Figures and tables

Figures

of calcite veins and matrix. Bar: 0.16 m. (Photo: D.B. Smith.)

(Figure 3.7) Mutual relationships of facies of the Trow Point Bed at its type locality. After Smith (1986, fig. 3).

(Figure 3.8) Large slide-block (olistolith) of thin-bedded dolomite mudstone/wackestone of the Raisby Formation, resting on a slightly discordant major submarine slide-plane cut onto undisturbed dolomite near the base of the Raisby Formation. The block moved from left to right (i.e. north-eastwards). Coastal cliffs at the north-west side of Frenchman's Bay, South Shields. Bar: 1 m. (Photo: D.B. Smith.)

(Figure 3.9) 'Tepee'-like structures in thin-bedded dolomite mudstone of the Raisby Formation on the shore platform about 140 m north of Frenchman's Bay, South Shields. Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.10) The Frenchman's Bay to Velvet Beds sector, showing the main features of geological interest. Except in Frenchman's Bay and in an anticline *c.* 100-200 m north of Man Haven, all the strata are collapse-brecciated rocks of the Concretionary Limestone Formation.

(Figure 3.11) The Velvet Beds to Marsden Rock sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation.

(Figure 3.12) Sketch of the cliffs at the northern (above) and southern (below) ends of Marsden Bay, showing the main collapse-related features. All the strata depicted are of the Concretionary Limestone Formation and, where least altered, comprise an interbedded mid-slope sequence of slightly bituminous, finely laminated dolomite mudstones, and sparingly fossiliferous turbiditic and/or slumped dolomite packstones and grainstones. Where severely altered, much of the rock is a hard crystalline secondary limestone (dedolomite). Sketch after Woolacott (1909, plate 2). See (Figure 3.13) for detailed distribution of rock types near Velvet Beds.

(Figure 3.13) Foundered strata of the lower part of the Concretionary Limestone Formation, showing massive dedolomitized collapse-breccias sharply overlain by slightly to severely collapse-brecciated dolomite and limestone; late-stage breccia-gashes (or collapse-pipes) cut the latter. The residue of the Hartlepool Anhydrite probably lies 2-5 m below the lowest rocks shown. Cliffs at Velvet Beds, north end of Marsden Bay, South Shields. The field of view lies near the northern end of the cliffs shown in (Figure 3.12) (upper section). After Smith (1994).

(Figure 3.14) The Marsden Rock to Lizard Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.

(Figure 3.15) The Lizard Point to Souter Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.

(Figure 3.16) Tight slump folds in high-slope thin-bedded calcite mudstones of the Concretionary Limestone Formation. Coastal cliffs *c.* 500 m south of Potter's Hole, Whitburn Colliery. Hammer: 0.33 m. Reproduced by permission of the Director. British Geological Survey: NERC copyright reserved (NL 138).

(Figure 3.17) *Kirkbya permiana* (Jones), a typical ostracod from high-slope calcite mudstones of the Concretionary Limestone Formation. Top of coastal cliffs on the south side of Byer's Hole, Whitburn Colliery. Bar: 0.43 mm. (Photo: Sunderland Museum TWCMS: P1004.)

(Figure 3.18) The Souter Point to Whitburn Bay sector, showing the main features of geological interest. All exposed strata north of Rackley Way Goit (*) are of the Concretionary Limestone Formation but those to the south may include lower beds of the Roker Dolomite Formation.

(Figure 3.19) Preserved faces within the complex of former limestone quarries on Fulwell Hills, Sunderland; numbers refer to quarry faces described in the text.

(Figure 3.20) Mutually interfering subspherical calcite concretions ('cannon-balls') in a matrix of fine-grained dolomite. Note the parallel bedding traces preserved on the surface of some of the concretions. Loose specimen from floor of Southwick Quarry. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (NL 130).

(Figure 3.21) Hylton Castle (Rotherfield Road) Cutting and its immediate surroundings, showing the main features of geological interest.

(Figure 3.22) Claxheugh Rock, Cutting and Ford Quarry, showing the position of the main features of geological interest.

(Figure 3.23) Section of strata at Claxheugh Rock, Cutting and Ford Quarry, based on Smith (1970a, fig. 17).

(Figure 3.24) Steeply south-south-eastwards sloping contact between Basal Permian Sands (pale) and dolomite boundstone of the Ford Formation reef. The slope is interpreted as the northern flank of an east-northeastwards trending submarine slide canyon (Smith, 1971c). The field of view is about 18 m high. (Photo: D.B. Smith.)

(Figure 3.25) Dawson's Plantation Quarry, Penshaw, and its environs.

(Figure 3.26) Debris flow of dolomite- and calcite mudstone a few metres above the base of the Raisby Formation. View to south-east near north-east end of Dawson's Plantation Quarry, Penshaw. Note the imbrication in the partly rounded clasts towards the top of the unit, and the mollusc shells seen in section in the uppermost fine-grained bed, interpreted as a fall-out tail. Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.27) Disturbed strata in the Raisby Formation at Dawson's Plantation Quarry, showing their lateral variation. After Lee (1990, fig. 2.21).

(Figure 3.28) Humbledon Hill Quarry and its immediate surroundings, showing the position of the GCR site and the main features of geological interest.

(Figure 3.29) Sketch of the stratal relationships in the southern part of the main face of Humbledon Hill Quarry, based on an unpublished drawing made by the writer in 1953.

(Figure 3.30) Typical elements of the fauna of the boundstone bodies in reef dolomite in Humbledon Hill Quarry, comprising the pinnate bryozoan *Fenestella retiformis* and the pedunculate brachiopods *Dielasma elongatum* and *Pterospirifer alatus.* Field of view about 67 x 100 mm. (Photo: N.T.J. Hollingworth.)

(Figure 3.31) Tunstall Hills (north and south), showing the position of the main exposures and features of geological interest.

(Figure 3.32) The main quarry face on the north side of the more southerly of Maiden Paps, Tunstall Hills. Most of the rock is brown bryozoan boundstone, locally with profuse encrustations. At least two of the tension gashes have partial central voids. Simplified from a sketch by Aplin (1985, p. 378).

(Figure 3.33) Laminar to botryoidal (?algal) limestone (possibly dedolomite) lining the footwall of a steeply inclined fissure in boundstone of the shelf-edge reef of the Ford Formation on the north side of the main exposure at Tunstall Hills (north). Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.34) Relationships of reef and off-reef (including post-reef) strata at the south-east end of Tunstall Hills and in the Ryhope Cutting (diagrammatic). See (Figure 3.31) for the location of the various exposures.

(Figure 3.35) Dense ?algal encrustations in reef boundstone in the main old quarry (d) at the south-east end of Tunstall Hills. Delicate bryozoan frame elements form less than 5% of the rock. Coin: 26 mm across. (Photo: D.B. Smith.)

(Figure 3.36) Gilleylaw Plantation Quarry and its immediate surroundings, showing the position of the main features of geological interest.

(Figure 3.37) Sketch of patch-reef in the east and south faces of Gilleylaw Plantation Quarry, incorporating some details of strata formerly exposed, but not now visible.

(Figure 3.38) Contemporaneous minor mound-like structure in backreef dolomite of the Ford Formation in the south face of Gilleylaw Plantation Quarry. Bar: 0.32 m. (Photo: D.B. Smith.)

(Figure 3.39) The Seaham GCR site, showing the position of the main features of geological interest.

(Figure 3.40) Strong contortions in the lower part of the Seaham Residue at the type locality, showing detached blocks of cross-laminated ooid grainstone (middle) and the lowest part of the bedded ooid grainstones that here form a median unit in the Residue. Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.41) Typical limestones of the Seaham Formation immediately north of the harbour at the type locality, showing massive secondary spherulitic limestone overlying unevenly, mainly thin-bedded, *Ca[cinema* bivalve calcite mudstones and wackestones with shallow mega-ripples and cut-and-fill structures. Note the minor step-fault at top right. Bar: 0.32 m. (Photo: D.B. Smith.)

(Figure 3.42) Location of Stony Cut, Cold Hesledon.

(Figure 3.43) Laminar ?algal bindstone sheets with high primary east-northeastwards dip, in reef boundstone of the Ford Formation near the north-east end of Stony Cut, Cold Hesledon. The sheets are thought to mark the temporary position of the upper part of the reef foreslope and grade upwards into the reef-crest and reef-flat dolomite. Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.44) High Moorsley Quarry and its immediate surroundings, showing the main features of geological interest.

(Figure 3.45) Crumpled bedding in the lower beds of the Raisby Formation near the north end of the east face of High Moorsley Quarry, with evidence of contemporaneous truncation at the top of the disrupted beds. Hammer (middle top): 0.33 m. (Photo: D.B. Smith.)

(Figure 3.46) Hawthorn Quarry, showing the location of the main features of geological interest.

(Figure 3.47) Section across Hawthorn Quarry, showing the relationships of the main geological features. The line of section is shown in (Figure 3.46).

(Figure 3.48) Small columnar stromatolites just above the boulder conglomerate of the Hesleden Dene Stromatolite 13iostrome near the middle of the south face of Hawthorn Quarry. Bar: 0.32 m. (Photo: D.B. Smith.)

(Figure 3.49) Slight concentrations of manganese dioxide coating a bedding plane in the 'Crinkly Beel' near tl!e base of the Hesleclen Dene Stromatolite Biostrome near the miclclle of the south face of Hawthorn Quarry. Note the asymmetry of the ?algal growth-forms, indicating water flow from the right. Coin: 20 mm across. (Photo: D.B. Smith.)

(Figure 3.50) Location of Horden Quarry and the main features of geological interest.

(Figure 3.51) Sketch of the north-west face of Horden Quarry as seen in 1954 and later (parts of the face are now covered).

(Figure 3.52) A reef crest in the north-west face of Borden Quarry (for position see (Figure 3.50) and (Figure 3.51)). Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.53) South side of old quarry (now filled) on the east side of Townfield Hill, Easington Colliery, showing the crest and stromatolitic seaward face of the shelf-edge reef, and succeeding residue and collapse-breccias. This quarry was recommended for SSSI designation but was filled before action could be taken; it is included here for the purposes of comparison.

(Figure 3.54) Blackballs Rocks GCR site and its environs, showing the location of the main geological features.

(Figure 3.55) Geological strata in the cliffs of the Blackhalls Rocks GCR site (diagrammatic). The laminites and conglomerate together comprise the Hesleden Dene Stromatolite Biostrome. Slightly modified from Smith (1984, p. 24).

(Figure 3.56) Typical example of the boulder conglomerate at the base of the biostrome, comprising clasts mainly of dolomite boundstone from the reef of the Ford Formation, in a matrix of smaller, but otherwise similar, fragments (many of which are coated), algal debris, scarce bioclasts and some laminar cavity-fill and lining. Coastal cliffs near north end of Blackhalls Rocks, c. 200 m north-west of Gin Cave. Bar: 0.16 m. (Photo: D.B. Smith.)

(Figure 3.57) Laminar algal bindstone of the 'Crinkly Bed' at the base of the Hesleden Dene Stromatolite Biostrome. Coastal cliffs *c.* 60 m south of Gin Cave (see (Figure 3.54)). Coin: 26 mm across. (Photo: D.B. Smith.)

(Figure 3.58) Thin section of multi-coated pisoids from steep-sided pockets in the upper part of the 'Crinkly Bed' in coastal cliffs near Gin Cave, Blackhalls Rocks. Interstices and the core of some formerly leached pisoids are occupied by equant dolomite microspar, but many of the pisoids are nucleated on to abraded dolomite clasts including portions of earlier fractured pisoids. Bar: 8 mm. (Photo: D. Kitson.)

(Figure 3.59) Broad dolomite stromatolite domes in about the middle of the Hesleden Dene Stromatolite Biostrome, on the foreshore near Green Stairs, Blackhalls Rocks. Hammer: 0.33 m. (Photo: D.B. Smith.)

(Figure 3.60) Trimdon Grange Quarry and its immediate surroundings, showing the main features of geological interest.

(Figure 3.61) Raisby Quarries: the north face in the cast is the type locality of the Raisby Formation (Smith *et al.*, 1986).

(Figure 3.62) Trace fossils on uneven bedding plane low in the Raisby Formation at the type locality. Coin: 26 mm across. (Photo: T.H. Pettigrew.)

(Figure 4.1) The distribution of Permian marine rocks in the Yorkshire Province, showing the location of Permian marine GCR sites: 1, River Ure Cliff; 2, Quarry Moor; 3, Newsome Bridge Quarry; 4, Micklefield Quarry; 5, South Elmsall Quarry; 6, Bilham Quarry; 7, Cadeby Quarry; 8, Ashfield Brick-clay Pit; 9, New Edlington Brick-clay Pits; 10, Wood Lee Common, Maltby.

(Figure 4.2) Approximate stratigraphical position of marine Permian GCR sites in the Yorkshire Province of north-east England (diagrammatic). Some sites cannot be shown on this line of section and have been omitted.

(Figure 4.3) The River Ure cliff section and its environs, showing the position of the main features of geological interest. Modified from part of fig. 3 of James *et al.* (1981).

(Figure 4.4) Sketch (top left to bottom right) of the main face of the River Ure Cliff, showing the principal geological features; slightly modified from Forbes (1958, fig. 2). Gypsum lies mainly at the base of the cliff except at the southern end. Total length of section shown is about 220 m, height about 7.5 m.

(Figure 4.5) Gypsum, possibly equivalent to the Hayton Anhydrite, forming most of the river cliff at the southern end of the main rock section at Ripon Parks. Note the abundant sub-concordant sheet-veins of fibrous gypsum (white) in the upper part of the section. (Photo: A.H. Cooper.)

(Figure 4.6) Sharp fold in mainly siliciclastic strata of the Edlington Formation with bedded gypsum (?=Hayton Anhydrite) at the base, and with many sub-concordant sheet-veins of fibrous gypsum (white). The fold is still recognizable at the southern end of the middle sector in Forbes' drawing of 1958 (Figure 4.4). The cliff is about 6 m high at this point. (Photo: A.H. Cooper.)

(Figure 4.7) Quarry Moor, Ripon, showing the location of the preserved face.

(Figure 4.8) The sequence of late Permian strata at Quarry Moor. Most of the section lies in the uppermost part of the Sprotbrough Member of the Cadeby Formation, but some of the higher beds may be part of the overlying Edlington Formation.

(Figure 4.9) Sketches of late Permian strata at the west side of Quarry Moor. (A) In private property immediately south of the preserved face. (B) In the preserved face. Numbers refer to beds depicted in (Figure 4.8). flow, volume changes resulting from the formation, dehydration, hydration and dissolution of evaporites (mainly sulphates but possibly including halite) and, in some examples, to early lithification and expansion (Smith, 1976). The 'tepee'-like structures (Figure 4.10) comprise asymmetrical domes or anticlines about 1–1.5 m across and 0.5 m high in which competent (i.e. already lithified) carbonate beds have been fractured and thrust by lateral expansion; interbedded softer strata have been folded and squeezed-out by this process which, judging from onlap of overlying beds against the sides of the structures, and erosion at the top, must have been contemporaneous.

(Figure 4.10) (A) Non-tectonic 'tepee'-like anticline in beds 2, 3 and 4 of the sequence at Quarry Moor, with a 0.3 m shortening shown by overthrust near the base and a minor fault near the top. Note the almost level bedding and apparent onlap in the uppermost strata, implying contemporaneous formation and burial. For position see (Figure 4.9)(B). (B) Detail of ?contemporaneous overthrust at bottom right of (A).

(Figure 4.11) Newsome Bridge Quarry and its environs, showing the position of the main features of geological interest.

(Figure 4.12) Sketch of the main faces of Newsome Bridge Quarry showing the inferred bryozoan-algal patch-reef centred on an eminence in the Carboniferous–Permian unconformity here cut onto Upper Plompton Grit.

(Figure 4.13) East face of the Newsome Bridge Quarry, showing the inferred patch-reef of the Wetherby Member of the Cadeby Formation and equivalent bedded strata, resting unconformably on Upper Carboniferous strata. For scale and interpretation see (Figure 4.12). (Photo: Total Oil Company.)

(Figure 4.14) Position of Micklefield Quarry GCR site.

(Figure 4.15) Section of the Hampole Beds and other strata at Micklefield Quarry. Abbreviations signify parts of the typical Hampole Beds sequence: HD, Hampole Discontinuity; LD, lower dolomite; MM, middle mudstone; UD, upper dolomite; UM, upper mudstone. The lower mudstone is absent. The Wetherby Member–Sprotbrough Member contact is taken at the top of the lower dolomite.

(Figure 4.16) Sketch of the southern part of the main face at Micklefield Quarry, showing the cross-stratification in the Sprotbrough Member of the Cadeby Formation and the position of the Hampole Beds. Slightly modified from Kaldi (1980, fig. 3.3).

(Figure 4.17) The Hampole Discontinuity (arrowed) and adjoining strata, as seen in 1967 before filling of the lower part of Micklefield Quarry. The white layer is the lower dolomite of the Hampole Beds and the grassy cleft conceals the less resistant upper parts of the Hampole Beds. (Photo: D.B. Smith.)

(Figure 4.18) South Elmsall Quarry, showing the position of the GCR site.

(Figure 4.19) Cross-section of an algal-stromatolite reef in peloid grainstones of the Wetherby Member of the Cadeby Formation, South Elmsall Quarry. The core of the reef is of massive bryozoan boundstone and is overlain by more extensive stromatolites that pass laterally NNW into sparingly skeletal peloid grainstone. The stromatolites extend at least 30 m to the right of the area depicted. Note: lowest strata depicted are now covered. Slightly modified from Smith (1981b, fig. 12).

(Figure 4.20) Complexly domed dolomitized algal-stromatolites discordantly overlying thin-bedded dolomite peloid grainstones. Central part of east face of South Elmsall Quarry. Bar: 1 m. (Photo: D.B. Smith.)

(Figure 4.21) The preserved area of Bilham Quarry and its environs.

(Figure 4.22) Cadeby Quarry and its environs, showing the location of the main features of geological interest.

(Figure 4.23) Diagrammatic sketch showing the relationships of the stratigraphical units and main rock types in the north-west face of Cadeby Quarry. The face is about 22 m high. 1, Wetherby Member; 2, Sprotbrough Member; 3, Hampole Beds, resting on the Hampole Discontinuity.

(Figure 4.24) Ashfield Brick-clay Pit, Conisbrough, and its environs, showing the location of the main features of geological interest.

(Figure 4.25) Sandstone-filled desiccation cracks at the type locality of the Edlington Formation. Coin: 30 mm across. (Photo: D.B. Smith.) (Figure 4.26) Casts of halite crystals on the underside of an argillaceous siltstone bed at the type locality of the Edlington Formation. The large cast is about 10 mm across. (Photo: D.B. Smith.)

(Figure 4.26) Casts of halite crystals on the underside of an argillaceous siltstone bed at the type locality of the Edlington Formation. The large cast is about 10 mm across. (Photo: D.B. Smith.)

(Figure 4.27) Wood Lee Common GCR site, Maltby, South Yorkshire. Most of the reef 'tors' are in the central and northern parts of the designated area.

(Figure 4.28) Reef 'tor' in the central part of Wood Lee Common GCR site, showing the characteristic subdivision into 'saccoliths'. Hammer (centre-right): 0.33 m. (Photo: D.B. Smith.)

Tables

((Table 1.1) Classification and correlation of Permian marine and associated strata in north-west England and adjoining areas, showing the main depositional cycles. The Manchester Marl of south Lancashire and north Cheshire is a general correlative of the St Bees Evaporites but precise correlation is uncertain. Based on Smith (1992, table 9.2). Cycles after Jackson *et al.* (1987).

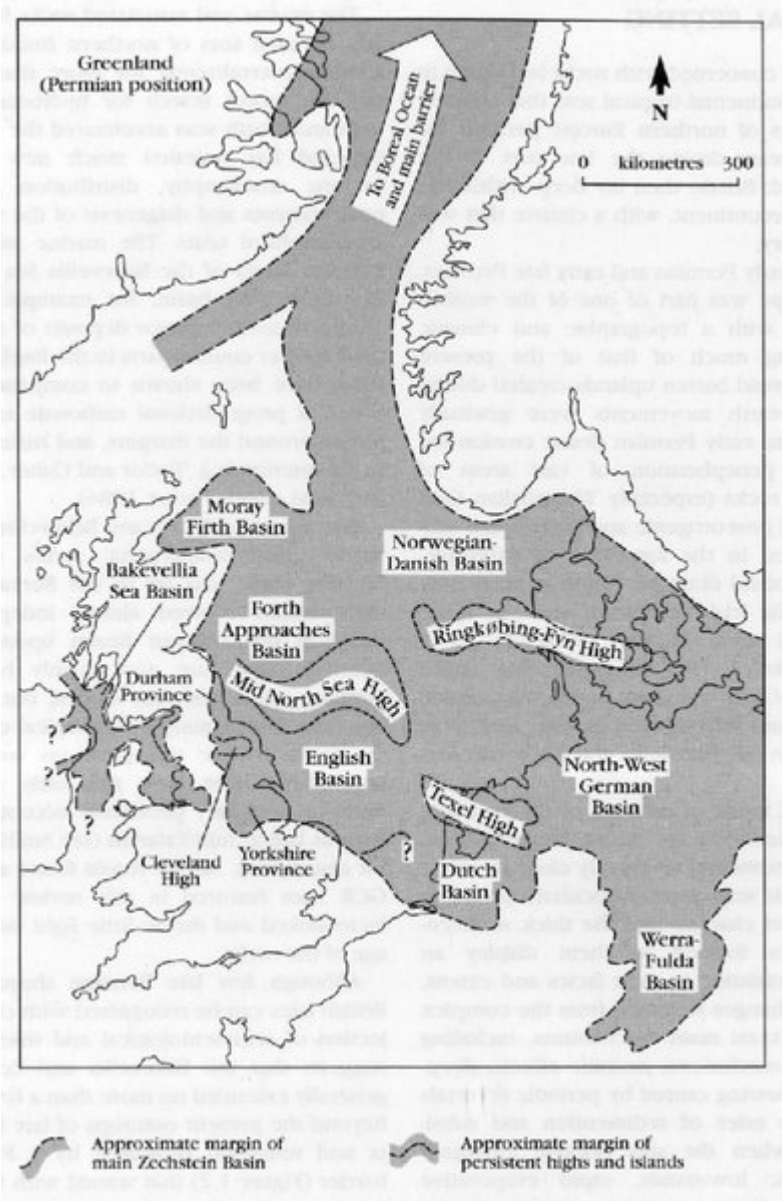
((Table 1.2) The main stratigraphical units in the marine Permian sequence of the two provinces of north-east England, showing the nomenclature used here and (in brackets) equivalent traditional names. Based on Smith *et al.* (1986, table 1). Note that the Edlington Formation, in parts of the Yorkshire Province where the Kirkham Abbey Formation is absent, extends downwards to the top of the Sprotbrough Member of the Cadeby Formation (see also (Table 1.3) and may include an equivalent of the Hayton Anhydrite.

((Table 1.3) Classification and correlation of Permian marine and associated strata in north-east England, showing the main depositional cycles and a representative sequence from Holland and northern Germany. After Smith (1989, table 1).

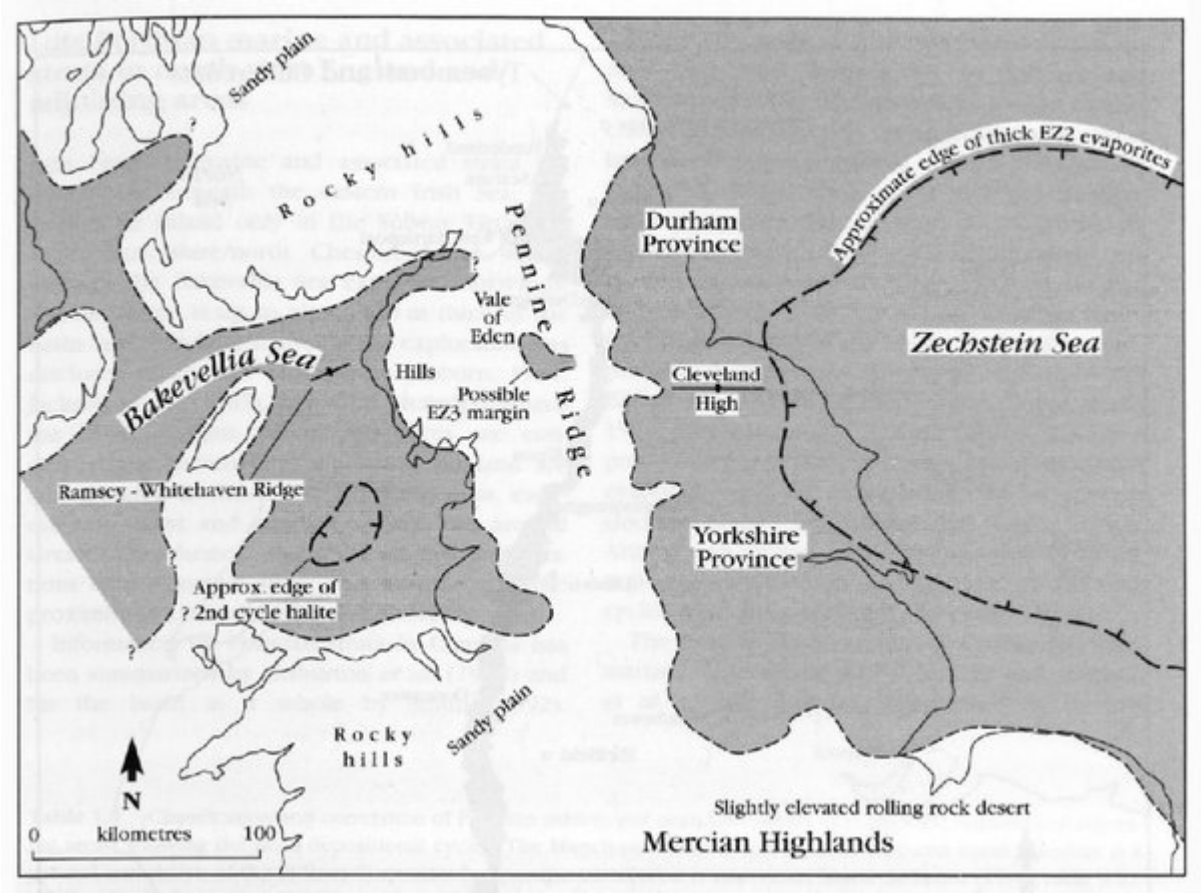
((Table 3.1) Main geological features of the marine Permian GCR sites in the Durham Province of the English Zechstein

((Table 4.1) Main geological features of the marine Permian GCR sites in the Yorkshire Province of the English Zechstein.

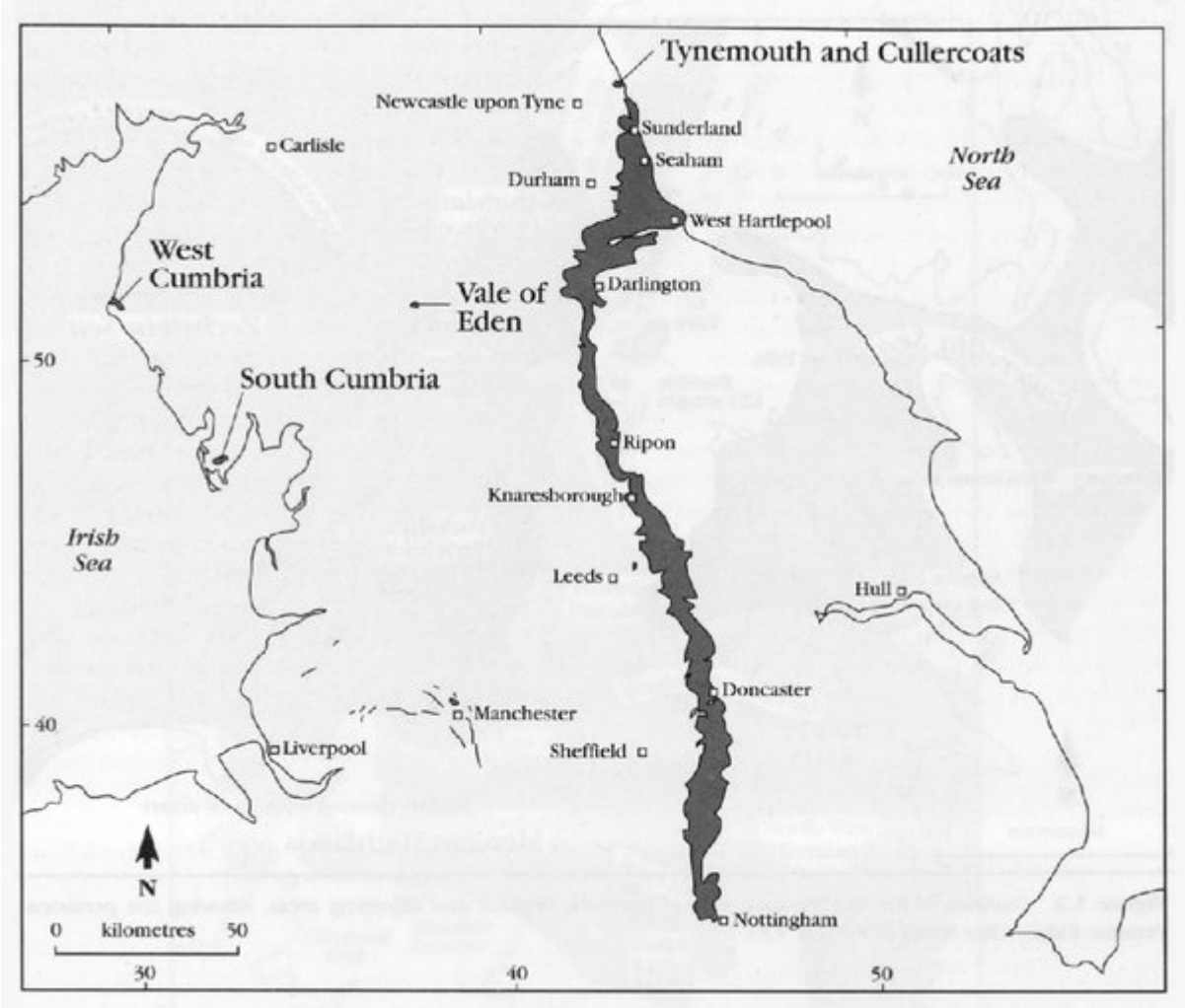
References



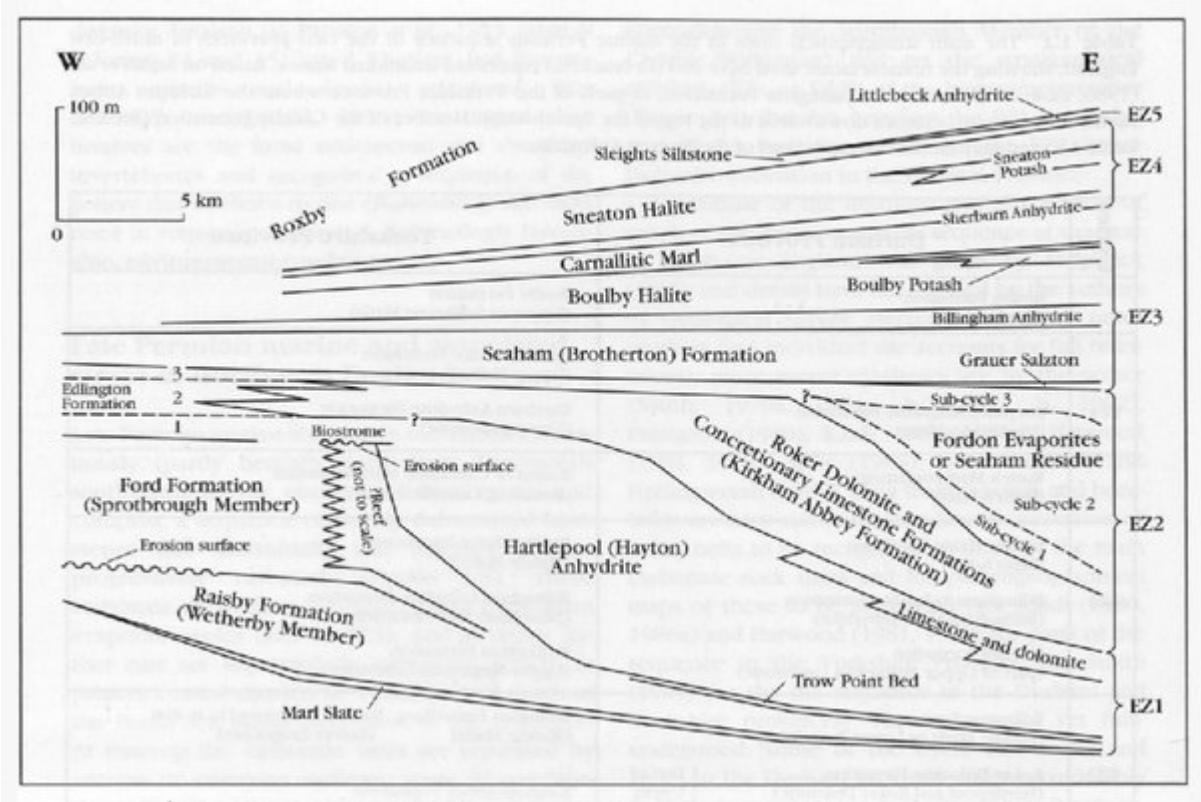
(Figure 1.1) The Zechstein Sea and its environs. After Smith (1980a, fig. 1).



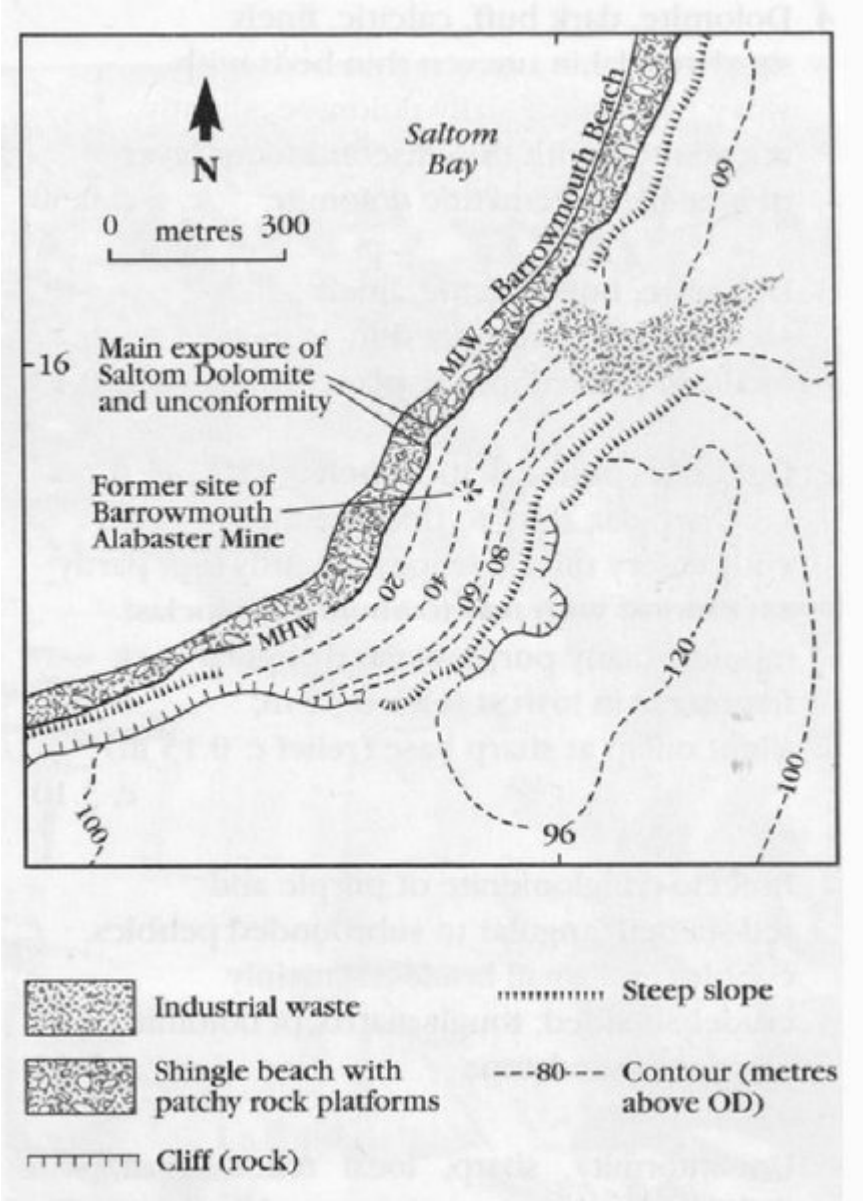
(Figure 1.2) Outlines of the late Permian seas of northern England and adjoining areas, showing the persistent Pennine Ridge. After Smith (1992, fig. 9.8).



(Figure 1.3) Outcrops of marine Permian strata in mainland Britain.

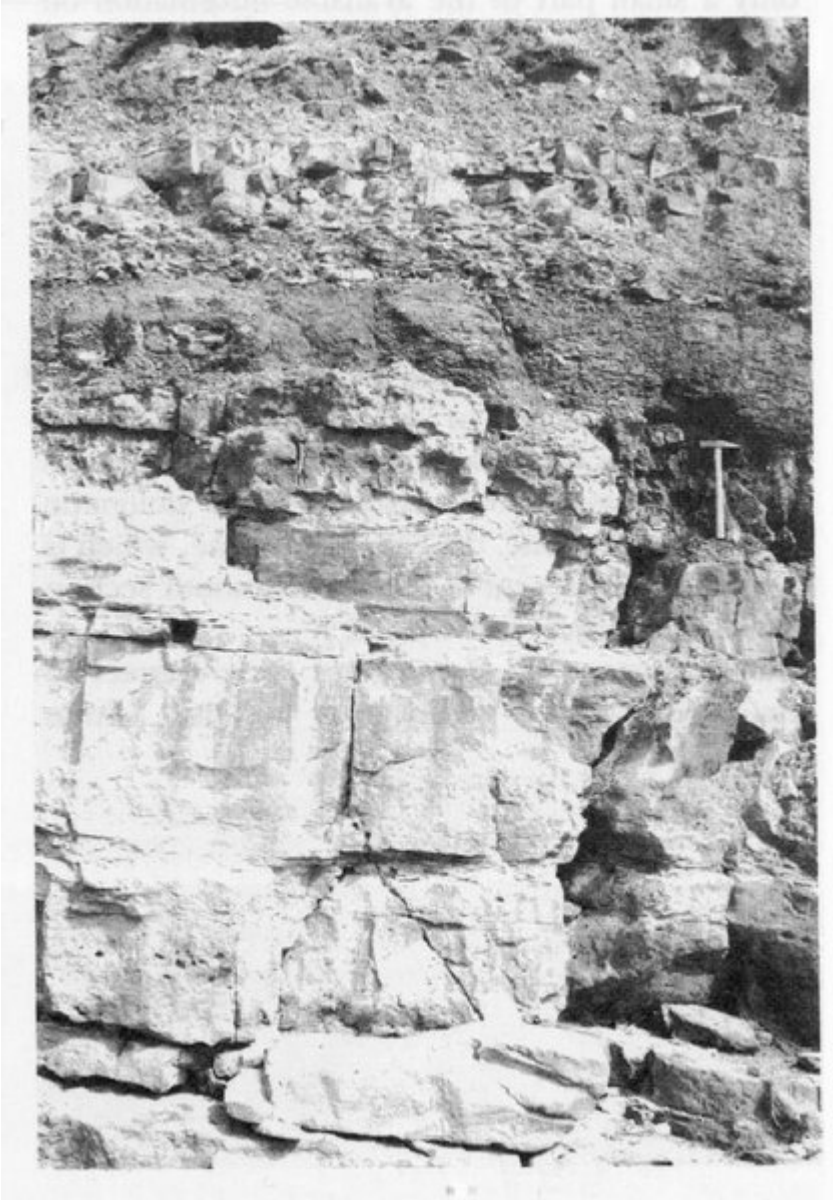


(Figure 1.4) Late Permian (Zechstein) lithostratigraphical units in north-east England; names as in the Durham Province with Yorkshire Province names (where different) in brackets. In Yorkshire, the Wetherby Member and Sprotbrough Member together comprise the Cadeby Formation. The erosion surface shown between the Wetherby and Sprotbrough members is the Hampole Discontinuity which lies up to 3 m below the top of the Wetherby Member; it has not been recorded in the Durham Province. Slightly modified from Smith (1989, fig. 1).

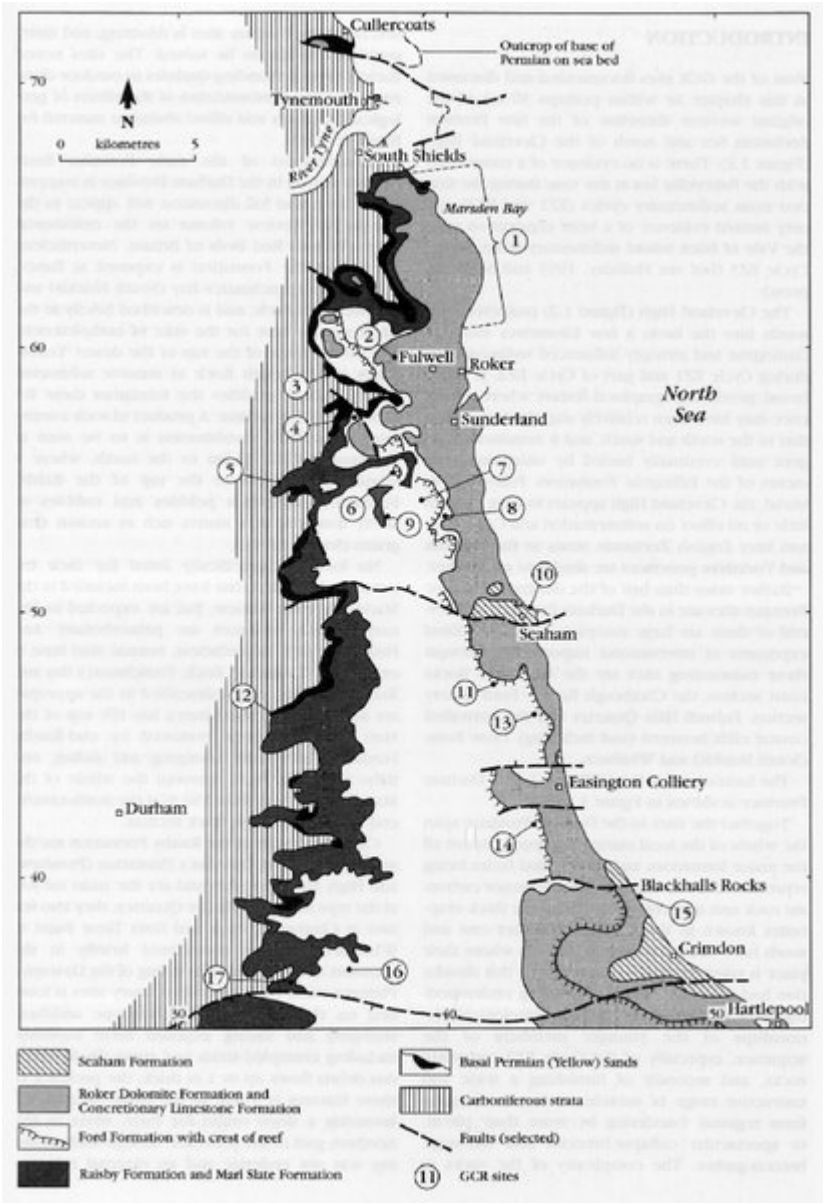


(Figure 2.1) The Barrowmouth Beach GCR site, Saltom Bay, Whitehaven, showing the position of the main features of geological interest.

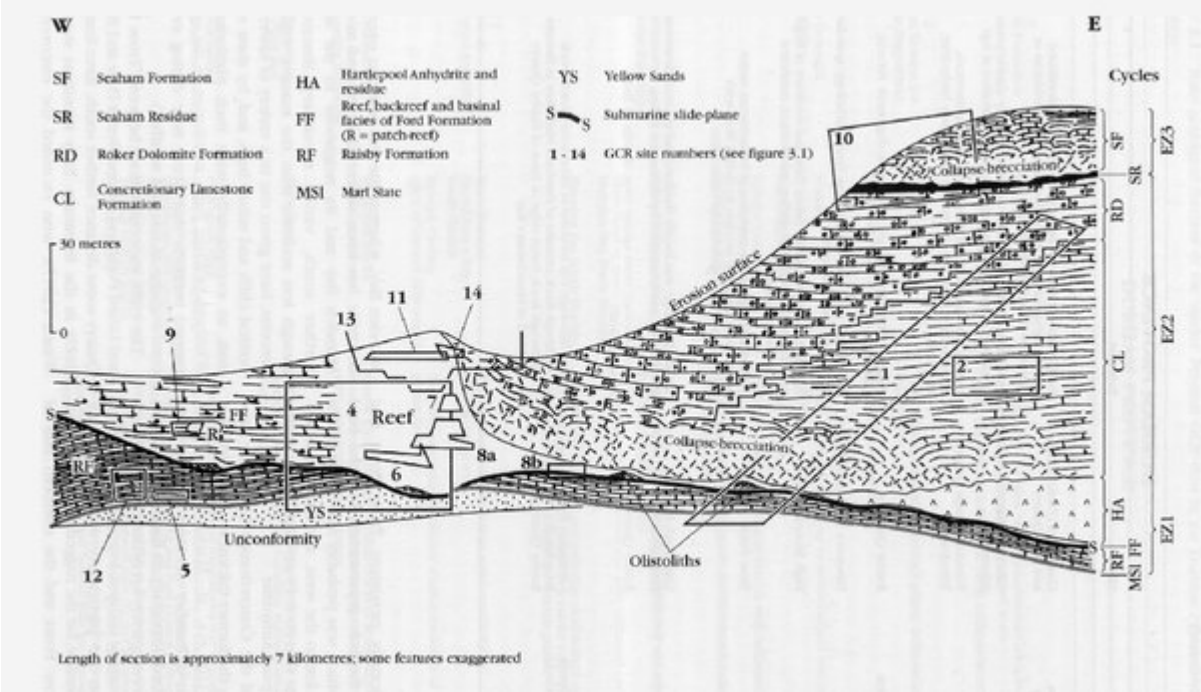
(Figure 2.2) Lower beds of the Permian sequence at the south-west end of the Barrowmouth Beach (Saltom Bay) section, showing Saltom Dolomite resting on the slightly uneven surface of the Brockram or Basal Breccia. Hammer: 0.33 m. (Photo: D.B. Smith.)



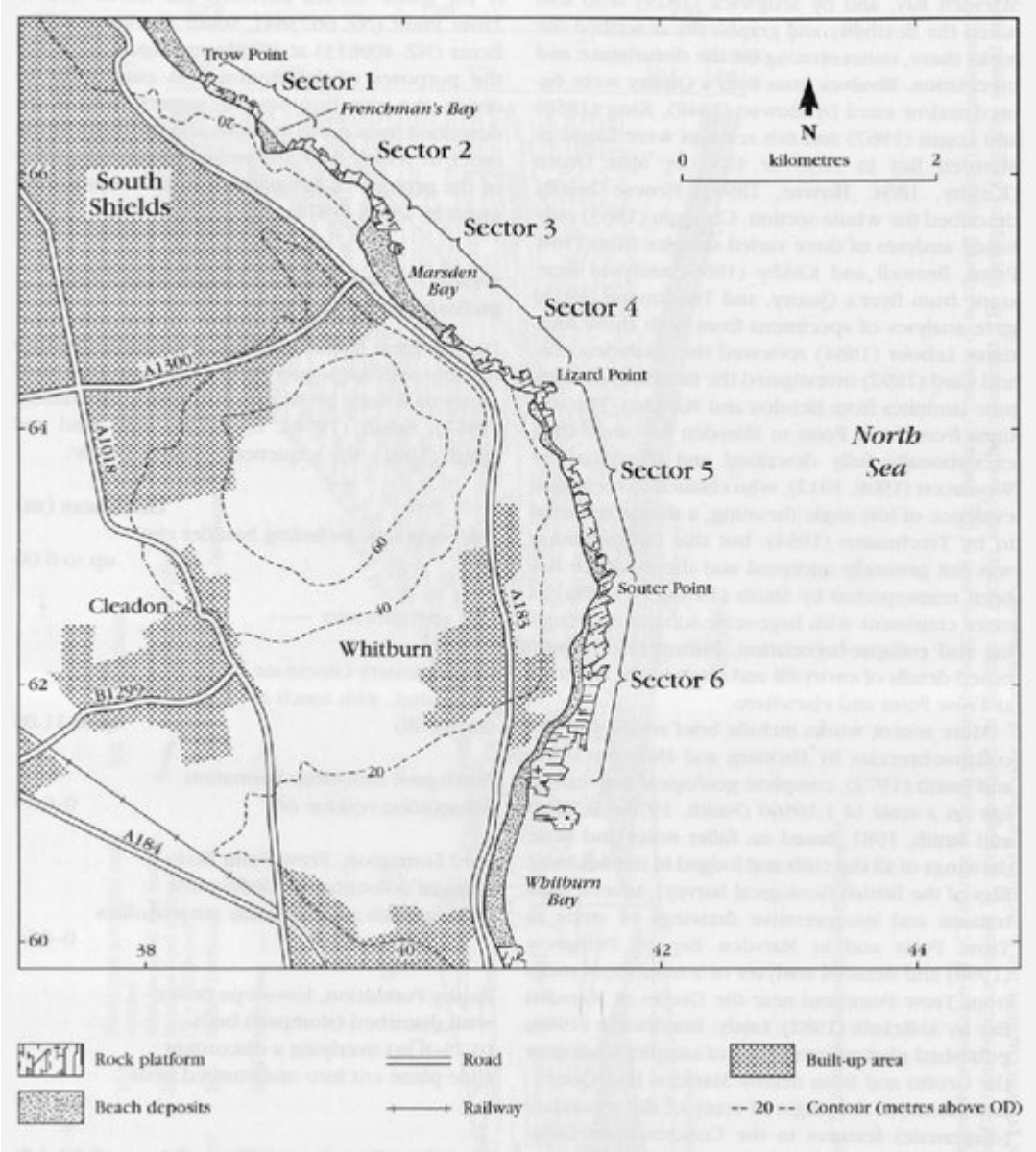
(Figure 2.3) Higher beds of the Permian sequence in Barrowmouth Bay, a few metres southwest of the view in (Figure 2.2). The line of small cavities in dolomite near the base of this photograph is also visible near the top of the section in Figure 2.2. Most or all of the beds here form part of the Saltom Dolomite, but it is possible that bed 6 may be part or all of the Fleswick Dolomite. Hammer: 0.33 m. (Photo: D.B. Smith.)



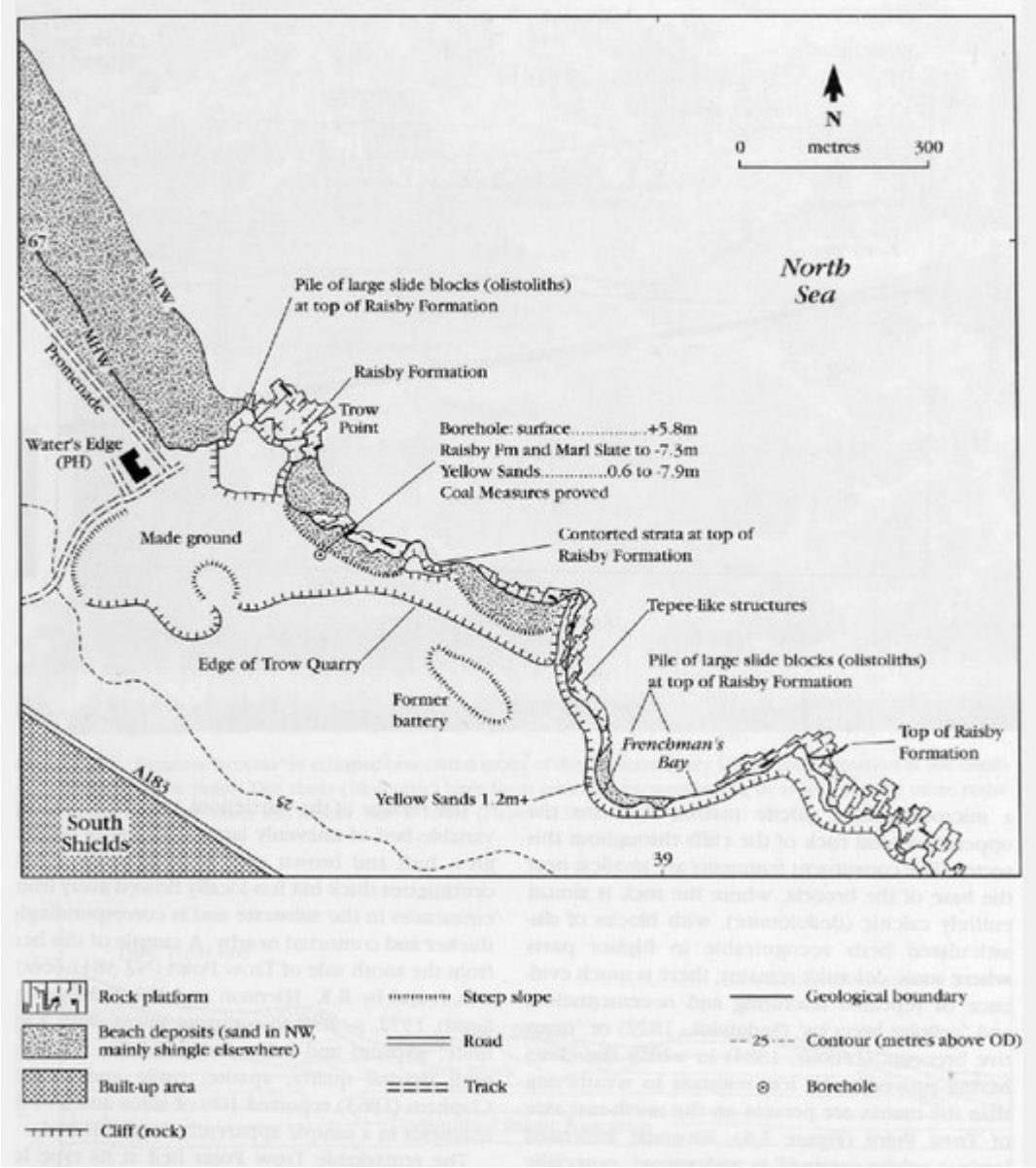
(Figure 3.1) The distribution of Permian marine rocks in the Durham Province, showing the location of Permian marine GCR sites: 1, Trow Point to Whitburn Bay; 2, Fulwell Hills Quarries; 3, Hylton Castle Cutting; 4, Claxheugh Rock, Cutting and Ford Quarry; 5, Dawson's Plantation Quarry, Penshaw; 6, Humbledon Hill Quarry; 7, Tunstall Hills (north); 8, Tunstall Hills (south) and Ryhope Cutting; 9, Gilleylaw Plantation Quarry; 10, Seaham; 11, Stony Cut, Cold Hesledon; 12, High Moorsley Quarry; 13, Hawthorn Quarry; 14, Horden Quarry; 15, Blackhalls Rocks; 16, Trimdon Grange Quarry; 17, Raisby Quarries. The map is based on Smith (1980b, fig. 9).



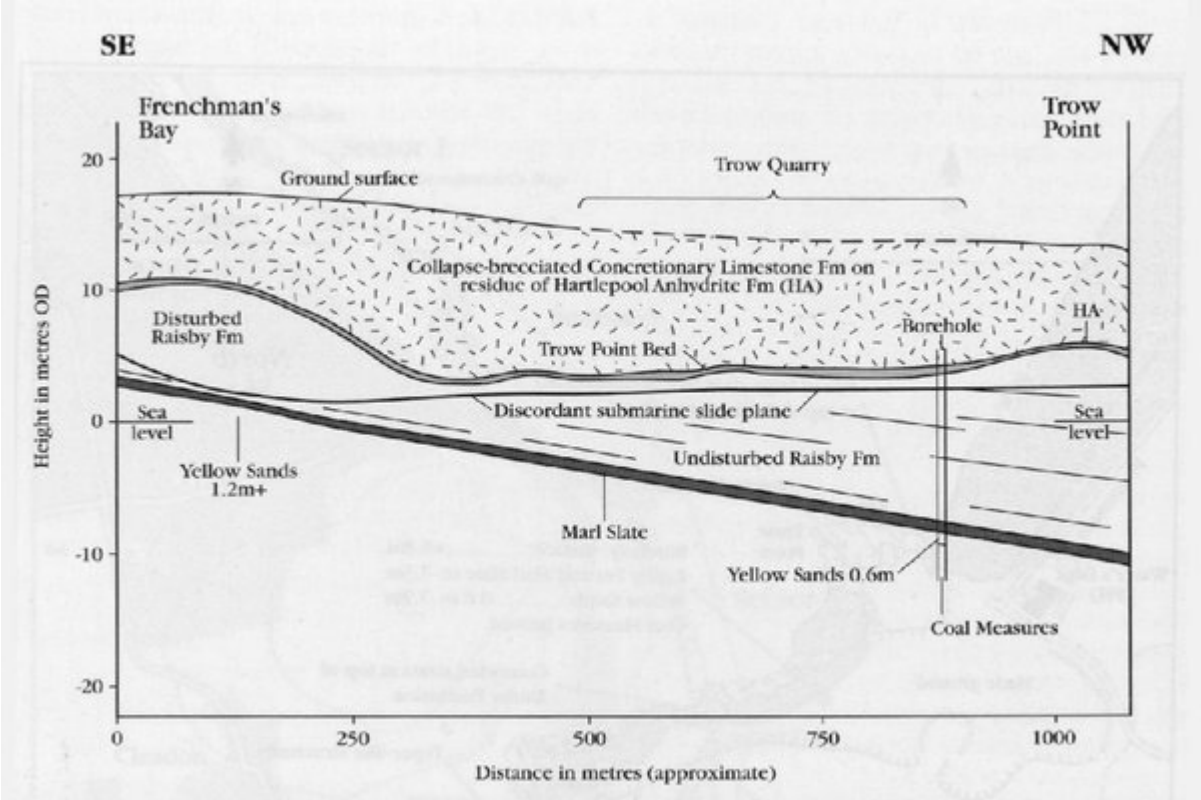
(Figure 3.2) Approximate stratigraphical position of GCR marine Permian sites in the northern part of the Durham Province of north-east England (diagrammatic). Some sites in the southern part of the Durham Province cannot be accommodated on this line of section and have been omitted. The Hartlepool Anhydrite would not normally be present so close to the present coastline but is included for the sake of completeness.



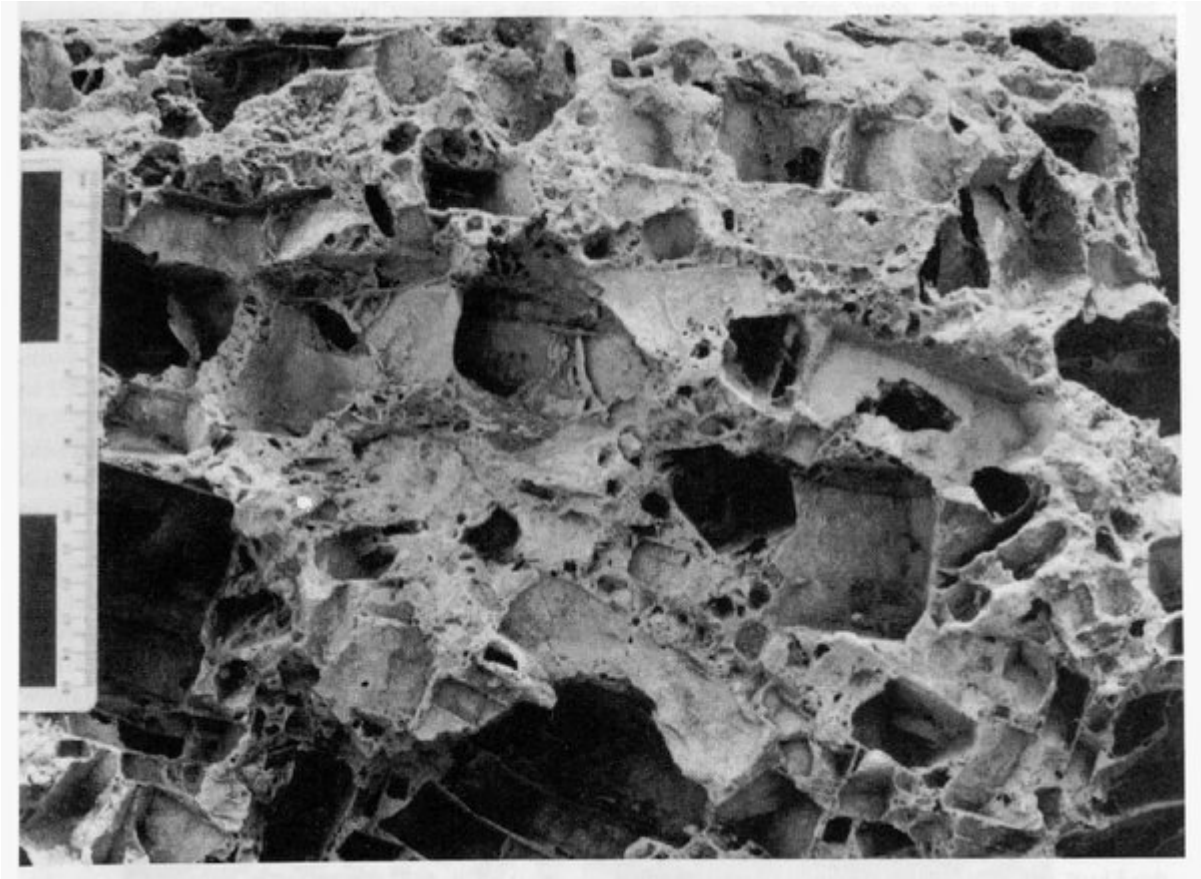
(Figure 3.3) Location of the Trow Point to Whitburn Bay GCR site, showing the sectors described in the text.



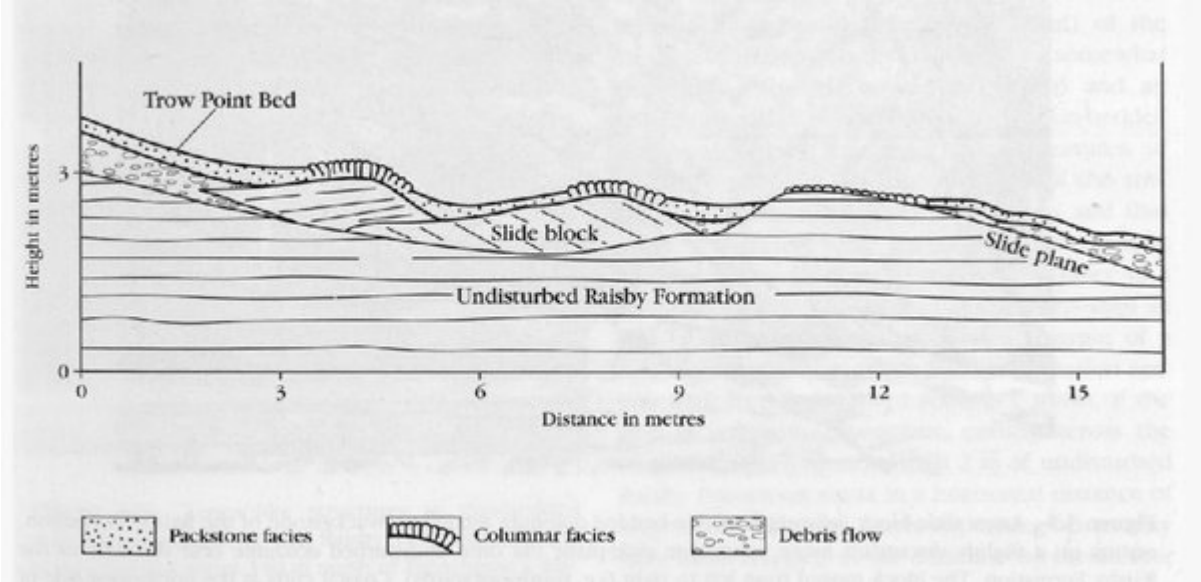
(Figure 3.4) The Trow Point to Frenchman's Bay sector, showing the main features of geological interest. In general, strata above high-tide level are collapse-brecciated rocks of the Concretionary Limestone Formation and those below are of the Raisby Formation.



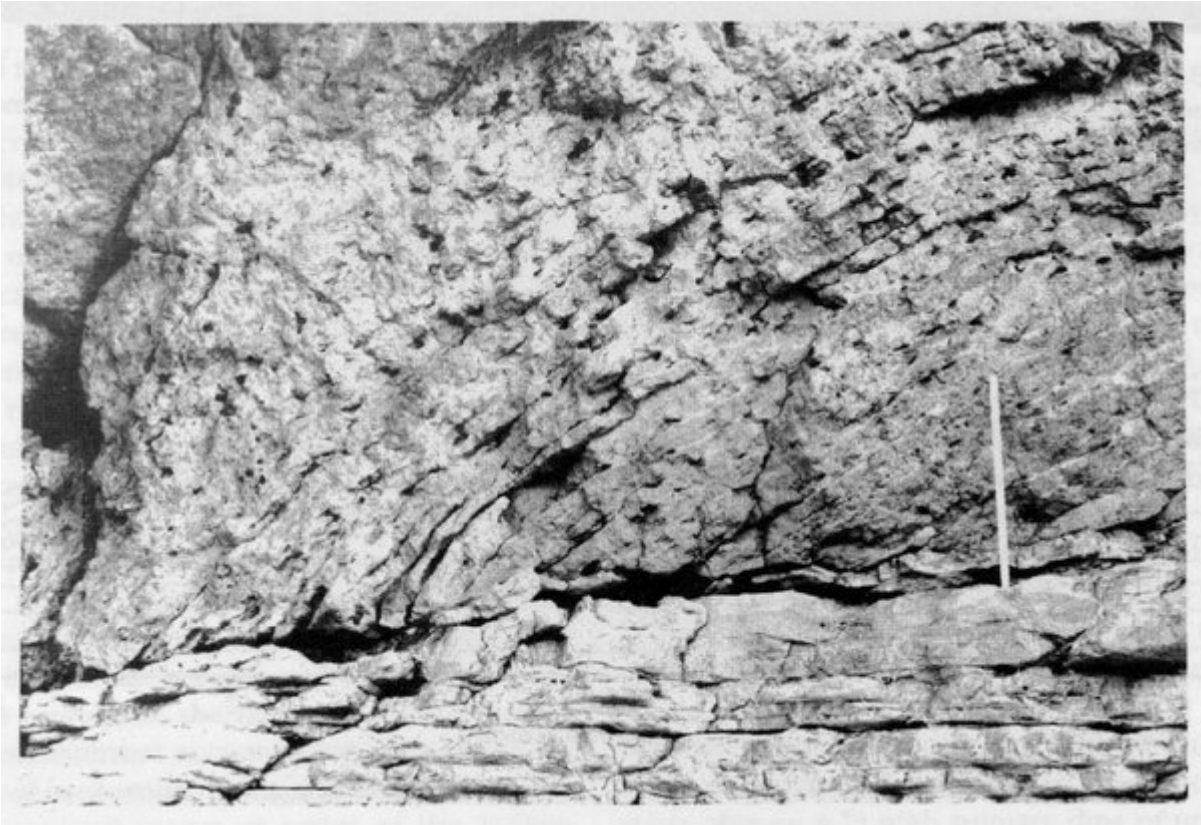
(Figure 3.5) Stratigraphical relationships of Permian rock units in the Trow Point to Frenchman's Bay sector, as seen from the north-east.



(Figure 3.6) 'Negative breccia' in collapse-brecciated strata of the Concretionary Limestone Formation at the northeast corner of Trow Point. The clasts (?dolomite) have been removed by weathering so as to leave the more resistant network of calcite veins and matrix. Bar: 0.16 m. (Photo: D.B. Smith.)

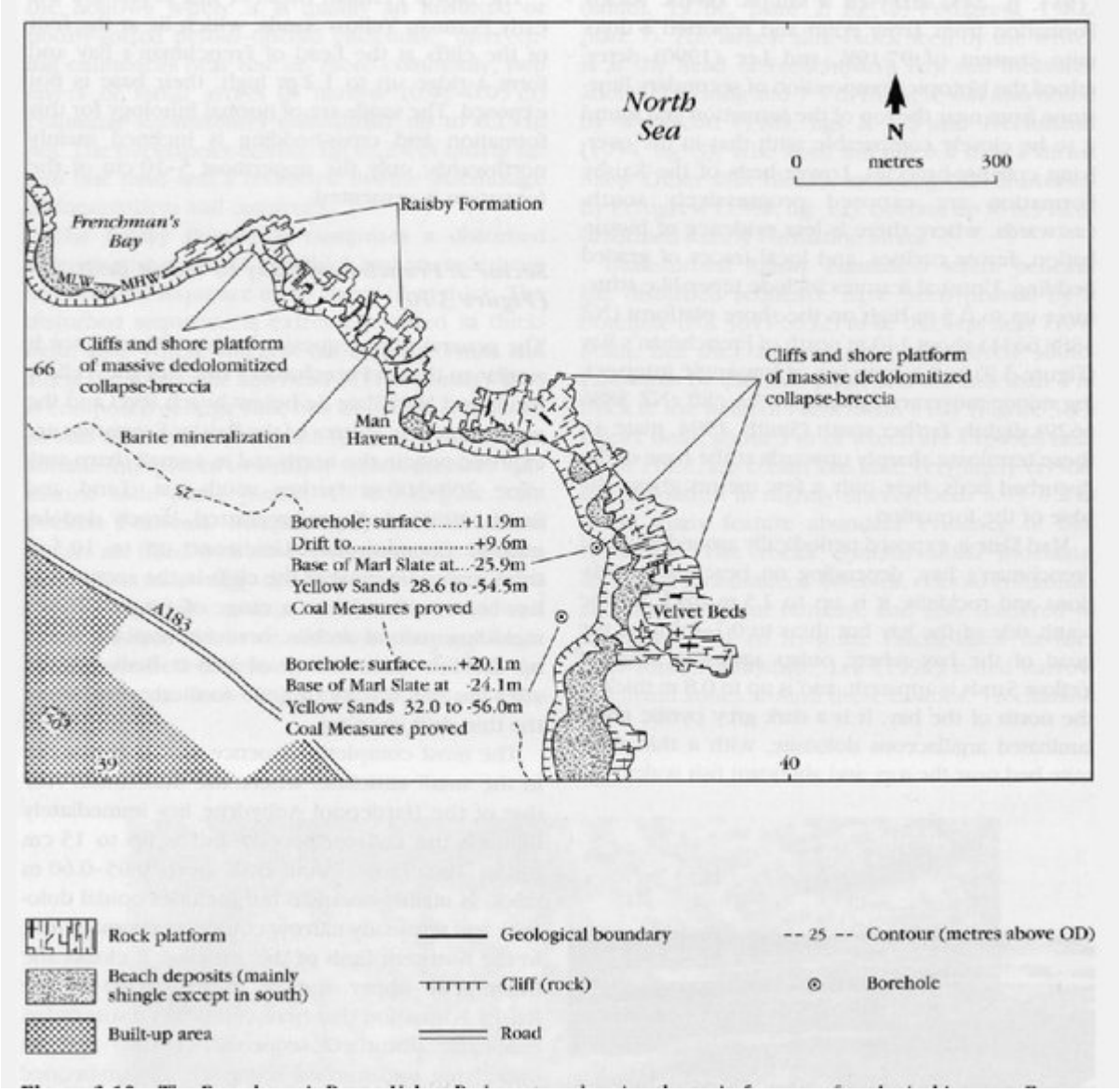


(Figure 3.7) Mutual relationships of facies of the Trow Point Bed at its type locality. After Smith (1986, fig. 3).

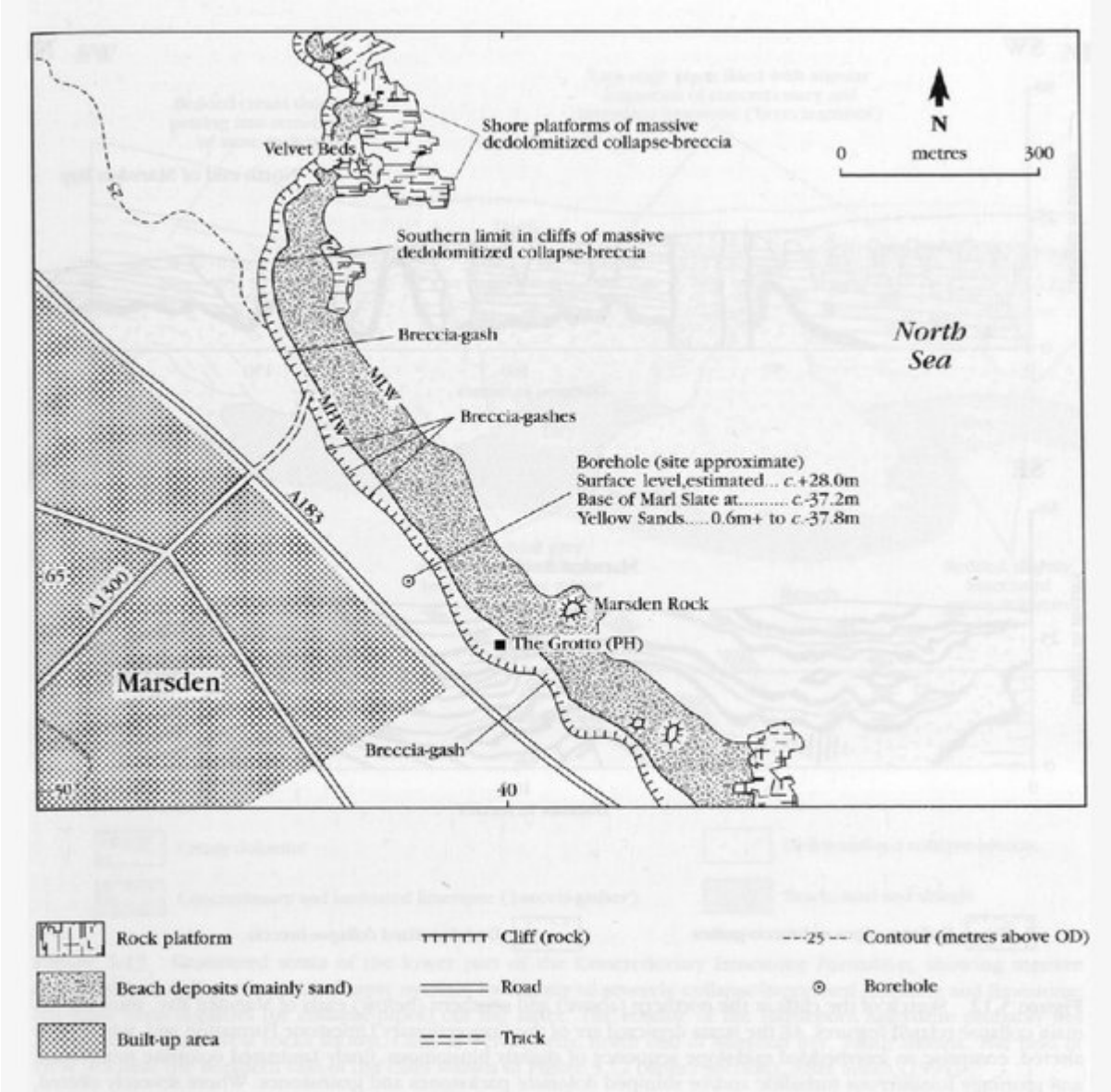


(Figure 3.8) Large slide-block (olistolith) of thin-bedded dolomite mudstone/wackestone of the Raisby Formation, resting on a slightly discordant major submarine slide-plane cut onto undisturbed dolomite near the base of the Raisby Formation. The block moved from left to right (i.e. north-eastwards). Coastal cliffs at the north-west side of Frenchman's Bay, South Shields. Bar: 1 m. (Photo: D.B. Smith.)

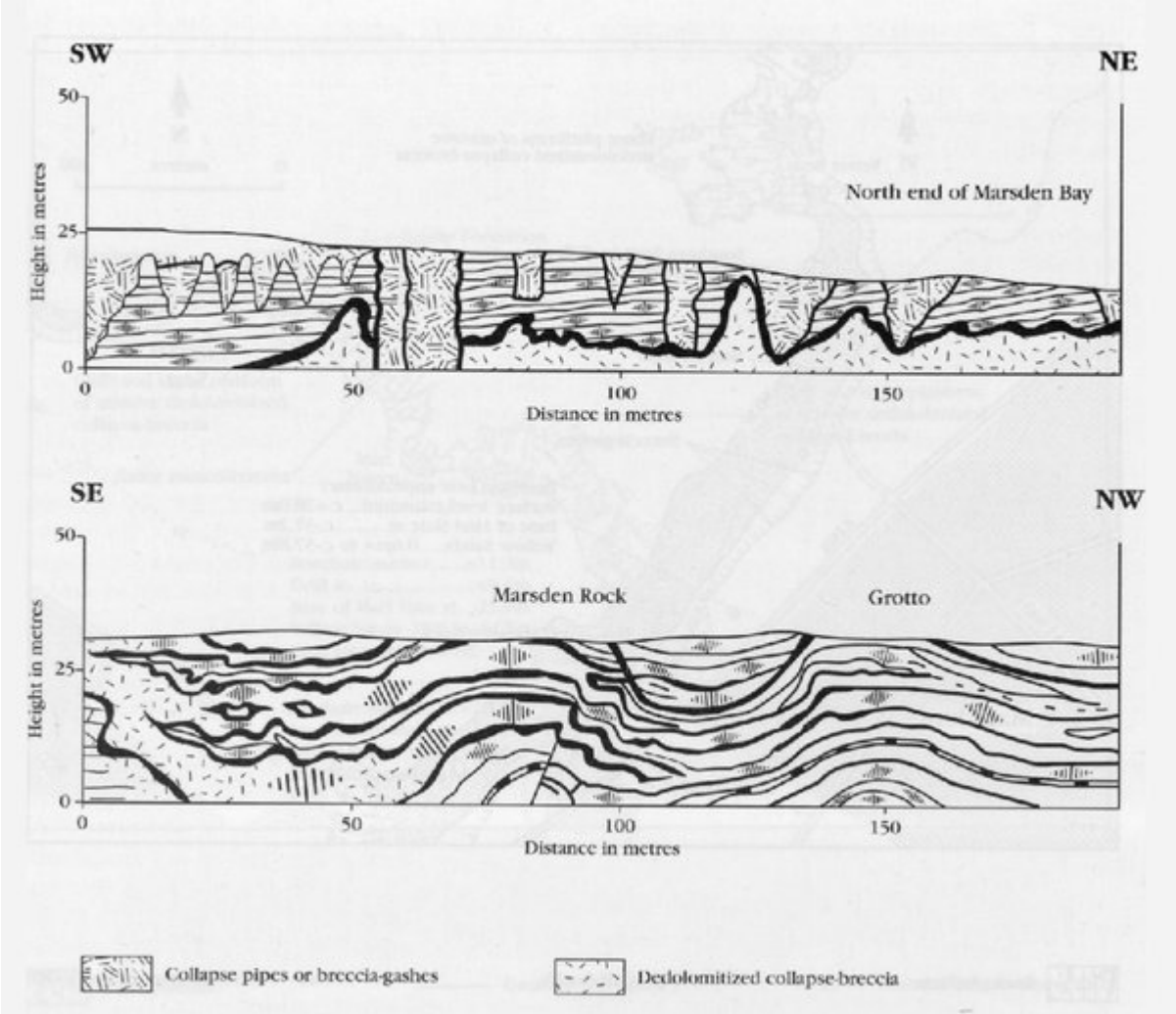
(Figure 3.9) 'Tepee'-like structures in thin-bedded dolomite mudstone of the Raisby Formation on the shore platform about 140 m north of Frenchman's Bay, South Shields. Hammer: 0.33 m. (Photo: D.B. Smith.)



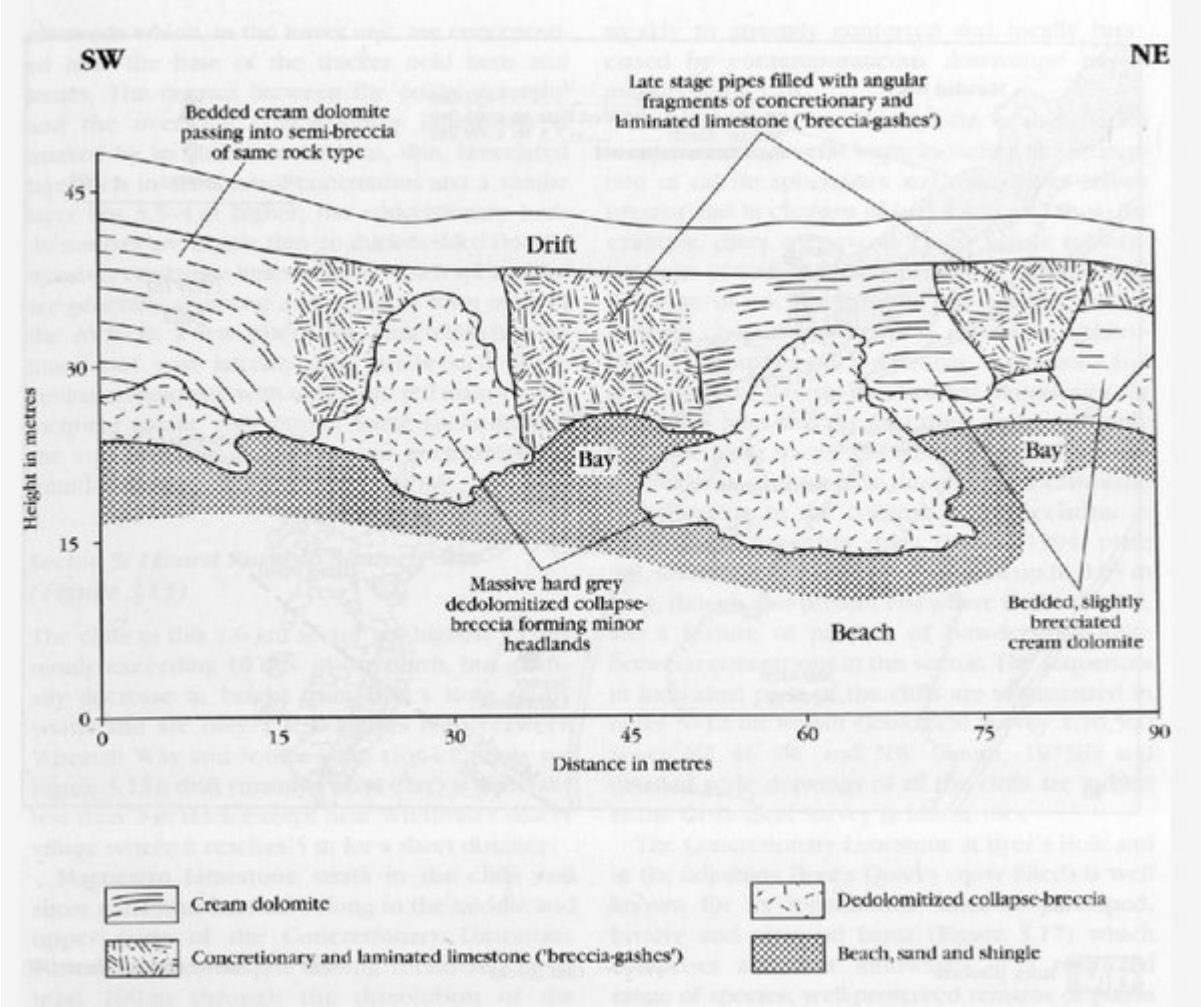
(Figure 3.10) The Frenchman's Bay to Velvet Beds sector, showing the main features of geological interest. Except in Frenchman's Bay and in an anticline c. 100-200 m north of Man Haven, all the strata are collapse-brecciated rocks of the Concretionary Limestone Formation.



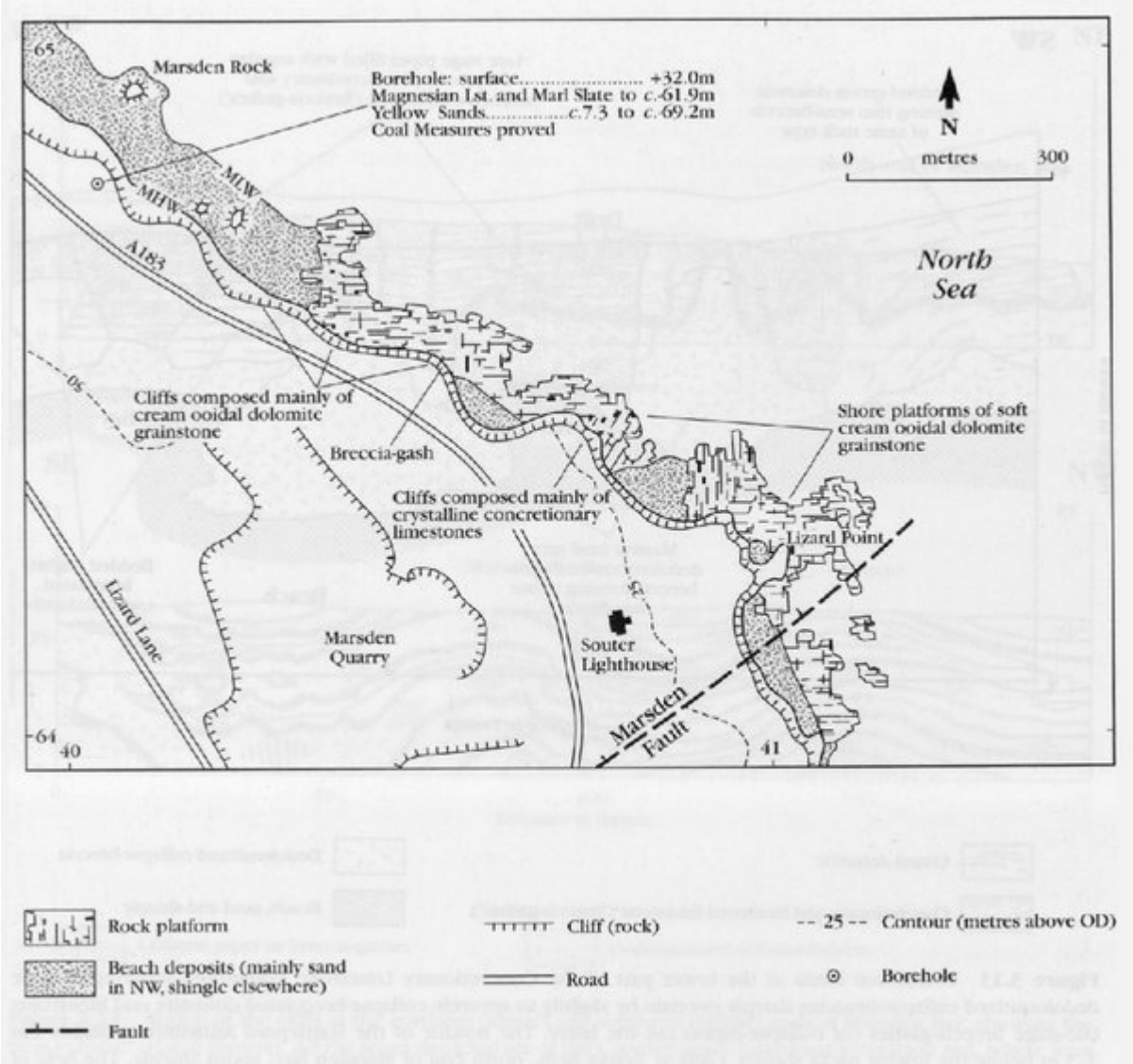
(Figure 3.11) The Velvet Beds to Marsden Rock sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation.



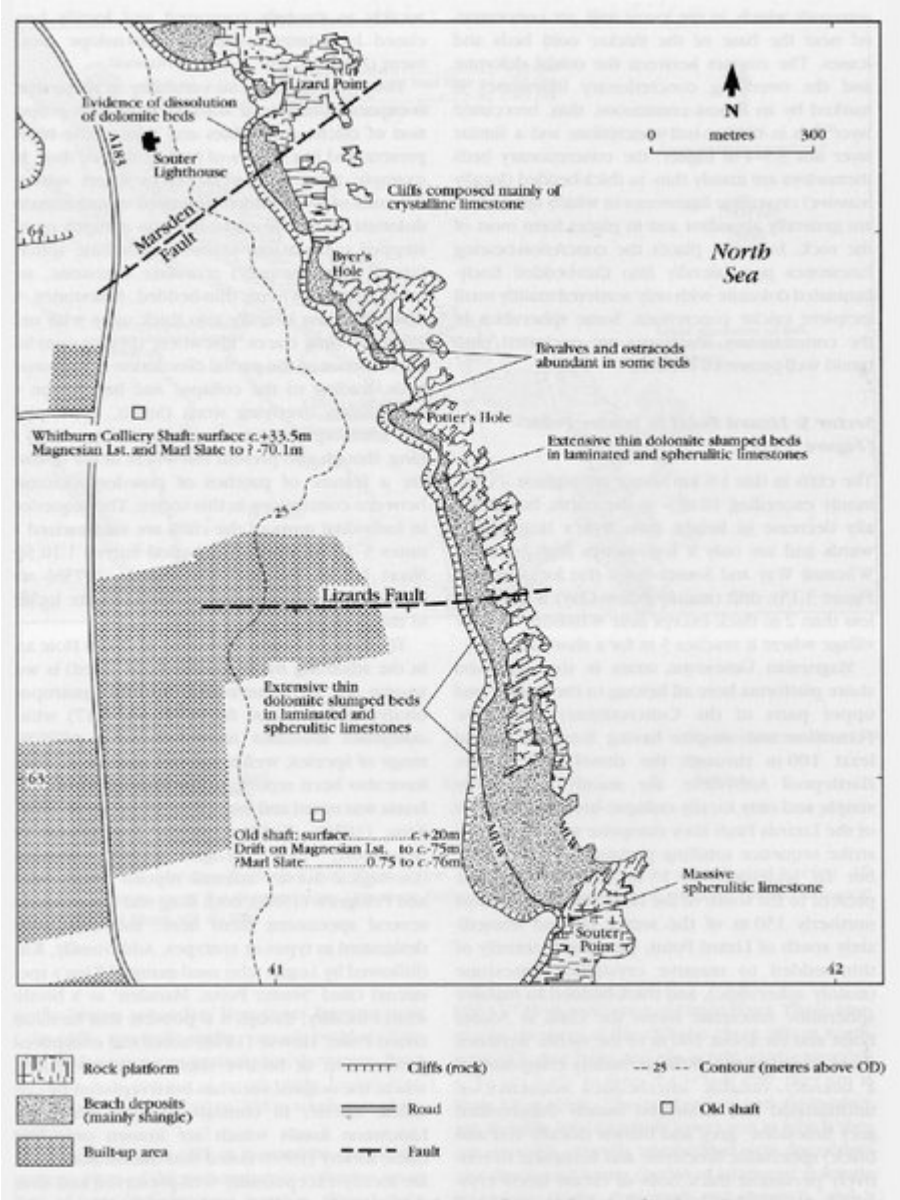
(Figure 3.12) Sketch of the cliffs at the northern (above) and southern (below) ends of Marsden Bay, showing the main collapse-related features. All the strata depicted are of the Concretionary Limestone Formation and, where least altered, comprise an interbedded mid-slope sequence of slightly bituminous, finely laminated dolomite mudstones, and sparingly fossiliferous turbiditic and/or slumped dolomite packstones and grainstones. Where severely altered, much of the rock is a hard crystalline secondary limestone (dedolomite). Sketch after Woolacott (1909, plate 2). See (Figure 3.13) for detailed distribution of rock types near Velvet Beds.



(Figure 3.13) Foundered strata of the lower part of the Concretionary Limestone Formation, showing massive dedolomitized collapse-breccias sharply overlain by slightly to severely collapse-brecciated dolomite and limestone; late-stage breccia-gashes (or collapse-pipes) cut the latter. The residue of the Hartlepool Anhydrite probably lies 2-5 m below the lowest rocks shown. Cliffs at Velvet Beds, north end of Marsden Bay, South Shields. The field of view lies near the northern end of the cliffs shown in Figure 3.12 (upper section). After Smith (1994).

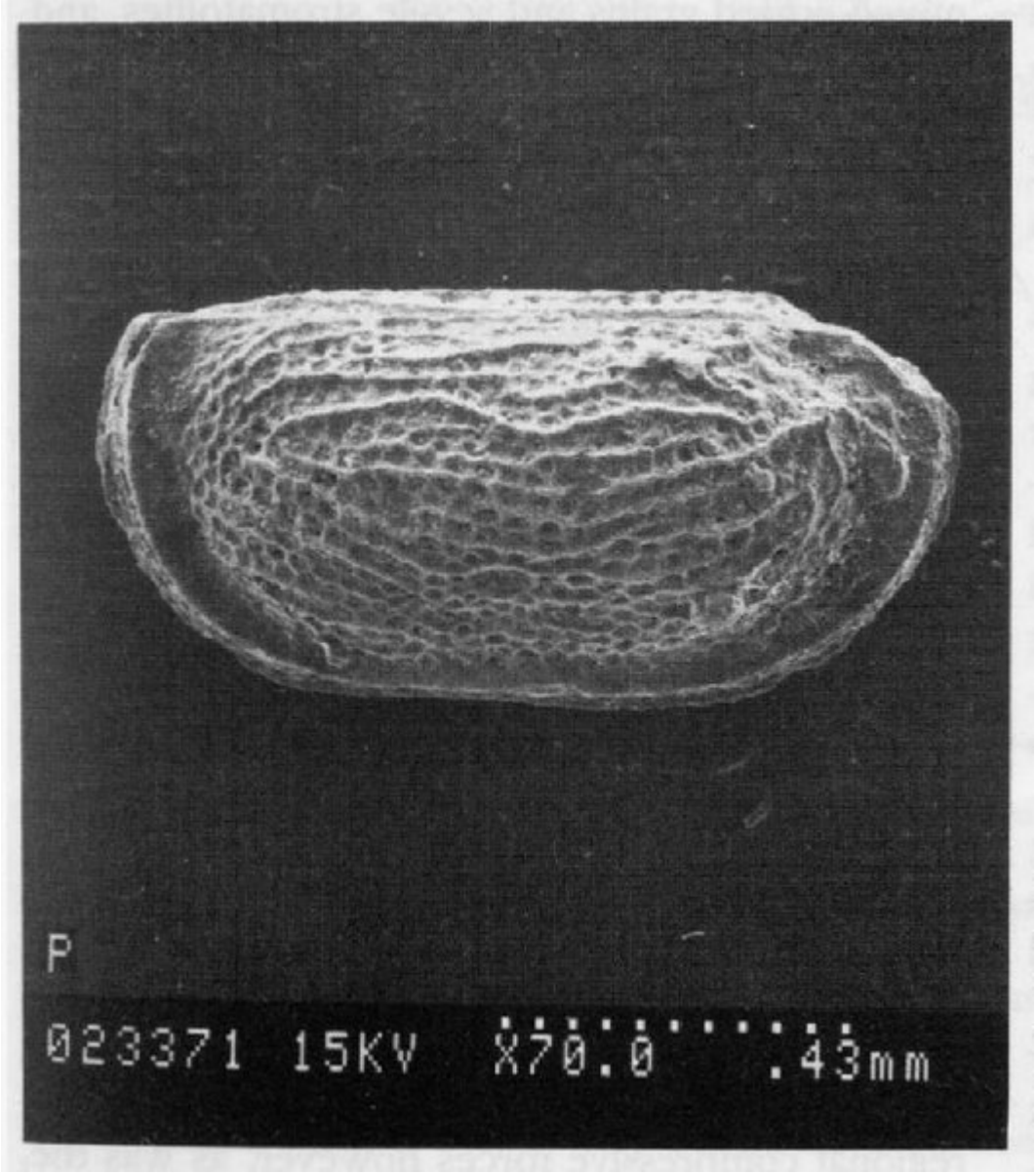


(Figure 3.14) The Marsden Rock to Lizard Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.

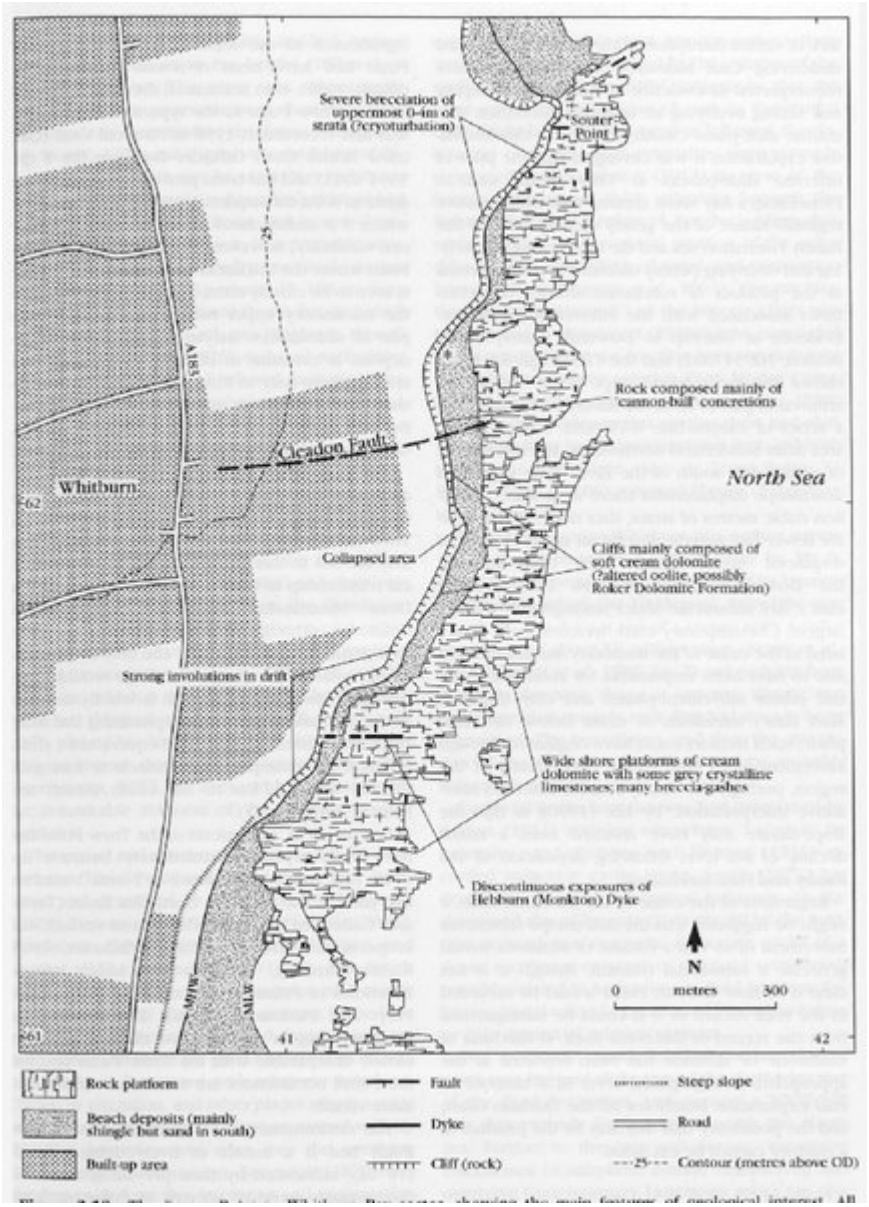


(Figure 3.15) The Lizard Point to Souter Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.

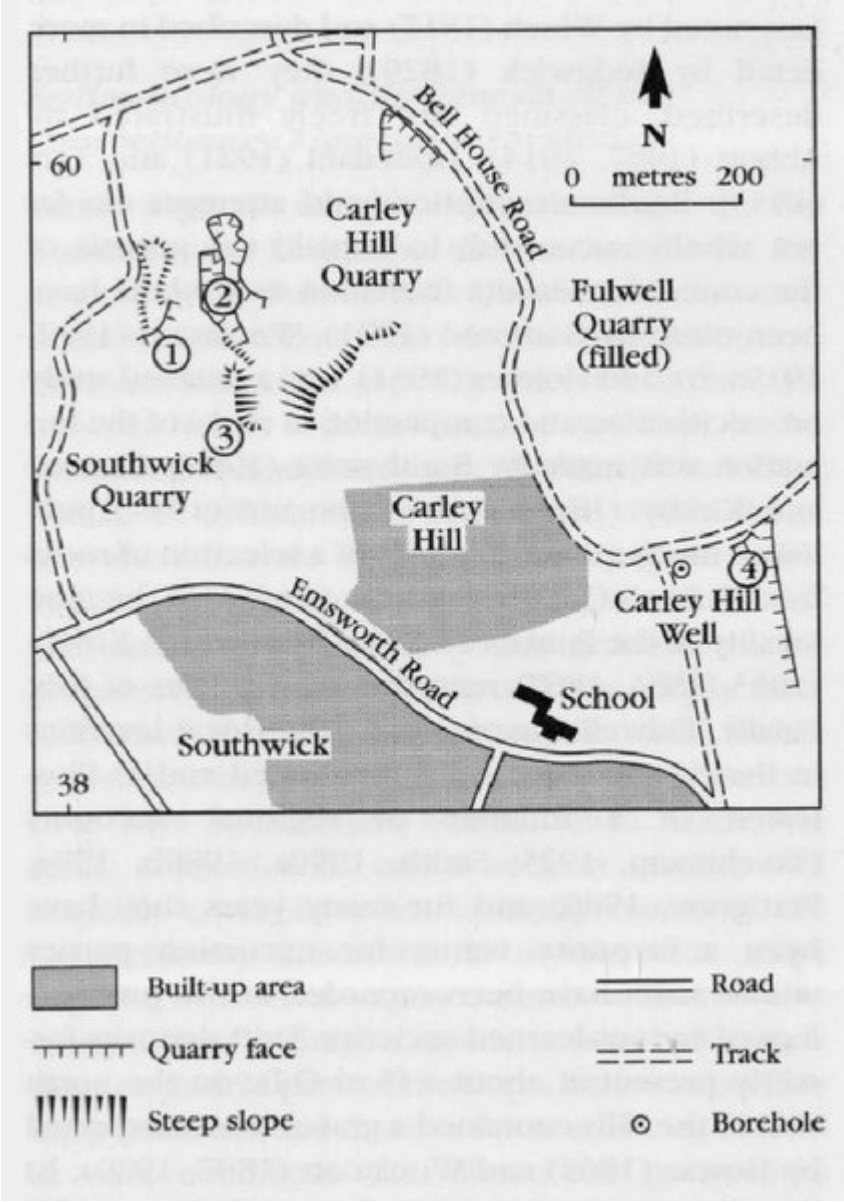
(Figure 3.16) Tight slump folds in high-slope thin-bedded calcite mudstones of the Concretionary Limestone Formation. Coastal cliffs c. 500 m south of Potter's Hole, Whitburn Colliery. Hammer: 0.33 m. Reproduced by permission of the Director. British Geological Survey: NERC copyright reserved (NL 138).



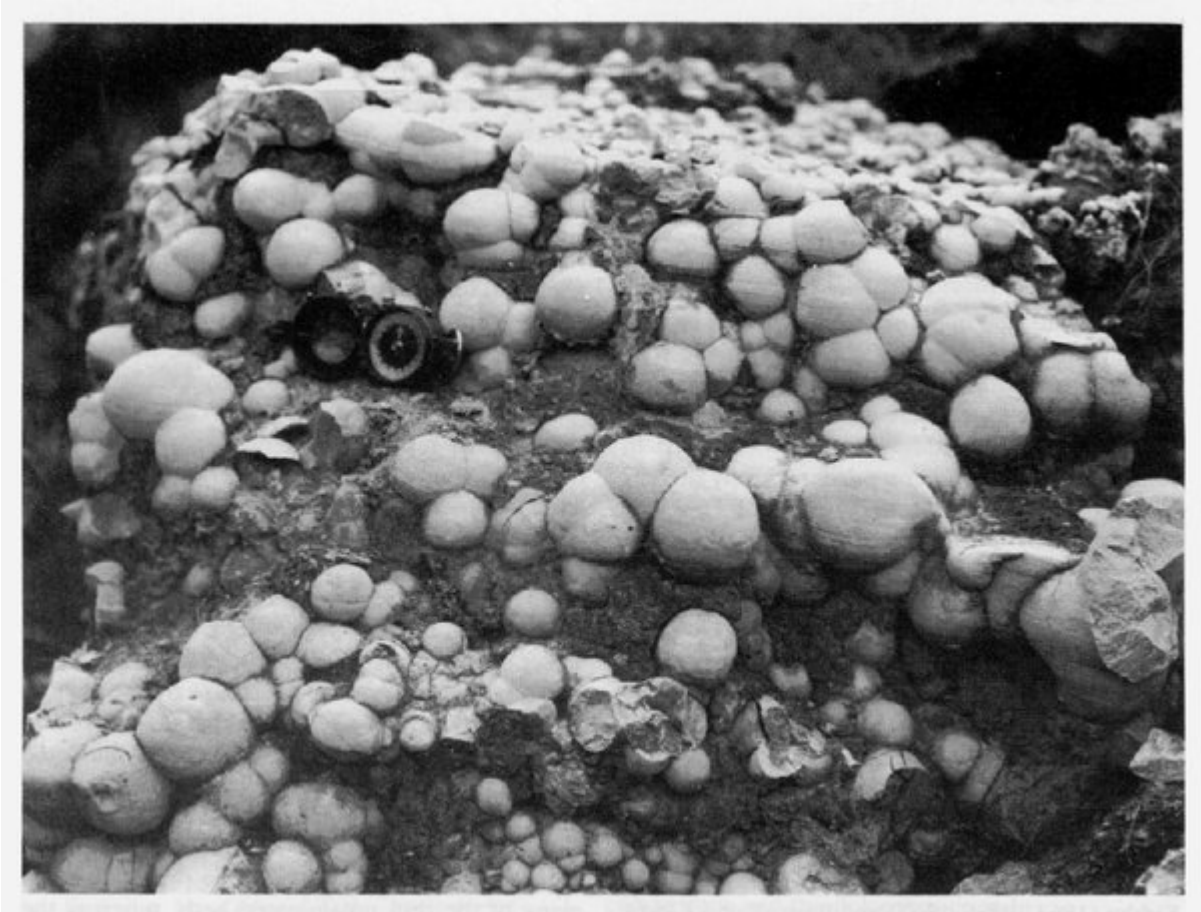
(Figure 3.17) Kirkbya permiana (Jones), a typical ostracod from high-slope calcite mudstones of the Concretionary Limestone Formation. Top of coastal cliffs on the south side of Byer's Hole, Whitburn Colliery. Bar: 0.43 mm. (Photo: Sunderland Museum TWCMS: P1004.)



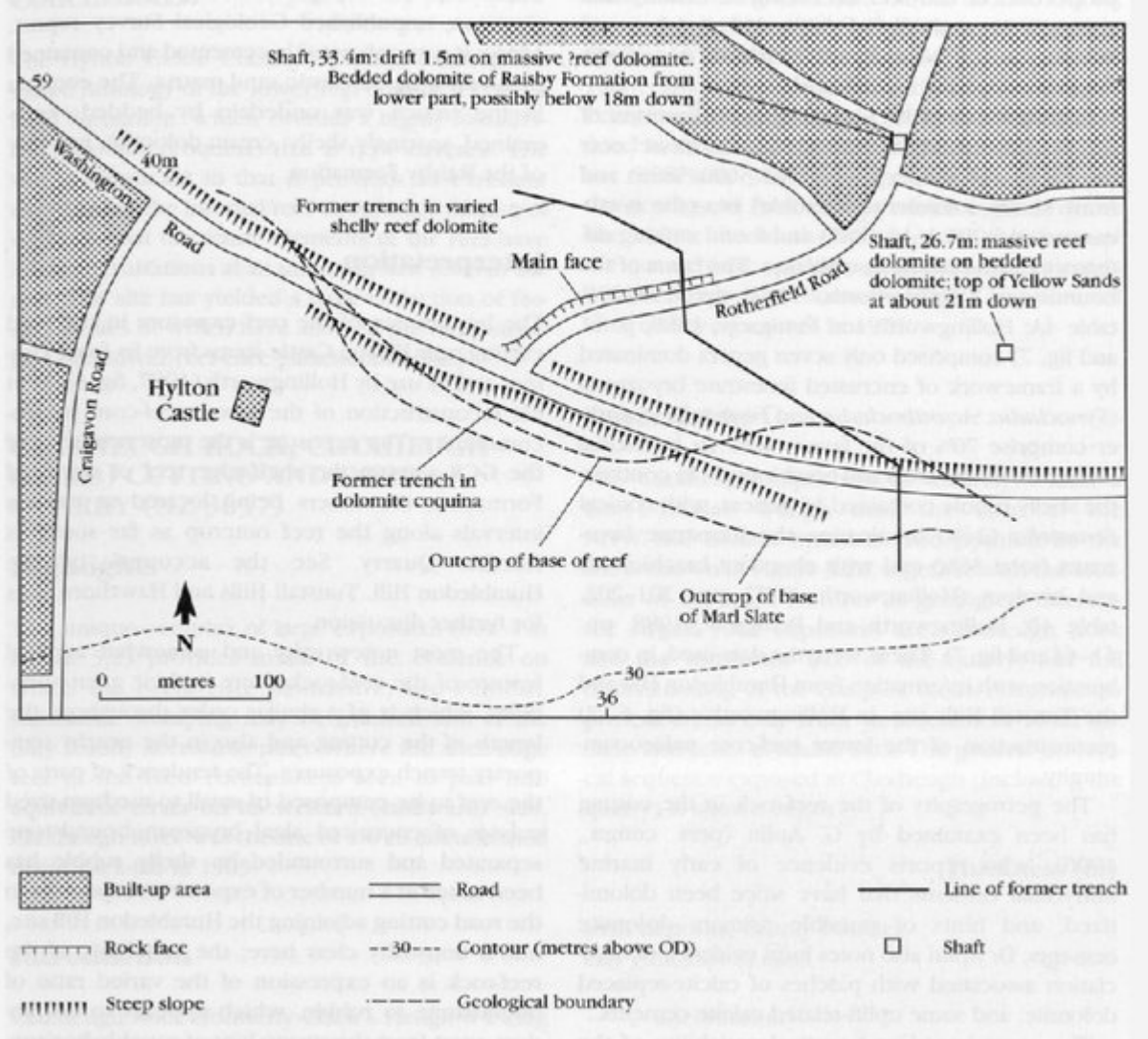
(Figure 3.18) The Souter Point to Whitburn Bay sector, showing the main features of geological interest. All exposed strata north of Rackley Way Goit (*) are of the Concretionary Limestone Formation but those to the south may include lower beds of the Roker Dolomite Formation.



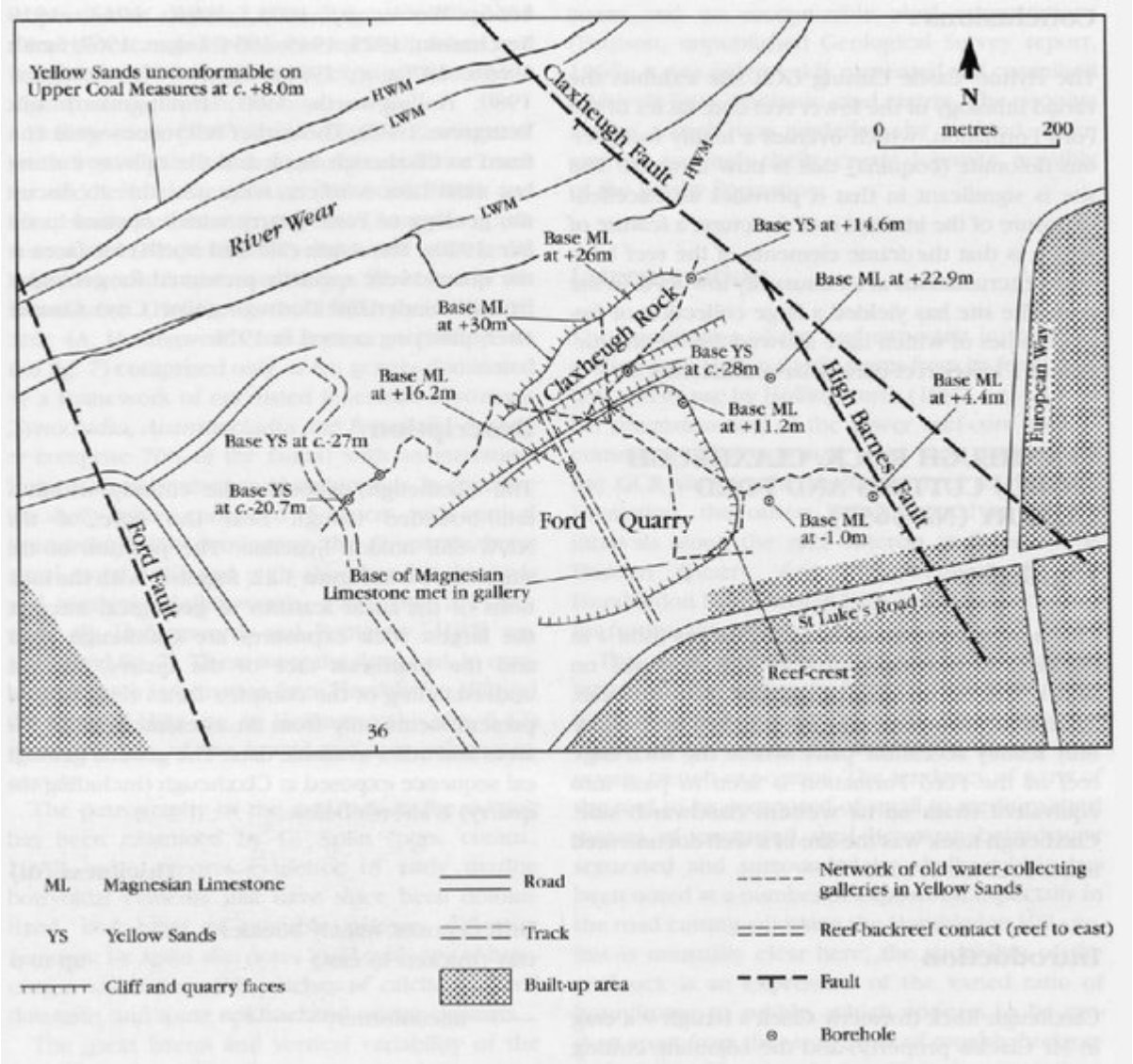
(Figure 3.19) Preserved faces within the complex of former limestone quarries on Fulwell Hills, Sunderland; numbers refer to quarry faces described in the text.



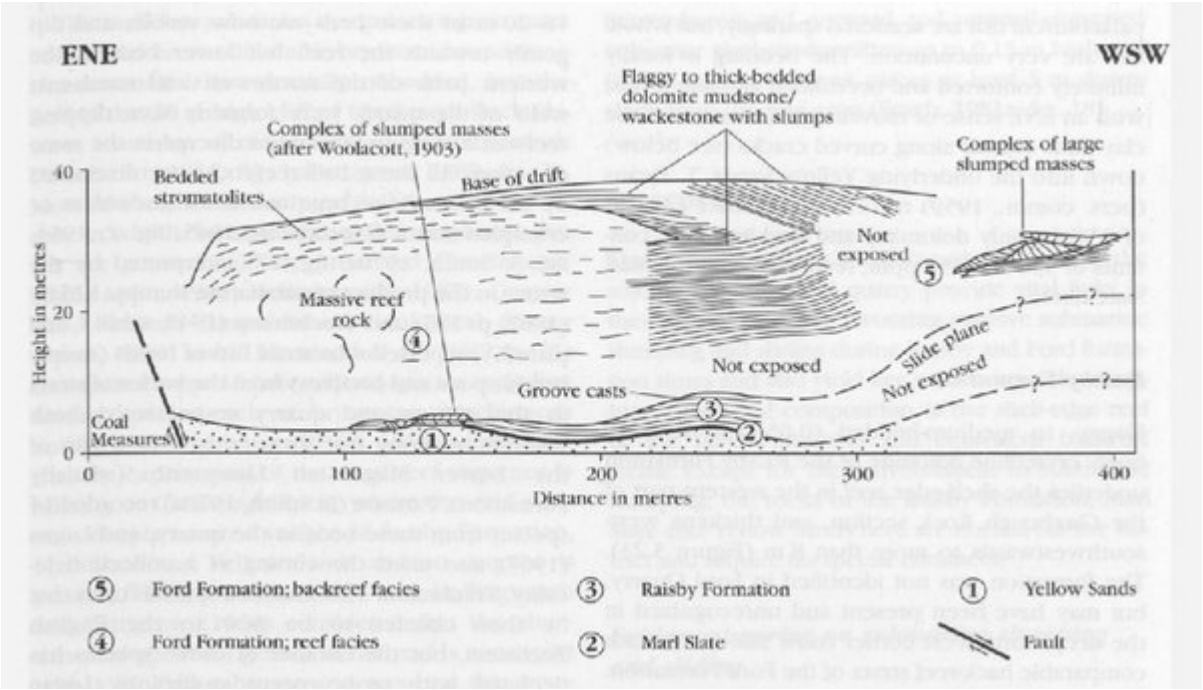
(Figure 3.20) Mutually interfering subspherical calcite concretions ('cannon-balls') in a matrix of fine-grained dolomite. Note the parallel bedding traces preserved on the surface of some of the concretions. Loose specimen from floor of Southwick Quarry. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (NL 130).



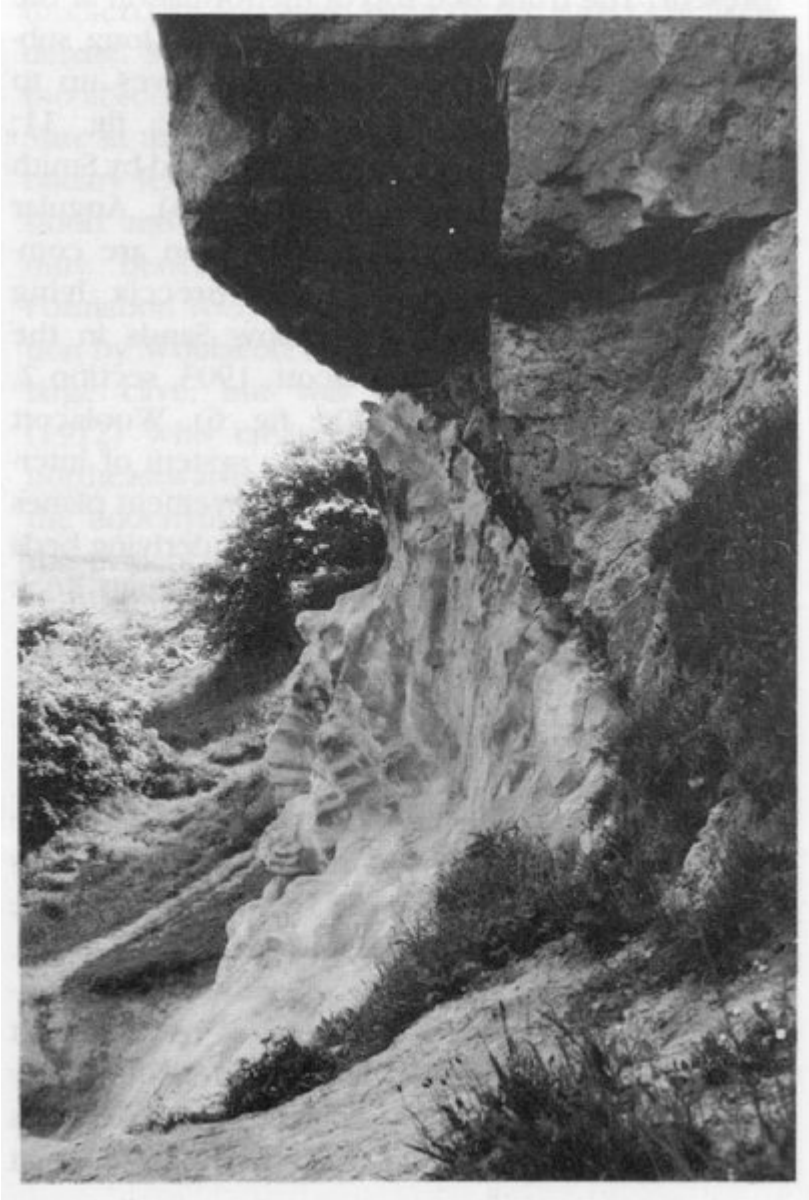
(Figure 3.21) Hylton Castle (Rotherfield Road) Cutting and its immediate surroundings, showing the main features of geological interest.



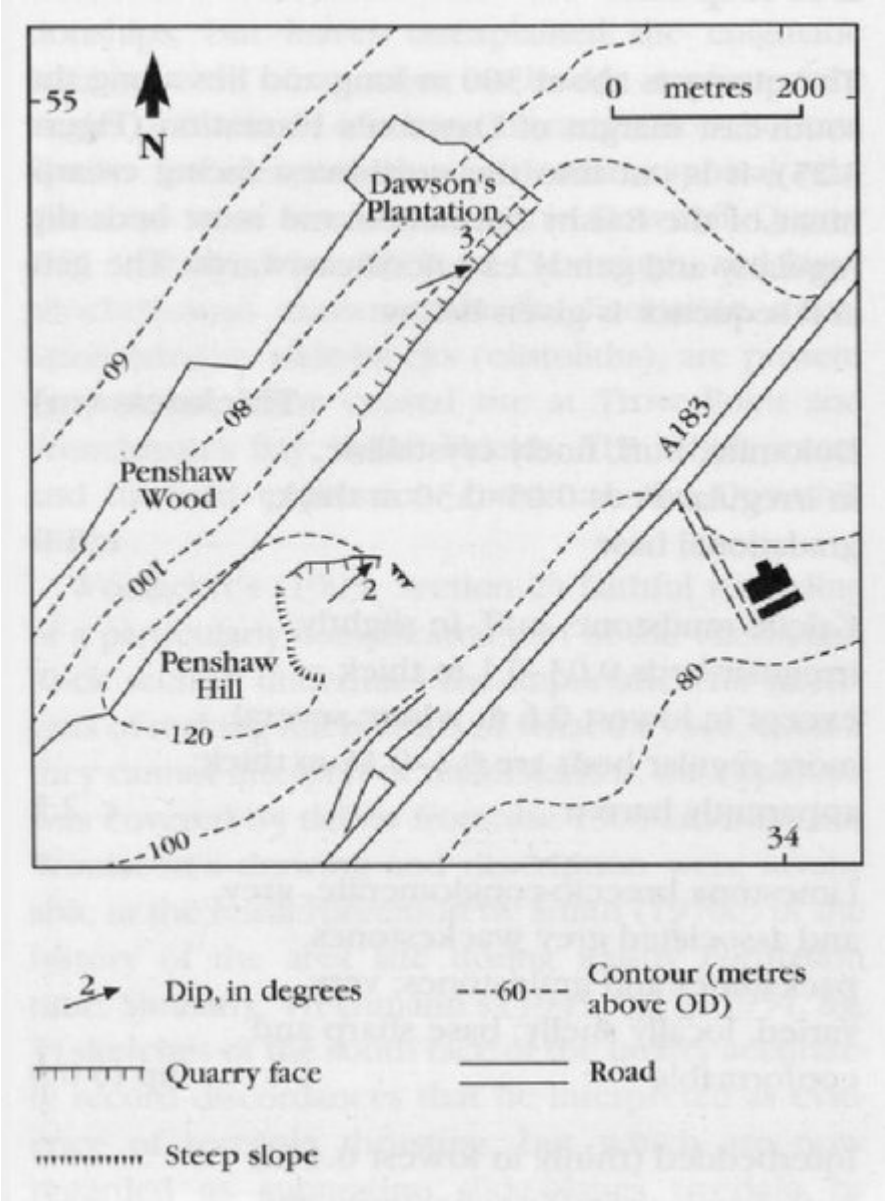
(Figure 3.22) Claxheugh Rock, Cutting and Ford Quarry, showing the position of the main features of geological interest.



(Figure 3.23) Section of strata at Claxheugh Rock, Cutting and Ford Quarry, based on Smith (1970a, fig. 17).

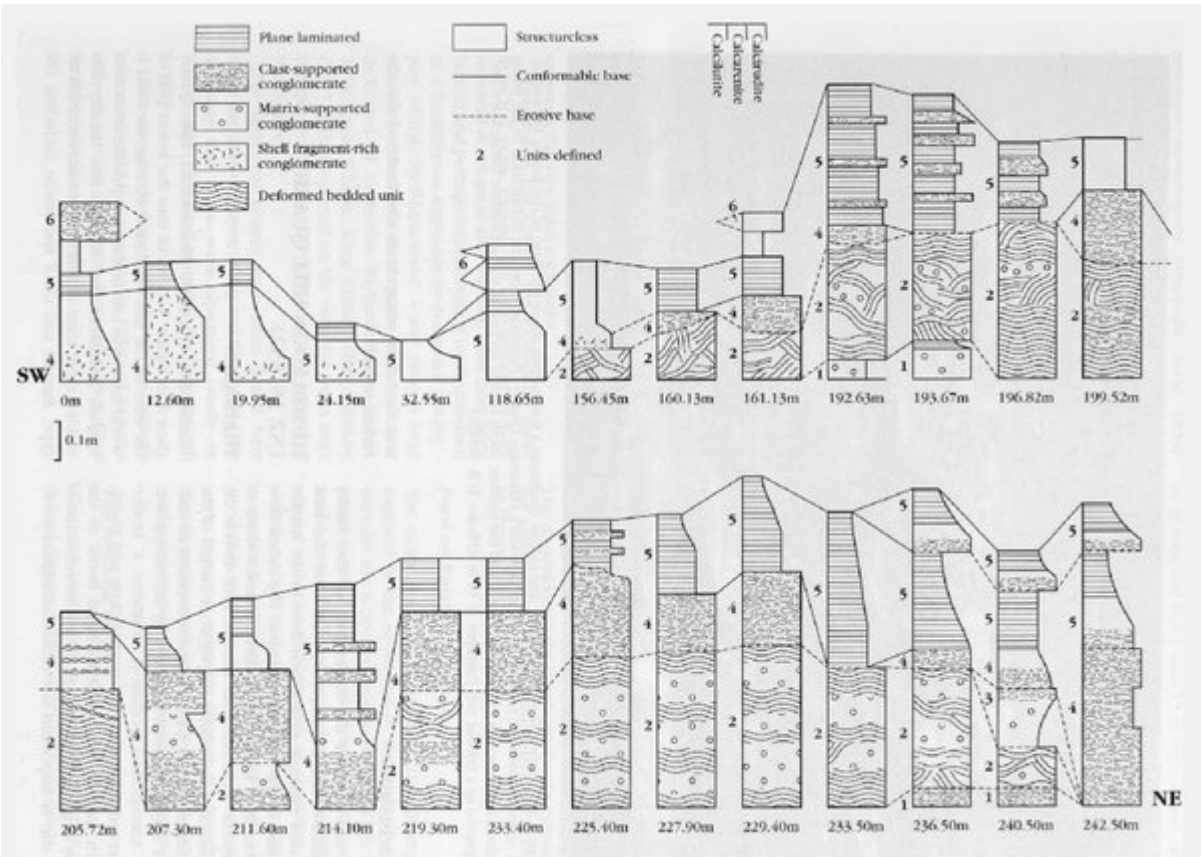


(Figure 3.24) Steeply south-south-eastwards sloping contact between Basal Permian Sands (pale) and dolomite boundstone of the Ford Formation reef. The slope is interpreted as the northern flank of an east-northeastwards trending submarine slide canyon (Smith, 1971c). The field of view is about 18 m high. (Photo: D.B. Smith.)

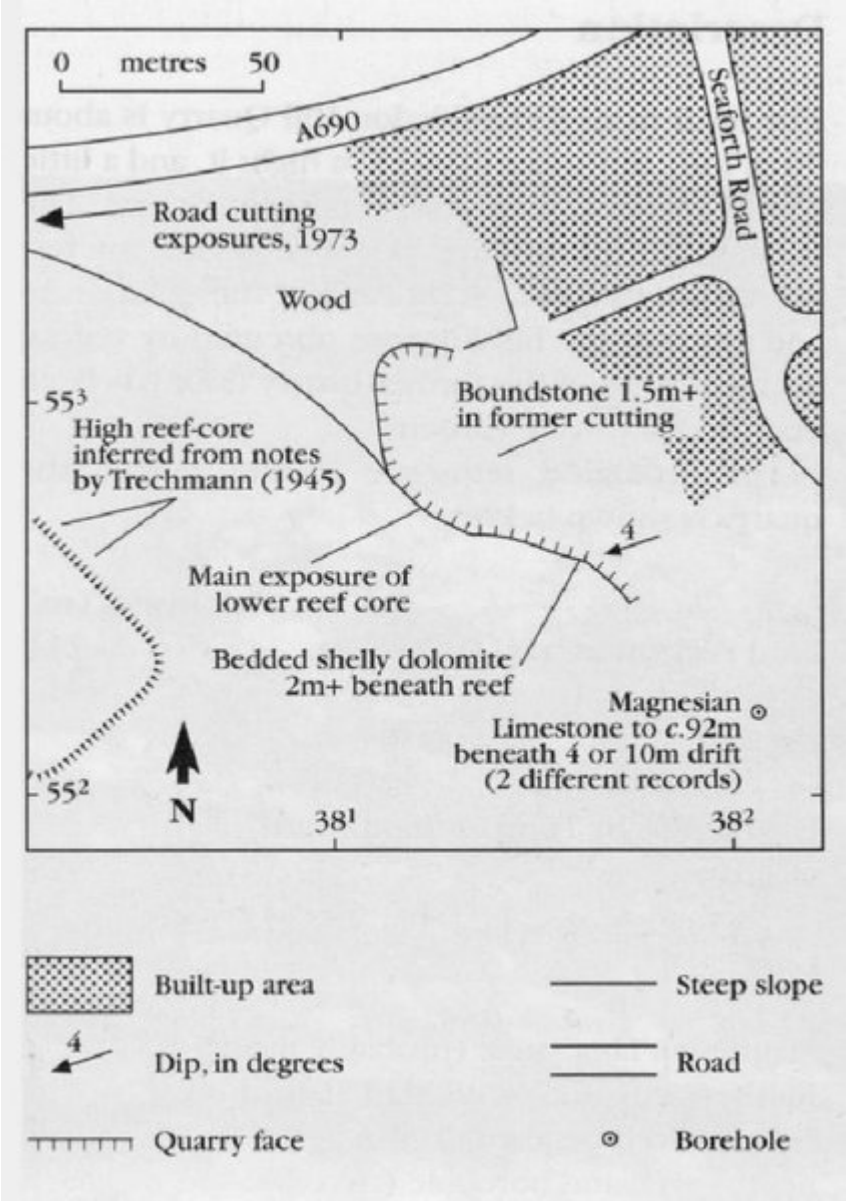


(Figure 3.25) Dawson's Plantation Quarry, Penshaw, and its environs.

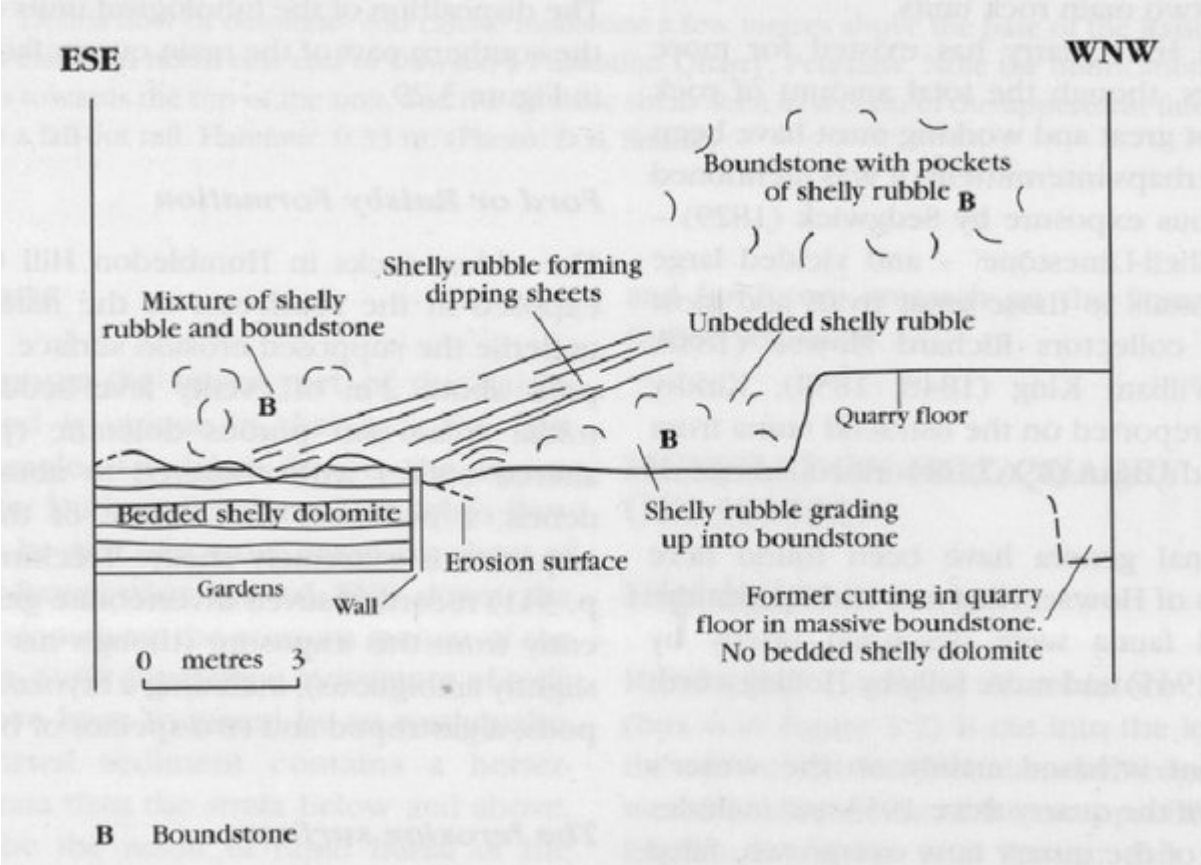
(Figure 3.26) Debris flow of dolomite- and calcite mudstone a few metres above the base of the Raisby Formation. View to south-east near north-east end of Dawson's Plantation Quarry, Penshaw. Note the imbrication in the partly rounded clasts towards the top of the unit, and the mollusc shells seen in section in the uppermost fine-grained bed, interpreted as a fall-out tail. Hammer: 0.33 m. (Photo: D.B. Smith.)



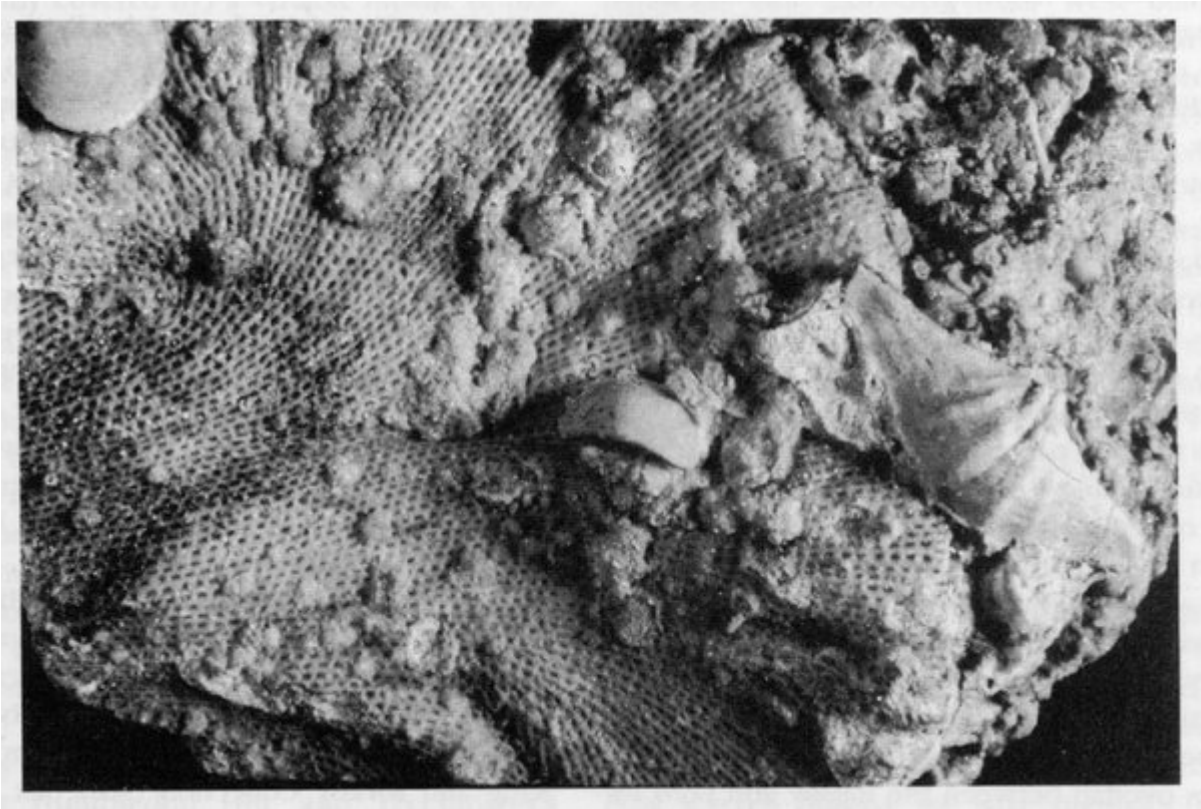
(Figure 3.27) Disturbed strata in the Raisby Formation at Dawson's Plantation Quarry, showing their lateral variation. After Lee (1990, fig. 2.21).



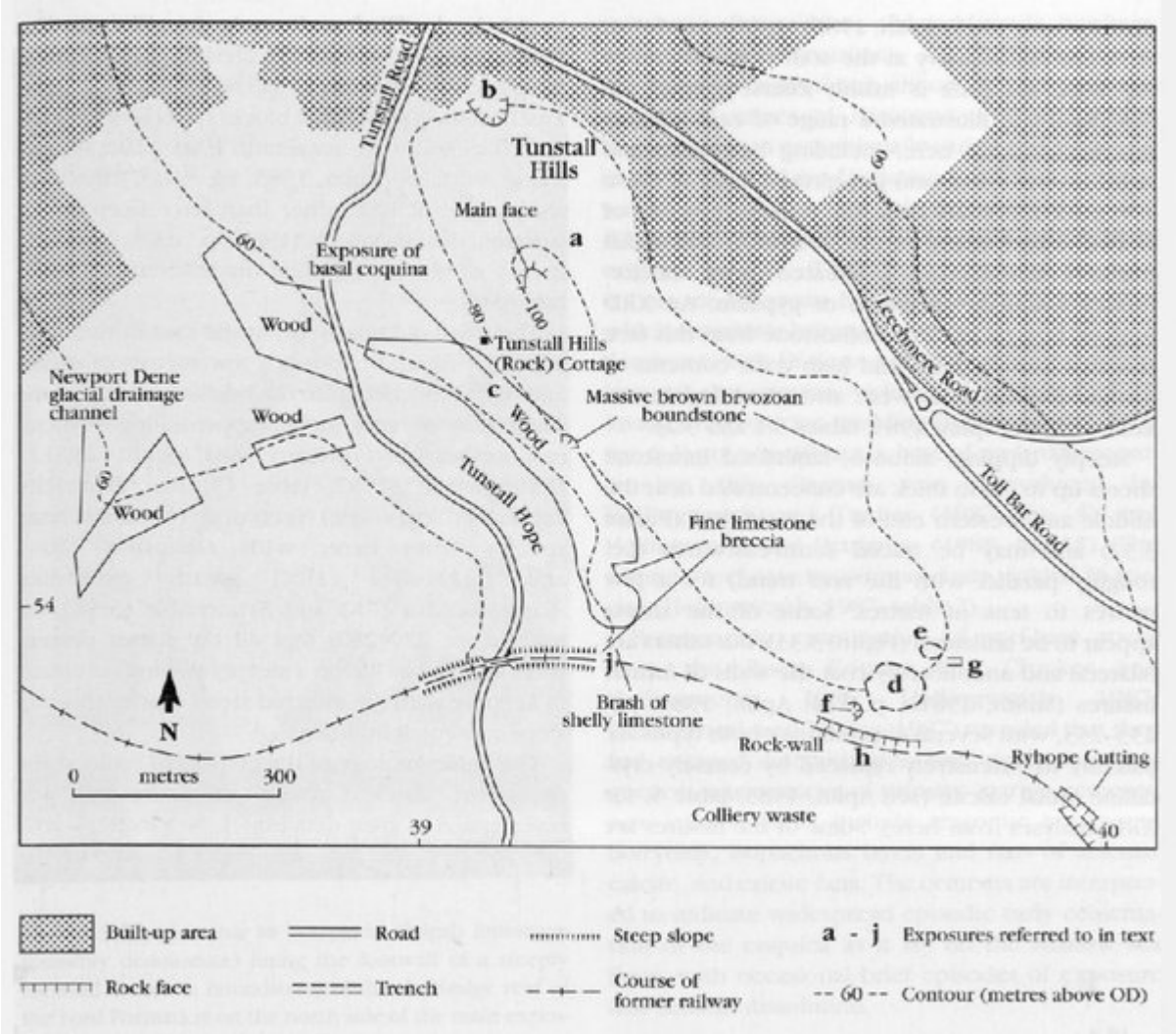
(Figure 3.28) Humbledon Hill Quarry and its immediate surroundings, showing the position of the GCR site and the main features of geological interest.



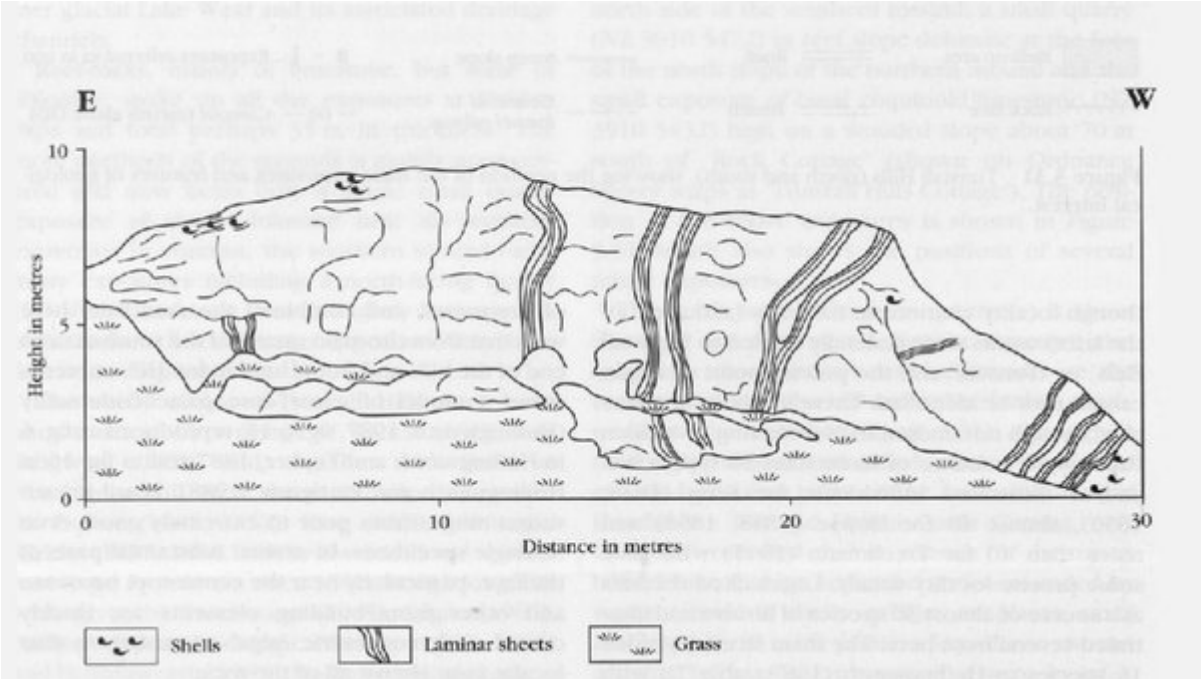
(Figure 3.29) Sketch of the stratal relationships in the southern part of the main face of Humbledon Hill Quarry, based on an unpublished drawing made by the writer in 1953.



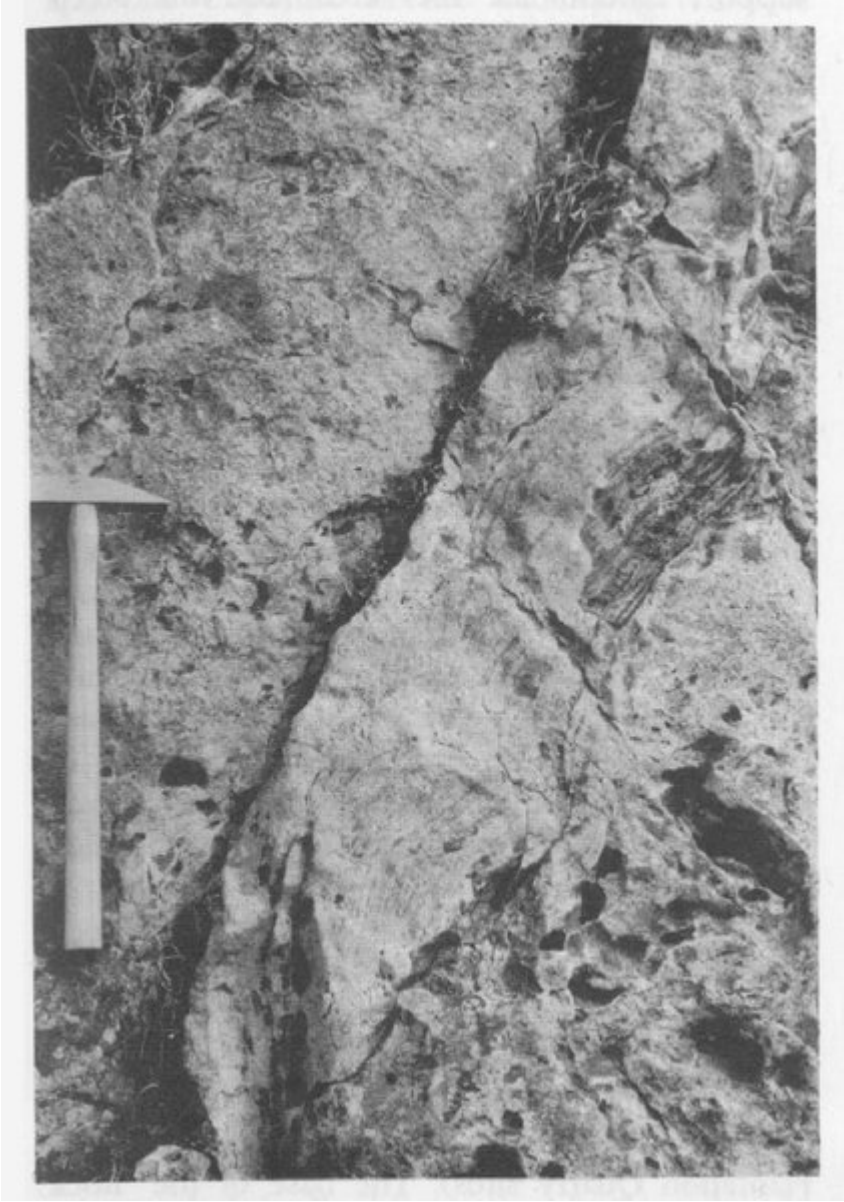
(Figure 3.30) Typical elements of the fauna of the boundstone bodies in reef dolomite in Humbledon Hill Quarry, comprising the pinnate bryozoan Fenestella retiformis and the pedunculate brachiopods Dielasma elongatum and Pterospirifer alatus. Field of view about 67 x 100 mm. (Photo: N.T.J. Hollingworth.)



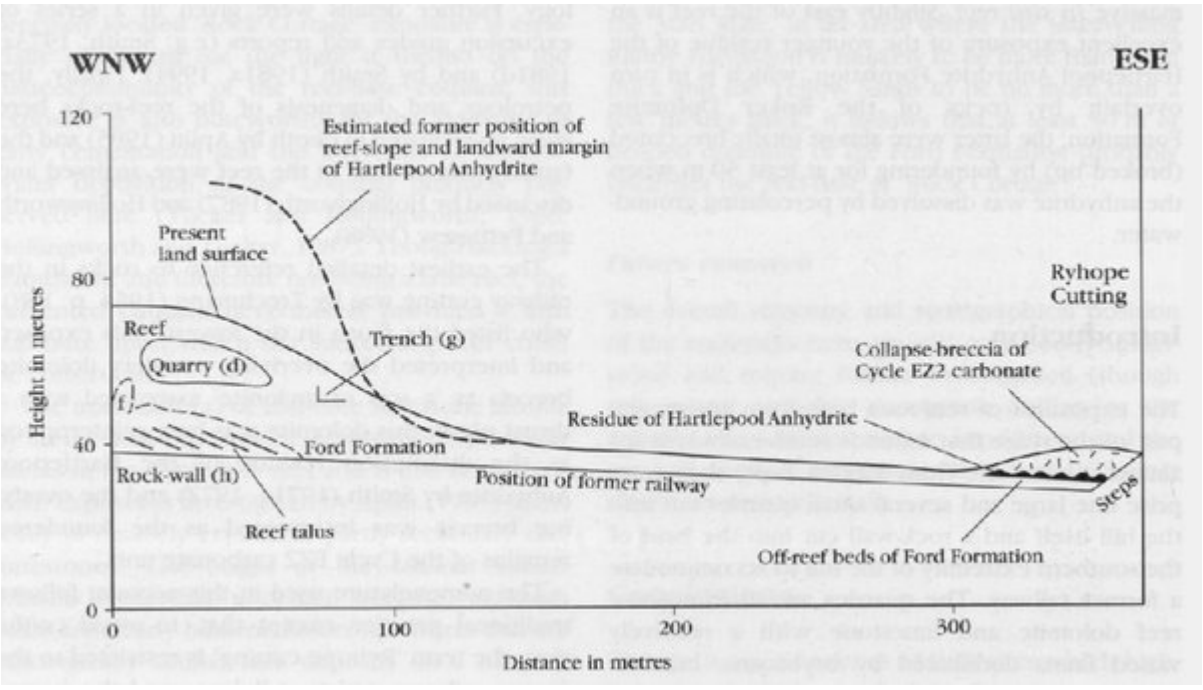
(Figure 3.31) Tunstall Hills (north and south), showing the position of the main exposures and features of geological interest.



(Figure 3.32) The main quarry face on the north side of the more southerly of Maiden Paps, Tunstall Hills. Most of the rock is brown bryozoan boundstone, locally with profuse encrustations. At least two of the tension gashes have partial central voids. Simplified from a sketch by Aplin (1985, p. 378).

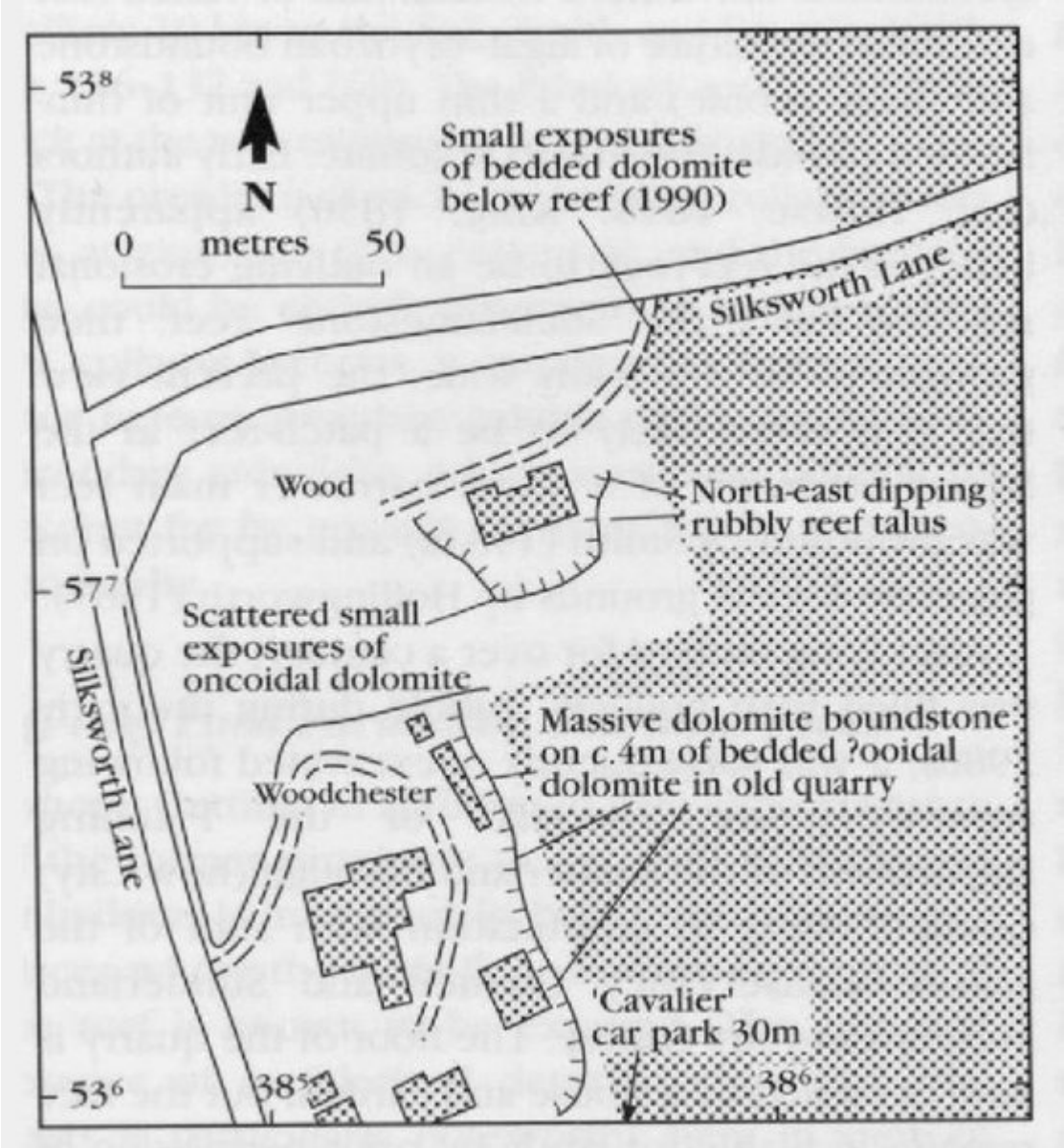


(Figure 3.33) Laminar to botryoidal (?algal) limestone (possibly dedolomite) lining the footwall of a steeply inclined fissure in boundstone of the shelf-edge reef of the Ford Formation on the north side of the main exposure at Tunstall Hills (north). Hammer: 0.33 m. (Photo: D.B. Smith.)

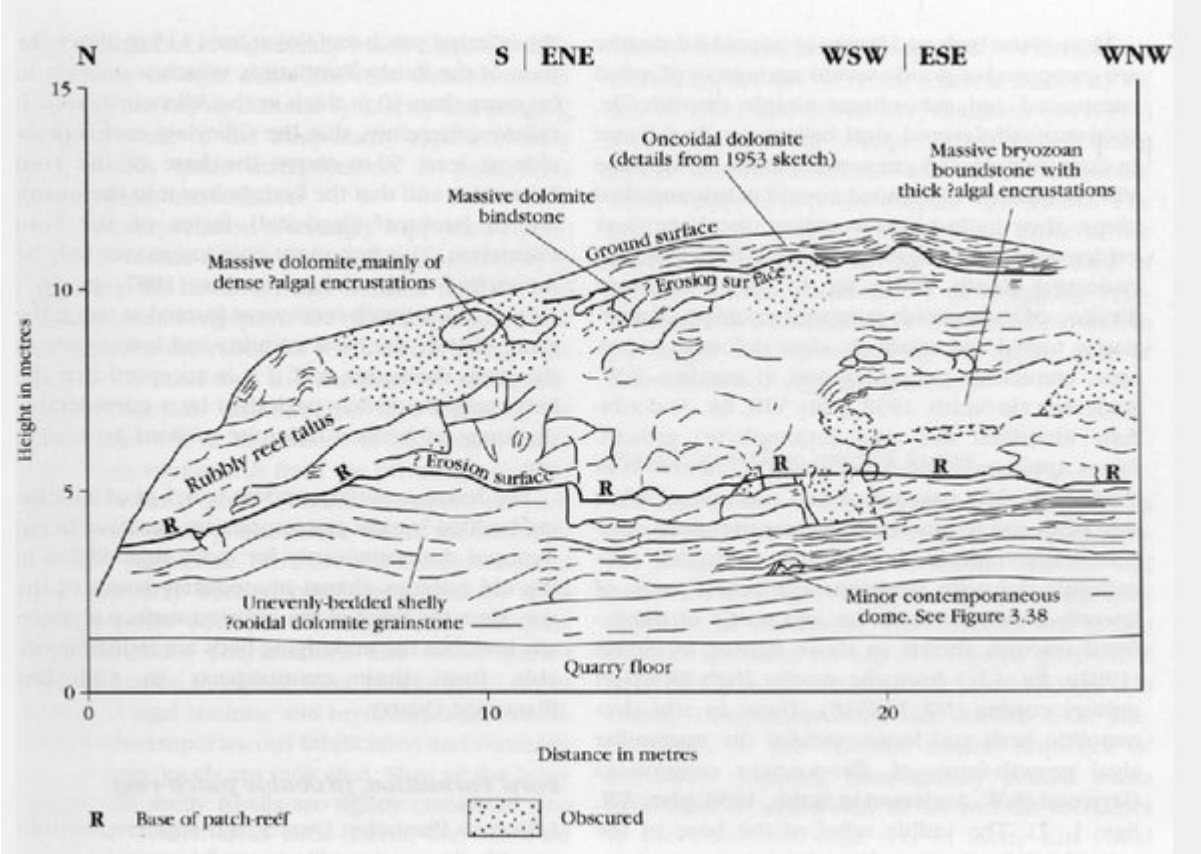


(Figure 3.34) Relationships of reef and off-reef (including post-reef) strata at the south-east end of Tunstall Hills and in the Ryhope Cutting (diagrammatic). See (Figure 3.31) for the location of the various exposures.

(Figure 3.35) Dense ?algal encrustations in reef boundstone in the main old quarry (d) at the south-east end of Tunstall Hills. Delicate bryozoan frame elements form less than 5% of the rock. Coin: 26 mm across. (Photo: D.B. Smith.)

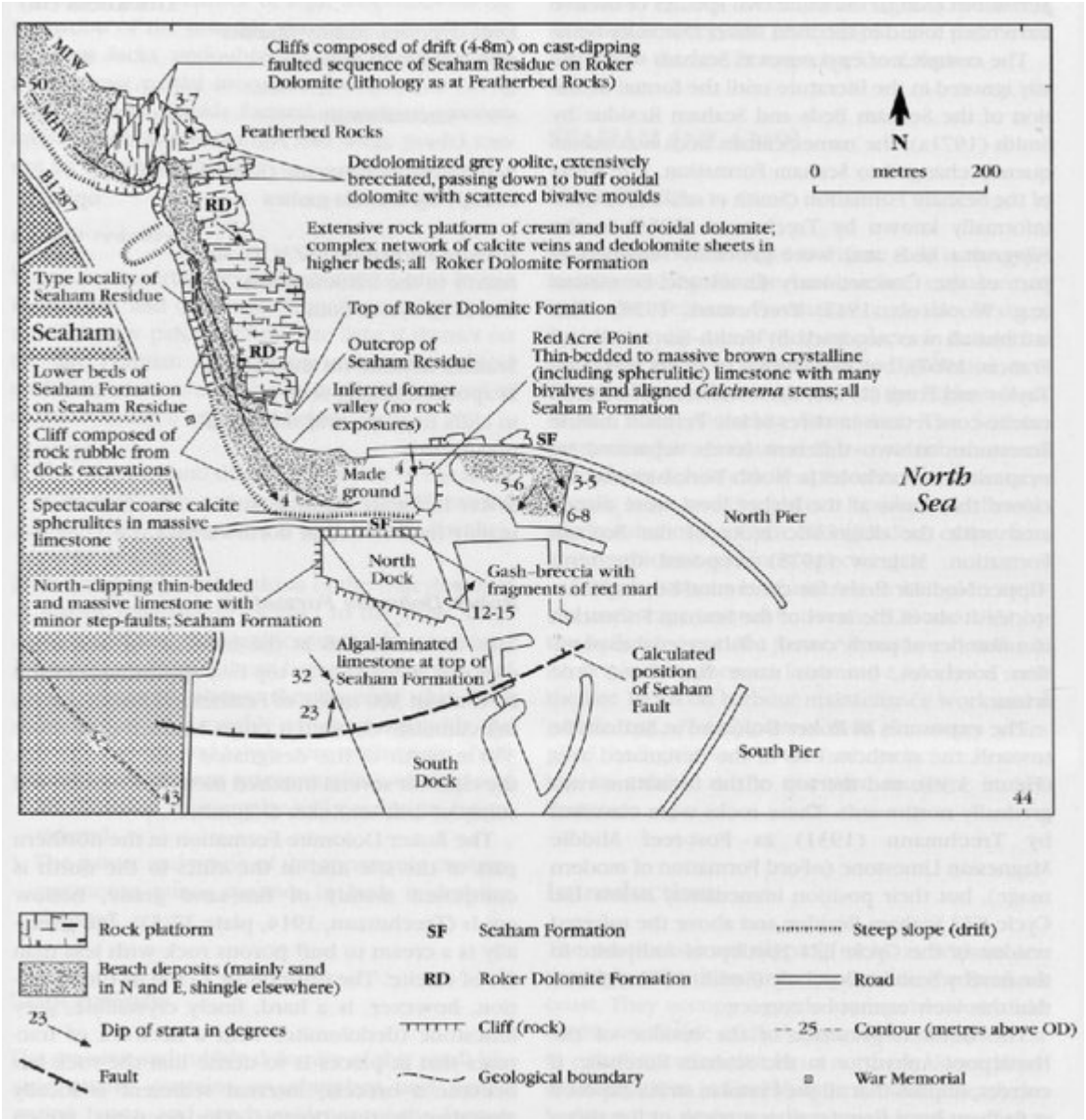


(Figure 3.36) Gilleylaw Plantation Quarry and its immediate surroundings, showing the position of the main features of geological interest.



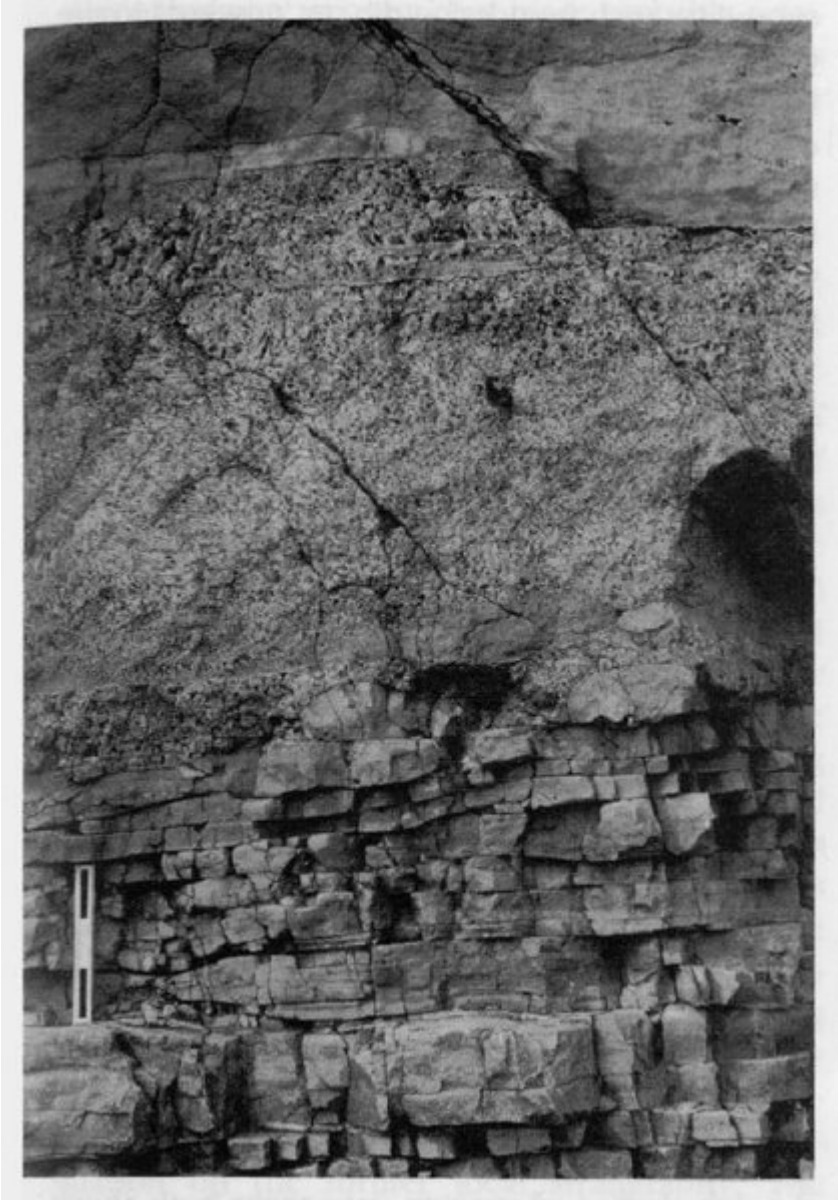
(Figure 3.37) Sketch of patch-reef in the east and south faces of Gilleylaw Plantation Quarry, incorporating some details of strata formerly exposed, but not now visible.

(Figure 3.38) Contemporaneous minor mound-like structure in backreef dolomite of the Ford Formation in the south face of Gilleylaw Plantation Quarry. Bar: 0.32 m. (Photo: D.B. Smith.)

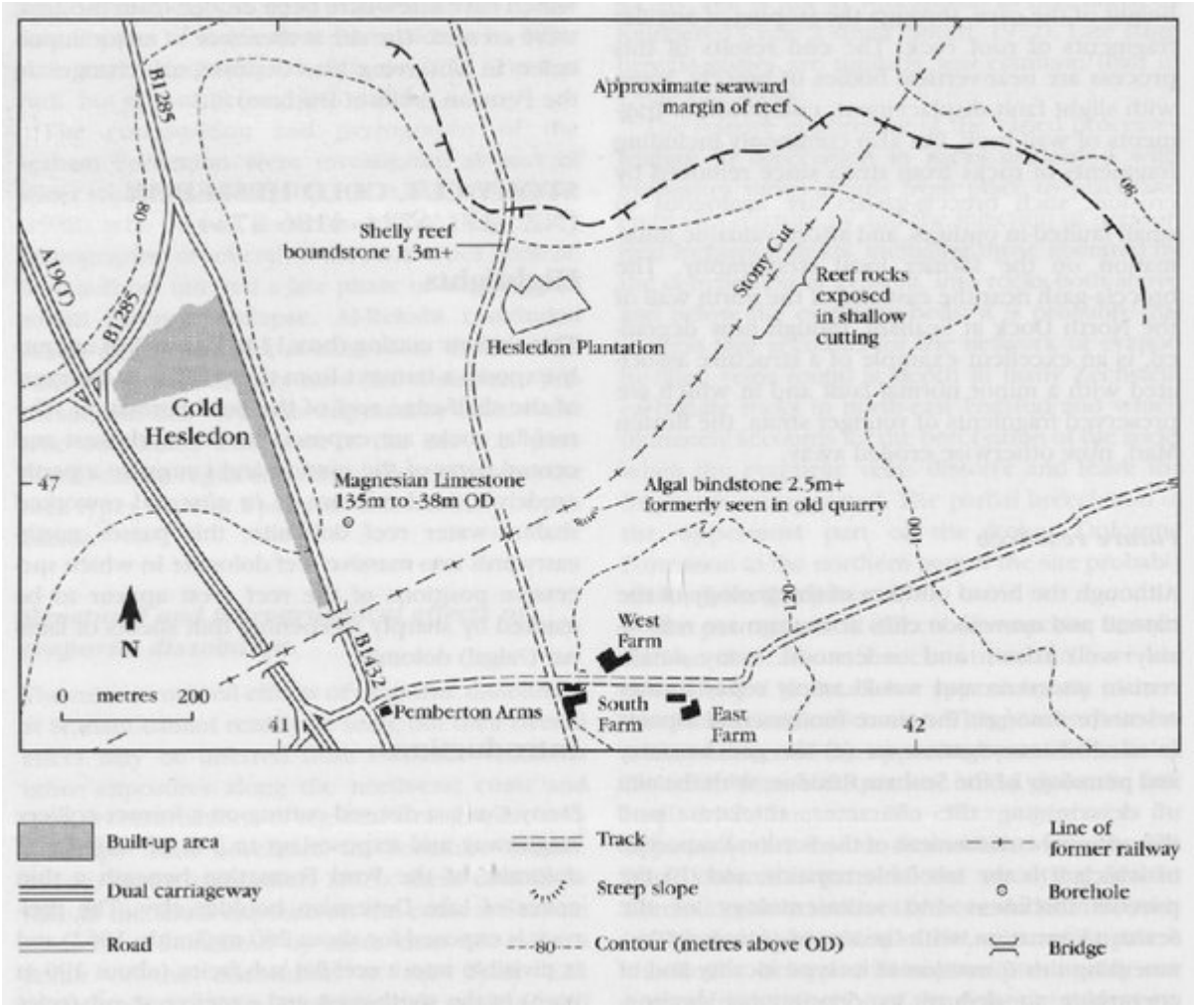


(Figure 3.39) The Seaham GCR site, showing the position of the main features of geological interest.

(Figure 3.40) Strong contortions in the lower part of the Seaham Residue at the type locality, showing detached blocks of cross-laminated ooid grainstone (middle) and the lowest part of the bedded ooid grainstones that here form a median unit in the Residue. Hammer: 0.33 m. (Photo: D.B. Smith.)

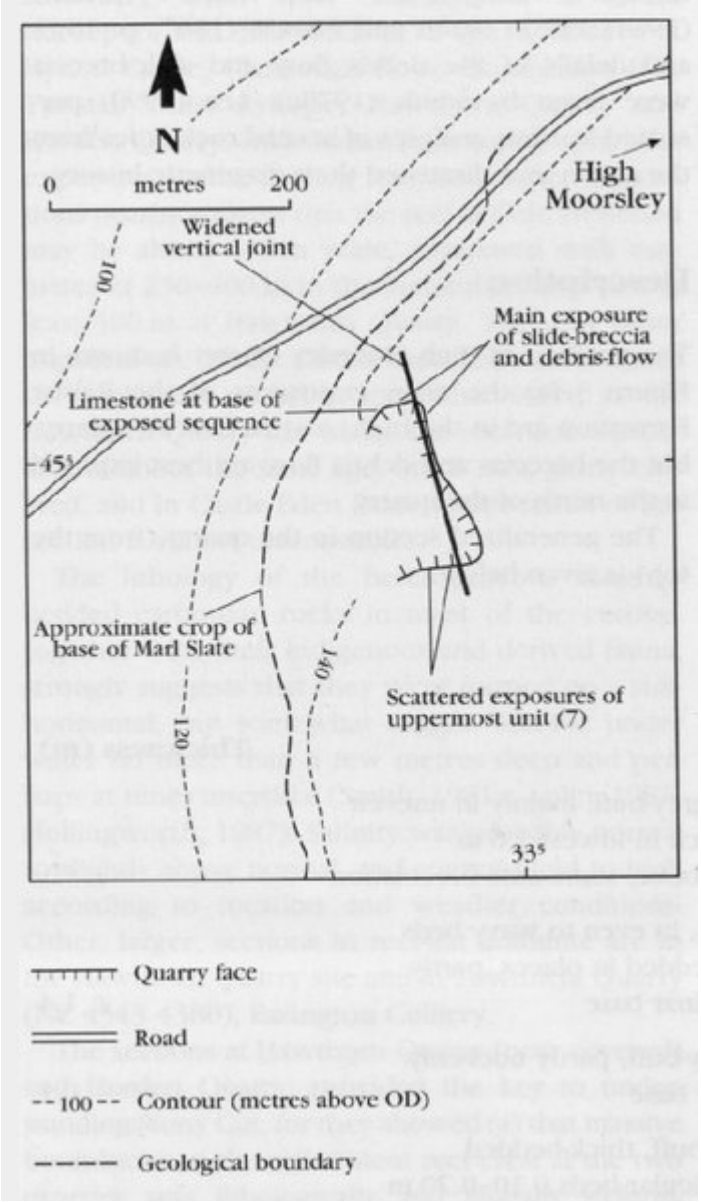


(Figure 3.41) Typical limestones of the Seaham Formation immediately north of the harbour at the type locality, showing massive secondary spherulitic limestone overlying unevenly, mainly thin-bedded, Ca[cinema bivalve calcite mudstones and wackestones with shallow mega-ripples and cut-and-fill structures. Note the minor step-fault at top right. Bar: 0.32 m. (Photo: D.B. Smith.)



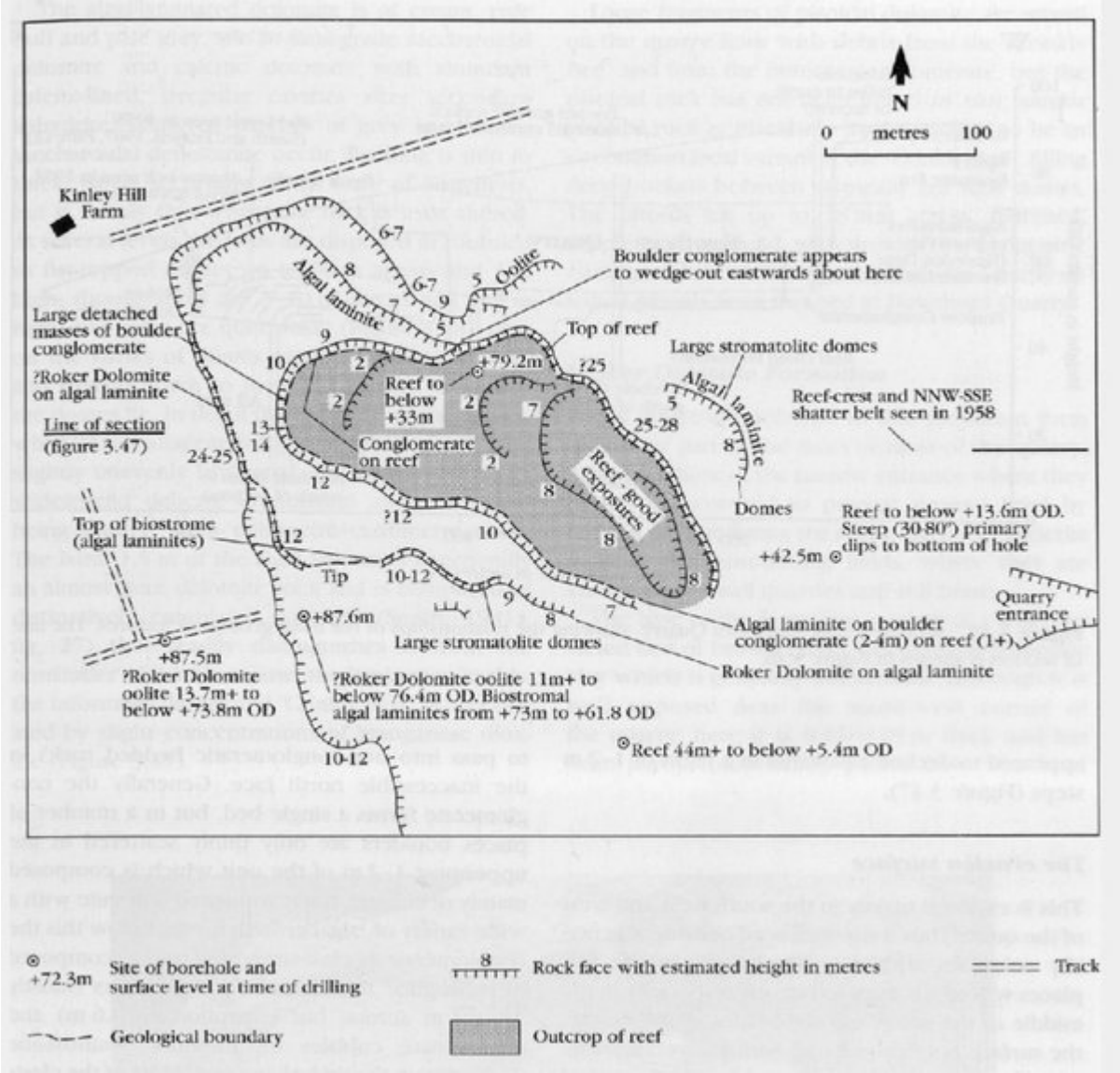
(Figure 3.42) Location of Stony Cut, Cold Hesledon.

(Figure 3.43) Laminar ?algal bindstone sheets with high primary east-northeastwards dip, in reef boundstone of the Ford Formation near the north-east end of Stony Cut, Cold Hesledon. The sheets are thought to mark the temporary position of the upper part of the reef foreslope and grade upwards into the reef-crest and reef-flat dolomite. Hammer: 0.33 m. (Photo: D.B. Smith.)

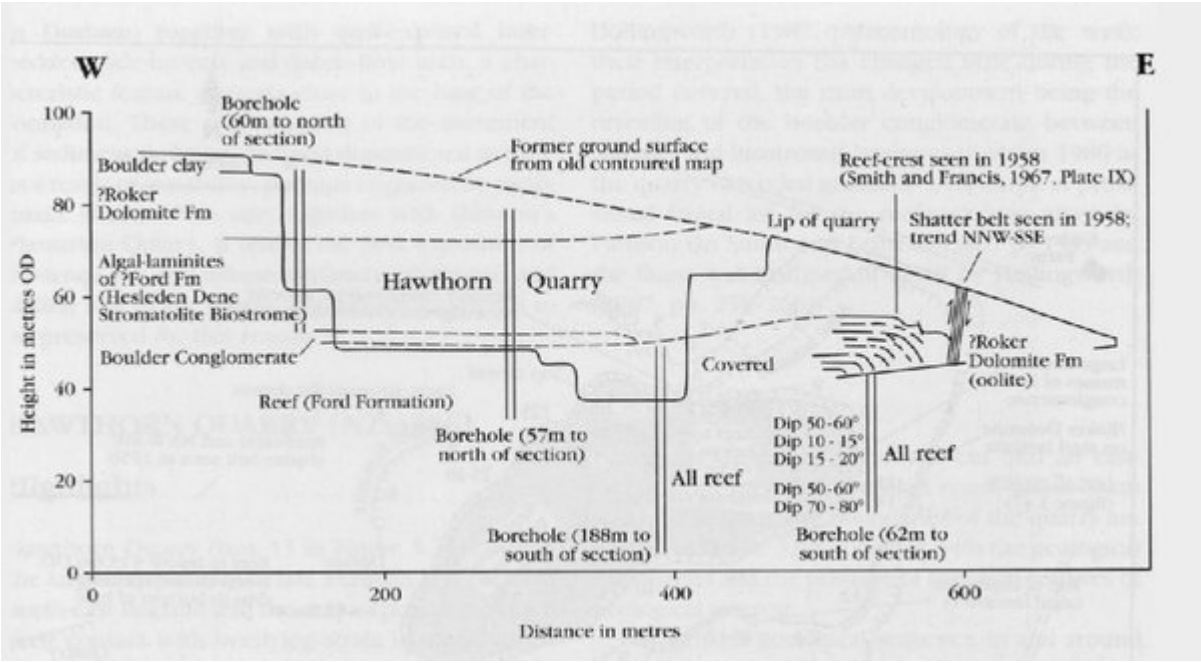


(Figure 3.44) High Moorsley Quarry and its immediate surroundings, showing the main features of geological interest.

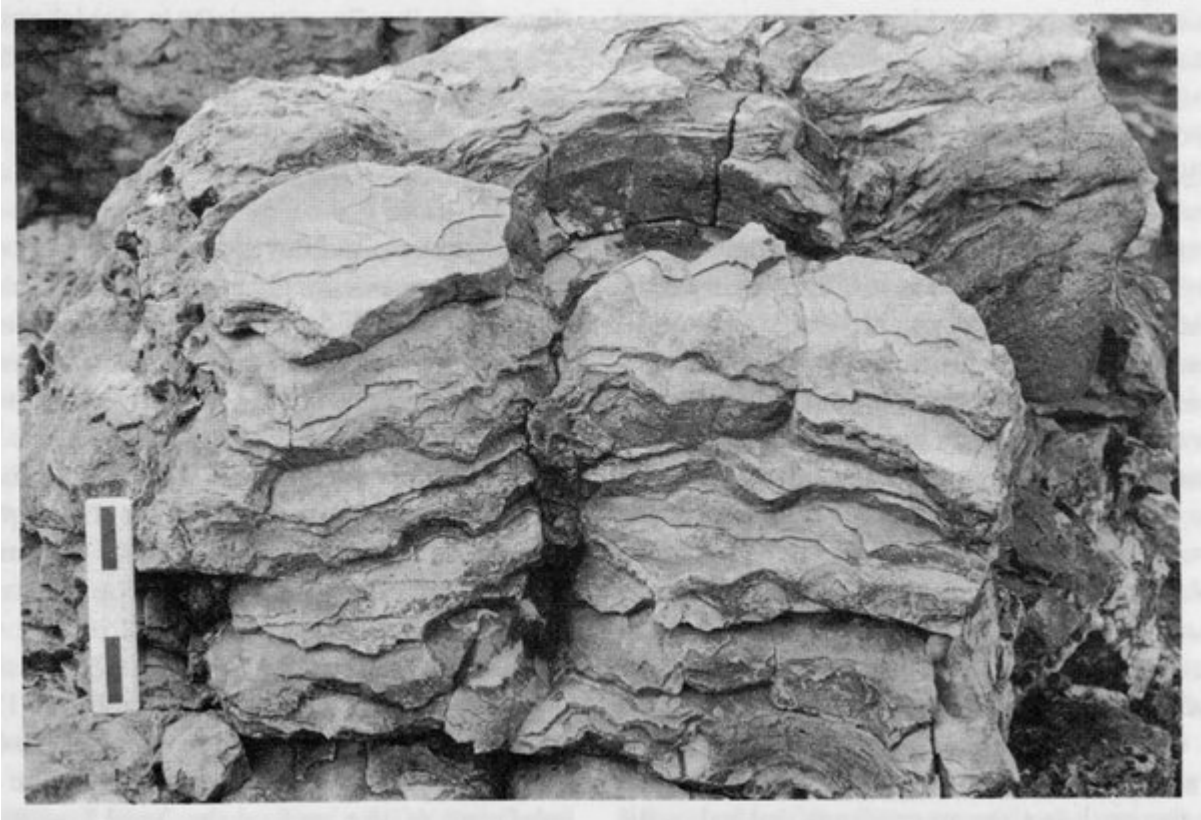
(Figure 3.45) Crumpled bedding in the lower beds of the Raisby Formation near the north end of the east face of High Moorsley Quarry, with evidence of contemporaneous truncation at the top of the disrupted beds. Hammer (middle top): 0.33 m. (Photo: D.B. Smith.)



(Figure 3.46) Hawthorn Quarry, showing the location of the main features of geological interest.

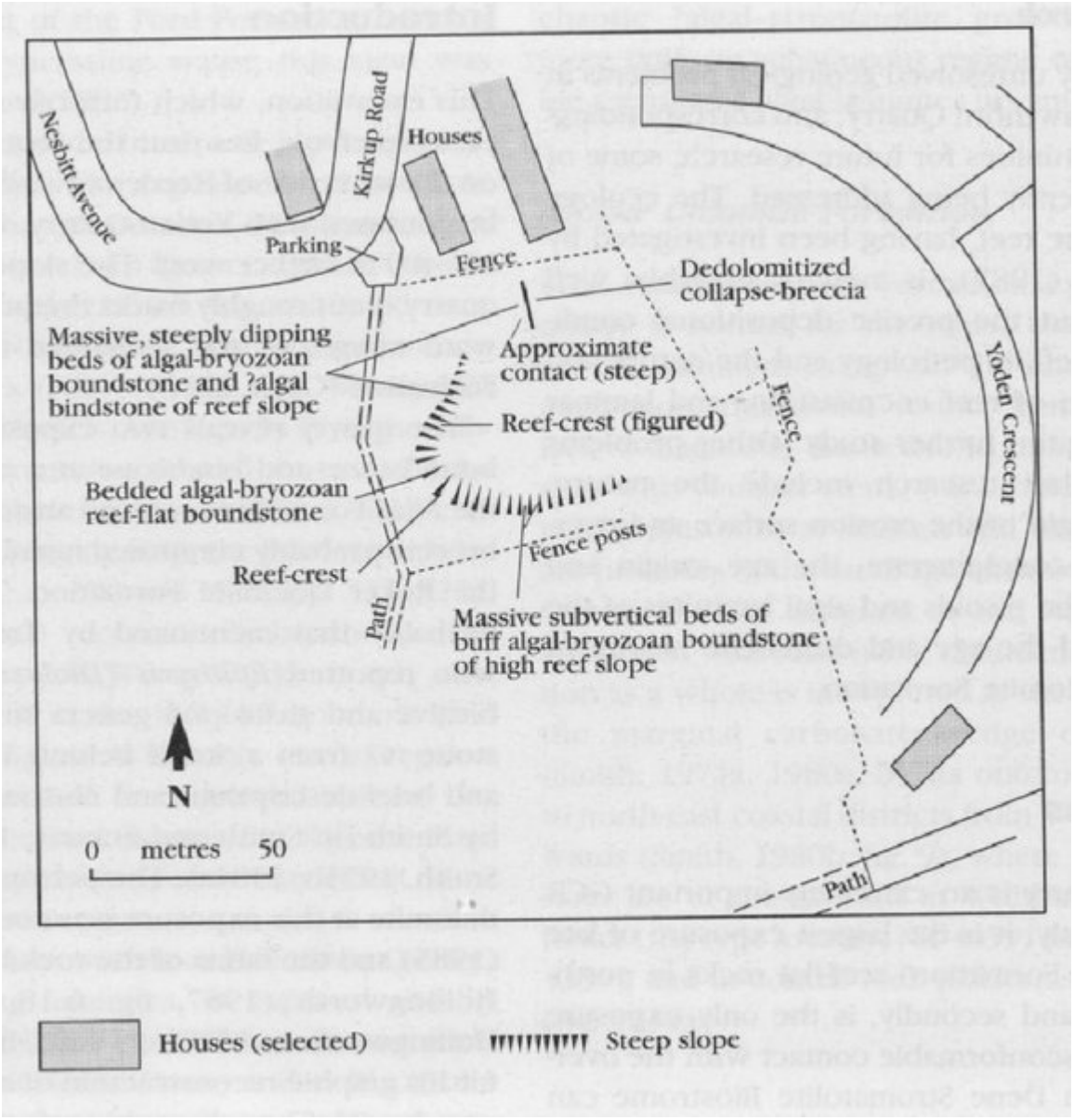


(Figure 3.47) Section across Hawthorn Quarry, showing the relationships of the main geological features. The line of section is shown in Figure 3.46.

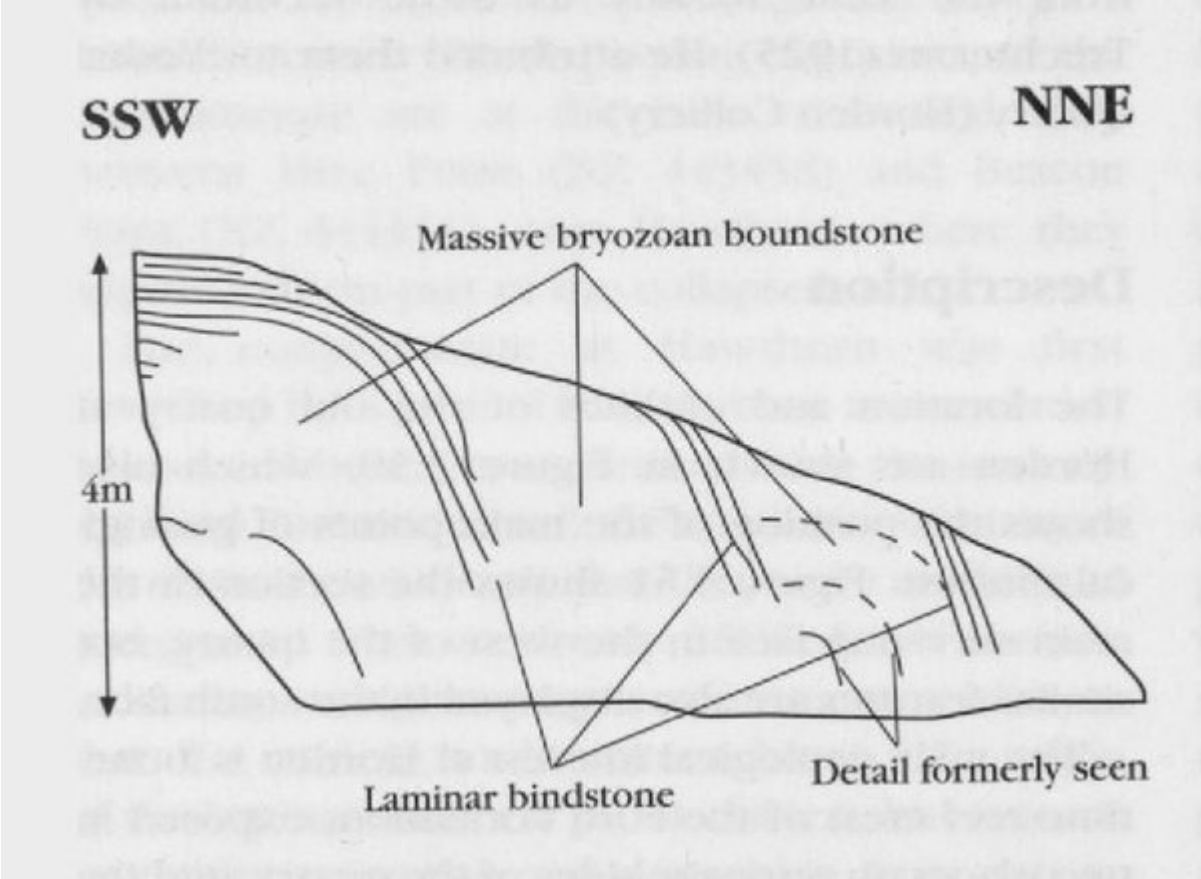


(Figure 3.48) Small columnar stromatolites just above the boulder conglomerate of the Hesleden Dene Stromatolite 13iostrome near the middle of the south face of Hawthorn Quarry. Bar: 0.32 m. (Photo: D.B. Smith.)

(Figure 3.49) Slight concentrations of manganese dioxide coating a bedding plane in the 'Crinkly Beel' near tl!e base of the Hesleclen Dene Stromatolite Biostrome near the miclclle of the south face of Hawthorn Quarry. Note the asymmetry of the ?algal growth-forms, indicating water flow from the right. Coin: 20 mm across. (Photo: D.B. Smith.)

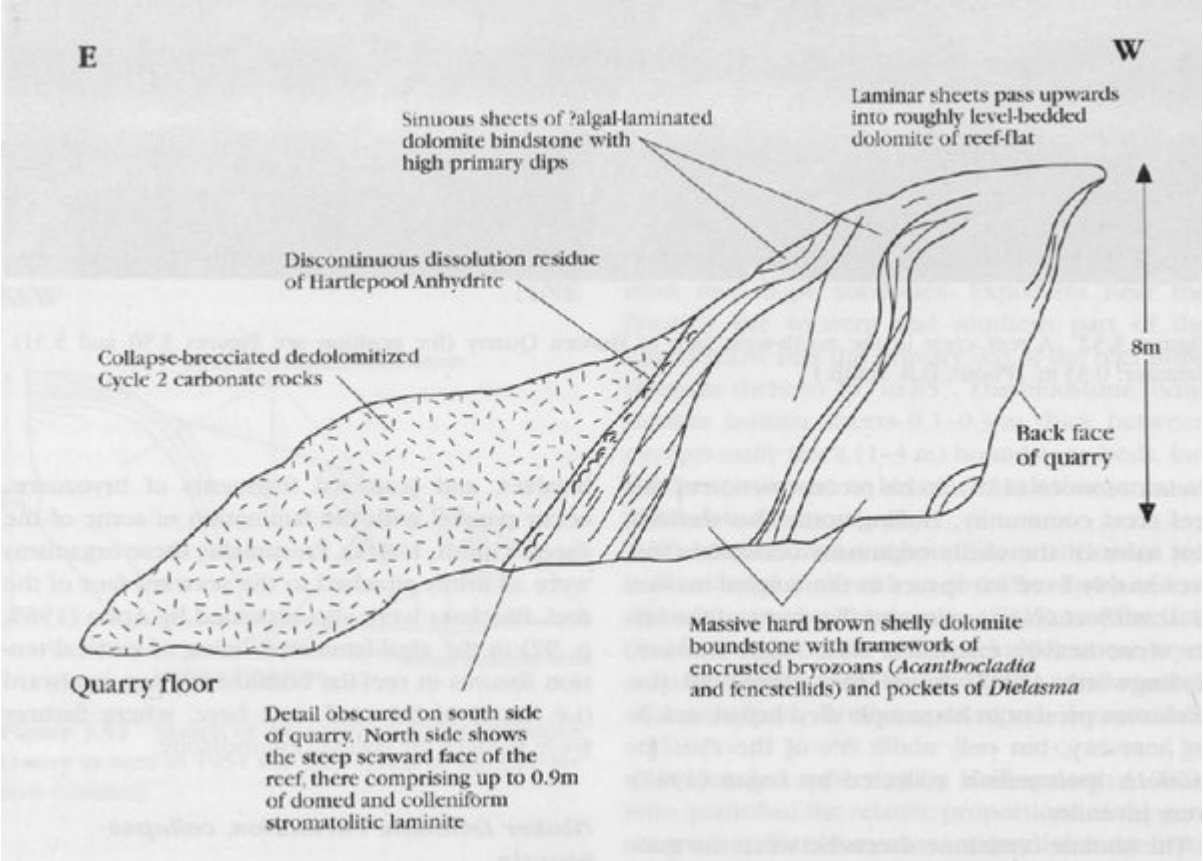


(Figure 3.50) Location of Horden Quarry and the main features of geological interest.

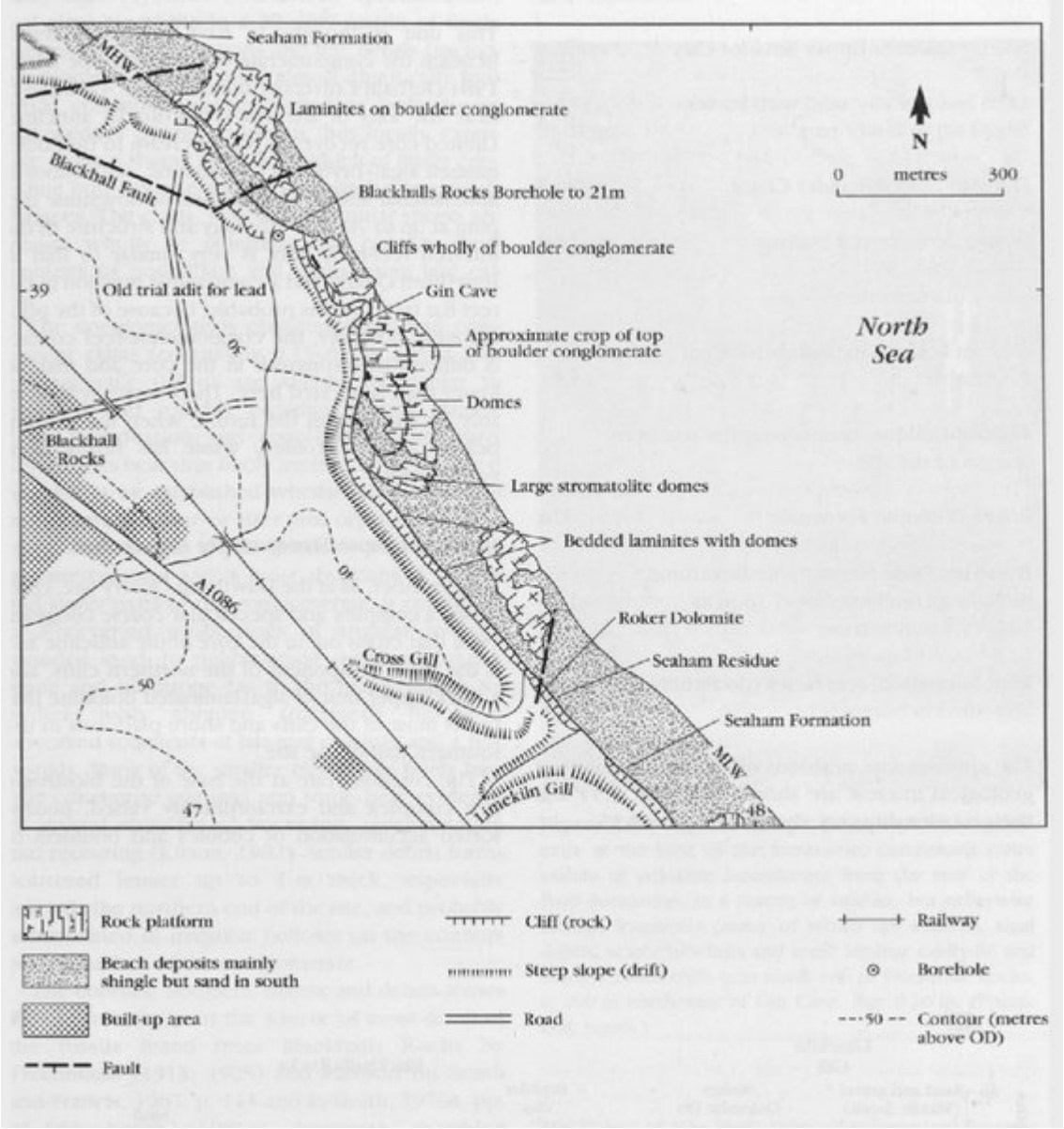


(Figure 3.51) Sketch of the north-west face of Horden Quarry as seen in 1954 and later (parts of the face are now covered).

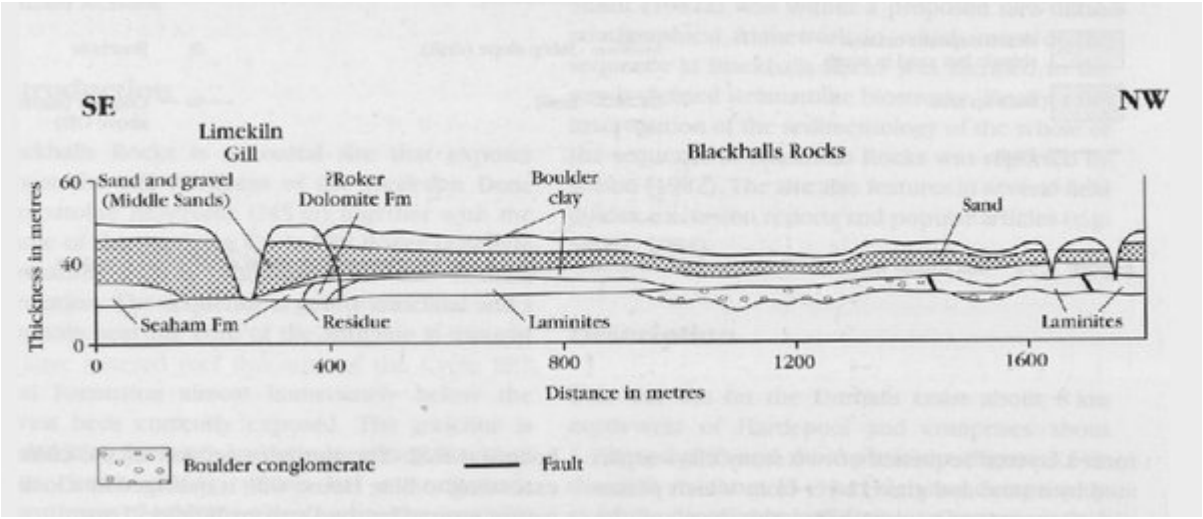
(Figure 3.52) A reef crest in the north-west face of Borden Quarry (for position see (Figure 3.50) and (Figure 3.51)). Hammer: 0.33 m. (Photo: D.B. Smith.)



(Figure 3.53) South side of old quarry (now filled) on the east side of Townfield Hill, Easington Colliery, showing the crest and stromatolitic seaward face of the shelf-edge reef, and succeeding residue and collapse-breccias. This quarry was recommended for SSSI designation but was filled before action could be taken; it is included here for the purposes of comparison.

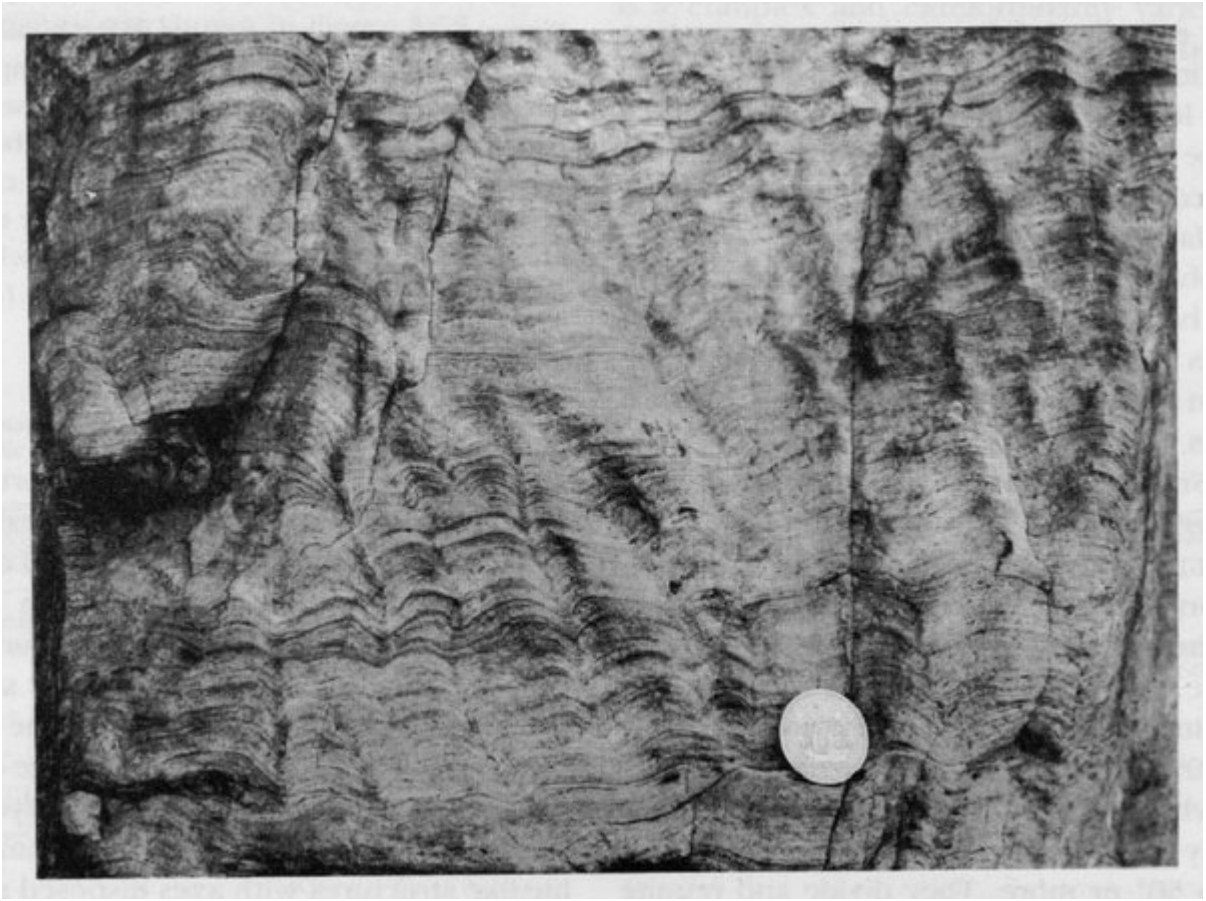


(Figure 3.54) Blackballs Rocks GCR site and its environs, showing the location of the main geological features.



(Figure 3.55) Geological strata in the cliffs of the Blackhalls Rocks GCR site (diagrammatic). The laminites and conglomerate together comprise the Hesleden Dene Stromatolite Biostrome. Slightly modified from Smith (1984, p. 24).

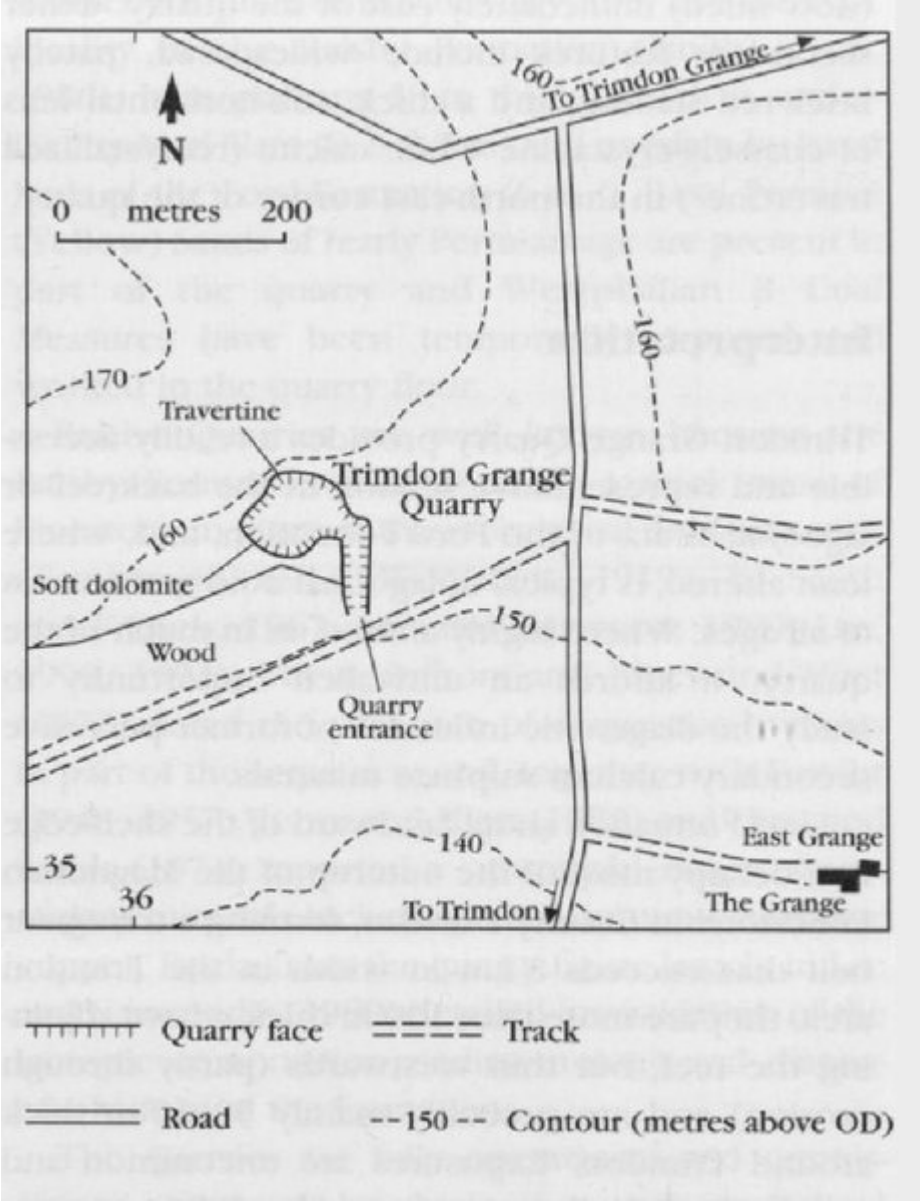
(Figure 3.56) Typical example of the boulder conglomerate at the base of the biostrome, comprising clasts mainly of dolomite boundstone from the reef of the Ford Formation, in a matrix of smaller, but otherwise similar, fragments (many of which are coated), algal debris, scarce bioclasts and some laminar cavity-fill and lining. Coastal cliffs near north end of Blackhalls Rocks, c. 200 m north-west of Gin Cave. Bar: 0.16 m. (Photo: D.B. Smith.)



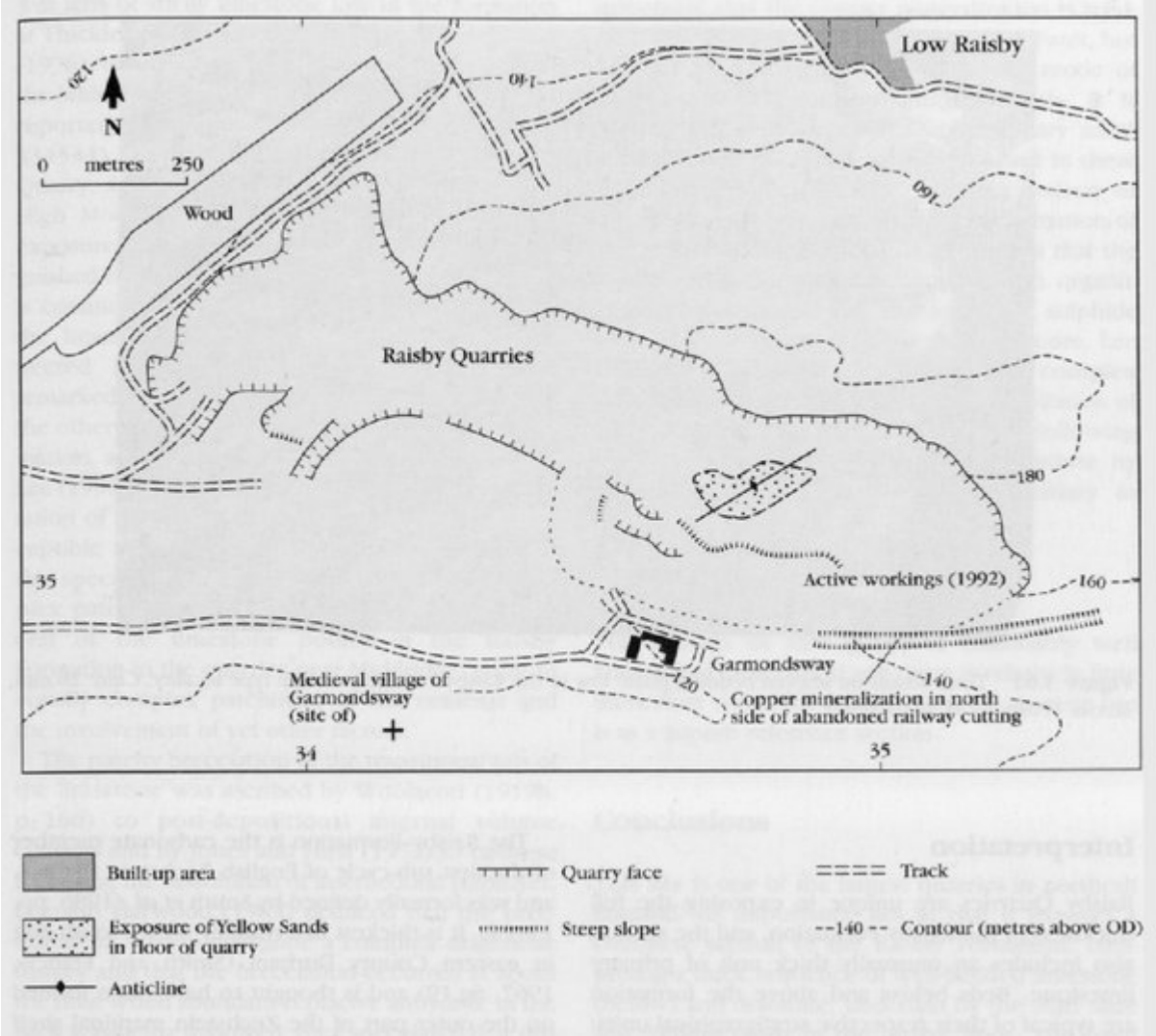
(Figure 3.57) Laminar algal bindstone of the 'Crinkly Bed' at the base of the Hesleden Dene Stromatolite Biostrome. Coastal cliffs c. 60 m south of Gin Cave (see (Figure 3.54)). Coin: 26 mm across. (Photo: D.B. Smith.)

(Figure 3.58) Thin section of multi-coated pisoids from steep-sided pockets in the upper part of the 'Crinkly Bed' in coastal cliffs near Gin Cave, Blackhalls Rocks. Interstices and the core of some formerly leached pisoids are occupied by equant dolomite microspar, but many of the pisoids are nucleated on to abraded dolomite clasts including portions of earlier fractured pisoids. Bar: 8 mm. (Photo: D. Kitson.)

(Figure 3.59) Broad dolomite stromatolite domes in about the middle of the Hesleden Dene Stromatolite Biostrome, on the foreshore near Green Stairs, Blackhalls Rocks. Hammer: 0.33 m. (Photo: D.B. Smith.)

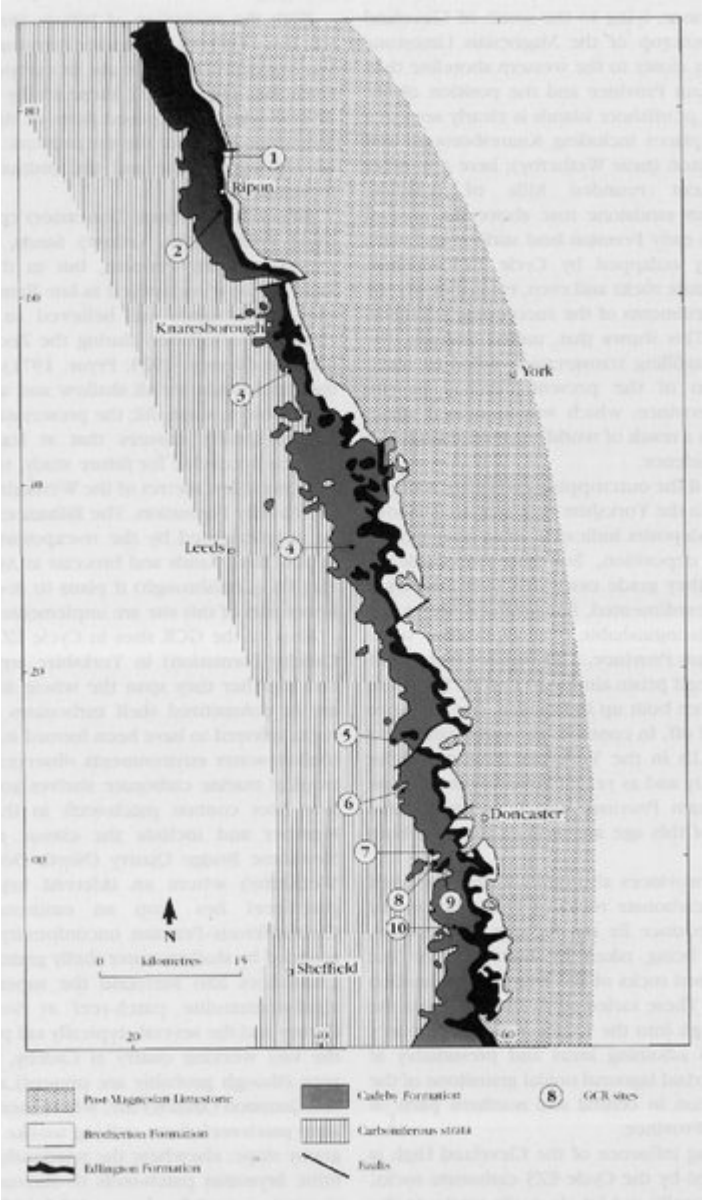


(Figure 3.60) Trimdon Grange Quarry and its immediate surroundings, showing the main features of geological interest.

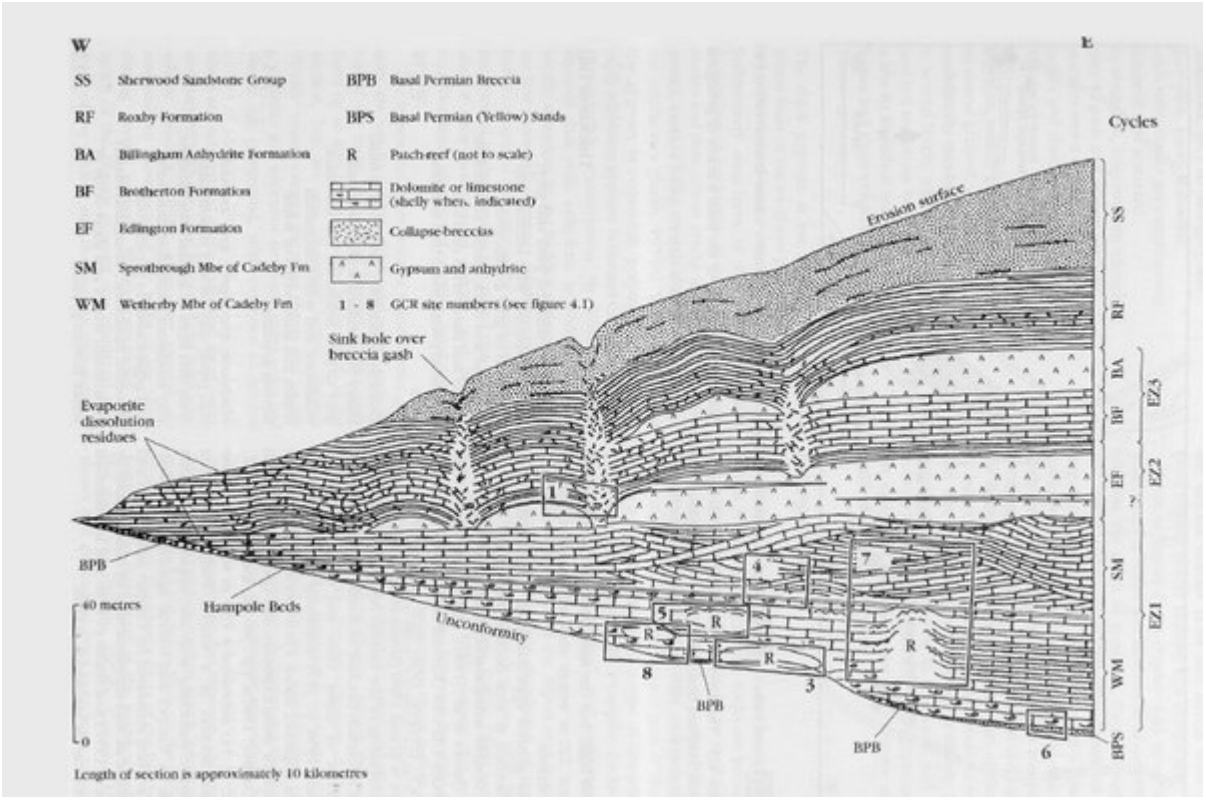


(Figure 3.61) Raisby Quarries: the north face in the cast is the type locality of the Raisby Formation (Smith et al., 1986).

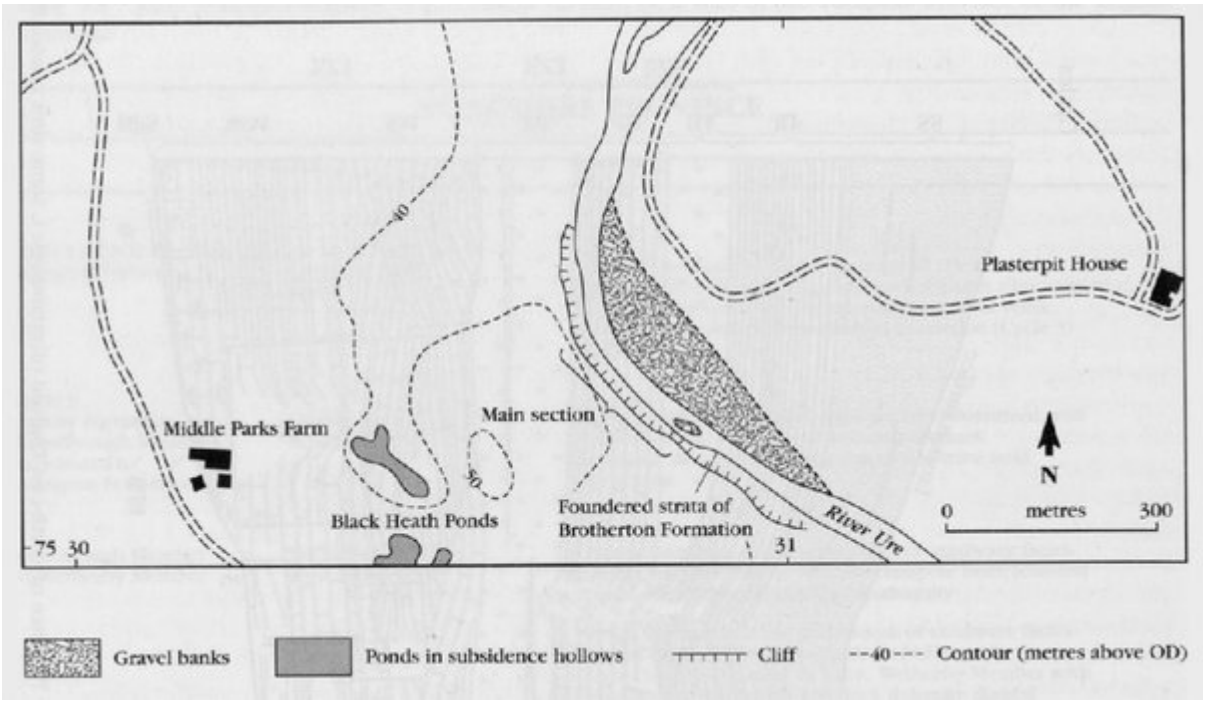
(Figure 3.62) Trace fossils on uneven bedding plane low in the Raisby Formation at the type locality. Coin: 26 mm across. (Photo: T.H. Pettigrew.)



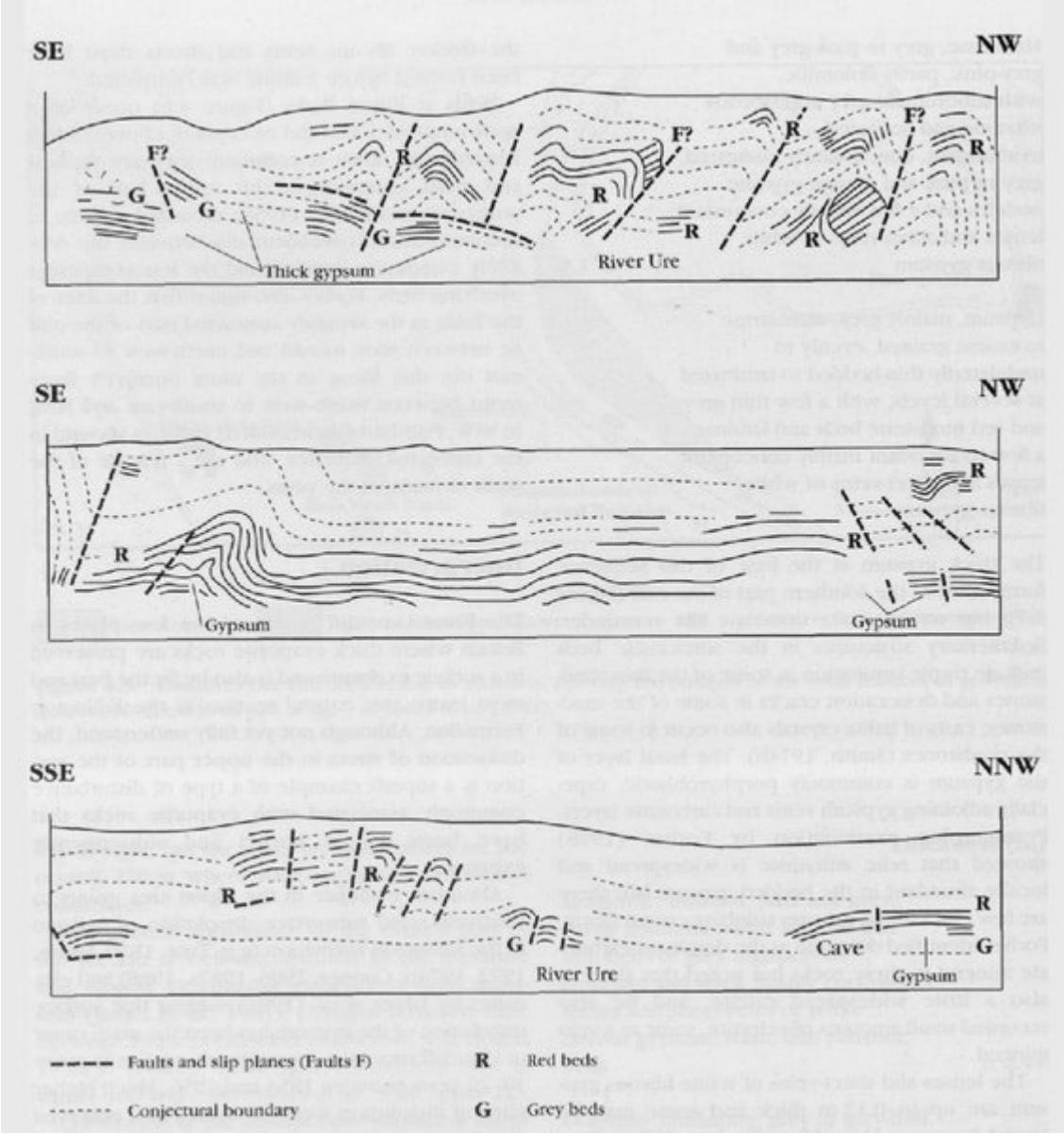
(Figure 4.1) The distribution of Permian marine rocks in the Yorkshire Province, showing the location of Permian marine GCR sites: 1, River Ure Cliff; 2, Quarry Moor; 3, Newsome Bridge Quarry; 4, Micklefield Quarry; 5, South Elmsall Quarry; 6, Bilham Quarry; 7, Cadeby Quarry; 8, Ashfield Brick-clay Pit; 9, New Edlington Brick-clay Pits; 10, Wood Lee Common, Maltby.



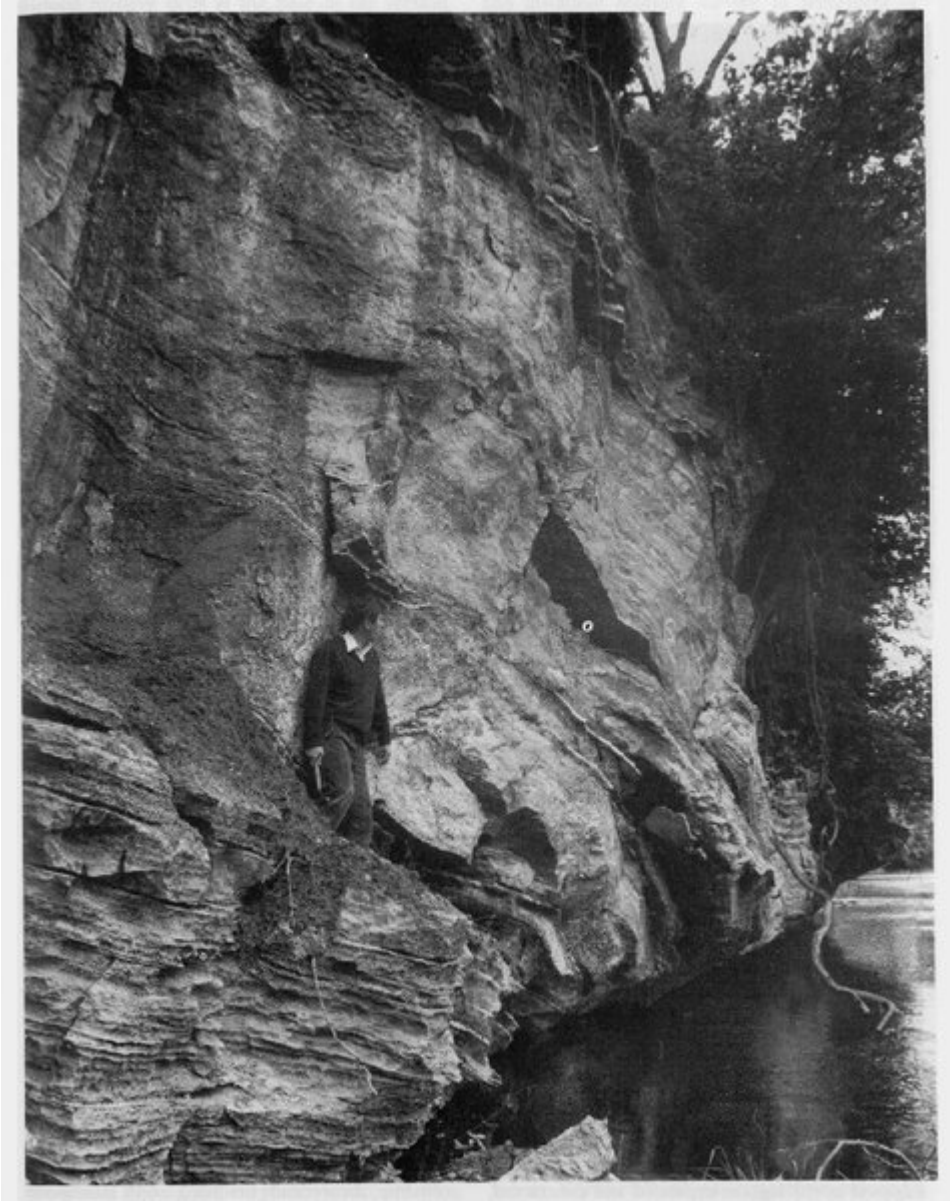
(Figure 4.2) Approximate stratigraphical position of marine Permian GCR sites in the Yorkshire Province of north-east England (diagrammatic). Some sites cannot be shown on this line of section and have been omitted.



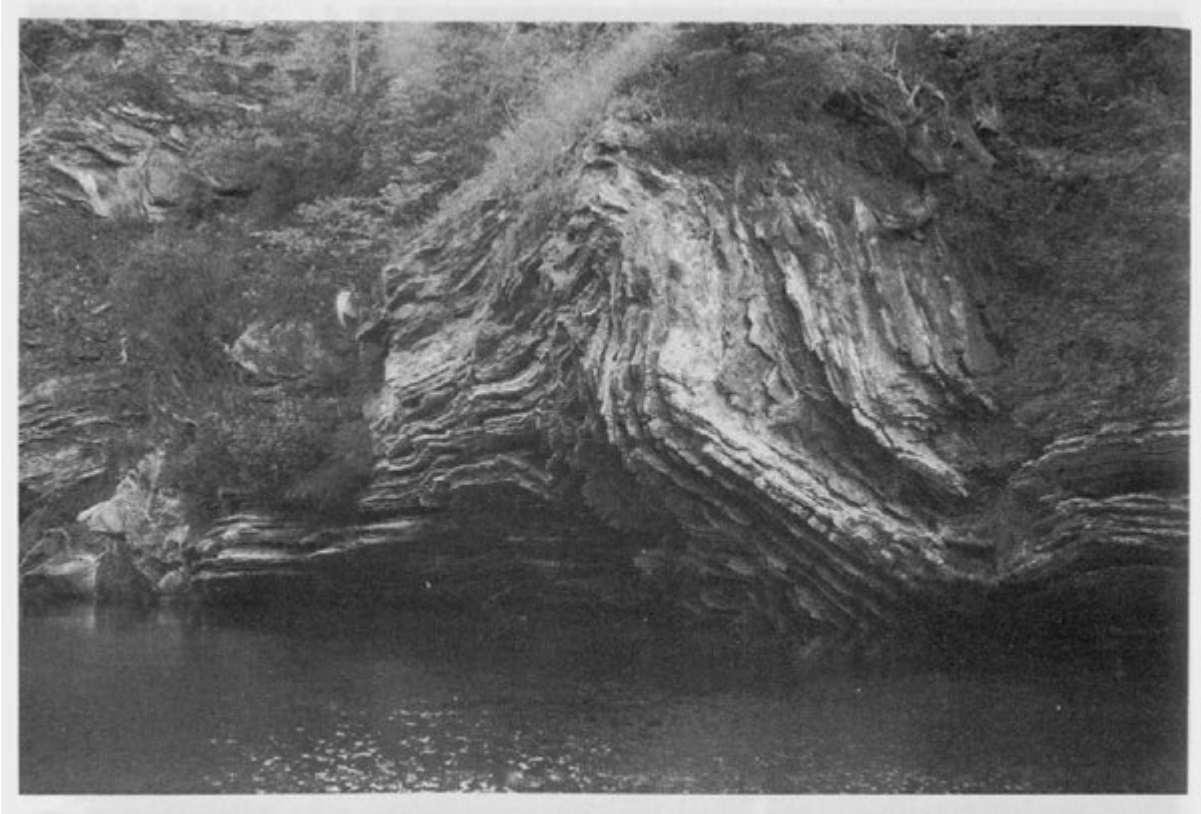
(Figure 4.3) The River Ure cliff section and its environs, showing the position of the main features of geological interest. Modified from part of fig. 3 of James et al. (1981).



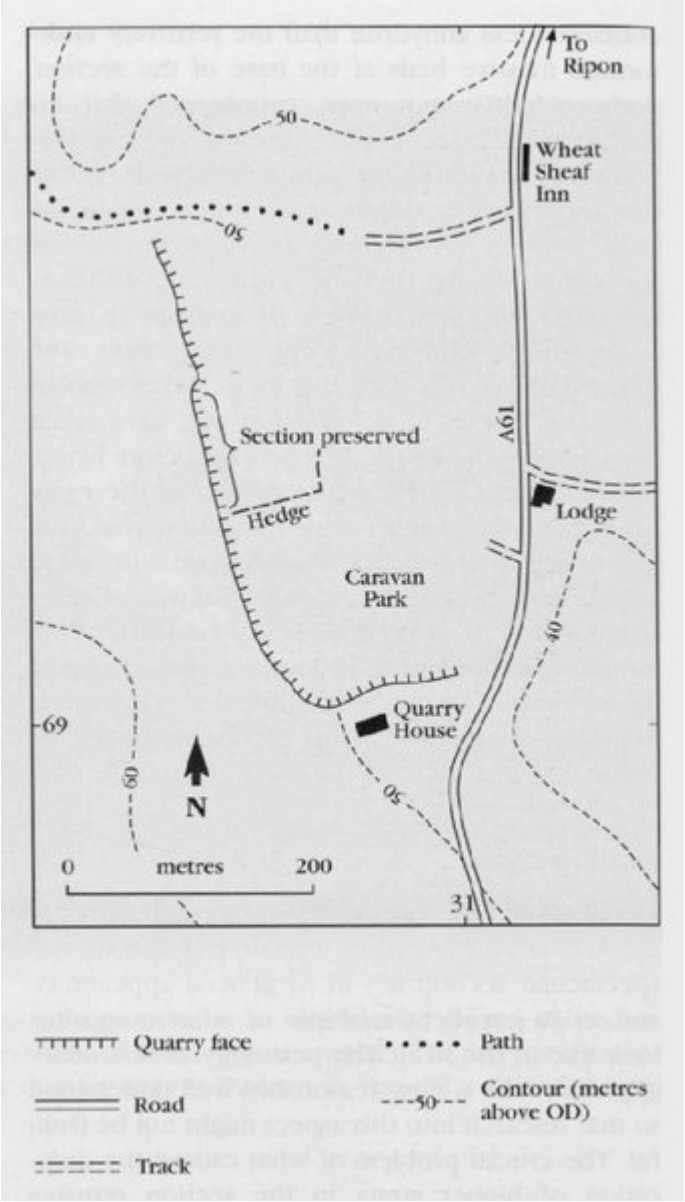
(Figure 4.4) Sketch (top left to bottom right) of the main face of the River Ure Cliff, showing the principal geological features; slightly modified from Forbes (1958, fig. 2). Gypsum lies mainly at the base of the cliff except at the southern end. Total length of section shown is about 220 m, height about 7.5 m.



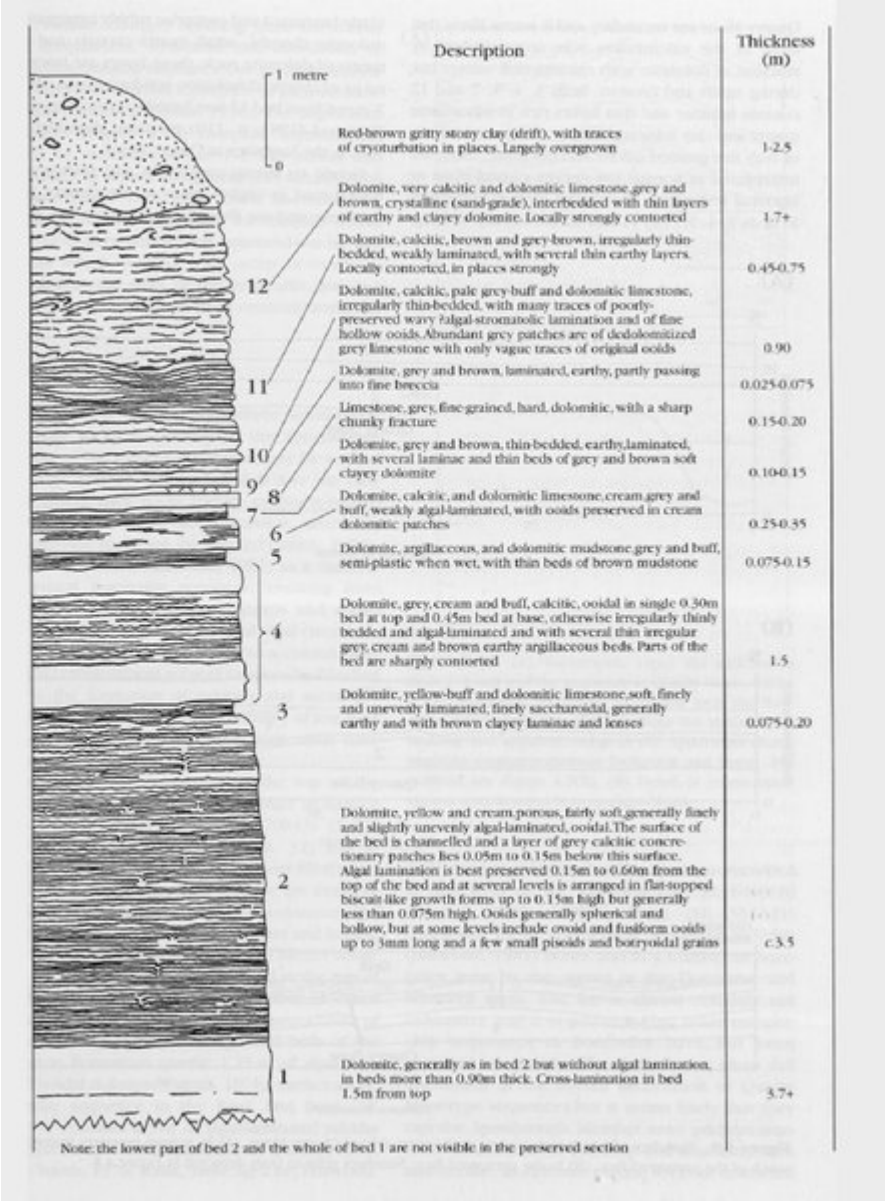
(Figure 4.5) Gypsum, possibly equivalent to the Hayton Anhydrite, forming most of the river cliff at the southern end of the main rock section at Ripon Parks. Note the abundant sub-concordant sheet-veins of fibrous gypsum (white) in the upper part of the section. (Photo: A.H. Cooper.)



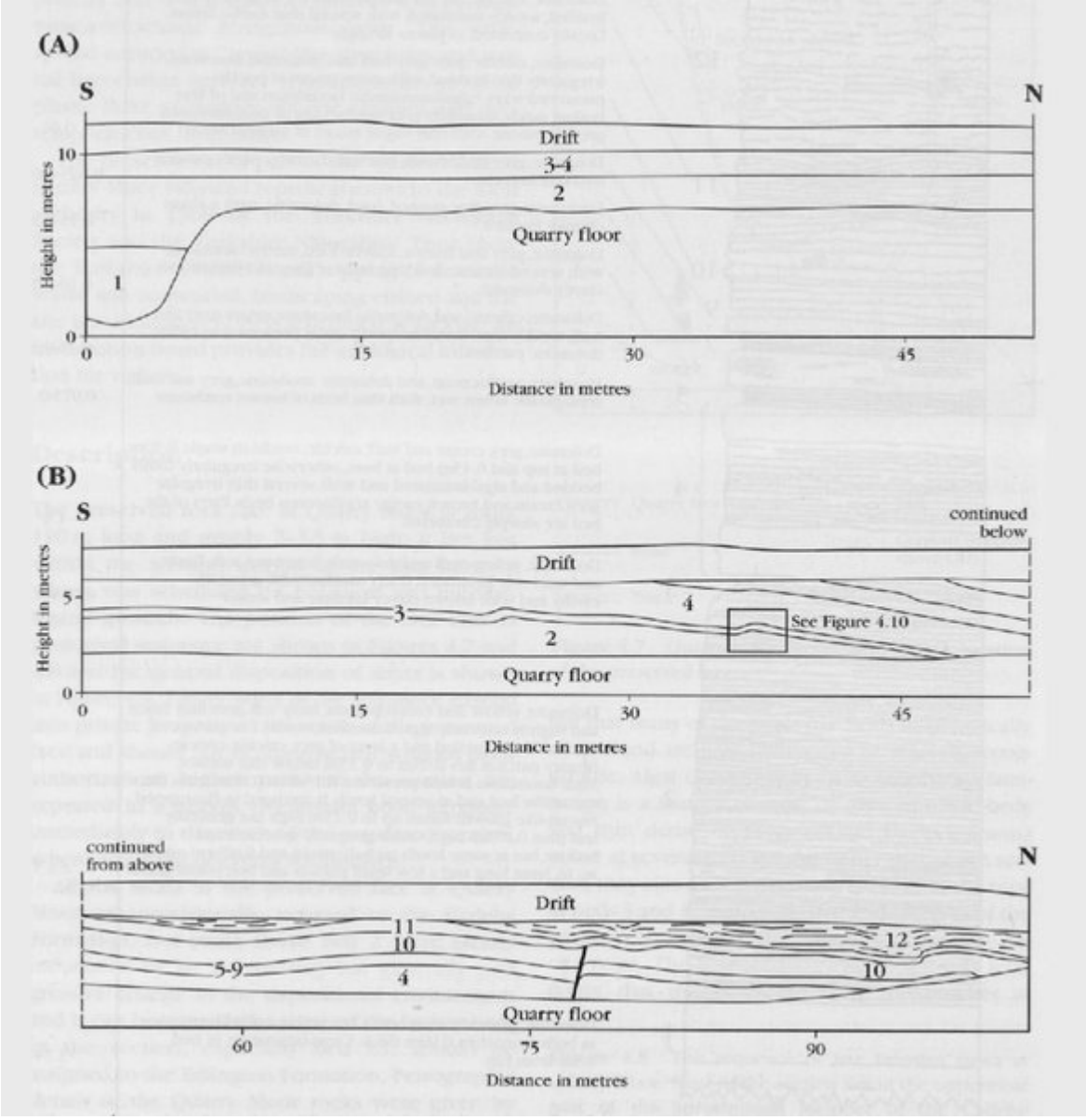
(Figure 4.6) Sharp fold in mainly siliciclastic strata of the Edlington Formation with bedded gypsum (?=Hayton Anhydrite) at the base, and with many sub-concordant sheet-veins of fibrous gypsum (white). The fold is still recognizable at the southern end of the middle sector in Forbes' drawing of 1958 (Figure 4.4). The cliff is about 6 m high at this point. (Photo: A.H. Cooper.)



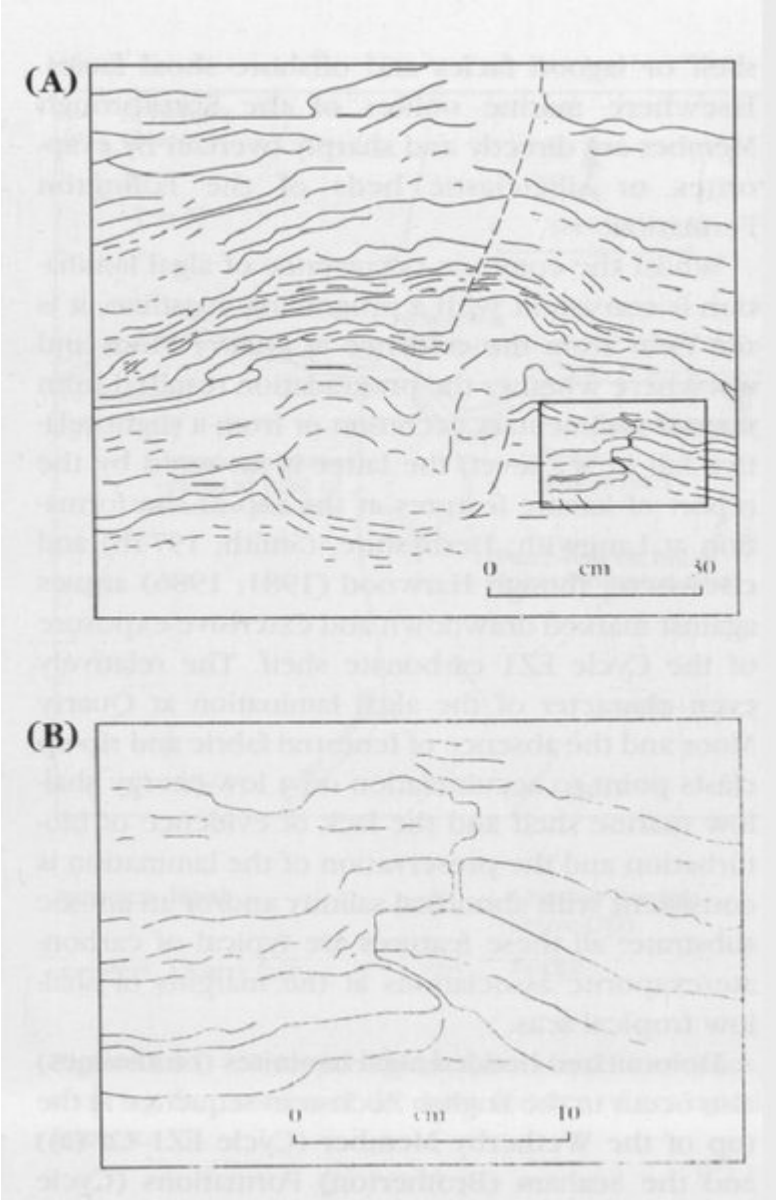
(Figure 4.7) Quarry Moor, Ripon, showing the location of the preserved face.



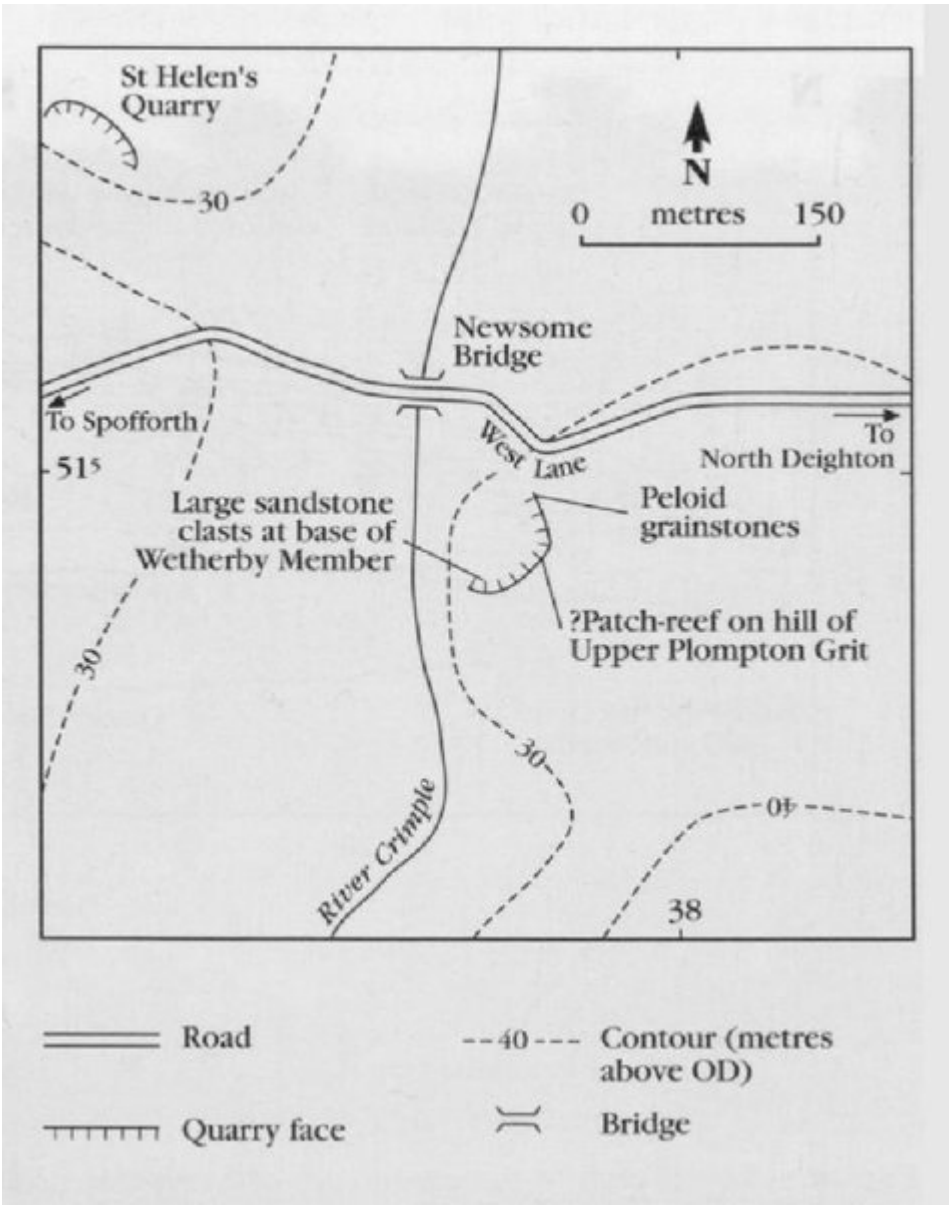
(Figure 4.8) The sequence of late Permian strata at Quarry Moor. Most of the section lies in the uppermost part of the Sprotbrough Member of the Cadeby Formation, but some of the higher beds may be part of the overlying Edlington Formation.



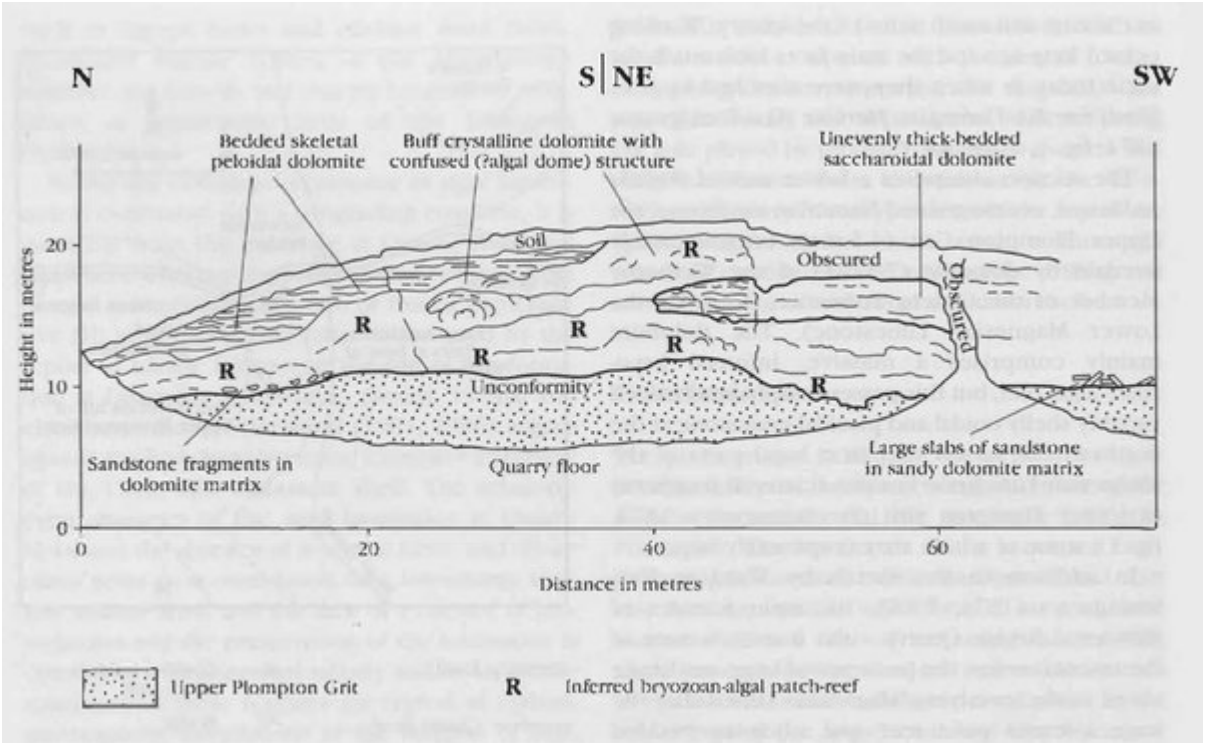
(Figure 4.9) Sketches of late Permian strata at the west side of Quarry Moor. (A) In private property immediately south of the preserved face. (B) In the preserved face. Numbers refer to beds depicted in Figure 4.8. flow, volume changes resulting from the formation, dehydration, hydration and dissolution of evaporites (mainly sulphates but possibly including halite) and, in some examples, to early lithification and expansion (Smith, 1976). The 'tepee'-like structures (Figure 4.10) comprise asymmetrical domes or anticlines about 1–1.5 m across and 0.5 m high in which competent (i.e. already lithified) carbonate beds have been fractured and thrust by lateral expansion; interbedded softer strata have been folded and squeezed-out by this process which, judging from onlap of overlying beds against the sides of the structures, and erosion at the top, must have been contemporaneous.



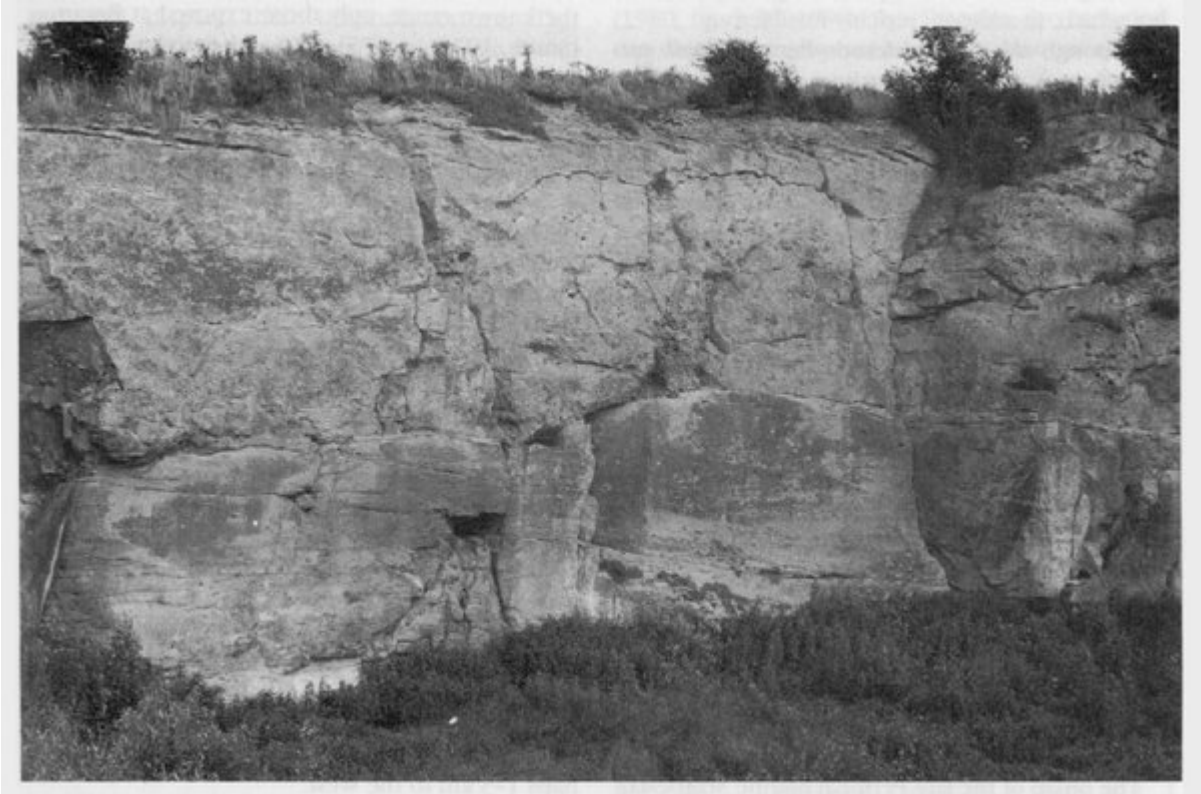
(Figure 4.10) (A) Non-tectonic 'tepee'-like anticline in beds 2, 3 and 4 of the sequence at Quarry Moor, with a 0.3 m shortening shown by overthrust near the base and a minor fault near the top. Note the almost level bedding and apparent onlap in the uppermost strata, implying contemporaneous formation and burial. For position see (Figure 4.9)(B). (B) Detail of ?contemporaneous overthrust at bottom right of (A).



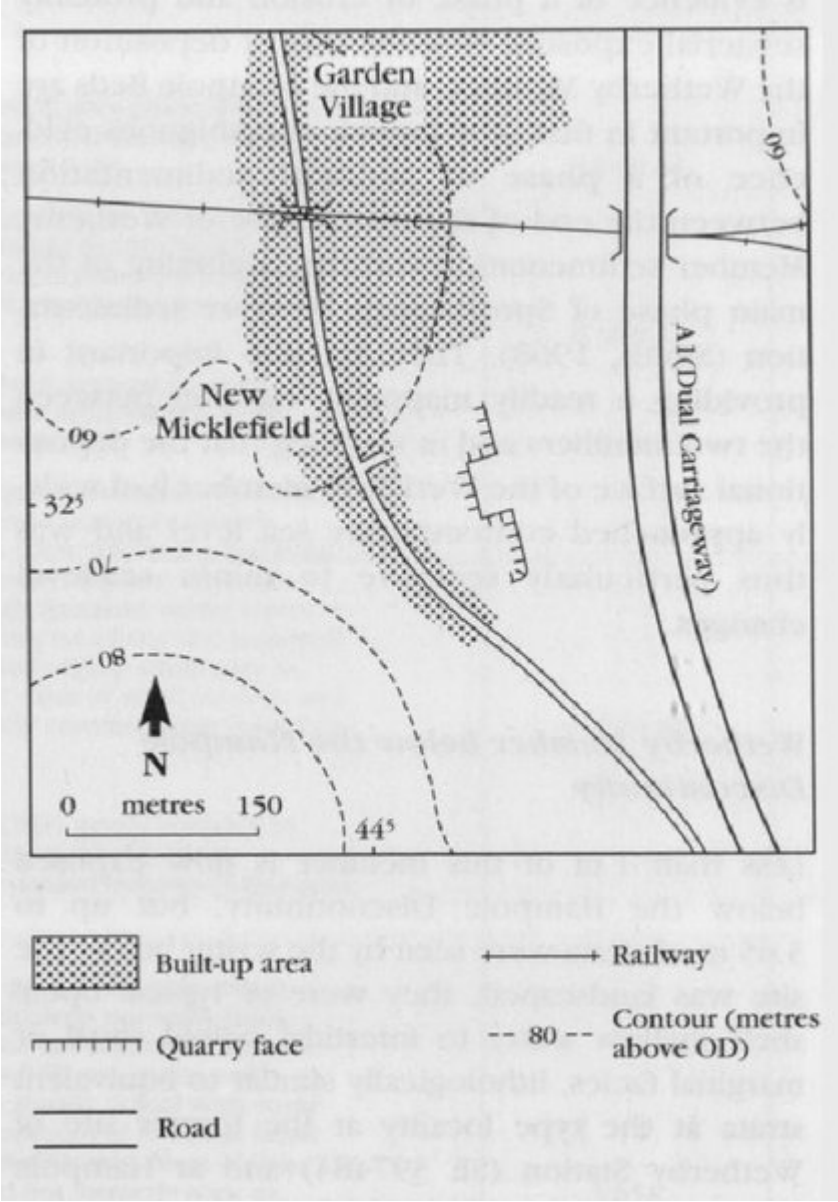
(Figure 4.11) Newsome Bridge Quarry and its environs, showing the position of the main features of geological interest.



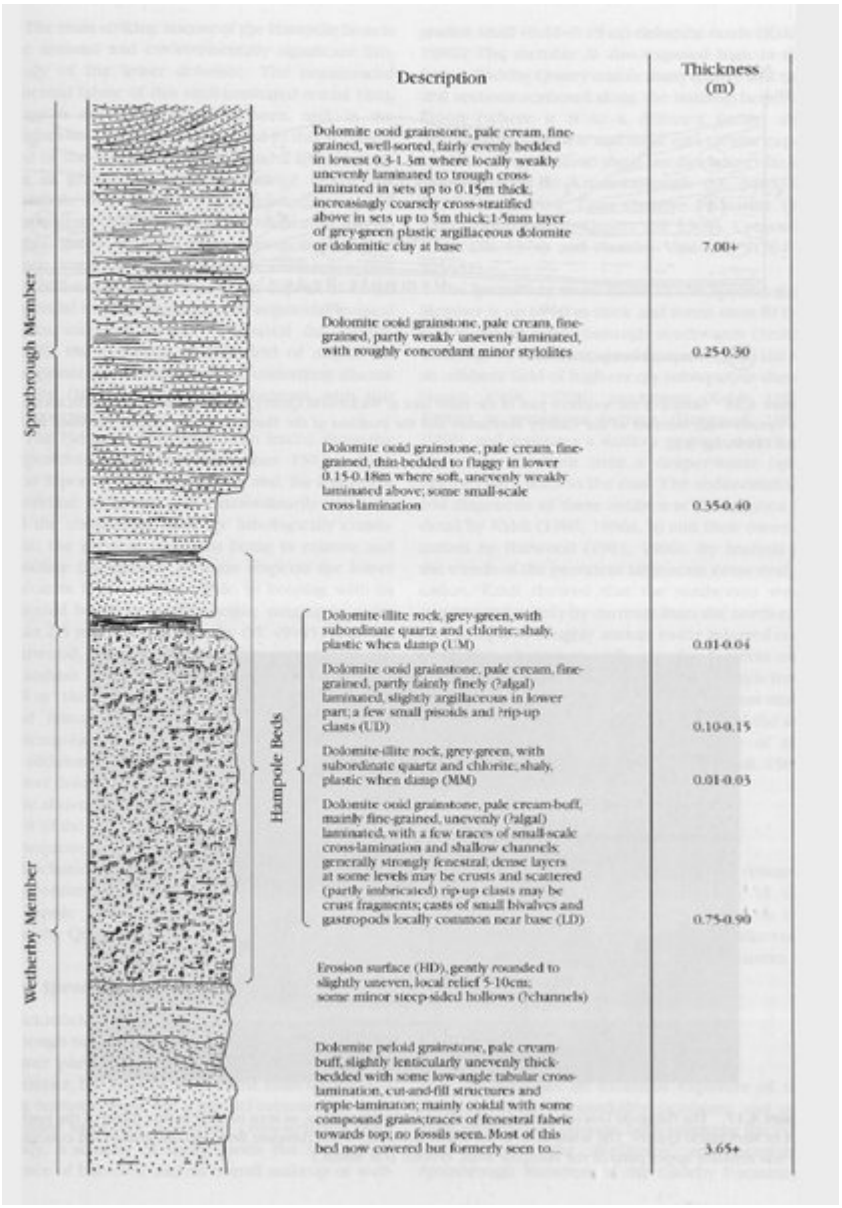
(Figure 4.12) Sketch of the main faces of Newsome Bridge Quarry showing the inferred bryozoan-algal patch-reef centred on an eminence in the Carboniferous–Permian unconformity here cut onto Upper Plompton Grit.



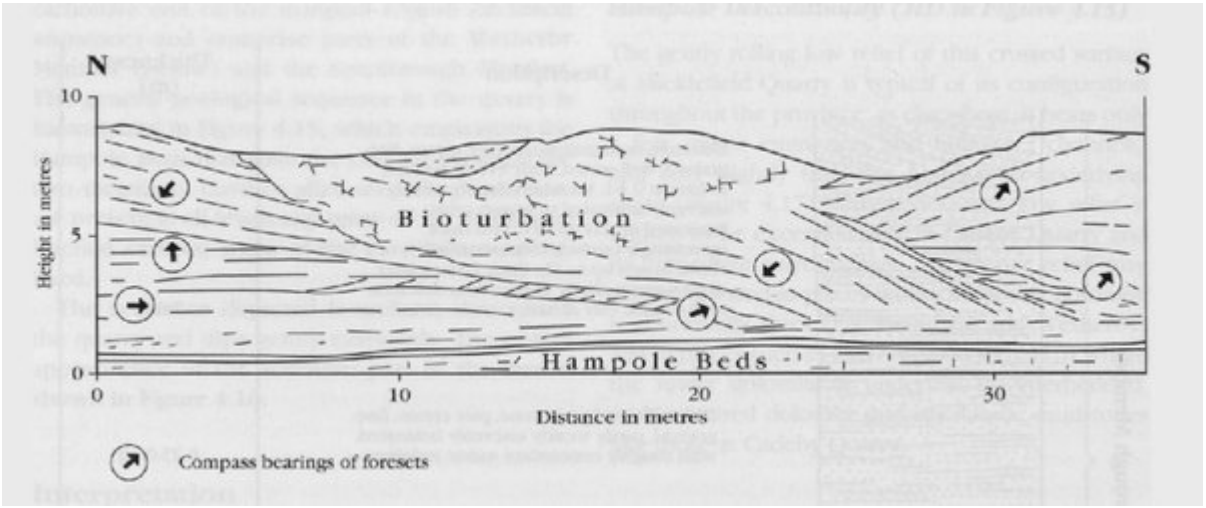
(Figure 4.13) East face of the Newsome Bridge Quarry, showing the inferred patch-reef of the Wetherby Member of the Cadeby Formation and equivalent bedded strata, resting unconformably on Upper Carboniferous strata. For scale and interpretation see (Figure 4.12). (Photo: Total Oil Company.)



(Figure 4.14) Position of Micklefield Quarry GCR site.

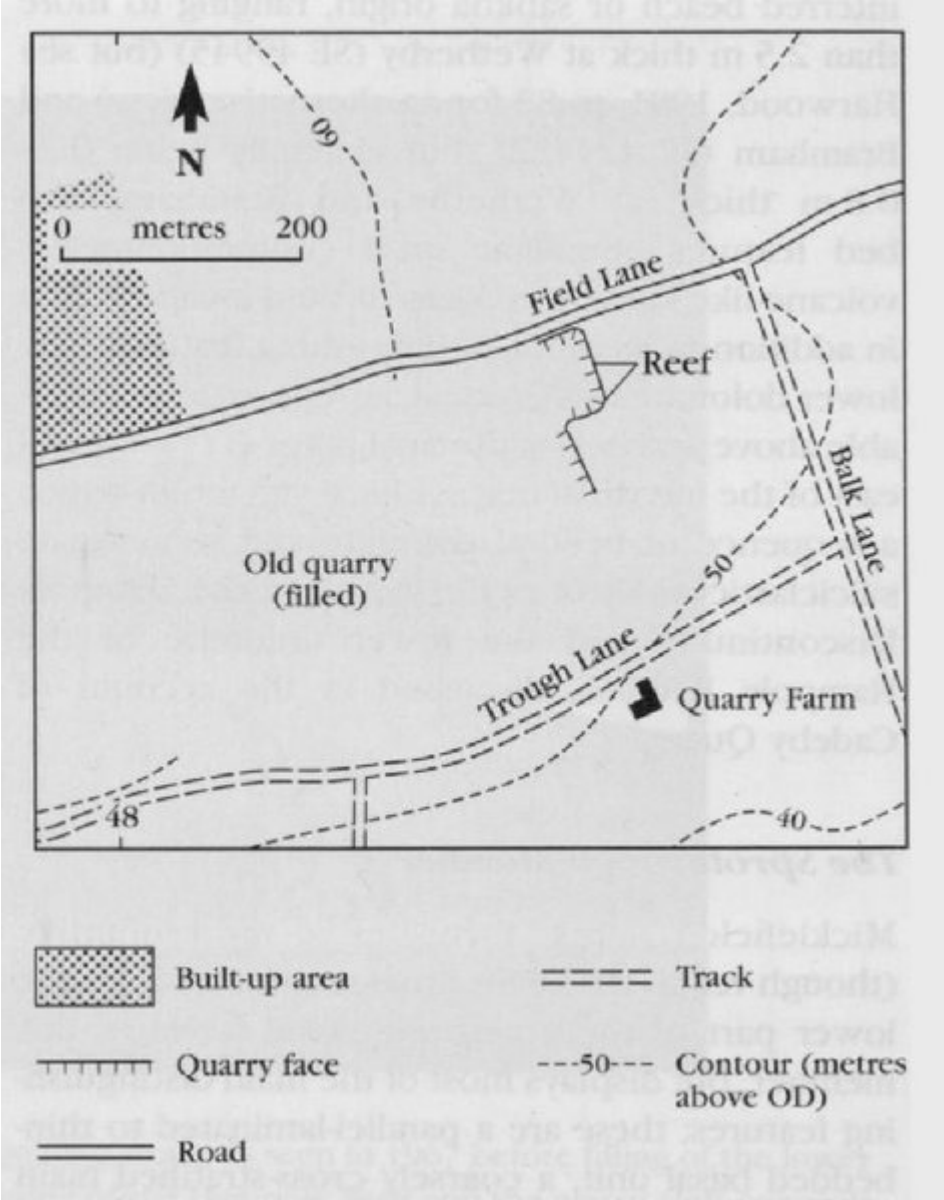


(Figure 4.15) Section of the Hampole Beds and other strata at Micklefield Quarry. Abbreviations signify parts of the typical Hampole Beds sequence: HD, Hampole Discontinuity; LD, lower dolomite; MM, middle mudstone; UD, upper dolomite; UM, upper mudstone. The lower mudstone is absent. The Wetherby Member–Sprotbrough Member contact is taken at the top of the lower dolomite.

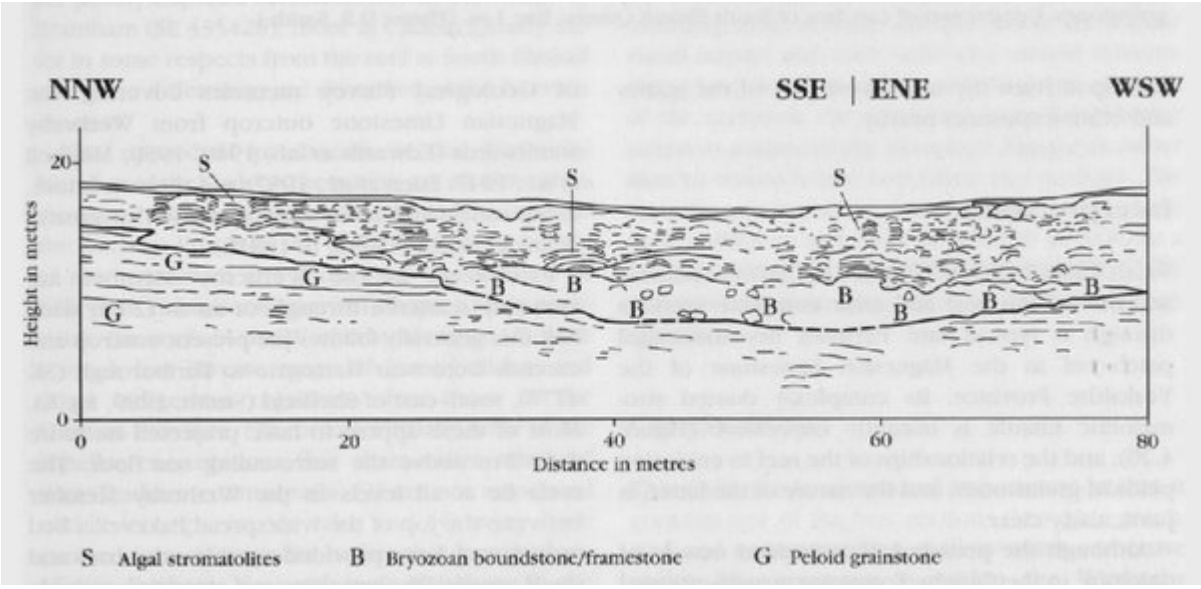


(Figure 4.16) Sketch of the southern part of the main face at Micklefield Quarry, showing the cross-stratification in the Sprotbrough Member of the Cadeby Formation and the position of the Hampole Beds. Slightly modified from Kaldi (1980, fig. 3.3).

(Figure 4.17) The Hampole Discontinuity (arrowed) and adjoining strata, as seen in 1967 before filling of the lower part of Micklefield Quarry. The white layer is the lower dolomite of the Hampole Beds and the grassy cleft conceals the less resistant upper parts of the Hampole Beds. (Photo: D.B. Smith.)



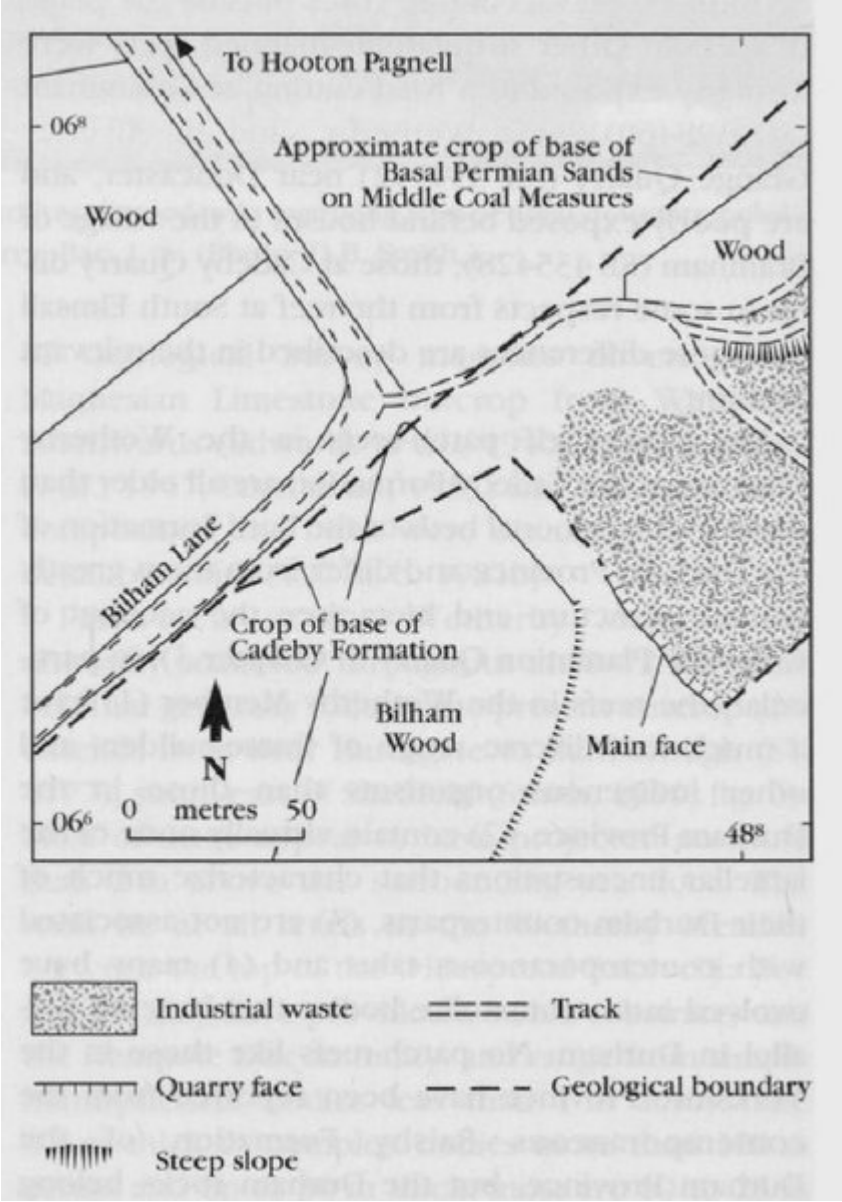
(Figure 4.18) South Elmsall Quarry, showing the position of the GCR site.



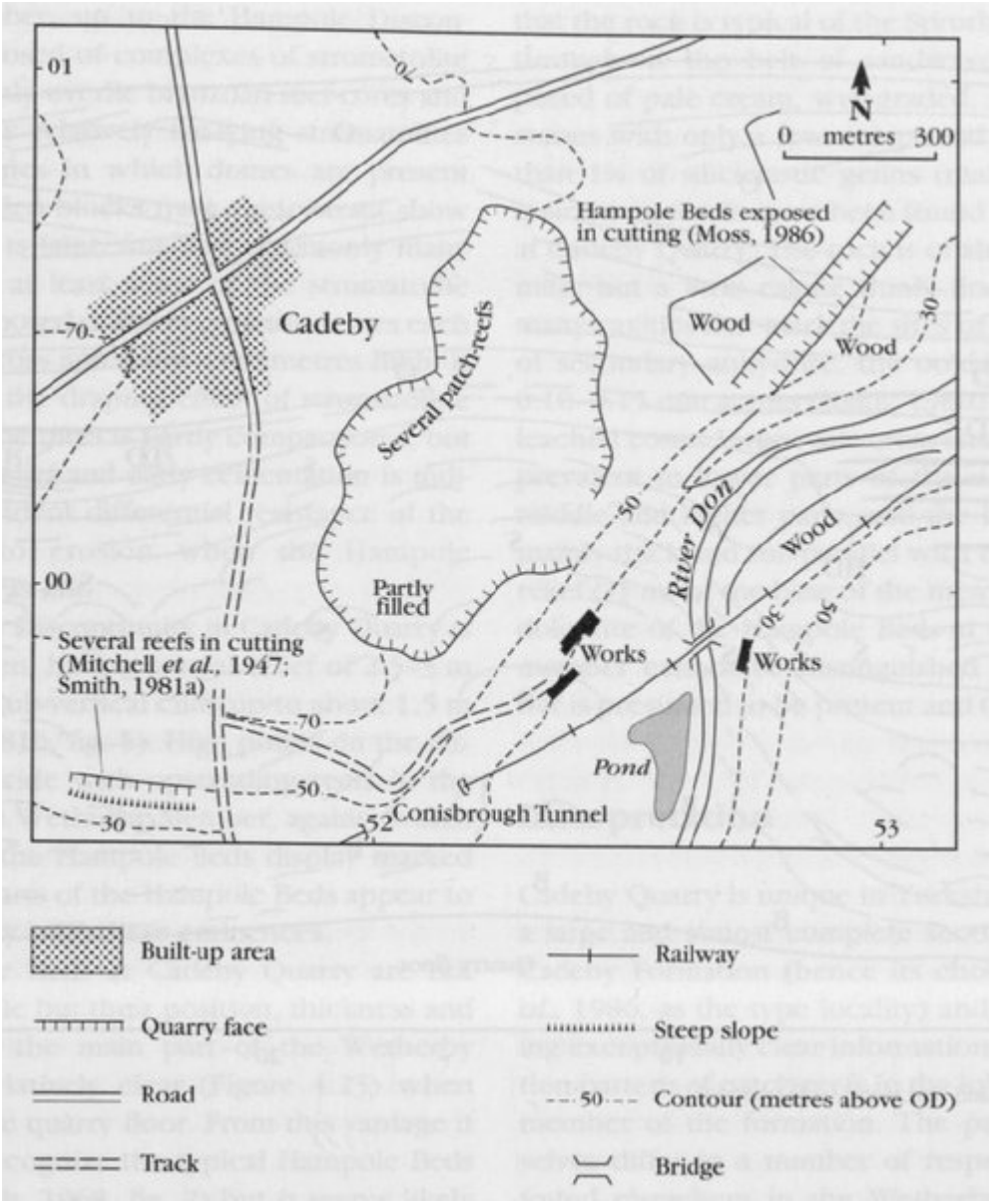
(Figure 4.19) Cross-section of an algal-stromatolite reef in peloid grainstones of the Wetherby Member of the Cadeby Formation, South Elmsall Quarry. The core of the reef is of massive bryozoan boundstone and is overlain by more extensive stromatolites that pass laterally NNW into sparingly skeletal peloid grainstone. The stromatolites extend at least 30 m to the right of the area depicted. Note: lowest strata depicted are now covered. Slightly modified from Smith (1981b,

fig. 12).

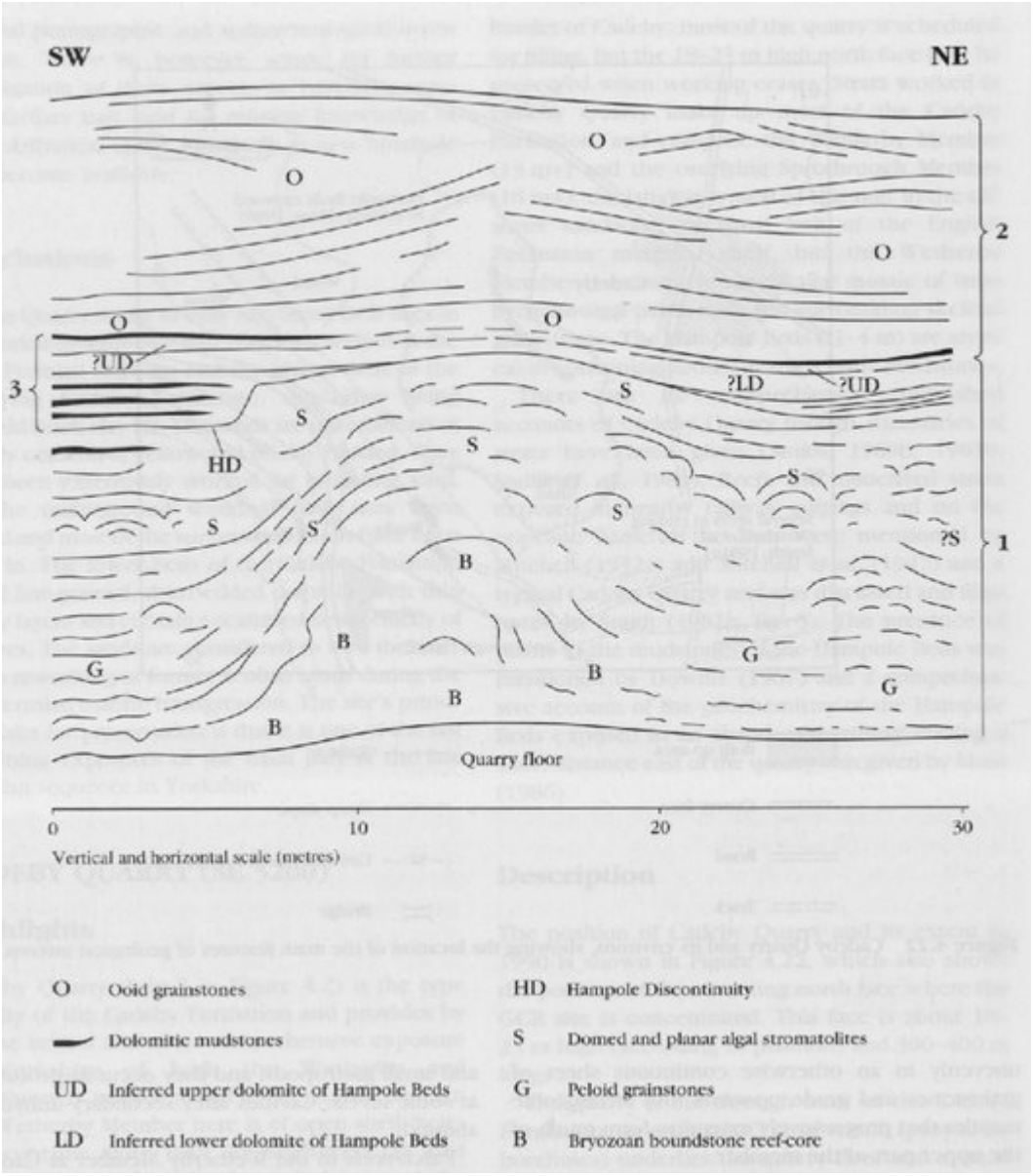
(Figure 4.20) Complexly domed dolomitized algal-stromatolites discordantly overlying thin-bedded dolomite peloid grainstones. Central part of east face of South Elmsall Quarry. Bar: 1 m. (Photo: D.B. Smith.)



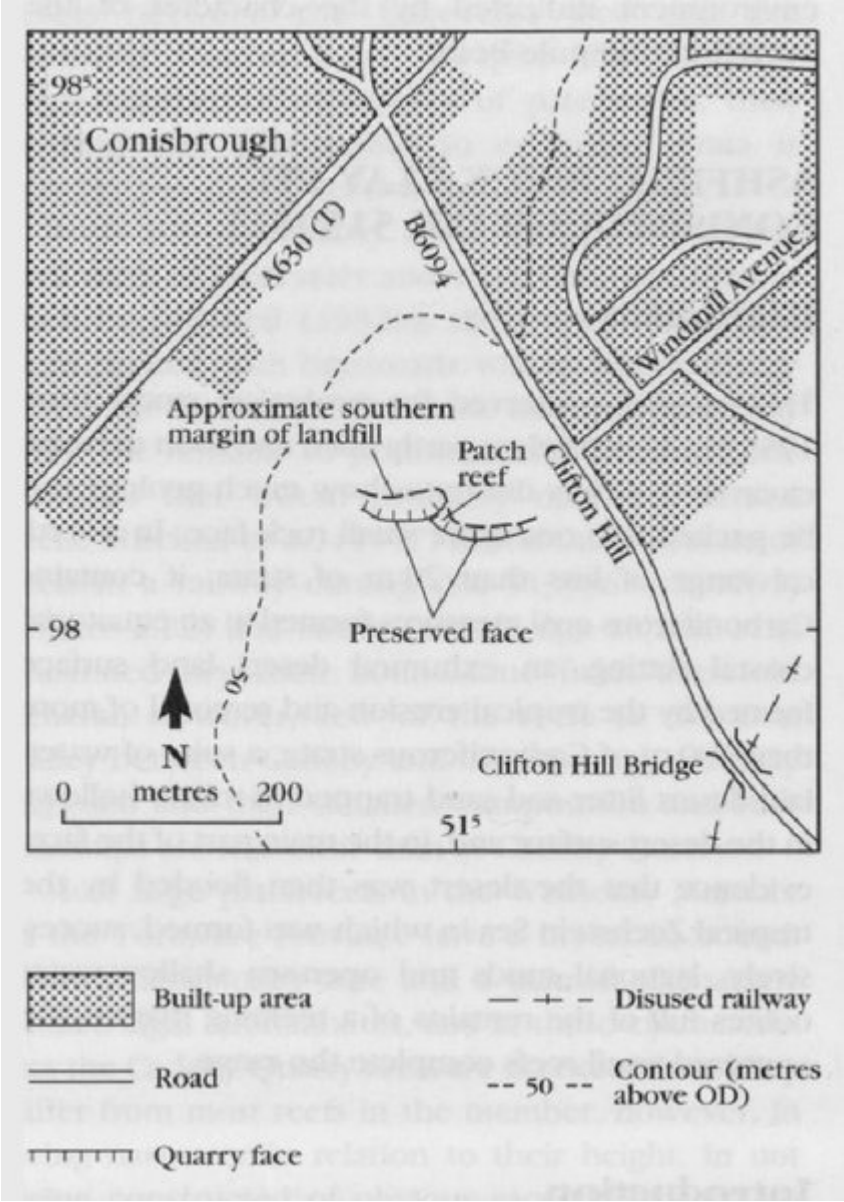
(Figure 4.21) The preserved area of Bilham Quarry and its environs.



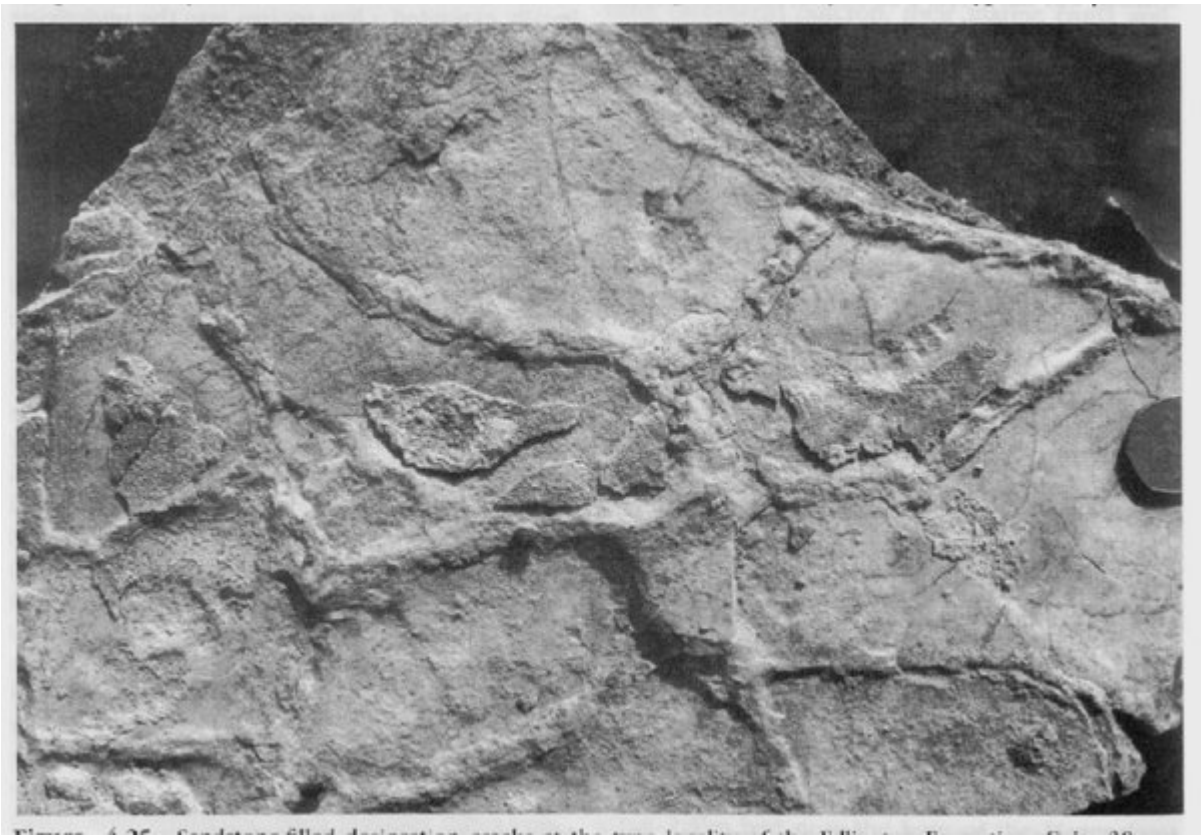
(Figure 4.22) Cadeby Quarry and its environs, showing the location of the main features of geological interest.



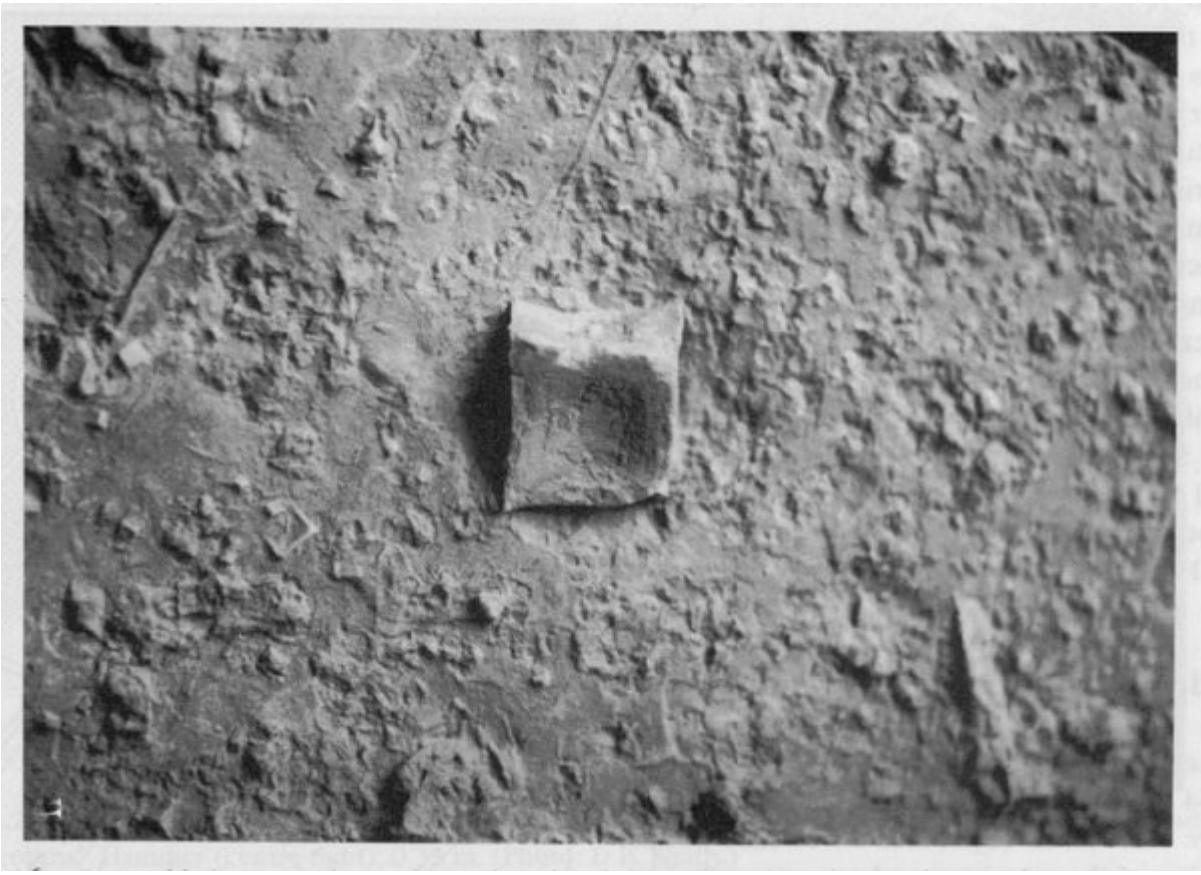
(Figure 4.23) Diagrammatic sketch showing the relationships of the stratigraphical units and main rock types in the north-west face of Cadeby Quarry. The face is about 22 m high. 1, Wetherby Member; 2, Sprotbrough Member; 3, Hampole Beds, resting on the Hampole Discontinuity.



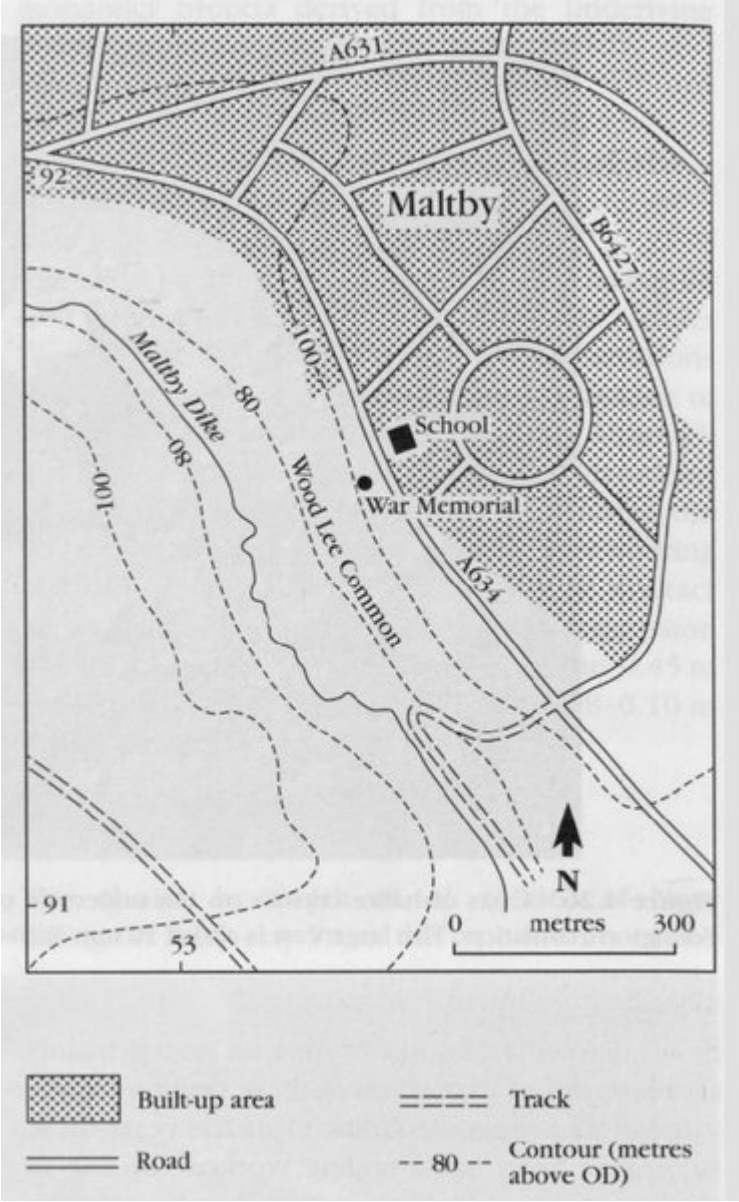
(Figure 4.24) Ashfield Brick-clay Pit, Conisbrough, and its environs, showing the location of the main features of geological interest.



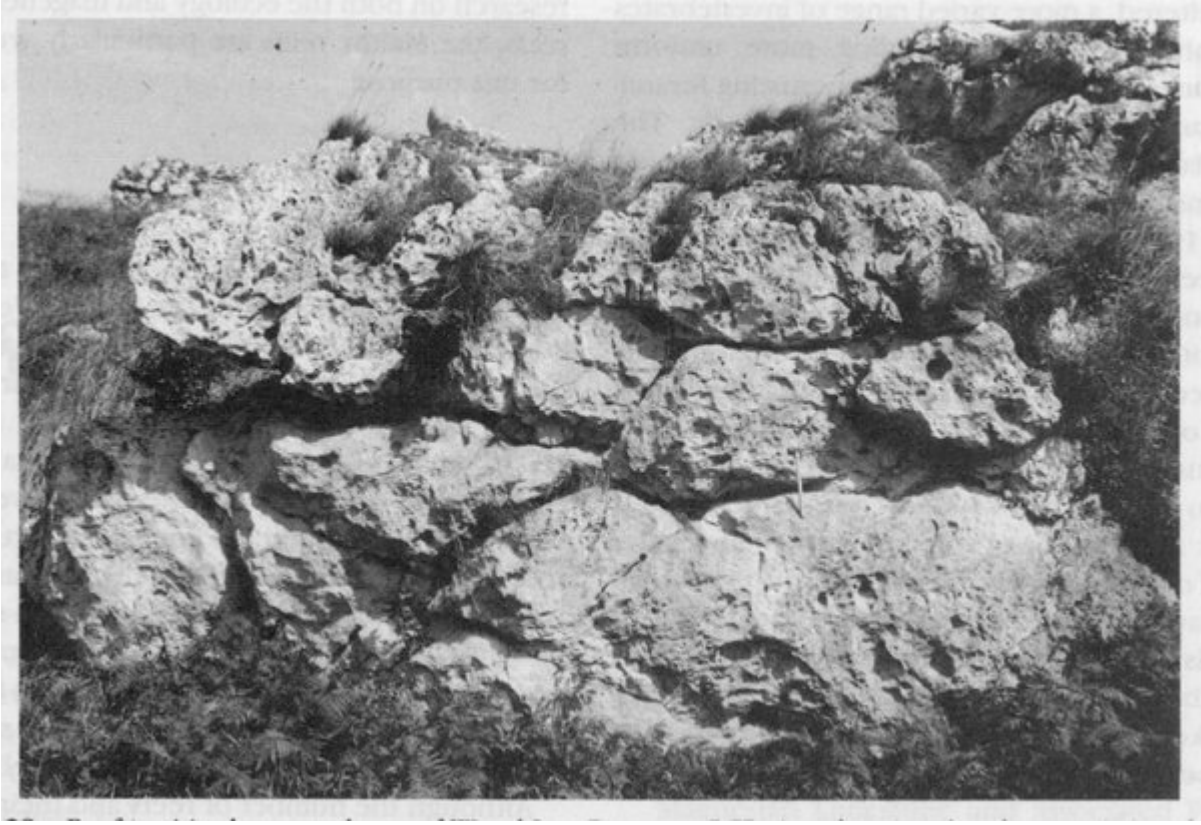
(Figure 4.25) Sandstone-filled desiccation cracks at the type locality of the Edlington Formation. Coin: 30 mm across. (Photo: D.B. Smith.) Figure 4.26 Casts of halite crystals on the underside of an argillaceous siltstone bed at the type locality of the Edlington Formation. The large cast is about 10 mm across. (Photo: D.B. Smith.)



(Figure 4.26) Casts of halite crystals on the underside of an argillaceous siltstone bed at the type locality of the Edlington Formation. The large cast is about 10 mm across. (Photo: D.B. Smith.)



(Figure 4.27) Wood Lee Common GCR site, Maltby, South Yorkshire. Most of the reef tors are in the central and northern parts of the designated area.



(Figure 4.28) Reef 'tor' in the central part of Wood Lee Common GCR site, showing the characteristic subdivision into 'saccoliths'. Hammer (centre-right): 0.33 m. (Photo: D.B. Smith.)

Cycles	Manx-Furness Basin (Central area)	South Cumbria	West Cumbria	Vale of Eden
BS4	St Bees Evaporites and Shales: Anhydrite / Anhydrite / Dolomite	St Bees Shales (with Brockram)	St Bees Shales (with Brockram): Blocky Facies	Eden Shales (with Brockram): Blocky Facies / D-Bed / Belah Dolomite
BS3	Halite	Roosecote Anhydrite / Roosecote Dolomite	St Bees Evaporites: Fleswick Anhydrite / Fleswick Dolomite	C-Bed
BS2	Anhydrite / Dolomite	Haverigg Haws Anhydrite / Gleaston Dolomite ('Magnesian Limestone')	Sandwith Anhydrite / Sandwith Dolomite	B-Bed
BS1	Dolomite, anhydrite, mudstone, etc.	'Grey Beds'	Saltom Dolomite / Saltom Siltstone	A-Bed and Hilton Plant Beds

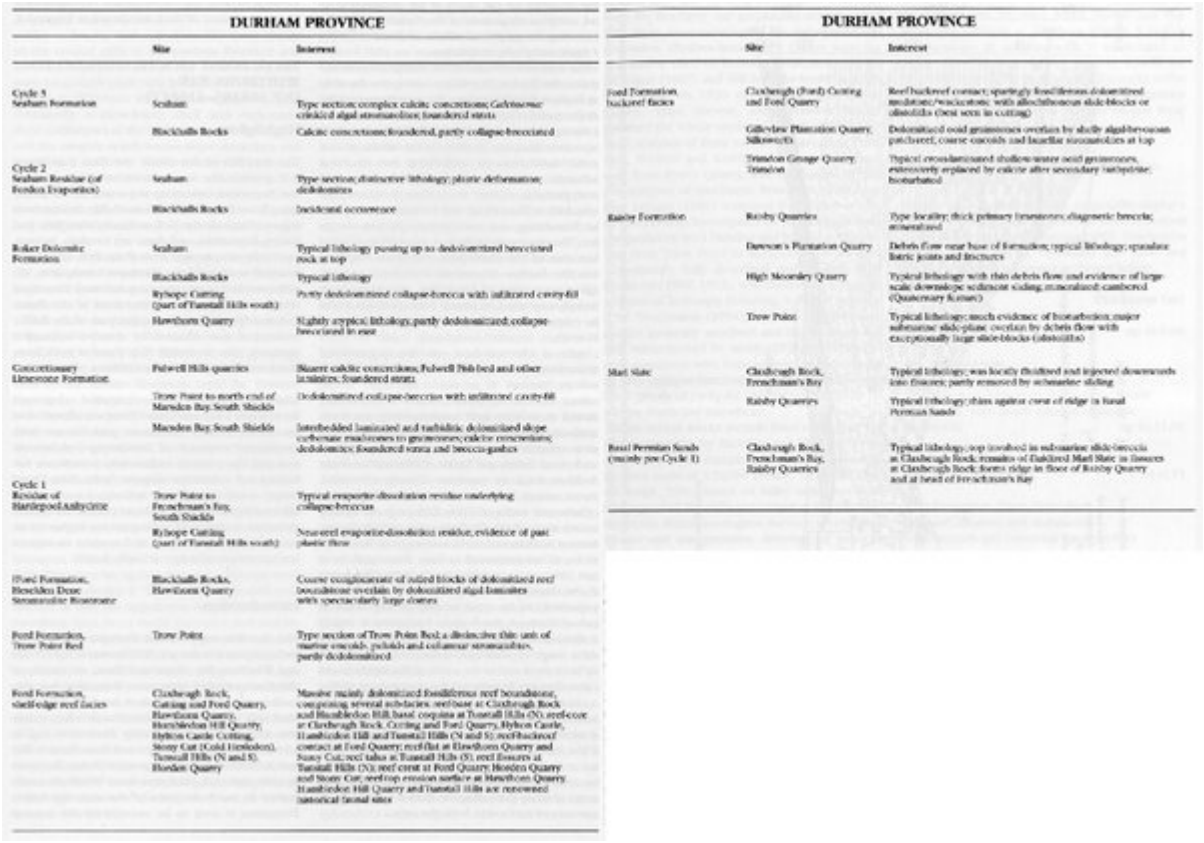
(Table 1.1) Classification and correlation of Permian marine and associated strata in north-west England and adjoining areas, showing the main depositional cycles. The Manchester Marl of south Lancashire and north Cheshire is a general correlative of the St Bees Evaporites but precise correlation is uncertain. Based on Smith (1992, table 9.2). Cycles after Jackson et al. (1987).

Cycles	Durham Province	Yorkshire Province
	Roxby Formation (Upper Marls)	Roxby Formation (Upper or Saliferous Marls)
EZ4	Sherburn Anhydrite Formation (Upper Anhydrite)	Sneaton Halite Formation (Upper Halite) Sherburn Anhydrite Formation (Upper Anhydrite)
	Rotten Marl Formation (Rotten Marl)	Rotten or Carnallitic Marl Formation (Rotten or Carnallitic Marl)
EZ3	Boulby Halite Formation (Main Salt) Billingham Anhydrite Formation (Billingham Main Anhydrite) Seaham Formation (part of Upper Magnesian Limestone)	Boulby Halite Formation (Middle Halite) Billingham Anhydrite Formation (Billingham Main Anhydrite) Brotherton Formation (Upper Magnesian Limestone)
EZ2	Edlington Formation (Middle Marls or Lower Evaporites) Roker Dolomite Formation (Hartlepool and Roker Dolomite) Concretionary Limestone Formation (Concretionary Limestone) — Part of Upper Mag. lst.	Edlington Fm in West : Fordon Evaporite Fm in East (Middle Marls) (Lower Evaporites) Kirkham Abbey Formation (Unnamed, ?absent at crop)
EZ1	Hartlepool Anhydrite Formation (Hartlepool Anhydrite) b Ford Formation (Middle Magnesian Limestone) a Raisby Formation (Lower Magnesian Limestone) Marl Slate Formation (Marl Slate)	Hayton Anhydrite Formation (Unnamed) Sprotbrough Member ('upper subdivision') Wetherby Member ('lower subdivision') — Cadeby Formation (Lower Magnesian Limestone) Marl Slate Formation (Marl Slate)

(Table 1.2) The main stratigraphical units in the marine Permian sequence of the two provinces of north-east England, showing the nomenclature used here and (in brackets) equivalent traditional names. Based on Smith et al. (1986, table 1). Note that the Edlington Formation, in parts of the Yorkshire Province where the Kirkham Abbey Formation is absent, extends downwards to the top of the Sprotbrough Member of the Cadeby Formation (see also Table 1.3) and may include an equivalent of the Hayton Anhydrite.

Groups	Cycles	Yorkshire Province (Outcrop area)	Durham Province (County Durham, east Tyne and Wear, County Cleveland)	Yorkshire Province (East and North Yorks and Humberside)	North Germany and Holland	Cycles
Eskdale Group	EZ5	Roxby Formation	Roxby Formation	Littlebeck Anhydrite Formation Sleights Siltstone Formation	Ohre Anhydrit Unterer Ohre Ton	Z5
Staintondale Group	EZ4	Sherburn Anhydrite Fm Rotten Marl Formation	Sherburn Anhydrite Formation Rotten Marl Formation	Sneaton Halite Formation Sherburn Anhydrite Formation Upgang Formation Carnallitic Marl Formation	Aller Salze Pegmatitanhydrit Thin unnamed carbonate Roter Salzton	Z4
Teesside Group	EZ3	Billingham Anhydrite Fm Brotherton Formation	Boulby Halite Formation Billingham Anhydrite Formation Seaham Formation	Boulby Halite Formation Billingham Anhydrite Fm Brotherton Formation Grauer Salzton	Leine Salze Hauptanhydrit Plattendolomit Grauer Salzton	Z3
Aislaby Group	EZ2	Edlington Formation	Seaham Residue Roker Dolomite and Concretionary Limestone Formation	Fordon Evaporite Formation Kirkham Abbey Formation	Stassfurt Salze and Basalanhydrit Hauptdolomit and equivalents	Z2
Don Group	EZ1 b Sprotbrough Member / a Wetherby Member — Cadeby Fm		Hartlepool Anhydrite Formation Ford Formation Raisby Formation Marl Slate Formation	Hayton Anhydrite Formation Cadeby Formation Marl Slate Formation	Werraanhydrit Zechsteinkalk Kupferschiefer	Z1
		Basal Permian (Yellow) Sands and Breccias	Yellow (Basal Permian) Sands and Breccias	Basal Permian Sands and Breccias	Rotliegendes	

(Table 1.3) Classification and correlation of Permian marine and associated strata in north-east England, showing the main depositional cycles and a representative sequence from Holland and northern Germany. After Smith (1989, table 1).



DURHAM PROVINCE

	Site	Interest
Cycle 5 Seaham Formation	Seaham	Type section; complex calcitic concretions; Gelyncrene crinkled algal stromatolites; foundered strata
	Blackhalls Rocks	Calcitic concretions; foundered, partly collapse-brecciated
Cycle 2 Seaham Residue (of Fordon Evaporites)	Seaham	Type section; distinctive lithology; plastic deformation; dedolomites
	Blackhalls Rocks	Incidental occurrence
Roker Dolomite Formation	Seaham	Typical lithology passing up to dedolomitized brecciated rock at top
	Blackhalls Rocks	Typical lithology
	Rybope Cutting (part of Tunstall Hills south)	Partly dedolomitized collapse-breccia with infiltrated cavity-fill
	Hawthorn Quarry	Slightly atypical lithology, partly dedolomitized; collapse-brecciated in part
Concretionary Limestone Formation	Fulwell Hills quarries	Bizarre calcitic concretions, Fulwell Pisb bed and other laminites; foundered strata
	Trow Point to north end of Marsden Bay, South Shields	Dedolomitized collapse-breccias with infiltrated cavity-fill
	Marsden Bay, South Shields	Interbedded laminated and turbiditic dolomitized slope carbonate mudstones to grainstones; calcite concretions; dedolomites; foundered strata and breccia-gashes
Cycle 1 Residue of Hartlepool Anhydrite	Trow Point to Frenchman's Bay, South Shields	Typical evaporite dissolution residue underlying collapse-breccias
	Rybope Cutting (part of Tunstall Hills south)	Near-reef evaporite-dissolution residue; evidence of past plastic flow
Ford Formation, Hesledon Dene Stromatolite Biostrome	Blackhalls Rocks, Hawthorn Quarry	Coarse conglomerate of rolled blocks of dolomitized reef boundstone overlain by dolomitized algal laminites with spectacularly large domes
Ford Formation, Trow Point Reef	Trow Point	Type section of Trow Point Reef; a distinctive thin unit of marine oncoids, cyliolids and columnar stromatolites, partly dedolomitized
Ford Formation, shelf-edge reef facies	Clavburgh Rock, Cutting and Ford Quarry, Hawthorn Quarry, Hawthorn Hill Quarry, Hylton Castle Cutting, Stony Cut (Cold Hesledon), Tunstall Hills (N and S), Horden Quarry	Massive mainly dolomitized fossiliferous reef boundstone, comprising several sub-facies: reef-base at Clavburgh Rock and Humbledon Hill; basal coquina at Tunstall Hills (N); reef-core at Clavburgh Rock, Cutting and Ford Quarry, Hylton Castle, Humbledon Hill and Tunstall Hills (N and S); reef-backreef contact at Ford Quarry; reef-flat at Hawthorn Quarry and Stony Cut; reef talus at Tunstall Hills (S); reef fissures at Tunstall Hills (N); reef crest at Ford Quarry, Horden Quarry and Stony Cut; reef-top erosion surface at Hawthorn Quarry, Humbledon Hill Quarry and Tunstall Hills are renowned historical fossil sites

DURHAM PROVINCE

	Site	Interest
Ford Formation, backreef facies	Clavburgh (Ford) Cutting and Ford Quarry	Reef-backreef contact; spectacularly fossiliferous dolomitized mudstone/wackestone with allochthonous slide-blocks or olistoliths (best seen in cutting)
	Gilleview Plantation Quarry, Silksworth	Dolomitized oolid grainstones overlain by shelly algal-bivalvian patchreef; coarse oncoids and bacellar stromatolites at top
	Trimdon Grange Quarry, Trimdon	Typical cross-laminated shallow-water oolid grainstones, extensively replaced by calcite after secondary sulphation; bioturbated
Raisby Formation	Raisby Quarries	Type locality; thick primary limestones; diagenetic breccia; mineralized
	Dawson's Plantation Quarry	Debris flow near base of formation; typical lithology; granular lintic joints and fractures
	High Moorsley Quarry	Typical lithology with thin debris flow and evidence of large scale downslope sediment sliding; mineralized; cambered (Quaternary Karst)
	Trow Point	Typical lithology; much evidence of bioturbation; major subaerial slide-plane overlain by debris flow with exceptionally large slide-blocks (olistoliths)
Marl Slate	Clavburgh Rock, Frenchman's Bay	Typical lithology; was locally fluidized and injected downwards into fissures; partly removed by submarine sliding
	Raisby Quarries	Typical lithology; thins against cores of ridge in basal Permian Sands
Basal Permian Sands (mainly pre Cycle 1)	Clavburgh Rock, Frenchman's Bay, Raisby Quarries	Typical lithology; cop involved in submarine slide-breccia at Clavburgh Rock; remains of fluidized Marl Slate in fissures at Clavburgh Rock; forms ridge in floor of Raisby Quarry and at head of Frenchman's Bay

(Table 3.1) Main geological features of the marine Permian GCR sites in the Durham Province of the English Zechstein

YORKSHIRE PROVINCE

	Site	Interest
Cycle 1 / Cycle 2 Edlington Formation	River Ure Cliff, Ripon	The only permanent surface exposure of Permian evaporites in north-east England; much gypsum after anhydrite, partly strongly internally folded; many satin-spar veins; foundered limestones of Brotherton Formation (Cycle 5) with *Calcinema*
Cycle 1 Cadeby Formation (Sprotbrough Member), transitional to Edlington Formation	Quarry Moor, Ripon	Unevenly interbedded algal-laminated dedolomitized ooid grainstones and evaporite dissolution residues; expansion structures; algal-laminated dolomite ooid grainstones
Sprotbrough Member on Wetherby Member	Micklefield Quarry, New Micklefield	Typical dolomitized ooid grainstones of sandwave facies rests on full sequence of peritidal Hampole Beds; fenestral ('birds' eye') fabric; Hampole Discontinuity
	Cadeby Quarry, Cadeby	Typical dolomitized ooid grainstones of sandwave facies rests on atypically thick Hampole Beds; Hampole Discontinuity with relief of 3 m+; Wetherby Member with unusually tall patch-reefs and thick dolomite domed algal laminites
Wetherby Member	Wood Lee Common, Maltby	Selectively eroded dolomitized bryozoan patch-reefs form tors on grassy slope
	South Elmsall Quarry	Dolomitized bryozoan-algal patch-reef in peloidal and oncoidal shelf grainstones; stromatolite domes
	Ashfield Brick-clay Pit, Conisbrough	Dolomitized bryozoan patch-reef in dolomitized ooid grainstones, on bedded skeletal grainstones and rudstones (coquinas), on dolomitic siliciclastic mudstones
	Newsome Bridge Quarry, North Deighton	Dolomitized inferred patch-reef in peloidal and oncoidal shelf grainstones lies on eminence in Carboniferous - Permian unconformity; rock litter
Wetherby Member on Basal Permian Sands	Bilham Quarry	Basal shelf dolomite mudstones/wackestones of the Cadeby Formation on incoherent marine-redistributed aeolian sand-rock
	Ashfield Brick-clay Pit, Conisbrough	Basal dolomitic siliciclastic mudstones on atypically pebbly red friable sandstone

(Table 4.1) Main geological features of the marine Permian GCR sites in the Yorkshire Province of the English Zechstein.