[1] I had the pleasure of discussing these with Dr. Kitchin shortly before his lamented death, and of comparing them with my new Ennmit Hill specimen, in which he displayed enthusiastic interest.

the progenitors of the giant *Glaucolithites*, *Behemoth* and *Titanites* are not so easy to trace. A fascinating problem awaits the palæontologist who will take up a monographic study of our Portlandian ammonites, a subject as yet almost untouched.

VIII. SUMMARY.

It is urged that the Portlandian Stage should be reinstated in stratigraphical literature and redefined on a proper historical basis, according to the scope of the Portland Beds as first defined by William Smith and Fitton in the type-locality, Dorset.

As a contribution to a better knowledge of the Portland Beds, the magnificent sections in Purbeck and between Lulworth and Portisham are described, with records of their faunal contents; and correlations are attempted along the 27 miles of outcrop from Swanage to Portisham.

The Freestone Series is found to thin from 50 ft. in Purbeck to 30% in the west; the Cherty Series from 65 ft. to 40%; the Portland Sands from 128 ft. to a minimum of about 60%. Marked changes in the stratigraphical succession to the Portland Island type occur about the middle of the outcrop, between Lulworth and Ringstead. The changes are abrupt and do not take place *pari passu* with the greatest attenuation, but independently of it and farther west. The causes are not clear, but the subject is worthy of the attention of palæogeographers.

The economic problem presented by the disappearance of the commercially valuable freestones of East Purbeck as they are traced westwards is shown to be the result, not of their being overlapped as previously supposed, but of their deteriorating and becoming cherty. This conclusion is arrived at by detailed correlation of the Cherty Series beneath. A consequence of the deterioration is that the level of the stone worked migrates upwards in the sequence from east to west as far as Lulworth.

The Portland Stone mapped by the Survey north of Weymouth is found to be a hard development of the middle of the Portland Sand. On the other hand it is found that the most recent writer has referred to the Portland Sand at Ringstead and Lulworth the greater part of the Cherty Series of the Portland Stone.

Finally, the field records of ammonites are summarised. On these and past records is based a discussion of the zonal sequence, with special reference to correlation with inland areas and the Boulonnais. No attempt is made to treat the ammonites monographically, for good reasons that are explained; but the first complete specimen of a true *Provirgatites* found *in situ* in the Portland Sand (*P. albani* sp. nov.) is described and figured, together with a comparable new form from Pomerania. A horizon has also been discovered yielding in abundance the rare *Terebratula bononiensis* Sauv. and Rig. and a new *Rhynchonella*, which will be described later in a supplement devoted to the Brachiopoda.

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EXPLANATION OF PLATES 19–26.

PLATE 19.

Vertical sections of the Portland Stone at the chief exposures in Purbeck:—Gad Cliff, St. Alban's Head, Winspit, Worth Quarry, and Seacombe. Vertical scale, 1 inch = 20 feet.

PLATE 20.

St. Alban's Head from the undercliff on the east side, showing precipice of the Cherty Series of the Portland Stone, capped with the freestones. The lower part of the cliff in the centre and to the right is formed by a slipped or faulted slice which repeats the section. The tops of the letter J's mark the Puffin Ledge.

PLATE 21.

A. Worbarrow Tout and Pondfield Cove seen from the foot of Gad Cliff. The large overhanging ledge near the centre is formed by the base of Block F; those on the right are in Block A, the Black Sandstones at the top of the Portland Sand, and on them are the ammonites shown in Pl. 22, A. The cliff on the Tout consists of the Freestone Series and the upper part of the Cherty Series.

B. St. Alban's Head, west side. Precipice of Portland Stone showing the Parallel Bands at the base, and the St. Alban's Head Marls forming the slope below.

PLATE 22.

A. Glaucolithitids on the under side of an overhanging ledge formed by the Black Sandstones, Gad Cliff. Weathering has brought out the "fucoidal" structure of the sandstone. The body-chambers of the ammonites have been dissolved away. Photograph taken upwards almost vertically. The larger ammonites measure about 1 foot in diameter.

B. Serpulite rock formed by *Serpula gordialis* (Schlotheim), from the Cherty Series, Block L, Winspit, near St. Alban's Head. Viewed upon (right) and across (left) the bedding. Natural size.

PLATE 23.

Gad Cliff from the sea. Pondfield Cove on the left. The upper of the two conspicuous white bands in the cliff is the Shrimp Bed; the lower is Block LM, which is crossed by oblique veins of chert. The white colouring under the notch below the projecting Portland Stone on the skyline is guano from shags.

PLATE 24.

Gad Cliff from the sea, closer view, showing detail. Some important beds lettered as in printed section, p. 313.

PLATE 25.

A. The sharp-crested ridge formed by the Portland Sand at Corvates road-cutting. Glauconitic sands are exposed in the sand-pit in centre. The Portland Stone crops out under the flat ground to the left of the road.

B. Corton road-cutting, showing massive sandy cementstones in the Portland Sand, with *Serpulæ*, *Exogyræ* and large ammonites, simulating Portland Stone.

C. View in dry valley between Chalbury Camp and Green Hill, near Preston, showing natural scar on hillside marking outcrop of hard cementstone band with the *Exogyra* bed in steeply-dipping Portland Sand.

PLATE 26.

Figs. 1, 1a. *Provirgatites pommerania* sp. nov. The holotype, side and peripheral views. *Scythicus* zone, Lower Portlandian, Schwantes-hagen, Pomerania. Preuss. Geol. Landes-Museum, Berlin. See p. 340.

Fig. 2. *Provirgatites albani* sp. nov. The holotype. *Scythicus* zone, Lower Portlandian. Bed, 11, Emmit Hill Marls, Emmit Hill, St. Alban's Head, Dorset. Author's Coll. See p. 339.

Fig. 3. *Provirgatites* sp. indet., a typical fragment of crushed ammonite from the dark stinkstones of the Emmit Hill Marls of Emmit Hill. Note the irregular alternation of triplicate, biplicate and simple ribs. (cf. the middle part of the outer whorl of the type of *P. scythicus* in Michalski's pl. vii., fig. 1a). Author's Coll.

All the figures are natural size.

DISCUSSION.

Mr. L. R. COX, in congratulating the author, remarked that the area was of considerable importance, both because the Kimeridgian-Portlandian succession was more complete there than elsewhere in England and because it was the type-area for the differentiation of these stages. There was a slight divergence in opinion as to where the base of the Portland Sand should be drawn, due mainly to an original inconsistency on Fitton's part. For while the thickness of 120 feet given by him for the Sand at Hounstout would indicate that the Massive Bed was taken as its base, his statement that a line of springs was thrown out at its base would mean that some 50 feet below the Massive Bed were also included. The incorporation by foreign authors of a large part of the Kimeridgian in the Portlandian was, however, inexcusable at the present day, and the speaker suggested that the standardization of Jurassic stage-nomenclature by reference to type-areas might be a suitable subject for discussion at an International Geological Congress. The speaker had studied the rich non-cephalopod molluscan faunas of the basal and top beds of the Portland Stone in Portland and had been impressed by the number of species common to the two horizons. It was plain that the Portland Stone did not represent a very long period of geological time, and probable that the two ammonite zones into which Salfeld had divided it would prove sufficient. The range of the species "*Perisphinctes*" *gorei*, which Dr. Arkell regarded as characteristic of the upper part of the Portland Sand, might prove to extend to higher horizons; a specimen had certainly been found in the shell-bed at the base of the Stone in Portland. The speaker asked Dr. Arkell if he could explain Blake's statement that a similar shell-bed was developed at St. Alban's Head, where he (the speaker) had searched unsuccessfully for it.

Mr. F. H. EDMUNDS congratulated the author on the very clear and interesting account of the many sections that had been given, and on the conclusive manner in which the massive stone bed north of Weymouth had been proved to be a development of the Portland Sand. He said that he himself was well acquainted with the sections, and was very interested to find that Dr. Arkell considered the chert to be of secondary origin; he had formed the opinion that it was a primary constituent of the beds.

DR. VERNON WILSON also congratulated the author on another fine contribution to Jurassic stratigraphy. He wished to pursue the point

raised by the previous speaker regarding the origin of the chert in the Cherty Series, because he was not quite happy about its secondary origin as accepted by the author. From observations on chert occurrences in the Durness Limestone, in the Carboniferous Limestone in Yorkshire, and in the Corallian Series in East Yorkshire, he was convinced of a primary origin in each case. He enquired of the author for further details of the mode of occurrence and field relations of the chert in the Cherty Series. If it occurred as ill-defined masses or bands within individual beds, or forming the cores of limestone or mudstone nodules, then he could not visualise a secondary origin, but favoured some form of segregation or differentiation from an original uncompacted sediment containing interstitial colloidal silica particles. Even if the chert occurred as sharply defined nodules along bedding planes, its primary origin was possible, according to the Syngenetic Theory sponsored by Tarr ("The Origin of Chert and Flint," *Univ. Missouri Studies*, vol. i., No. 2 1926) and Twenhofel ("Treatise on Sedimentation," 1932, pp. 519–546.)

THE AUTHOR thanked the speakers and others for their cordial reception of his paper. In reply to the questions as to the primary or secondary origin of the chert, he said that he had not wished to appear to dogmatise. He had noticed, however, that at Gad Cliff and Dungy Head, close to the steep limb of the Purbeck anticline, where tilting is sharp, but not in East Purbeck, where the strata are less disturbed, thick bands of chert cross from one bedding-plane to another like sills. One bed of limestone, shown in Plate 24 accompanying the paper is crossed obliquely by numerous bands of chert at 45° to the bedding. These instances prove that the Portland Beds have been saturated with a solution rich in silica at some time during or since the Tertiary earth-movements, and it is consequently *a priori* probable that most or all of the chert dates from that time. He recalled Rowe's criticisms of Barrois for correlating parts of the Chalk by means of the relative concentration of flints. Nevertheless he (the speaker) thought that the explanation offered in the paper (p. 317) justified bed-for-bed correlation by this means in the Portlands over distances of a few miles. The silica may well have been derived from the deposits in which the chert is found.

In reply to Mr. Cox, he stated that he had been unable to obtain any verification of Blake's mention of a Shell Bed at the base of the Portland Stone in Purbeck. Its absence, and the absence of the Black Sandstones in Portland, made it uncertain that the boundary between the Stone and Sand was drawn on the same horizon in Purbeck as in Portland. He had not detected any ammonites resembling *Glaucolithites gorei* above the Black Sandstones. His objections to including in the Portland Sand any strata below the Massive Bed were: in the first place the strata from the Massive Bed to the top of the Black Sandstones correspond to Fitton's description of the Portland Sand at Emmit Hill, both in constituent beds and in thickness (see above, p. 311); in the second place no definite line offers itself at a lower level. There are three or four lines of springs, as can be seen on the west side of Hounstout. Buckman drew his boundary at the highest line, about 50 ft. below the Massive Bed, but Blake was equally justified in selecting one of the other lines, at least another 50 ft. lower. In his time the seepage at that level may have been more prominent.