# ALGAL GROWTHS IN THE RHAETIC COTHAM MARBLE OF SOUTHERN ENGLAND

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ABSTRACT. The Cotham Marble horizon in the Upper Rhaetic of southern England includes the two well-known rocks, Landscape Marble and Crazy Cotham Marble. Previous hypotheses concerning the origin of Landscape Marble are listed and the widely quoted gas-bubble explanation is discussed critically. An algal origin is proposed for the Landscape Marble, and the Crazy Cotham Marble is shown to be a current-concentrated breccia.

COTHAM Marble occurs in the Upper Rhaetic Cotham Beds in many localities in South Wales, the Bristol district of southern England and southwards through the Taunton area to Charton and Pinhay Bays on the south coast. It occurs at one horizon only. Two distinct types of Cotham Marble may be present, namely Landscape Marble and Crazy Cotham Marble. Landscape Marble (Pl. 39, fig. 1), known as a geological curiosity for over two centuries, is characterized in vertical section by tree-like structures giving the impression of a wooded landscape. Crazy Cotham Marble is made up of an apparently jumbled mass of slabs and flakes of muddy limestone set in a matrix of similar lithology. Although the two types of limestone usually occur separately, it is not unusual to find them intimately associated.

## TERMINOLOGY

Landscape Marble was originally known as Cotham Stone, the name used by Owen (1754, p. 164) in the description of the limestone from Cotham, Bristol, where it is associated with Crazy Cotham Marble. Subsequently the alternative names Landscape or Cotham Marble and Crazy or False Cotham Marble have gained acceptance. Short (1903, pp. 138–9) distinguished seven varieties of Cotham Marble. He proposed that the term Cotham Marble should include all these varieties, reserving Landscape Marble for the variety with aborescent structures and Crazy Cotham Marble for the flaky aggregates. This usage is adopted in the following discussion together with his use of the descriptive terms 'hedge', 'trees', 'canopy', and 'atmosphere' for the component parts of the landscape. From the present reinterpretation it will be seen that the additional types distinguished by Short are natural variations of either Landscape or Crazy Cotham Marble.

## LANDSCAPE MARBLE

*General description.* The first description (a very complete one) was given by Owen (1754, pp. 163–78) and Landscape Marble has been discussed subsequently by several writers. Typically it occurs as well-defined lenses or mounds (Pl. 39, fig. 1). The upper surface is irregularly ridged or hummocky (Pl. 39, fig. 2) and is composed of finely laminated material which drapes down the sides of the lens, clearly separating the lens from the enclosing muddy sediments. The size of the lenses varies from about 0·3 to 3·0 metres across and 3 cm. to more than 20 cm. in depth. The landscape rests on

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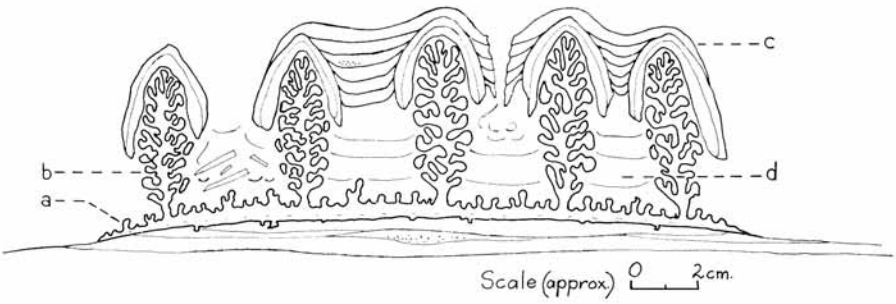
laminated muddy limestone which often shows small scale sedimentary structures such as scour and fill, sand pockets, and penecontemporaneous deformation structures. The landscape itself is composed of (text-fig. 1):

(*a*) The 'hedge'—a basal dark horizon with many small rising projections.
(*b*) The 'trees'—arborescent structures rising from the hedge.
(*c*) The 'canopy'—finely laminated material bending over the top of the trees and forming the ridged top of the lens.
(*d*) The 'atmosphere'—material overlying the hedge, between the trees and below the canopy.

The dark basal horizon is normally continuous and convex upward, being strongly convex towards the margins. The convex surface on which it rests cuts across the laminae




TEXT-FIG. 1. Components of Landscape Marble (Diagrammatic). *a*, 'Hedge'. *b*, 'Tree'. *c*, 'Canopy'. *d*, 'Atmosphere'.

of the underlying limestone so the whole landscape rises from a low mound of sediments. Typically the height of the hedge averages about 5 mm. and many small projections rise from the upper surface into the atmosphere. The trees rise from the hedge and the branches are lobes or pillars that may be directed upwards, laterally or downwards. The tops of the trees become more foliate or bushy. The height of fully developed trees is surprisingly constant, about 4 to 5 cm. but this often decreases towards the margins of the lens.

The upper surface of the lens has branching ridges and where the sides of the ridges are steep the canopy is often broken between them (Pl. 39, fig. 1). The ridges occur over the arborescent structures so that the latter are not isolated structures but linear, and form a reticulate pattern in plan (Short 1903, p. 137). The crowns of some of the trees have an arrow-head of laminated material draped over them (Pl. 40). The lower edges of the arrow-head fall below the general level of the canopy. There is often an 'unconformity' between the laminae of the arrow-head and the adjacent laminae of the canopy (text-fig. 1). The canopy is normally present immediately over fully developed trees, but where the trees are low a canopy may lie on sediments some distance above the trees (Pl. 39, fig. 1). Usually, however, the canopy closely overlies the trees.

Between the trees there is a light blue-grey indistinctly bedded, muddy limestone descriptively termed the atmosphere. In this the bedding is often bent upwards adjacent to the trees, sometimes it is horizontal, and Short (1903, p. 137) reports that in some specimens it slopes down a little. Where the canopy is continuous, successive bedding planes can be traced laterally between several trees. Where the canopy is discontinuous this cannot be done. In some cases only the upper beds of the atmosphere are disturbed, but in others the whole atmosphere may show contorted and inclined bedding (text-fig. 1, Pl. 40). Such atmospheres may contain shell fragments, usually concave upwards, and small or even large flakes, similar to those forming Crazy Cotham Marble, which have sunk into the atmosphere (Pl. 40). Some of these flakes bear a hedge.

Landscape Marble occurs most commonly as a single landscape, i.e. with a hedge, trees, atmosphere, and a canopy. In the Bristol area especially it is not uncommon to find two or even three landscapes, one on top of the other. Such rocks are called Double Landscape Marble (Pl. 39, fig. 1) and Triple Landscape Marble respectively. In both Double and Triple Landscape Marble the successive landscapes have a lateral extent almost corresponding to that of the basal landscape, and they often become increasingly convex upwards.

*Previous explanations of the origin.* These (reviewed by Short 1903, pp. 139–42 and Shrock 1948, pp. 277–9) suggest that the arborescent structures originate from the dark basal horizon and invoke either chemical or mechanical processes.

Short (1903, pp. 142–8) thought the process was chemical accretion, whilst Woodward (1887, pp. 243–4) and Wells and Kirkaldy (1951, p. 203) suggest mineral infiltration. The following mechanical processes have been suggested: rising gas bubbles (Owen 1754 and Thompson 1894), squeezing up along lines of breakage (Fisher, *see* Thompson 1894, p. 410), differential subsidence (Woodward 1901, p. xci), shrinkage of the canopy (North 1930, p. 174), changes in hydrostatic head (Rettegen 1935, p. 288), and density differences (Nettleton 1936, pp. 92–97).

Most of these explanations invoke rather special conditions to account for the well-defined lenses of Landscape Marble. If Landscape Marble is really confined to one stratigraphical horizon these conditions must have been more or less synchronous over an extensive area of southern England. Further, in many places as at Cotham, such conditions must have recurred at precisely the same spot to form the double and triple landscapes.

Of the above processes the only serious contender, and still the most widely quoted, is the gas-bubble hypothesis. In his original description of Landscape Marble Owen (1754, pp. 174–8) suggested that the formation of the rock was due to the rise of gas bubbles trapped in the basal, possibly carbonaceous layer forming the hedge. The rising bubbles carried up organic material to produce the arborescent structures and deform the canopy. Thompson (1894, pp. 401–10) elaborated this idea, suggesting that the gas was formed by decomposition of organic matter in the hedge, and that the canopy was

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EXPLANATION OF PLATE 39

Fig. 1. Vertical section through a lens of Double Landscape Marble, showing two landscapes. Locality, Cotham, Bristol. Cb 3850, Bristol Museum Coll.

Fig. 2. Exterior of a lens of Landscape Marble showing branching ridges on the upper surface and the canopy draping down the margin of the lens. Locality, Cotham, Bristol. 14238, Geology Department, Reading University.

formed by the outflow and spreading of the decomposed material to completely roof in the arborescent structures.

This mechanism raises many difficulties. Pit and mound or gas-pit structures are not uncommon in sedimentary rocks from which gas has escaped. Despite Twenhofel's statement (1932, p. 682) that pit and mound phenomena could give rise to features similar to those displayed in Landscape Marble, no examples of comparable structures known to have such an origin have been found in the literature. Gases would carry material upwards only on release from moderate pressure. Such a pressure is unlikely to have been attained by burial to a depth of only about 6 cm., the combined height of the trees and the canopy. This depth of burial is certain, for the sediments overlying the lenses do not show deformation sympathetic with the ridges of the canopy. Thus the ridges must have been formed prior to the deposition of the sediments immediately overlying the canopy.

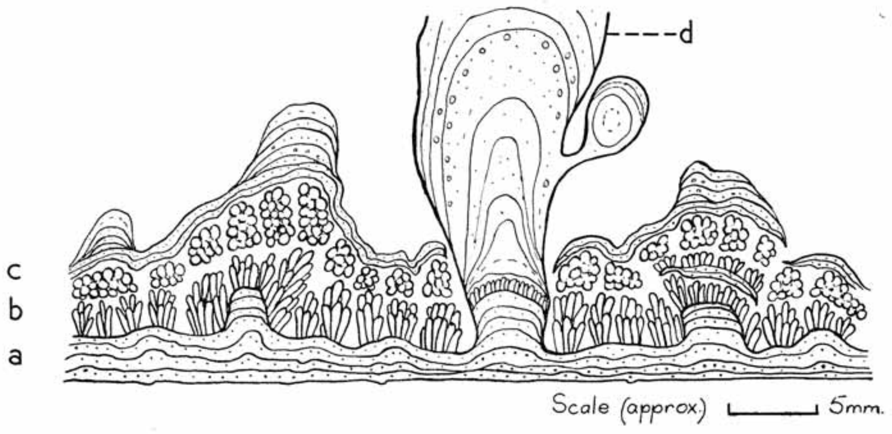
Further, bubbles would tend to rise from random points, whereas the trees have a linear arrangement in plan. Woodward (1892, pp. 110–14), whilst then considering the bubble mechanism possible, sought to explain the linear arrangement of the trees by the rise of organic material along cracks caused by the partial drying of the lower layers. The intimate penetration of even the lower layers of the atmosphere by the arborescent structures (Pl. 41) hardly seems compatible with partial drying out of the sediments. Further, the pattern of the ridges is not typical of desiccation cracks.

Owen also attributed the arching of the canopy to the rise of gas bubbles. This presupposed that the lower layers (the atmosphere) were sufficiently fluid to allow the passage of a bubble whereas the upper layers (the canopy) were relatively coherent and easily deformed. However, in no specimen examined is there any trace at the top of the trees of either the escape of a bubble through the canopy or of a cavity that would indicate the position of the trapped bubble. The canopy forms bifurcating ridges and not domes as would be expected from the rise of gas bubbles. Furthermore, the supposedly deformed canopy is not a normal sedimentary bed for it drapes down the margins of the lens (Pl. 41, fig. 2) and does not extend beyond it.

The source of the gas is attributed to decomposing organic matter in the hedge. To deform the canopy the generation of gas must either have been delayed until the atmosphere and the canopy were laid down, or have continued during the deposition of this material. In the latter case deposition and deformation would have occurred almost simultaneously.

*Organic origin*. Curiously, no reference has been found directly suggesting an organic origin for Landscape Marble. The lensoid masses with clearly defined margins, in which the marble occurs, strongly suggest organic growth. Further, the forms of the hedge, trees and canopy are not very different from those normally attributed to algal growth. However, Mr. N. E. Butcher, Geology Department, Reading University, has brought to the author's notice, 'Faunal and Lithological Sequence in the Carboniferous Limestone Series (Avonian) of Burrington Combe (Somerset)', in which S. H. Reynolds and A. Vaughan (1911) point out the close similarity of the 'concretionary beds' of $S_2$ and Landscape Marble. Dr. F. A. Bather and Dr. G. J. Hinde, who examined the $S_2$ specimens, both suggested that the 'concretionary beds' may be due to calcareous algae. The implication of these interpretations has apparently been overlooked in discussions of the origin of Landscape Marble subsequent to 1911.

Microscopic examination of section shows that the hedge is usually tripartite (text-fig. 2). It consists of: (1) A basal finely laminated horizon, about 1 mm. thick and domed on the upper surface (cf. Anderson 1950, fig. 1B). These undulose laminae are superficially similar to *Malacostroma undulosum* Gürich (1906, pl. xix, figs. 2 and 3). (2) Cylindrical filaments now filled with clear calcite. These rise vertically from the horizontal parts of the basal horizon and radially from the domes. These filaments are overlain by more bulbous ones. (3) Finely laminated encrusting layers, crowning some of these filamentous structures and forming the projections of the hedge. This encrusting




TEXT-FIG. 2. Structure of the 'hedge' (diagrammatic). *a*, Basal laminated horizon. *b*, Zone of cylindrical and bulbous filaments. *c*, Upper laminated layer. *d*, 'Tree'. Drawn from a slide.

layer is apparently similar in structure to the basal horizon (1) and also the canopy over the trees. A comparable relationship of algal structures has been noted in *Stylophycus* by Johnson (1940, pp. 587–9). In this growth-form the digitate pillars are covered with laminae similar to the basal laminae from which the pillars rise.

The trees in Landscape Marble usually rise from the basal laminated horizon of the hedge and pass through the second layer (text-fig. 2). In some cases, however, they develop from the projections of the hedge (Pl. 41). They are thus a complex growth-form of the lower laminated horizons. Convex laminae are present in the lower parts of the trees and may continue into the lobes, cross-sections of which show concentric laminae. Towards the top of the trees there is often a gradual suppression of the laminae as the internal structure becomes patchy or 'flocculent'. These arborescent structures bear some similarity to the branching *Malacostroma plumosa* Gürich (1906, pl. xviii,

EXPLANATION OF PLATE 40

Flakes of Crazy Cotham Marble penetrating Double Landscape Marble. Algal growths encrust some of the flakes and those on the largest flake give rise to arborescent structures. Locality, Cotham, Bristol. Cb 4128, Bristol Museum Coll.

fig. 1), though in Landscape Marble they are more tree-like. They are notably more complex than any of the growth-forms described by Anderson (1950, pp. 5–28).

The canopy is an encrusting algal deposit. It is finely laminated with a flocculent structure between the laminations and appears to be similar to *M. concentricum* Gürich (1906, pl. xix. figs. 2 and 3). The relation of the trees to the canopy is shown in Pl. 41, where laminae of the canopy are seen to be continuous with the structure of a tree. Gürich showed that *M. concentricum* and *M. plumosa* are often associated (1906, pl. xviii, fig. 1, pl. xxii, fig. 2) but he considered these to be two separate forms. The laminae of the canopy in Landscape Marble are most continuous in the upper portions where they can be traced over many ridges to form a sheet blanketing the algal colony. The arrow-heads which penetrate the canopy from below (text-fig. 1, and Pl. 40) suggest that the crowns of the trees were colonized first to form separate canopy ridges. Only subsequently did the canopy spread over the adjacent ridges (text-fig. 1) probably after sedimentation had bridged the gap between the trees. The more even and continuous canopy is therefore a later growth stage than where the ridges are separated by deep depressions.

Where the canopy developed as a continuous sheet it protected the bedded sediments below. In such atmospheres, the up-turned bedding planes adjacent to the trees may be due to the growth of the arborescent structures and/or compaction and lithification. Discontinuities in the canopy may be due either to rupturing of the sheet after its establishment or to incomplete development of the algal sheet between the ridges. The two cases are easily distinguished. Ruptured edges are often irregular and the laminae end abruptly at the break (text-fig. 1). Natural growth edges of the canopy are smooth and the laminae fuse at the margin. Where the canopy ridges remained separate the spaces between the trees were open continuously to sedimentation of clastic and bioclastic material (Pl. 40).

In this figured specimen (Pl. 40) the large flakes penetrate the lower landscape of Double Landscape Marble and are colonized by an algal growth similar to the hedge. Encrusting growths may cover the tops, bottoms, and sides of some flakes. Perhaps algae colonized these flakes prior to their settling into the atmosphere. However, the growth of mature arborescent structures from the large flake shown in this figure suggests the growth of algae *after* the flakes had entered the atmosphere. Often the hedges and trees on flakes encrust the upper ends of the flakes, that is the portion probably standing above sediment level. Development of an arborescent habit is, in all probability, the response to further deposition of sediment. A similar response would account for the development of both the projections on the hedge and the arborescent structures in typical Landscape Marble.

One further feature of the canopy suggests an algal growth-form. Several specimens have been found showing sedimentary material filling small depressions on a former surface of the canopy. The sediment has later been covered by continuous laminae extending into the canopy (text-fig. 1). The light patches (right of centre in the upper canopy of Pl. 39, fig. 1) originated in this way (as also the divided canopy on the lower right of the same specimen).

The convexity of both the hedge and the lens as a whole has been noted above. That of the hedge is determined by the convex sedimentary surface on which it grew. This is probably an eroded surface for it truncates the bedding of the underlying limestone.

Apparently algae colonized such mounds selectively. In many cases the convexity of the lens as a whole is increased towards the margins by the diminution in height of the trees, as in the lower landscape of Pl. 39, fig. 1. Anderson (1950, p. 12) refers to the marked convexity of many algal colonies. He states:

> It has been demonstrated that the rate of secretion or precipitation of $CaCO_3$ by modern algae is dependent on light intensity (Berthold, 1882, p. 419) so that once the convex form is established, the tendency is for the convexity to become more acute, i.e. for the growth to be vertical rather than lateral. This fact that $CaCO_3$ precipitation usually takes place more rapidly in the vertical axis of the colony provides one criterion by which these organic growths can be distinguished from inorganic structures.

This helps to explain the increasing convexity towards the margins of many lenses of Double and Triple Landscape Marble. Further it has already been noted that the successive landscapes in these forms are similar in size to the basal landscape. The extent of the basal landscape sets a limit to the size of successive landscapes for these are outgrowths of the immediately underlying canopy (Pl. 39, fig. 1). In such cases the later-formed hedge differs from the basal hedge in having no cylindrical or bulbous filaments. The change in habit from canopy to hedge was brought about probably by a change in the rate of sedimentation.

On page 11 of the same article Anderson states:

> Regarding the simple growth-forms . . . it is clear that they have very different survival values . . . the following points become evident . . . that the encrusting sheets possess maximum stability but are most vulnerable to burial; that the conical, cylindrical and branching types are most likely the response to a muddy habitat, but are unstable, and therefore probably lived in comparatively quiet waters.

The closely bedded muddy limestone of the Cotham Marble horizon also suggests the general prevalence of quiet water during growth of the algal colonies. Currents, however, did occur, for channels are fairly common in this horizon and Crazy Cotham Marble was obviously formed by current action.

## CRAZY COTHAM MARBLE

In spite of the several different explanations advanced to explain the origin of Landscape Marble there has been no such divergence of views concerning the origin of Crazy Cotham. Short (1903, p. 148) interprets the flakes as chemically formed layers later broken by disturbed water conditions.

The flakes are blue-grey muddy limestone weathering like Landscape Marble to a buff colour, and set in a matrix of muddy to sandy limestone. Sometimes the flakes found in a specimen have their long axes aligned, in subparallel fashion, in the major bedding plane. In these specimens the size of the flakes is often fairly uniform. The flakes frequently stand edgewise, displaying a fan-shaped arrangement in vertical sections normal to their long axes. Examination of such sections reveals the typical features

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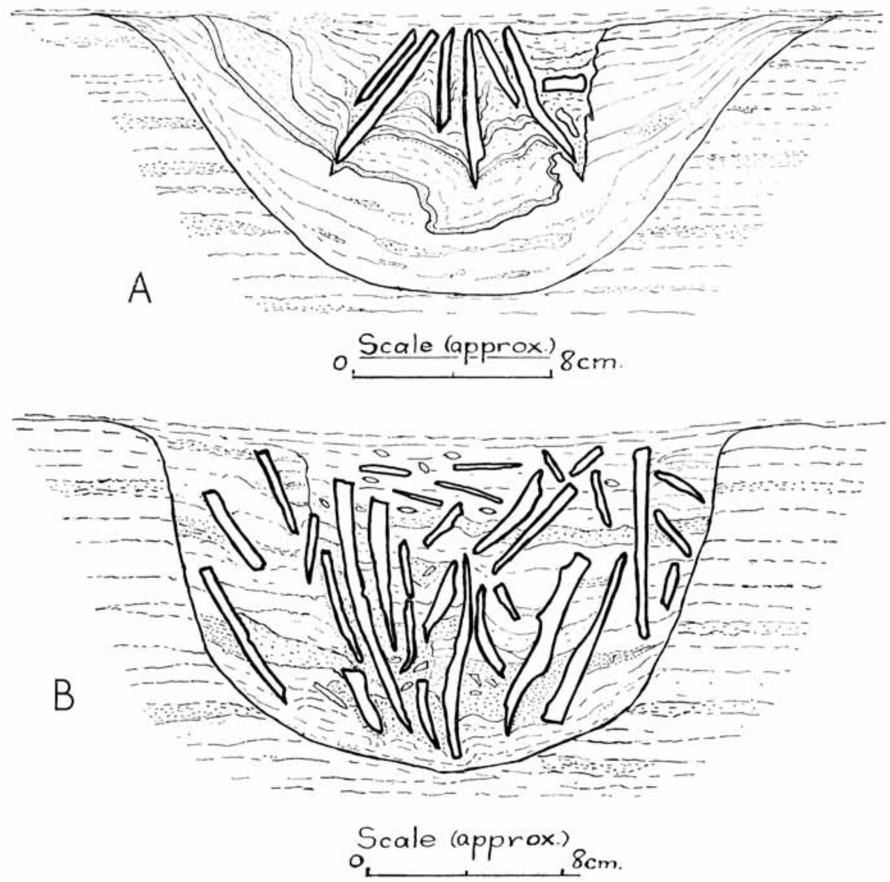
EXPLANATION OF PLATE 41

Structure of the algal growths in Landscape Marble. Laminae of the canopy rise from the right-hand margin of the arborescent structure. Growth has been arrested at this stage by the influx of clastic sediment (top) which has buried the algae. The hedge is atypical for there are few basal laminae and few bulbous structures overlying the lower cylindrical filaments. The landscape encrusts a flake. Locality, Lady Hill Road Cutting, Newport, Mon. 14277, Geology Department, Reading University.

of eroded channels filled with channel-deposits. The flakes are aligned lengthwise along the channels and penetrate the formerly soft sediment of the channel bottom. The fan-shaped arrangement may be inverted or upright. The inverted arrangement (i.e. con-




TEXT-FIG. 3. The fan-wise arrangement of flakes of Crazy Cotham Marble in channel fillings. A, Inverted fan-wise arrangement. B, Upright fan-wise arrangement. Diagrammatic reconstructions, A from 14239, Aust Cliff, B from 14240, Long Ashton, Bristol.

vergence towards the top) was produced by splaying outwards of aligned flakes sinking edgewise through the watery sediments in a more or less completely filled channel (text-fig. 3A). The upright fan-wise arrangement (text-fig. 3B) was apparently formed by the accumulation of flakes in more open channels. The channel shape and the current in it controlled the arrangement of the flakes.

In both the above arrangements, the flakes probably fell edgewise from above or over the side into the channel, were held by the soft channel-fill and responded like a wind-vane to the currents. Not all flakes in channels are aligned in this fashion. In some specimens the flakes show varying degrees of imbrication, resulting from the rolling of flakes in the channel. Probably alignment parallel to the current persisted only in weak currents whilst faster currents produced imbricated deposits.

As already noted, Crazy Cotham and Landscape Marble may be associated (Pl. 40) for clastic flakes are often trapped between the ridges and lenses of Landscape Marble. Colonization of the Crazy Cotham Marble flakes by a hedge is common but not universal. Short (1903, p. 139) stated that trees never develop from the hedge on Crazy Cotham Marble. However, specimens collected from Pinhay Bay and the specimen illustrated in Pl. 41, show a well-developed landscape rising from Crazy Cotham Marble.

There can be no doubt that the flakes have a mechanical origin and the similarity of their lithology to the enclosing sediments suggests a penecontemporaneous origin from a nearby source. They must have been partially lithified before transport for they retain sharp edges, often penetrate soft sediments and may damage the algal growths in Landscape Marble. Probably the flakes were formed by the drying out of exposed sediment. This is supported by the following characters of the flakes: they have approximately the same thickness, a smooth upper and an irregular lower surface and some are bent (Short 1903, p. 148). The dried flakes were then concentrated by currents to form mud-flake breccias. Anderson (1950, p. 12) observes that the association of breccias and algal beds is quite common.

## CONCLUSIONS

Landscape Marble is evidently a biohermal association of algal growth-forms. The hedge, trees, and canopy all have an algal origin, being the structures formed by sediment-binding algae. Probably the bioherms were restricted to a geographical zone (cf. Black 1933, p. 169, Rezak 1957, pp. 145–6) and the features strongly suggest an intertidal environment. Without further information it is not possible to decide if they were strictly coeval throughout the area of outcrop.

Crazy Cotham Marble has a mechanical origin. As the Rhaetic includes much shallow-water sediment it is probable that exposure and drying out took place at different times and places. Hence the presence of Crazy Cotham Marble in itself cannot be taken as evidence of coeval strata without other supporting evidence. Indeed, comparable structures have been noted in the Westbury Beds at Sedbury Cliff.

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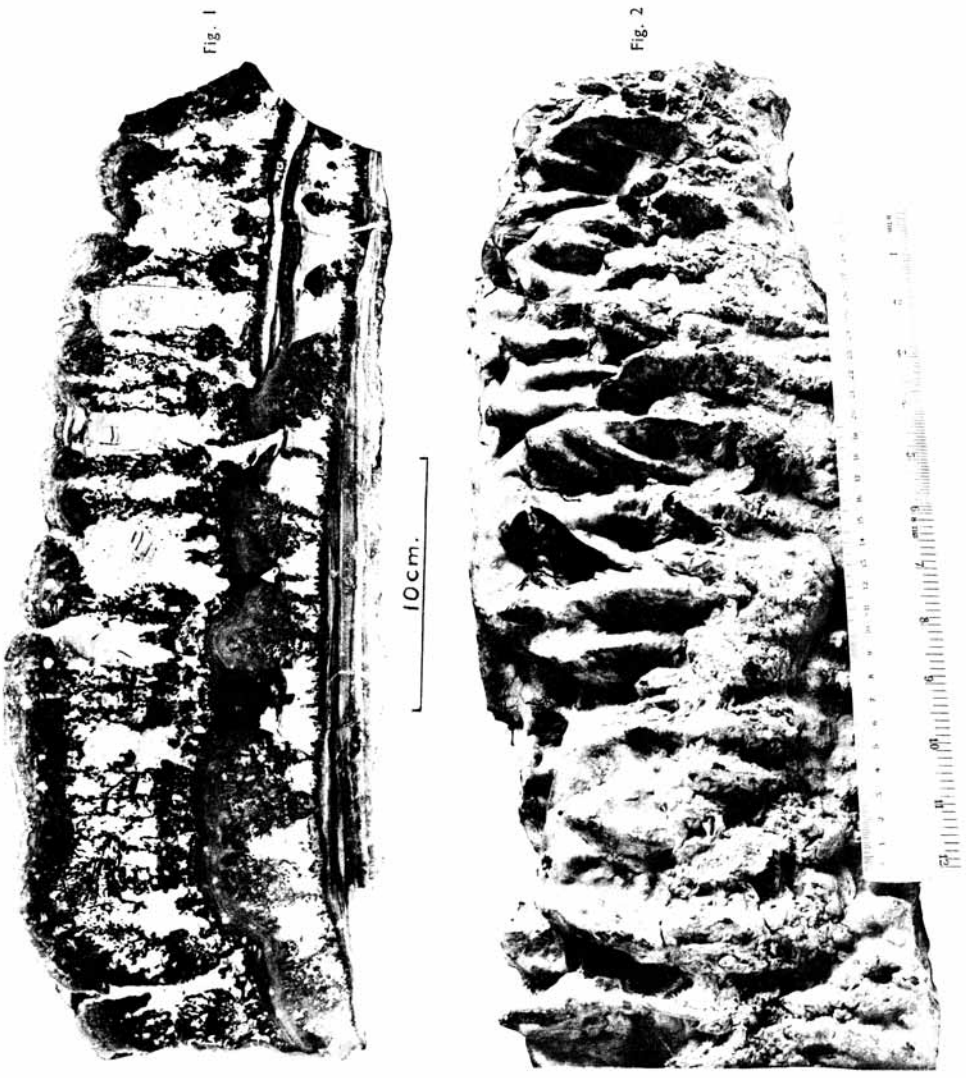


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