Trow Point (South Shields) to Whitburn Bay

[NZ 388 383]–[NZ 410 612]

Highlights

The sea cliffs of this classic site (box 1 in (Figure 3.2)) provide the key to understanding much of the Magnesian Limestone sequence. In the north, from Trow Point to Frenchman's Bay, lowest beds exposed include the Yellow Sands, Marl Slate and Raisby Formation, and these are overlain, in turn, by (1) the unique algal Trow Point Bed, (2) the dissolution residue of the Hartlepool Anhydrite, (3) collapsed and brecciated Concretionary Limestone strata and (4) possible lower beds of the Roker Dolomite Formation; the upper part of the Raisby Formation was affected by massive submarine slumping (the 'Downhill Slide') and at both Trow Point and Frenchman's Bay contains piles (olistostromes) of large slumped masses (olistoliths). Slightly higher strata exposed between Frenchman's Bay and Lizard Point are almost all of the Concretionary Limestone and feature both spectacular evidence of foundering and brecciation and also primary sedimentary lamination, turbidites and submarine slumps. Strata from Lizard Point southwards are mainly less-obviously affected by foundering and brecciation but feature abundant evidence of sedimentation higher on an unstable submarine slope and contain an important but restricted range of shelly fossils.

Introduction

The bewilderingly varied Permian sedimentary rocks exposed in the sea cliffs between Trow Point and Whitburn Bay, Tyne and Wear, are mainly of the Concretionary Limestone Formation but also include glimpses of the Yellow Sands (1.2 m+) and Marl Slate (0.1–1.5 m) in Frenchman's Bay, extensive exposures of the Raisby Formation (up to 13 m) between Trow Point and Frenchman's Bay and intermittent views of possible Roker Dolomite in cliffs and rock platforms from Whitburn southwards. In northern parts of the site, the Raisby Formation is seen to be overlain by the unusual and exceptionally persistent Trow Point Bed (0–0.60 m), the sole representative of the Ford Formation which was probably more than 100 m thick only 6 km to the west, and this bed is succeeded by the thin (0–0.15 m) dissolution residue of the Hartlepool Anhydrite.

All beds of the Concretionary Limestone have foundered by the former thickness of the dissolved anhydrite (?100 m+ at Marsden) and have responded in a number of ways ranging from barely disturbed (especially in higher parts of the formation) to completely brecciated and dedolomitized; the limestone collapse-breccias at the base of the formation are particularly resistant and are mainly responsible for the ruggedness of the coast between Trow Point and the northern end of Marsden Bay, whereas the less resistant overlying dolomite has been differentially eroded to form Marsden Bay and its neighbour to the south. Farther south, varied secondary limestones, though less resistant than the massive collapse-breccias, have given rise to a variety of lower sub-vertical cliffs and minor bays, and, by their recession, to exceptionally wide rock platforms off Whitburn (=White Burn, an allusion to the white-capped breakers that occur here during certain combinations of tide and weather).

The cliffs, especially those between Trow Point and Lizard Point and around Byer's Hole and Byer's Quarry some distance farther south, have featured freely in the literature. Early mentions were by Winch (1817), who recorded the discovery by Nichol of flexibility in dolomite laminites in Marsden Bay, and by Sedgwick (1829) who also noted the flexibility and graphically described the rocks there, concentrating on the disturbance and brecciation. Bivalves from Byer's Quarry were figured and/or cited by Howse (1848), King (1850) and Logan (1967) and fish remains were found in Marsden Bay in 1836 or 1837 by Miss Green (Kirkby, 1864; Howse, 1891); Howse briefly described the whole section. Clapham (1863) published analyses of three varied samples from Trow Point, Browell and Kirkby (1866) analysed limestone from Byer's Quarry, and Trechmann (1914) gave analyses of specimens from both these locations. Lebour (1884) reviewed the 'gash-breccias' and Card (1892) investigated the flexibility of dolomite laminites from Hendon and Marsden. The sections from Trow Point to Marsden Bay were then exceptionally fully described and illustrated by Woolacott (1909, 1912), who claimed to recognize evidence of low-angle thrusting, a theme returned to by Trechmann

(1954), but this interpretation was not generally accepted and the evidence has been reinterpreted by Smith (1970a, c, 1985a) as more consistent with large-scale submarine slumping and collapse-brecciation. Burton (1911) published details of cavity-fill and chert in the breccias at Trow Point and elsewhere.

More recent works include brief reviews of the collapse-breccias by Hickling and Holmes (1931) and Smith (1972), complete geological map coverage on a scale of 1:10560 (Smith, 1975a, b; Land and Smith, 1981, based on fuller notes and scale drawings of all the cliffs and lodged in the fieldnote files of the British Geological Survey), several illustrations and interpretative drawings of strata at Trow Point and in Marsden Bay by Pettigrew (1980) and detailed analyses of a number of rocks from Trow Point and near the Grotto in Marsden Bay by Al-Rekabi (1982). Lastly, Braithwaite (1988) published photomicrographs of samples from near the Grotto and from nearby Marsden Hall Quarry, and discussed the origin of many of the secondary (diagenetic) features in the Concretionary Limestone exposed there. All the northern exposures have also been visited repeatedly by geological excursion parties and numerous guides and excursion reports have been published by local and national geological societies (e.g. Smith, 1973a).

Description

The scheduled site comprises the steep sea cliffs and rock-shore platforms extending uninterruptedly for about 6.5 km between the north side of Trow Point [NZ 384 667], South Shields and The Bents [NZ 409 613] at Whitburn (Figure 3.3). For the purposes of description it is convenient to divide the site into several sectors, which are described from north to south and the rocks in the order in which they are encountered; summaries of the geology of key parts of these sectors were given by Smith (1975a, b).

Sector 1: Trow Point to Frenchman's Bay, inclusive (Figure 3.4)

Despite great lateral variation, these cliffs display a broadly uniform sequence that has been described partly or wholly by Woolacott (1909), Trechmann (1954), Smith (1970a, c, 1973a) and Land and Smith (1981); the sequence is shown below:

	Thickness (m)
Drift deposits, including boulder clay	up to 6.00
———— unconformity ————	
Concretionary Limestone Formation, mainly brecciated, with much internal sediment (cavity-fill)	up to 11.00
Hartlepool Anhydrite Formation (dissolution residue of)	0–0.15
Ford Formation, Trow Point Bed; peloidal dolomite and dedolomite with oncoids and columnar stromatolites	0–0.60
Raisby Formation, low-slope facies, with disturbed (slumped) beds (0.75–8 m) overlying a discordant slide plane cut into undisturbed beds	0–15.00
Marl Slate (Frenchman's Bay only)	0.10–1.50
Yellow Sands (Frenchman's Bay only)	1.20+

The relationships of the several stratigraphical units are shown diagrammatically in (Figure 3.5).

The Concretionary Limestone Formation here mainly comprises a massive, resistant breccia of angular fragments of thinly interbedded laminated and unlaminated calcite .mudstone (dedolomite) in a microcrystalline calcite matrix; it forms the uppermost solid rock of the cliffs throughout this sector. The constituent fragments are smallest near the base of the breccia, where the rock is almost entirely calcitic (dedolomite), with blocks of disarticulated beds recognizable in higher parts where some dolomite remains; there is much evidence of repeated fracturing and re-cementation, and 'cellular breccias' (Sedgwick, 1829) or 'negative breccias' (Lebour, 1884) in which the clasts having proved to be less resistant to weathering than the matrix are present on the north-east side of Trow Point (Figure 3.6). Silt-grade infiltrated laminar calcite cavity-fill is widespread, especially near the base of the breccia, and contains clasts of detached roof-rocks; the fill bears abundant evidence of intermittent accumulation punctuated by episodes of contortion, tilting and brecciation. The well-documented report of grains of the Yellow Sands in cavity-fill at Trow Point (Burton, 1911) cannot now be verified but is puzzling in view of the known depth of at least 13 m to the top of the 0.6 m Yellow Sands Formation there.

The residue of the Hartlepool Anhydrite is a thin variable bed of unevenly laminated, partly plastic, grey, buff and brown clay; it is generally a few centimetres thick but has locally flowed away from eminences in the substrate and is correspondingly thicker and contorted nearby. A sample of this bed from the south side of Trow Point [NZ 3841 6660] was found by R.K. Harrison and K.S. Siddiqui (in Smith, 1972, p. 260) to comprise micas, illite, kaolinite, gypsum and subordinate calcite, together with detrital quartz, apatite, rutile and zircon; Clapham (1863) reported 10% of silica and 35% of magnesia in a sample apparently from this bed.

The remarkable Trow Point Bed at its type locality has been described in detail by the writer (Smith, 1986). It comprises up to 0.6 m of buff dolomite with subordinate grey limestone (dedolomite), and drapes the underlying hummocky substrate (Figure 3.7) with primary dips of up to 40° and a local relief at Trow Point of about 3 m; in the sector as a whole, its relief relative to the base of the Raisby Formation is at least 14 m. The deposit commonly comprises two beds and is thickest in the hollows where it is mainly an unsorted or poorly-sorted peloid–oncoid packstone; intervening eminences bear one or, more commonly, two layers of radial arrays of narrow (0.01–0.05 m) columnar stromatolites individually up to 0.15 m tall. The packstones contain up to 2% of quartz silt and fine sand and a restricted marine assemblage of foraminifera and ostracods.

The Raisby Formation comprises a disturbed sequence up to about 8 m thick and an underlying undisturbed sequence up to about 11 m thick. The disturbed sequence is extremely varied in thickness, and, where thickest (as at Trow Point and along the south side and head of Frenchman's Bay) is composed of large slide-blocks (many contorted) of buff thin-bedded dolomite lying on a discordant surface interpreted as a major synsedimentary submarine slide plane (Smith, 1970c) (Figure 3.8). Pockets between, beneath and above the slide-blocks are filled with an unsorted mixture of dolomite clasts in a vuggy (i.e. containing many small cavities) dolomite matrix, and similar rock, with scattered slide-blocks or olistoliths, forms a single continuous bed commonly 0.6–1.5 m thick in the cliffs between Trow Point and Frenchman's Bay (Smith, 1970c, plate 2, fig. 2; Pettigrew, 1982, plate 7). The largest slide-block seen by the writer is at the head of Frenchman's Bay and measures about 72 m long and 7.5 m thick; it was also noted by Woolacott (1909, figs 2, 12) and Trechmann (1954, fig. 5), who both interpreted it as a thrust mass. Other slide-blocks, including that illustrated by Pettigrew (1982, fig. 12), contain up to 6.5 m of deformed Raisby Formation strata.

Undisturbed Raisby Formation strata beneath the disturbed sequence have been proved by a borehole [NZ 3847 6652] to be thickest near Trow Point, but they are cut out progressively southeastwards by the slide plane and are less than 1 m thick at the head of Frenchman's Bay (Figure 3.5). Upper beds, about 5 m of which are exposed near Trow Point, are cream and buff, very finely crystalline dolomites in slightly uneven beds 0.05–0.2 m thick; many feature abundant evidence of bioturbation. The rocks contain small bioclasts, including foraminifera, bivalves, crinoid columnals and obscure plant remains, and also scattered to abundant oval to irregular calcite-lined cavities after former anhydrite; Lee (1990) noted narrow calcitized zones around these cavities. Trechmann (1914, p. 245) analysed a sample of the Raisby Formation from Trow Point and reported a dolomite content of 97.19%, and Lee (1990) determined the isotopic composition of secondary limestone from near the top of the formation and found it to be closely comparable with that in the overlying collapse-breccias. Lower beds of the Raisby Formation are exposed progressively southeastwards, where there is less evidence of biotur-bation, fewer cavities, and local traces of graded bedding. Unusual features include tepee-like structures up to 0.5 m high on the shore platform [NZ 3888 6631] about 140 m north of Frenchman's Bay (Figure 3.9) and a complex of low-angle intersecting minor movement planes in the cliff [NZ 3886 6629] slightly farther south (Smith, 1994, plate 4); these terminate sharply upwards at the base of the disturbed beds, here only a few metres above the base of the formation.

Marl Slate is exposed periodically around much of Frenchman's Bay, depending on beach accumulations and rockfalls; it is up to 1.5 m thick on the south side of the bay but thins to 0.1–0.3 m at the head of the bay where onlap against a ridge of Yellow Sands is apparent, and is up to 0.8 m thick in the north of the bay. It is a dark grey pyritic finely laminated argillaceous dolomite, with a thin dolomite bed near the top, and abundant fish scales.

The oldest Permian rocks of this sector are the early Permian Yellow Sands, which lie at the foot of the cliffs at the head of Frenchman's Bay and form a ridge up to 1.2 m high; their base is not exposed. The sands are of normal lithology for this formation and cross-bedding is inclined mainly northwards; only the uppermost 5–10 cm of the formation is cemented.

Sector 2: Frenchman's Bay to Velvet Beds (Figure 3.10)

The general rock sequence in this 800 m sector is similar to that in Frenchman's Bay, but the Yellow Sands and Marl Slate lie below beach level and the uppermost few metres of the Raisby Formation are exposed only in the north and in a small sharp anticline 200–300 m farther south-east (Land and Smith, 1981). Collapse-brecciated, largely dedolomitized Concretionary Limestone up to 10.5 m thick makes up most of the cliffs in the sector, and has been sculpted into a range of rugged shapes including natural arches; breccias similarly make up the low promontory of Velvet Beds, named after the fine quality of grass formerly present on the thin drift capping.

The most complete sequence in this sector lies in the small anticline, where the dissolution residue of the Hartlepool Anhydrite lies immediately beneath the collapse-breccia and is up to 15 cm thick. The Trow Point Bed, here 0.05–0.60 m thick, is mainly oncoidal but includes ooidal dolomite and unusually narrow columnar stromatolites; in the northern limb of the anticline it cloaks the hummocky upper surface (relief 1.5 m) of the Raisby Formation that here comprises a somewhat enigmatic disturbed sequence (1–4 m) and an underlying undisturbed sequence of thin-bedded finely crystalline dolomites (5 m). Features of unusual interest in the southern limb of the anticline are widespread replacive patches and thin veins of pink and white baryte and some chert in all beds below the residue, and the presence of a well-marked, SSE-facing, 4 m high, steep step in the Trow Point Bed that may be a margin of a minor slump canyon of late Raisby Formation age. The base of the disturbed sequence north of the step is unusually discordant, cutting across the truncated edges of more than 2 m of undisturbed Raisby Formation strata in a horizontal distance of only 10 m. The rising baryte-depositing brines may have been trapped in the anticline by the former anhydrite seal.

Sector 3: Marsden Bay (Velvet Beds to Marsden Rock) (Figure 3.11)

The broad sweeping curve of Marsden Bay is backed by 15–30 m subvertical cliffs cut in foundered lower strata of the Concretionary Limestone Formation. The response to foundering was extremely varied, with severely collapse-brecciated rocks dominating the northern and southern flanks of the bay and with less dislocated and less altered rocks in the middle. Strata below the so-called 'Flexible Limestone', including the collapse-breccias, were traditionally classified as 'Post-reef Middle Magnesian Limestone' (i.e. Ford Formation) but were reclassified as part of the Concretionary Limestone Formation following detailed mapping and the discovery of a typical Cycle EZ2 fauna in turbidite lags well below the 'Flexible Limestone' (Smith, 1971a).

The disposition of strata in Marsden Bay was dramatically illustrated by Woolacott (1909, plate 2, fig. 8), partly reproduced here as (Figure 3.12); drift, not shown by Woolacott, is generally less than 2 m thick and is a sparingly pebbly silty deposit known locally as the Pelaw Clay.

Massive, dedolomitized collapse-breccias like those between Trow Point and Velvet Beds continue southwards into the north flank of the bay, with the top of the Raisby Formation lying an estimated 5–15 m below beach level at Velvet Beds and the top of the Yellow Sands lying at 24.1 m below Ordnance Datum at the site of the nearby Harton Borehole [NZ 3966 6564]. Strata on average dip gently south-eastwards and the sharp and jagged top of the collapse-breccias gradually declines below beach level; the breccias are overlain by about 54 m of cream, buff and grey dolomites and limestones that have been variably dislocated and contain many late-stage 'breccia-gashes' (Figure 3.13) filled with fragments of host rocks and of strata now otherwise eroded off. The most spectacular breccia-gashes are a few metres across and have vertical sides, but some are much larger and have been involved in complex multi-stage foundering and brecciation; the gashes are circular, linear or cruciform in plan.

Least altered and least-brecciated rocks in Marsden Bay comprise a thinly interbedded sequence of plane-laminated dolomite mudstones and dolomite wackestones, packstones and grainstones. The laminites comprise couplets (commonly 15–25 per centimetre), each composed of a carbonaceous film and a thicker dolomite mudstone layer; they contain no shelly fauna but fish remains were recorded (Kirkby, 1864; Howse, 1891) from the 'Flexible Limestone' here, a particularly finely laminated 3–4 m bed that first appears high in the cliff in the northern part of the bay and dips below the beach south of the Grotto (Figure 3.12). Most of the unlaminated beds are a few millimetres to a few centimetres thick and are of silt-grade dolomite; some are graded or reverse-graded. Other unlaminated beds are up to 4 m thick, and comprise dolomite packstones and grainstones (at least some ooidal) that feature a wide range of overfolds, contortions and shear-planes and commonly overlie a slightly discordant erosion surface or slide-plane; some of these thicker units have a basal lag concentrate of gastropods, bivalves and ostracods. Lenses of chert are not uncommon, and irregular to ovoid cavities after former replacive and displacive anhydrite are widespread and locally abundant.

In addition to passing laterally into collapse-breccias, all the dolomite rocks locally pass laterally into secondary, grey or brown, crystalline limestone, which also forms a thick concretion-rich bed high in the cliffs in the northern part of the bay and forms much of the cliff and parts of the stacks near the Grotto.

Sector 4: Marsden Rock to Lizard Point (Figure 3.14)

The geology of this 1.1 km sector of the GCR site is poorly documented in the literature, but the north-western end was included in Woolacott's (1909) drawing of strata in Marsden Bay and the whole sector was summarized by the writer (Smith, 1975a) in notes 1–5 on Geological Survey 1:10,560 Sheet NZ 46 SW; drawings and more detailed descriptions are in the fieldnote files of the British Geological Survey. The subvertical cliffs are generally 15–25 m high but locally approach 30 m, and drift (mainly Pelaw Clay) is generally 0.5–1.5 m thick.

The sequence in the north-western part of the sector is a continuation of that in Marsden Bay, with partly to severely dislocated collapse-brecciated laminated and unlaminated cream dolomites and grey to brown secondary limestones forming most of the cliffs; sparingly shelly, vaguely bedded, dolomite ooid packstones/grainstones, however, form the basal few metres of a relatively undisturbed sequence from about 130 to 200 m south-east of the Grotto.

Rocks forming the cliffs in most of the central and southern parts of the sector mainly comprise up to 20 m of vaguely-bedded to massive, altered dolomite ooid packstones/grainstones, but these are overlain by concretionary limestones from about 600 to 725 m north-west of Lizard Point. These limestones reappear at the cliff top about 400 m northwest of Lizard Point and dip gently south-eastwards so as gradually to form the whole cliff; they are at least 14 m thick. The packstones and grainstones are divisible into a variable lower unit in which they are unevenly coarsely interbedded with discontinuous sheets and lenses (?rafts) of laminated dolomite mudstone (some contorted and sheared), and a more uniform 9 m upper unit. Both units contain scattered to abundant bivalves, gastropods and ostracods which, in the lower unit, are concentrated near the base of the thicker ooid beds and lenses. The contact between the ooidal dolomite and the overlying concretionary limestones is marked by an almost continuous, thin, brecciated layer rich in cannon-ball concretions and a similar layer lies 3.5–4 m higher; the concretionary beds themselves are mainly thin- to thick-bedded (locally massive) crystalline limestones in which spherulites are generally abundant and in places form most of the rock. In a few places the concretion-bearing limestones pass laterally into thin-bedded finely-laminated dolomite with only scattered mainly small incipient calcite concretions. Some spherulites in the concretionary limestones are nucleated onto tumid well-preserved bivalves.

Sector 5: Lizard Point to Souter Point (Figure 3.15)

The cliffs in this 1.6 km sector are highest — commonly exceeding 10 m — in the north, but gradually decrease in height from Byer's Hole southwards and are only a few metres high between Wheatall Way and Souter Point (for locations see (Figure 3.15)); drift (mainly Pelaw Clay) is generally less than 2 m thick except near Whitburn Colliery village where it reaches 5 m for a short distance.

Magnesian Limestone strata in the cliffs and shore platforms here all belong to the middle and upper parts of the Concretionary Limestone Formation and, despite having foundered by at least 100 m through the dissolution of the Hartlepool Anhydrite, are mainly structurally simple and only locally collapse-brecciated; north of the Lizards Fault they comprise a gently rolling strike sequence totalling perhaps 20–25 m thick but an additional 10–15 m of strata may be present to the south of the fault. Cliffs in the most northerly 150 m of the sector, at and immediately south of Lizard Point, are almost entirely of thin-bedded to massive crystalline limestone (mainly spherulitic), and thick-bedded to massive spherulitic limestone forms the cliffs at Souter Point and for about 100 m to the north. Between these stretches the cliffs are mainly composed of a laterally variable interbedded sequence of unlaminated and laminated mainly thin-bedded grey limestone, grey and brown (locally red and black) spherulitic limestone and lenticular to relatively persistent thick beds of cream finely crystalline to powdery dolomite (some possibly of altered oolite); most of the latter, and many of the thick unlaminated limestone beds, have been weakly to strongly contorted and locally brecciated by contemporaneous downslope movement (Figure 3.16).

The remarkable lateral variability of these strata is expressed in several ways, including the proportion of calcite spherulites and thin calcite lenses present and in changes of bed thickness; thus, for example, there are several places where substantial units of well-bedded laminated or unlaminated dolomite- or calcite-mudstone pass abruptly or at a stepped contact into coarsely crystalline spheru-litic or (uncommonly) reticulate limestone, and other places where thin-bedded limestones or dolomites pass laterally into thick units with only vague bedding traces. Elsewhere there is convincing evidence of the partial dissolution of carbonate beds, leading to the collapse and brecciation of immediately overlying strata (Smith, 1994, plate 30). Idiomorphic calcite scalenohedra up to 0.05 m long, though also present elsewhere in the district, are a feature of patches of powdery dolomite between concretions in this sector. The sequences in individual parts of the cliffs are summarized in notes 5–12 on British Geological Survey 1:10,560 Sheet NZ 46 SW and NW (Smith, 1975b) and detailed scale drawings of all the cliffs are lodged in the Geological Survey fieldnote files.

The Concretionary Limestone at Byer's Hole and in the adjoining Byer's Quarry (now filled) is well known for its foraminifera, annelid, gastropod, bivalve and ostracod fauna (Figure 3.17) which comprises abundant individuals of a restricted range of species; well-preserved remains of plants have also been reported (Trechmann, 1914). The fauna was noted and listed by Howse (1848, 1858), King (1850), Kirkby (1858), Trechmann (in Woolacott, 1912), Logan (1967), Pattison (Geological Survey internal reports 1967; 1977) and Pettigrew (1980); both King and Logan figured several specimens from here, including some designated as types or syntypes. Additionally, King (followed by Logan who used many of King's specimens) cited 'Souter Point, Marsden' as a bivalve source locality, though it is possible that he meant Lizard Point. Howse (1848) noted the exceptional preservation of bivalve shells at Byer's Quarry, where the original shell has been replaced by crystalline calcite, in contrast to most Magnesian Limestone fossils which are known only from casts; Kirkby (1858) noted that the ostracods, too, are locally exceptionally well-preserved and abundant (see also Pettigrew, 1980, plate 13).

Analyses of grey limestones from Byer's Quarry (Browell and Kirkby, 1866; Woolacott, 1912; Trechmann, 1914) show that they are amongst the purest limestones in the area, with calcium carbonate contents ranging from 96.94 to 98.04% (three analyses); an interbedded brown friable bed analysed by Trechmann had a calculated composition of 93.2% of dolomite and 5.8% of calcite.

Sector 6: Souter Point to Whitburn Bay (Figure 3.18)

The cliffs in this most southerly sector (1.6 km) of the Trow Point to Whitburn Bay site are generally 6–10 m high, of which drift forms the uppermost 2–3 m from Souter Point to about 150 m north of White Steel; the drift then thickens gradually southwards so as to form the whole of the cliff from a point about 250 m north-east of The Bents. The thin drift in most northern parts of the sector is mainly of the sparingly stony Pelaw Clay but that in the south also includes Durham Lower Boulder Clay and interbedded laminated clay and sand and features widespread and locally intense contortion and involution (Smith, 1981c, fig. 6).

Foundered Magnesian Limestone strata in this sector are structurally and lithologically more varied than in the sector to the north but are similarly gently rolling; dip is generally eastwards at perhaps 3–5°, with a strike section between Souter Point and Rackley Way Goit passing southwards into a broad shallow apparent syncline with its axis about 50 m south of White Steel. Breccia-gashes occur at intervals throughout the sector and, together with several minor faults, are particularly well-exposed in the cliffs and wide shore platforms in the south of the sector (see Geological Survey 1:10,560 Sheet NZ 46 SW and notes and scale drawings in British Geological Survey fieldnote files).

Strata in the strike section north of Rackley Way Goit are probably about 12–15 m thick and belong to the upper part of the Concretionary Limestone Formation; they are lithologically and faunally similar to those exposed in the sector to the north and display comparably extreme lateral and vertical variation. Limestones in the cliffs in the most northerly 450 m of the sector (and locally elsewhere) have been partly to severely brecciated to depths of as much as 4 m below rockhead, probably by Devensian periglacial cryoturbation; drift erratics are mixed with angular limestone debris in the uppermost metre or so of this brecciated sequence.

Strata in the apparent syncline south of Rackley Way Goit total perhaps 20 m and may belong partly or wholly to the Roker Dolomite Formation. They are mainly of thin- to thick-bedded porous, cream, saccharoidal dolomite (probably mainly altered oolite) and include a spectacular basal 5 m bed packed with mutually-interfering 0.05–0.25 m calcite spheroids; this bed, which could be assigned either to the Concretionary Limestone or the Roker Dolomite, may equate with the famous 'cannon-ball Rocks' at Roker, 2.5 km farther south. Highest strata in the sector occupy a breccia-gash at the eastern tip of White Steel [NZ 4133 6192] and include dolomite laminites (?algal stromatolites) and remarkable cellular massive limestones interpreted by Dr G.M. Harwood (pers. comm. 1988) as compressed bivalve coquinas.

The subvertical Hebburn (or Monkton) tholeiite dyke, previously not known to crop out in the coastal area, was discovered in 1993 in the cliffs [NZ 4108 6156] of this sector by Mr G. Fenwick of Sunderland University. The dyke and its effects on the host-brecciated limestone are now being investigated.

Interpretation

The Magnesian Limestone rocks of the Trow Point to Whitburn Bay site together constitute a unique assemblage of exposures of truly international significance; the display of submarine slump products in the most northerly sector ranks high in such features anywhere in Britain, the overlying Trow Point Bed is unique in its extent and its range of mixed coated grains and sessile stromatolites, and the effects of evaporite dissolution on overlying Cycle EZ2 carbonate strata are spectacularly exposed between Trow Point and Lizard Point; where least affected by collapse brecciation, the Cycle EZ2 rocks bear striking evidence of carbonate deposition on an unstable submarine slope. The Yellow Sands, Marl Slate and undisturbed lower beds of the Raisby Formation are normal for those formations and require no special comment.

Disturbed beds of the Raisby Formation

The compelling evidence of lateral movement of large masses of bedded dolomite at the top of the Raisby Formation at Trow Point and in Frenchman's Bay was recognized and illustrated by Woolacott (1909, 1912) and Trechmann (1954), who attributed it to tectonic thrusting and interpreted the underlying plane of discontinuity as a thrust plane. The inferred directions of movement of the displaced masses were inconsistent with regional compressive forces however, as was the lack of similar disruption in the intensively worked underlying Coal Measures, and the data were reinterpreted as evidence of submarine slumping and sliding overlying an undulate discordant submarine slide-plane (Smith, 1970c). In this alternative explanation it was envisaged that the piles of inferred slide-blocks at Trow Point and in Frenchman's Bay were created following massive regional failure of the gently sloping floor of the Raisby Formation sea and the intervening, underlying and overlying pebbly dolomite was interpreted as the product of submarine slurries or debris flows associated with the inferred slope failure. Evidence at outcrop in Downhill Quarry (West Boldon, [NZ 347 602]) and the Claxheugh Rock site shows that the inferred slope failure led to the removal of part to all of the Raisby Formation from a series of canyon-like WSW/ENE scoops in the area from Sunderland northwards, and assessment of all the data south of the River Tyne suggested downslope displacement there of at least 50 million cubic metres of strata; data north of the Tyne are fewer but suggest at least an equal volume of displaced strata there also, thus ranking the Downhill–Claxheugh–Trow Point–Frenchman's Bay submarine slides amongst the world's largest. Contemporary earth tremors were postulated as the cause of the instability and are thought also to have been responsible for abundant spatulate minor movement-planes and clay (liquified Marl Slate) intrusions in strata below the slide plane; such tremors could have originated through movement along one of the major faults of the region, perhaps the Ninety Fathom Fault. An alternative interpretation, by Lee (1990), is that the slope-failure may have resulted from a major decline of sea level following deposition of the Raisby and Ford formations.

Regardless of the cause of the Downhill Slide, it might be supposed that the downslope submarine movement of so vast a volume of sediment would generate a substantial tsunami, though it is not clear if or how such an event would be recorded in the rock record or if it could be distinguished from the record of the event itself. A thin unit of sandstone or siltstone has been reported at the appropriate stratigraphical level in a number of coal exploration boreholes off the Durham coast, and the possibility that this may be the product of a tsunami cannot be excluded.

Trow Point Bed

The distribution, character and environmental significance of the remarkably persistent Trow Point Bed have been reviewed by the writer (Smith, 1986), who nominated the several cliff sections at Trow Point as the type locality. The bed was first recorded in 1958 in National Coal Board (now British Coal) Offshore Borehole No 1 [NZ 5334 4043] and has been proved in some form or other in most subsequent local offshore boreholes where it is mainly oncoidal; the key to its great lateral variability, however, is only apparent at Trow Point where the thickness and lithology of the bed is seen to be closely related to the configuration of the hummocky upper surface of the underlying pile of slide-blocks. Baryte mineralization of the deposit is common in offshore boreholes but is seen onshore only in Frenchman's Bay and in the small bay 200–300 m south-east of Frenchman's Bay where the disturbed and undisturbed beds at the top of the Raisby Formation are also affected.

The Trow Point Bed is the youngest Cycle EZ1 carbonate unit of the Ford Formation basinward of the reef, but it has not been identified between Trow Point and the toe of the reef foreslope and may die out in this 5 m-wide belt. Its stratigraphical relationship to both the reef and the Hesleden Dene Stromatolite Biostrome are therefore unknown, although it clearly occupies the same stratigraphical slot as the reef and may be partly or wholly synchronous; a post-reef age would imply that the period of reef growth is wholly unrepresented by basinal deposits, emphasizing the sharp eastward thinning of reef-equivalent strata inferred, for example, from tunnels at Easington Colliery some 22 km to the south (Smith and Francis, 1967, fig. 21).

Farther afield, equivalents of the Trow Point Bed have been reported immediately beneath the Cycle EZ1 anhydrite at depth in North Yorkshire and parts of the Southern North Sea Basin (Taylor and Colter, 1975), in boreholes and surface outcrops in northern Germany (Füchtbauer, 1968; Richter-Bernburg, 1982) and in widely spaced boreholes in Poland (e.g. Peryt and Peryt, 1975; Peryt and Piatkowski, 1976). The provings in Germany suggest that the bed there is probably closely comparable with the Trow Point Bed but the Polish occurrences are somewhat thicker and more varied.

The environmental interpretation of the Trow Point Bed is a matter of lively debate. Smith (1970a), influenced by then prevailing views on the uniquely peritidal growth of columnar algal stromatolites and of net-fabric sulphate rocks, initially inferred that the bed formed near contemporary sea level, which implied marine drawdown equivalent to the height (100 m+) of the reef foreslope. This view was subsequently modified when more recent work showed (a) that many modern stromatolites are formed subtidally (e.g. Monty, 1973) and (b) that the net-fabric of the Hartlepool Anhydrite may be secondary and therefore does not necessarily indicate intertidal sabkha accumulation. The Trow Point Bed is now interpreted as a basin-floor deposit, that probably accumulated slowly in somewhat unusual marine conditions at a depth of perhaps 25–100 m; deep drawdown is not necessitated (but is not excluded) on the evidence in north-east England, though Peryt and Piatkowski (1976) deduced such draw-down on the evidence of inferred pedogenic features in the supposedly equivalent beds in Poland.

The Hartlepool Anhydrite Residue and overlying collapse breccias

Though previously described as 'a sort of mylonite' by Woolacott (1909), who regarded it as part of his evidence for regional thrusting, the thin mixed layer between the Trow Point Bed and the Cycle EZ2 breccias is now accepted as the dissolution residue of the Hartlepool Anhydrite; in coal exploration boreholes offshore, the same stratigraphical interval is occupied by up to 150 m of massive anhydrite, which is directly underlain by the Trow Point Bed (Magraw *et al.,* 1963; Smith and Francis, 1967, plate 13A; Smith, 1986, fig. 10). The anhydrite is almost devoid of siliciclastic impurities (Trechmann, 1913, p. 243), which accounts for the remarkable thinness of the residue at most localities.

The varied and spectacular breccias of the cliffs between Trow Point and Lizard Point have been noted and described by Winch (1817), Sedgwick (1829), Howse and Kirkby (1863), Lebour (1884), Woolacott (1909, 1912, 1919a), Hickling and Holmes (1931), Trechmann (1954) and Smith (1972, 1985a, 1994). The brecciation and associated mineralogical changes are greatest in the lowest 10–30 m of the formation and diminish unevenly upwards, but there are places where large blocks of strata have foundered with relatively little brec-elation or alteration, and other places where severe brecciation and diagenetic changes extend well up into the formation and even into the overlying Roker Dolomite Formation. Sedgwick (1829) was the first to deduce that fracturing and cementation of many of the breccias had taken place repeatedly, and Howse and Kirkby (1863) were the first to suggest that the late-stage breccia-gashes (their 'breccia-dykes') were formed by the collapse of the roofs of large cavities. Early suggestions that the more extensive brecciation of rock in the coastal cliffs might have accompanied or followed the dissolution of interbedded evaporites were strongly supported by Trechmann (1913) in view of the known presence of thick anhydrite beneath the Roker Dolomite at Hartlepool, but the confirmation of the precise stratigraphical position of the anhydrite awaited the drilling of cored coal-exploration bores offshore (Magraw *et al.,* 1963). The calcitization ('dedolomitization') of the breccia clasts was investigated by Woolacott (1919a) who concluded that it resulted from the reaction between dolomite and calcium sulphate solution (Von Morlot's reaction) and Gillian Tester (pers. comm., 1988) records clear evidence that patchy chert and chalcedony nodules in the breccias have replaced both gypsum and anhydrite. Also at Trow Point, Al-Rekabi (1982, p. 106) reported fibrous chalcedony after calcite.

The discovery near Whitburn of a surface exposure of the Hebburn or Monkton Dyke by Mr G. Fenwick is important partly because of its bearing on the time when the Hartlepool Anhydrite was dissolved. The dyke is one of a swarm with a radiometric age of about 58 million years (Evans *et al.,* 1973; Mussett *et al.,* 1988, fig. 2) and, judging from its partly dendritic shape at outcrop, almost certainly intruded country rock that had already been brecciated. The brecciation, and thus the dissolution of the anhydrite here, is therefore probably Paleocene or older.

Cavity-fill in the breccias was first mentioned by Burton (1911) and has since been found to be extensive, and Hickling and Holmes (1931) recorded stalactitic cavity lining. Smith (1972) has drawn attention to the critical influence on the shape and size of breccia clasts played by the creation in basal post-evaporite carbonate rocks of a dense rectilinear network of sulphate veins, itself possibly related to high-pressure fluid injection following burial-related expulsion of formation brines or dehydration of primary gypsum.

The evaporite-dissolution collapse-breccias of north-east England all lie east of the shelf-edge reef of the Ford Formation, and occupy a NNW/SSE belt that extends for 2–5 km beneath the North Sea. Farther to the east and deeper, increasing thicknesses of anhydrite remain undissolved and overlying Concretionary Limestone rocks are progressively less brecciated. West of the present coastline the Concretionary Limestone in northern Durham passes into the Roker Dolomite and the character of the breccia clasts, as seen in the Ryhope Cutting GCR site, changes accordingly. The collapse-breccias between Trow Point and Lizard Point are amongst the most convincing of their type anywhere in Britain; other excellent (but generally less accessible) exposures of such breccias are in coastal cliffs between Ryhope and Horden (Smith, 1972) and in the Wear Gorge at Sunderland.

Although foundering and collapse following evaporite dissolution are now regarded as the main cause of brecciation in the Concretionary Limestone Formation, there are a number of places in the coastal cliffs (as, for example, just south of Lizard Point) where collapse-brecciation has resulted from the dissolution of carbonate beds (Smith, 1973a, 1994) and many places where partial to complete brecciation has been caused by interstratal carbonate dissolution and stylolite formation during late diagenesis (Braithwaite, 1988). Finally, as in the sector south of Souter Point, local severe brecciation of beds near rockhead appears to have been caused by intense periglacial cryoturbation.

Sedimentology and diagenesis of the Concretionary Limestone Formation

Some aspects of the sedimentology of the Concretionary Limestone are touched on in the account of the Fulwell Hills Quarries site, but most of the critical evidence on which current interpretations are founded is superbly exposed in the cliffs between Velvet Beds and Souter Point. Here, as the sector accounts and literature (Smith, 1970a, 1971a, 1980a, b, 1985a; Smith and Taylor, 1989) show, least-altered strata in the north comprise interbedded finely laminated and unlaminated graded carbonate mudstones in which grainstones and packstones with an exogenous fauna locally form discordant sheets and lenses, whilst strata farther south contain fewer laminites but many disturbed beds with an abundant benthic fauna. These features, coupled with others seen in quarries and borehole cores, have led to interpretation of the Concretionary Limestone as a submarine slope deposit, with strata exposed north of Lizard Point being formed mainly in anoxic or semi-oxic conditions on middle parts of the slope, below an oscillating pycnocline, and those to the south being formed in oxic conditions (i.e. above the pycnocline) higher on the slope and perhaps towards its top (Smith, 1994). In this interpretation, the laminites are envisaged as quiet-water deposits, perhaps as annual couplets (summer sapropel, winter carbonate mud), the graded unlaminated beds are seen as distal turbidites and the disturbed beds are viewed as proximal to medial submarine slumps that may pass downslope into the turbidites. The overall picture is of a gentle subaqueous slope several kilometres long on which differentially high carbonate mud productivity and sedimentation on the upper part resulted in inherent oversteepening and endemic sediment instability. The mud may have been derived by winnowing of the grainstone shoals and back-barrier lagoon of the equivalent shelf facies (i.e. the Roker Dolomite) and the shoals presumably were also the source, through shelf-edge and high-slope failure, of the grainstone sheets and lenses in the mid-slope domain in Marsden Bay as far south as Lizard Point.

Diagenetic changes in the Concretionary Limestone are discussed in the account of the Fulwell Hills site, and most of the secondary features seen in the Fulwell exposures are seen also in the cliffs between Velvet Beds and Souter Point; they were considered in detail by Al-Rekabi (1982) who illustrated and analysed rocks from Marsden Bay and by Braithwaite (1988) who deduced a long and complex diagenetic history. Calcite concretions in the Whitburn to Marsden area are predominantly spherulitic, lacking, however, some of the great range of concretionary patterns seen at the Fulwell Hills site and in coastal cliffs at Hendon (Sunderland). From this point of view, therefore, the Whitburn–Marsden cliffs are perhaps not the best place for the study of these enigmatic structures.

Future research

Although most major aspects of the geology of this remarkable stretch of coastal cliffs and shore platforms have been investigated during the last few years, and several aspects have been researched in detail, many parts of it remain poorly understood and much remains to be discovered. In particular, the detailed sedimentology and local stratigraphy and variation of the Concretionary Limestone are worthy of further detailed research, as are the nature and ecology of the indigenous fauna of the Concretionary Limestone and the diagenetic history of the collapse-breccias.

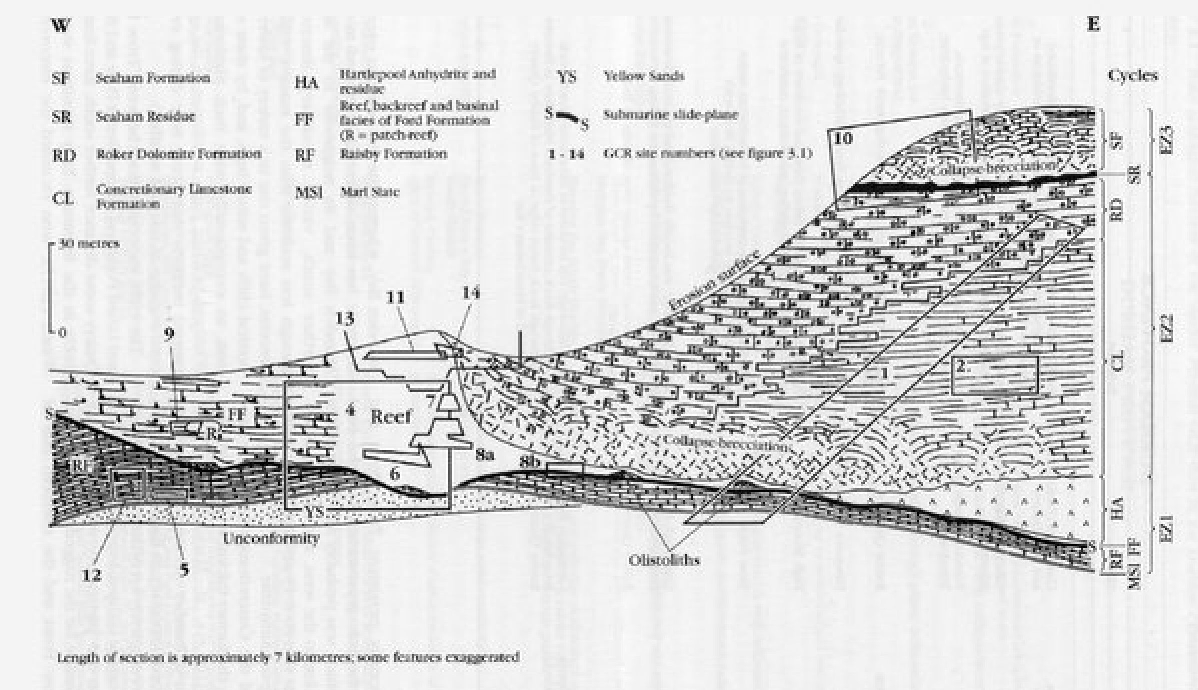
Conclusions

This very extensive GCR site is of international importance because it constitutes a unique set of exposures which display firstly, a whole range of marine Permian depositional features which characterize the western margin of the Zechstein Sea in north-eastern England, and secondly, the post-depositional effects of evaporite dissolution and associated foundering.

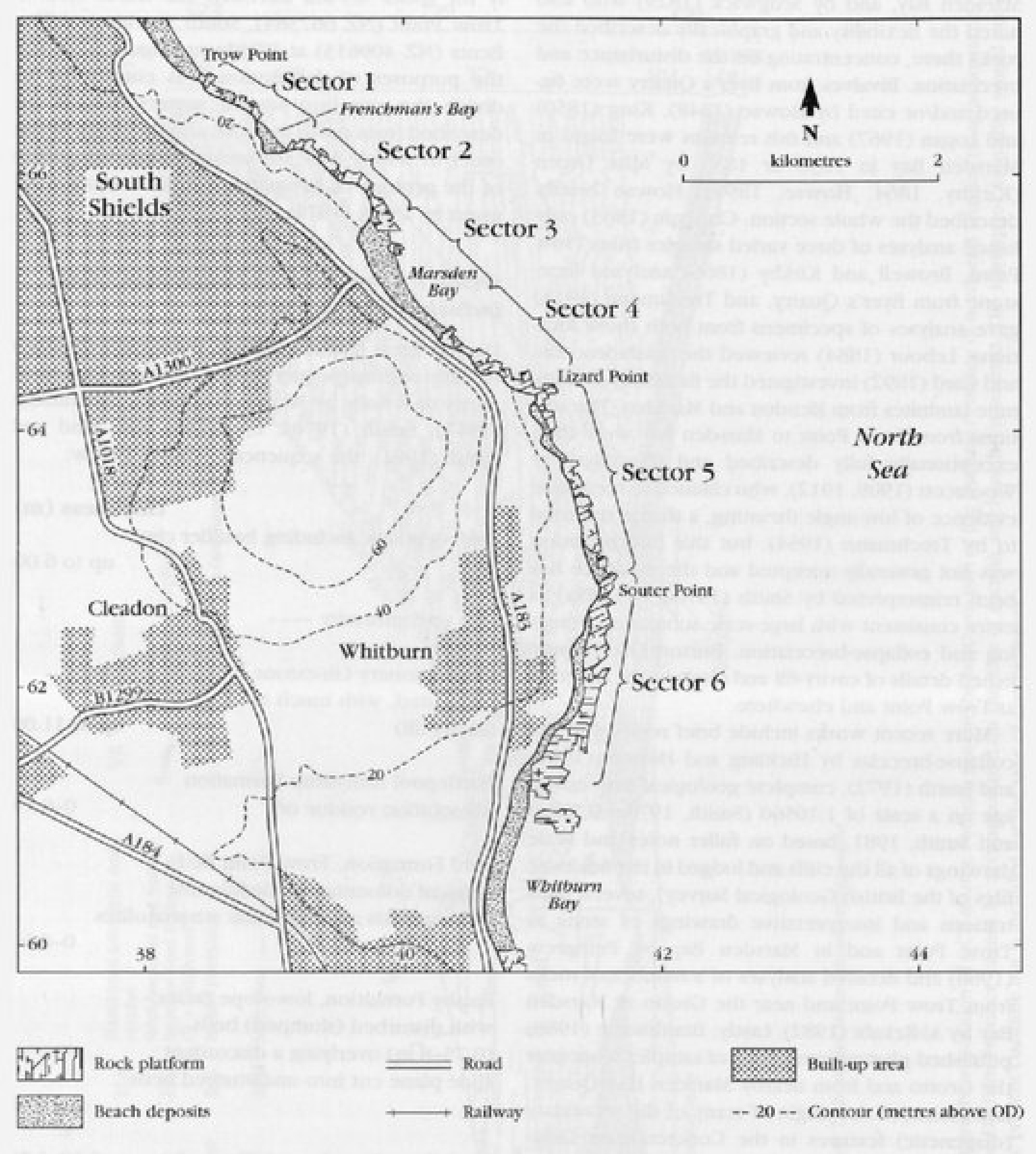
Notable are the Trow Point Bed, which can be traced eastwards across the Zechstein Sea into Germany and Poland, the Hartlepool Anhydrite dissolution residue, and the foundered and brecciated Concretionary Limestone beds. Within these strata are found an important but restricted shelly fauna, much of it transported from more congenial environments nearer to the land.

The section has long been studied, and much of it has been well documented in the literature. However, many parts still remain to be studied and understood, so that there is a need for future research, particularly on the sedimentology of the Concretionary Limestone, its associated fauna and the diagenetic history of the foundered strata.

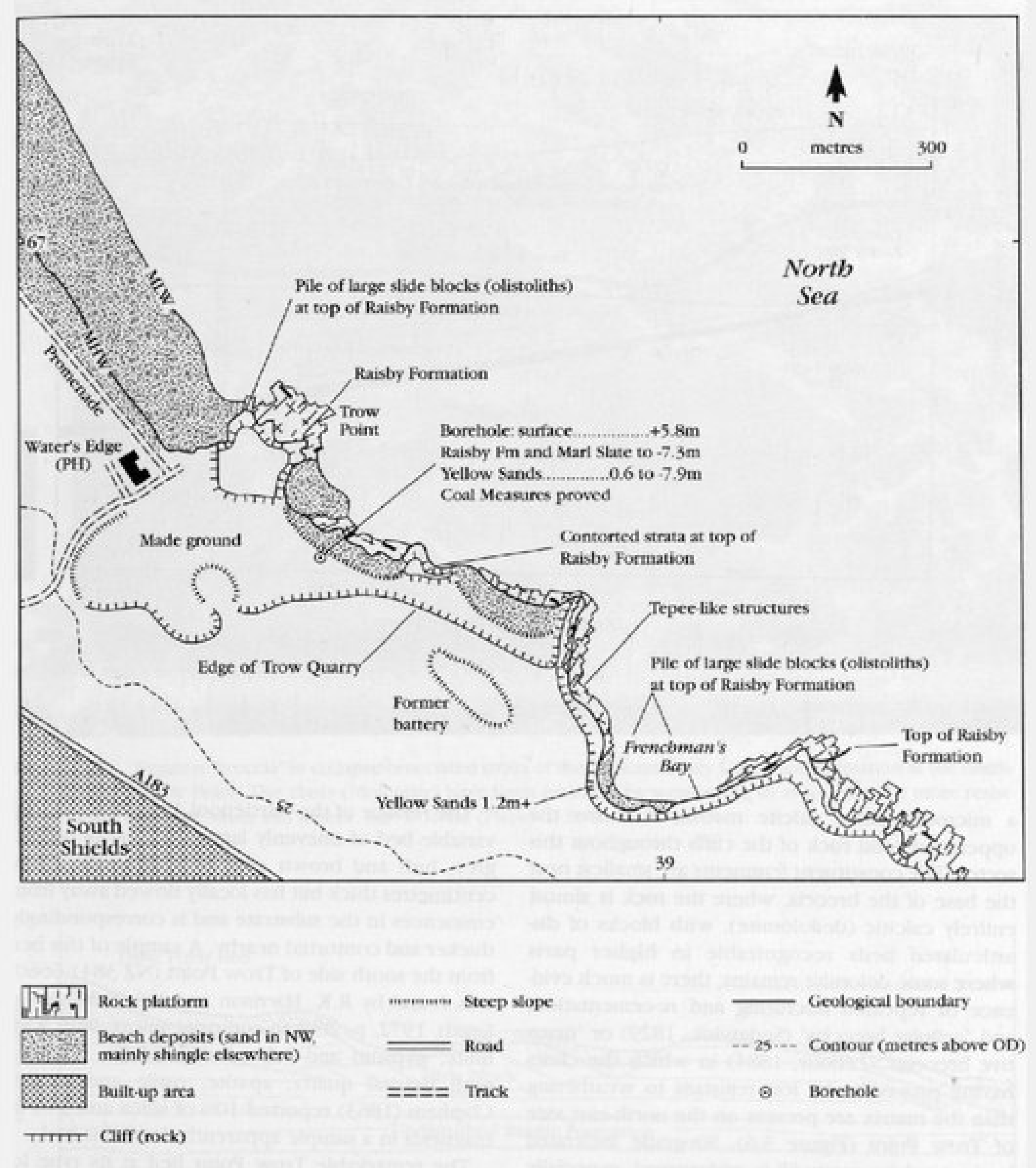
References



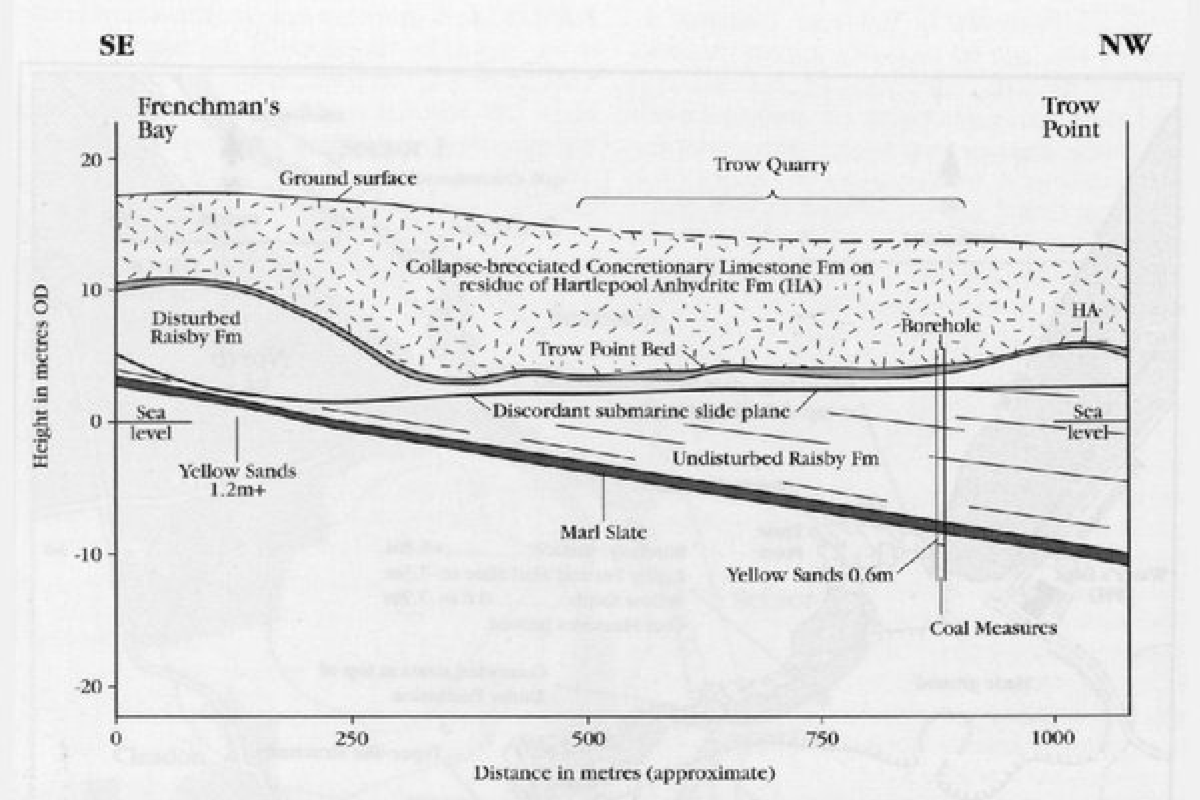
(Figure 3.2) Approximate stratigraphical position of GCR marine Permian sites in the northern part of the Durham Province of north-east England (diagrammatic). Some sites in the southern part of the Durham Province cannot be accommodated on this line of section and have been omitted. The Hartlepool Anhydrite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



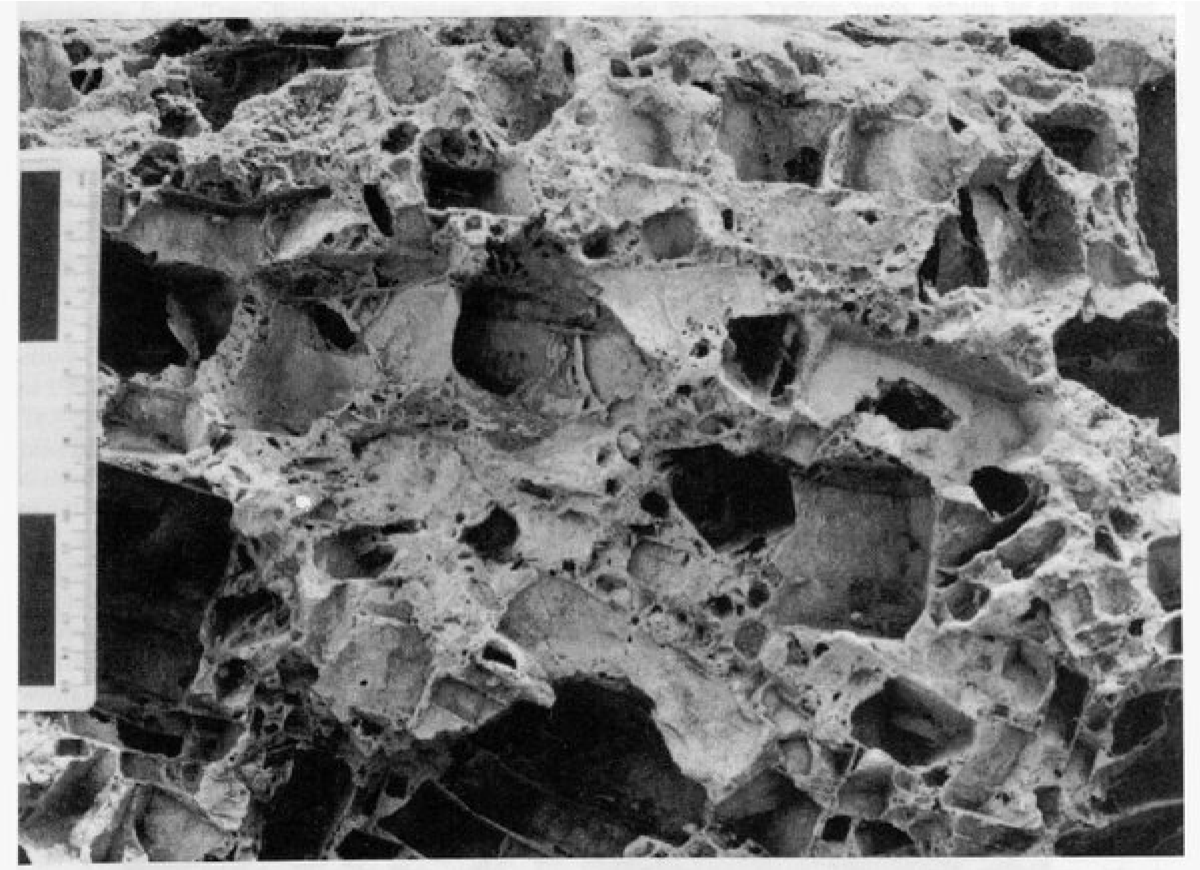
(Figure 3.3) Location of the Trow Point to Whitburn Bay GCR site, showing the sectors described in the text.



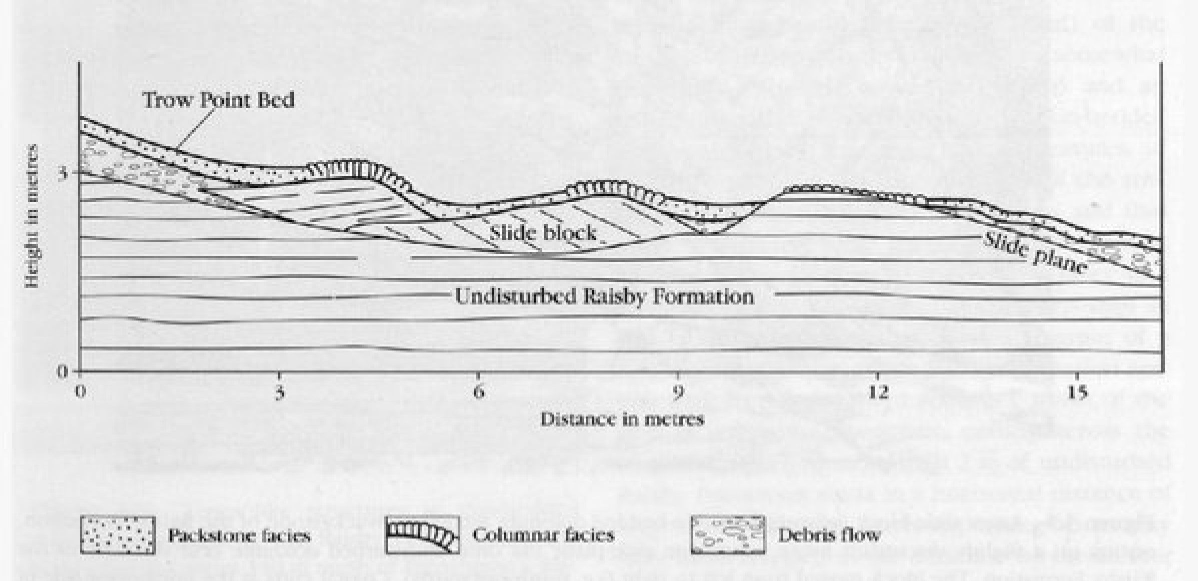
(Figure 3.4) The Trow Point to Frenchman's Bay sector, showing the main features of geological interest. In general, strata above high-tide level are collapse-brecciated rocks of the Concretionary Limestone Formation and those below are of the Raisby Formation.



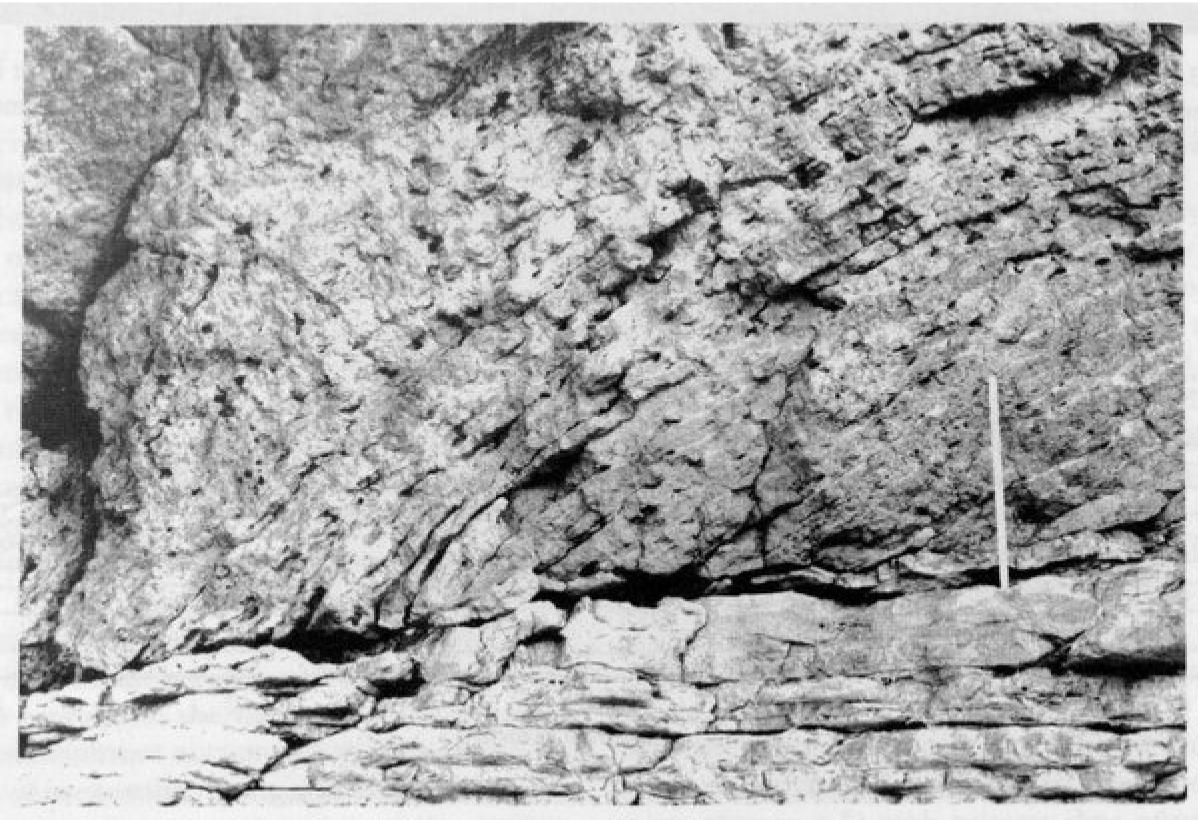
(Figure 3.5) Stratigraphical relationships of Permian rock units in the Trow Point to Frenchman's Bay sector, as seen from the north-east.



(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.)

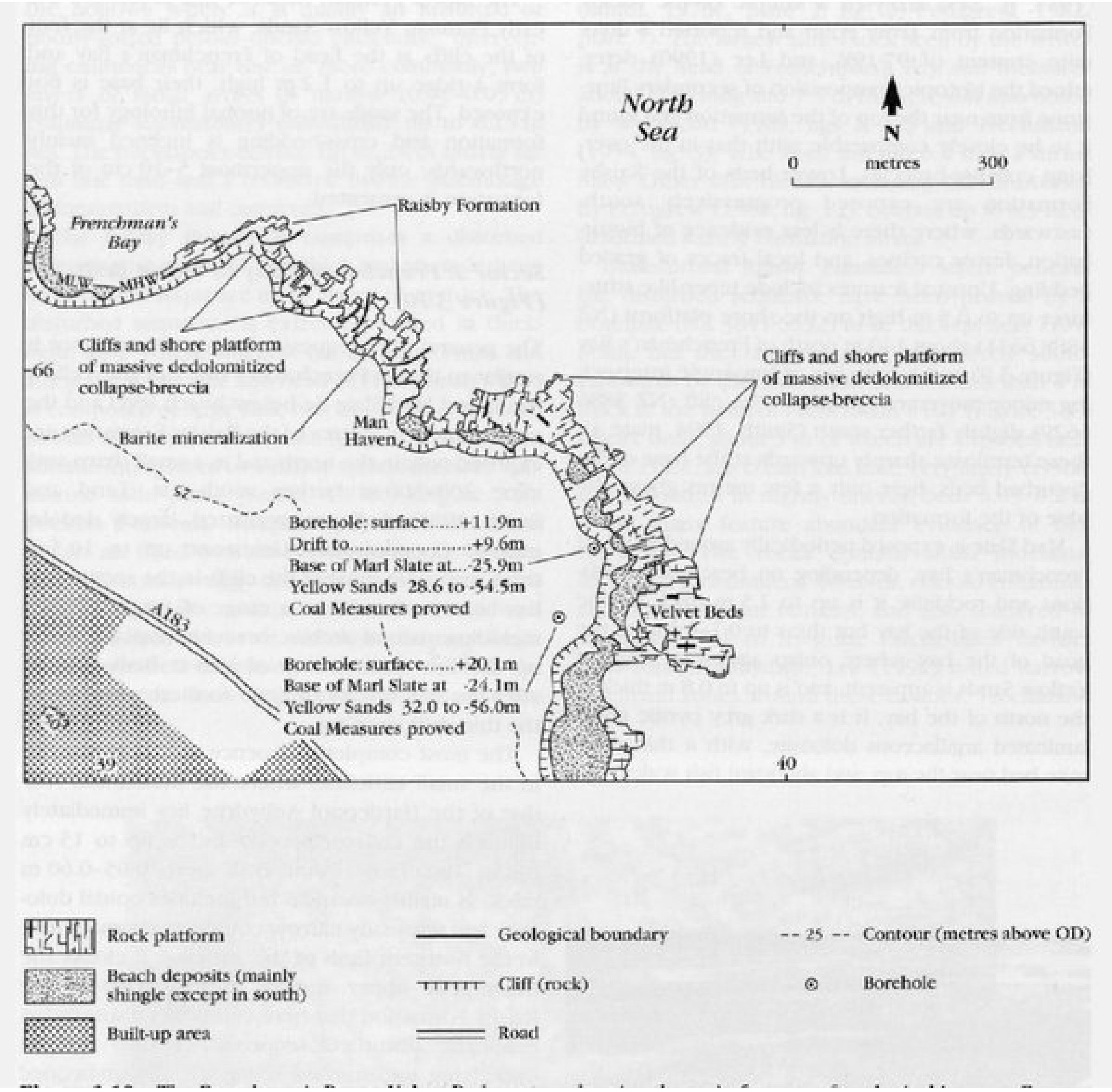


(Figure 3.7) Mutual relationships of facies of the Trow Point Bed at its type locality. After Smith (1986, fig. 3).

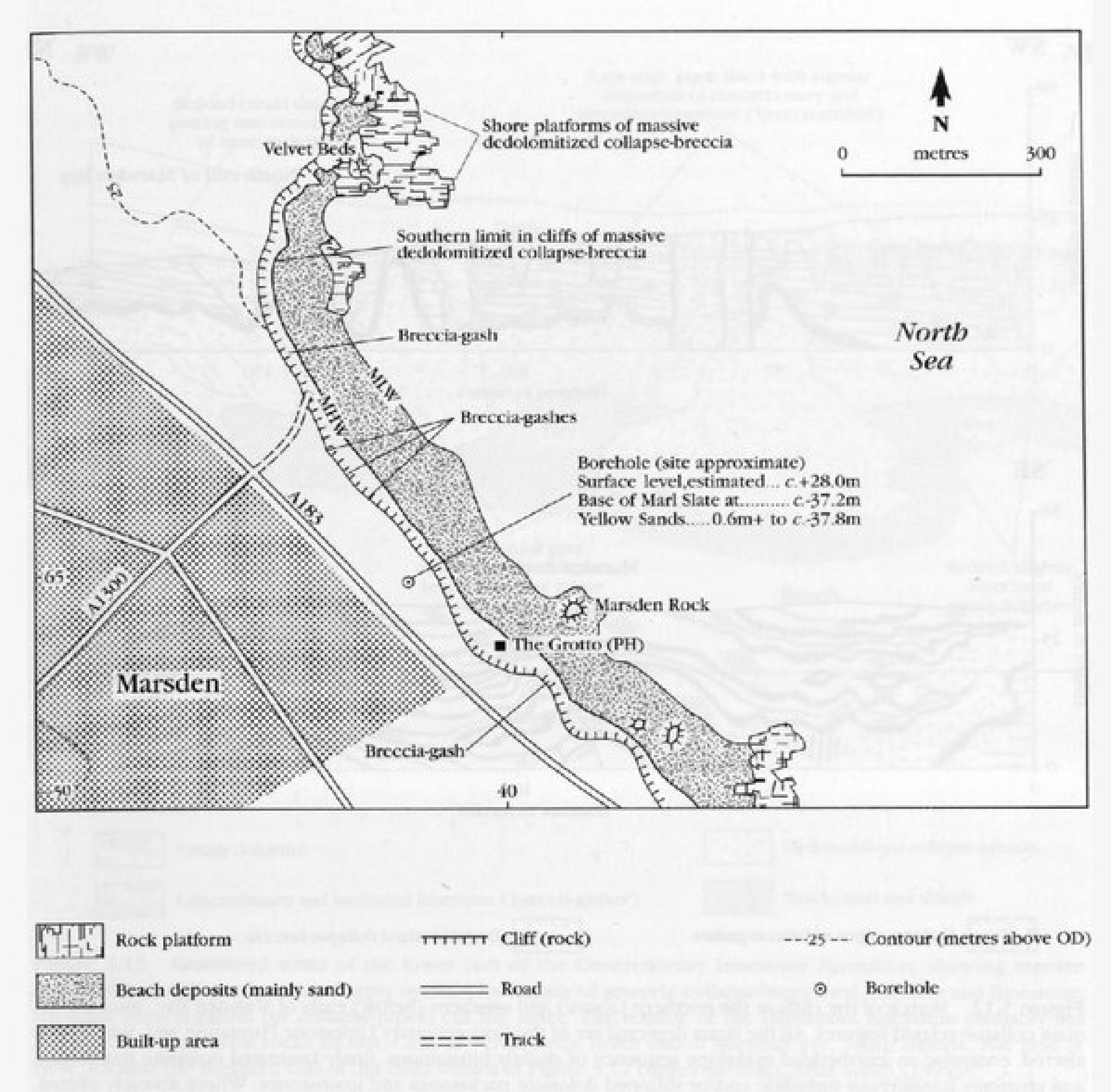


(Figure 3.8) Large slide-block (olistolith) of thin-bedded dolomite mudstone/wackestone of the Raisby Formation, resting on a slightly discordant major submarine slide-plane cut onto undisturbed dolomite near the base of the Raisby Formation. The block moved from left to right (i.e. north-eastwards).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

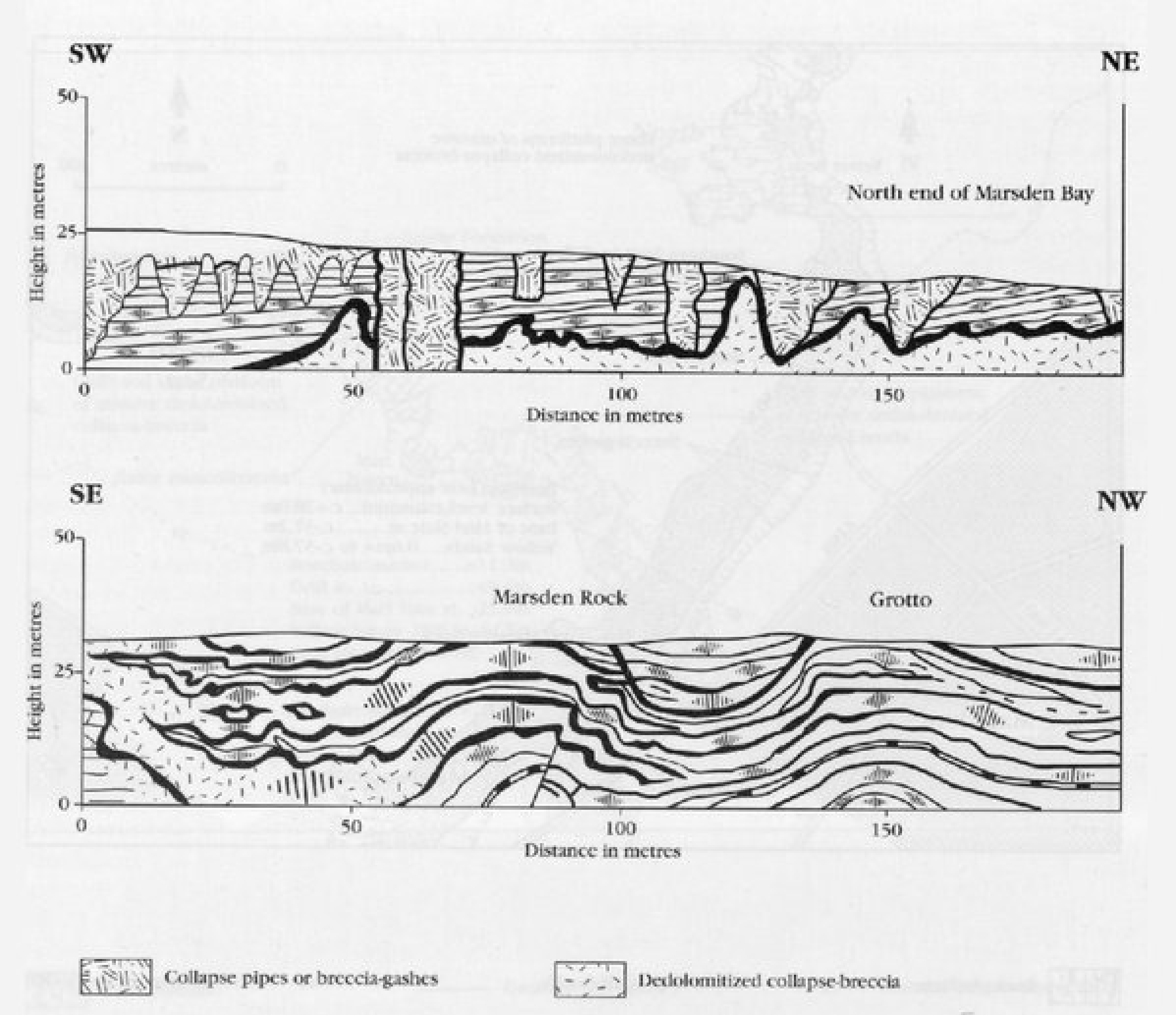
(Figure 3.9) 'Tepee'-like structures in thin-bedded dolomite mudstone of the Raisby Formation on the shore platform about 140 m north of Frenchman's Bay, South Shields. Hammer: 0.33 m. (Photo: D.B. Smith.)



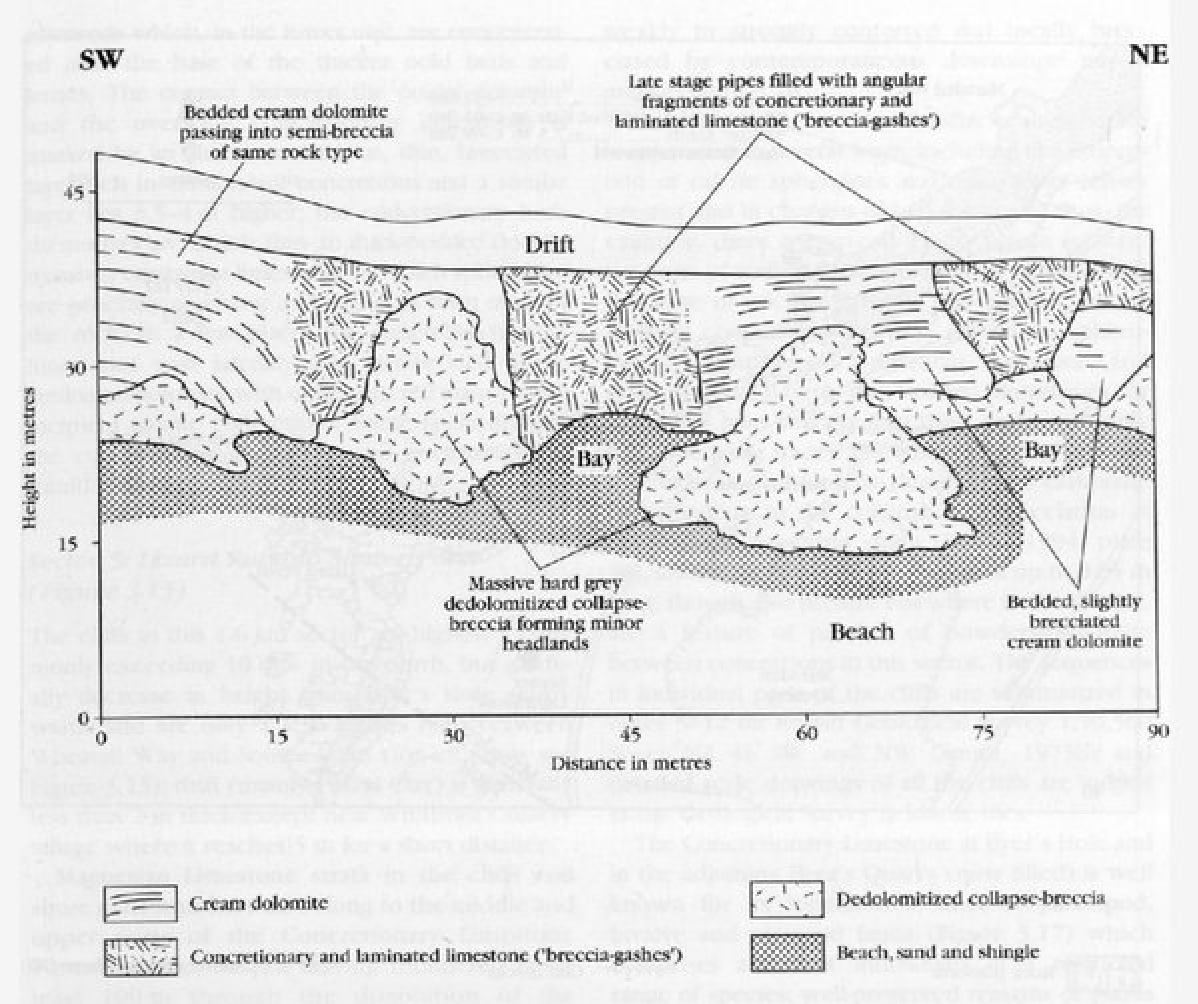
(Figure 3.10) The Frenchman's Bay to Velvet Beds sector, showing the main features of geological interest. Except in Frenchman's Bay and in an anticline c. 100-200 m north of Man Haven, all the strata are collapse-brecciated rocks of the Concretionary Limestone Formation.



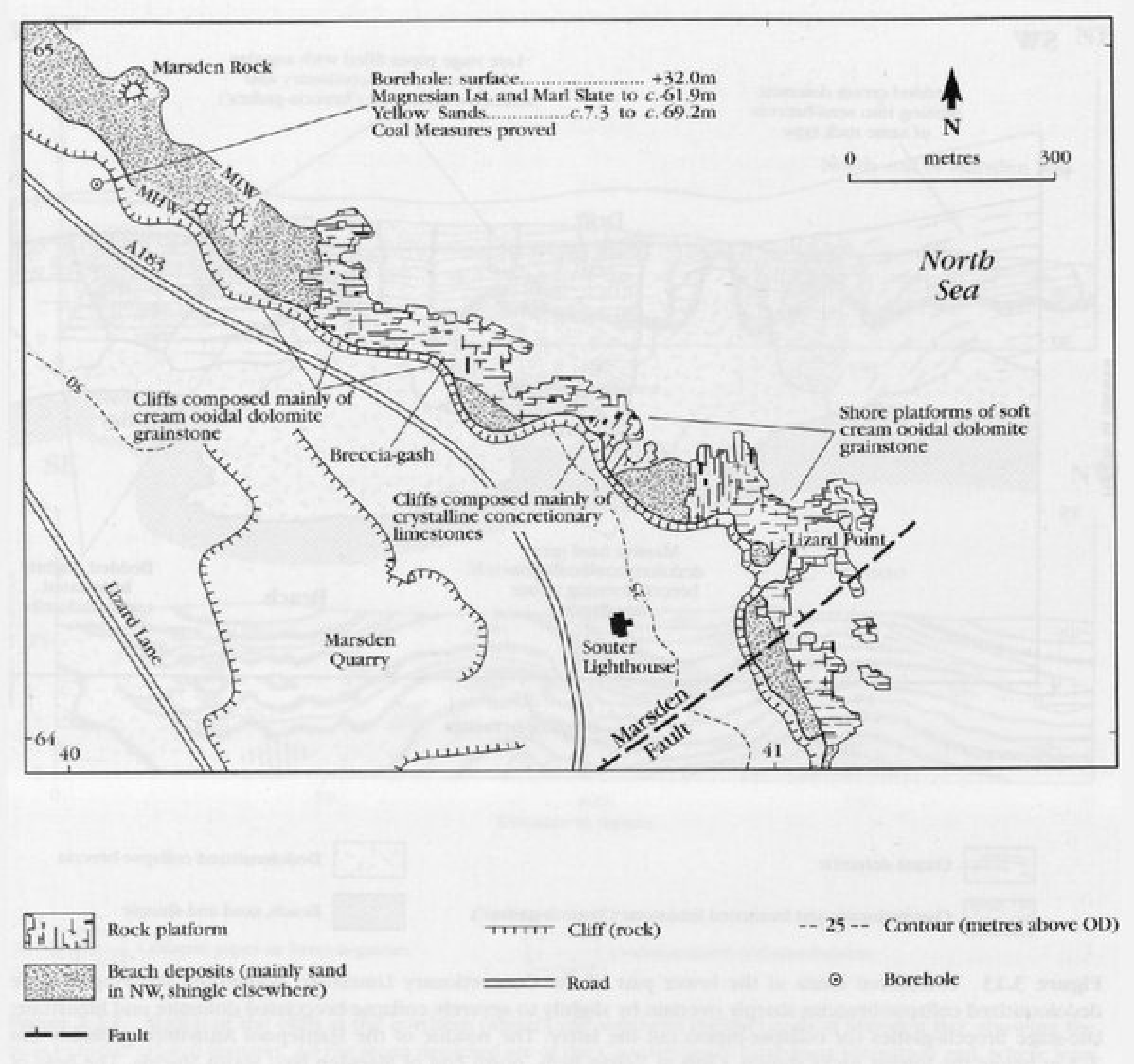
(Figure 3.11) The Velvet Beds to Marsden Rock sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation.



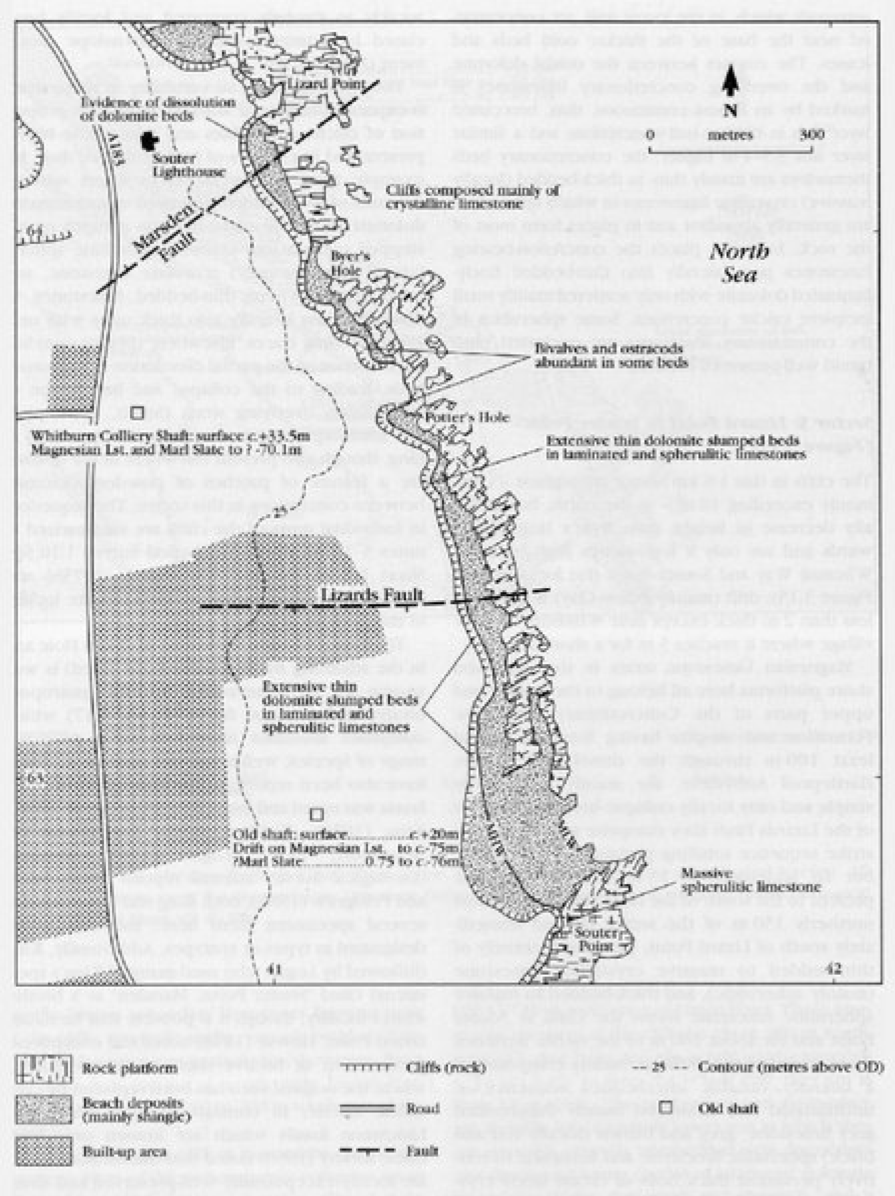
(Figure 3.12) Sketch of the cliffs at the northern (above) and southern (below) ends of Marsden Bay, showing the main collapse-related features. All the strata depicted are of the Concretionary Limestone Formation and, where least altered, comprise an interbedded mid-slope sequence of slightly bituminous, 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.



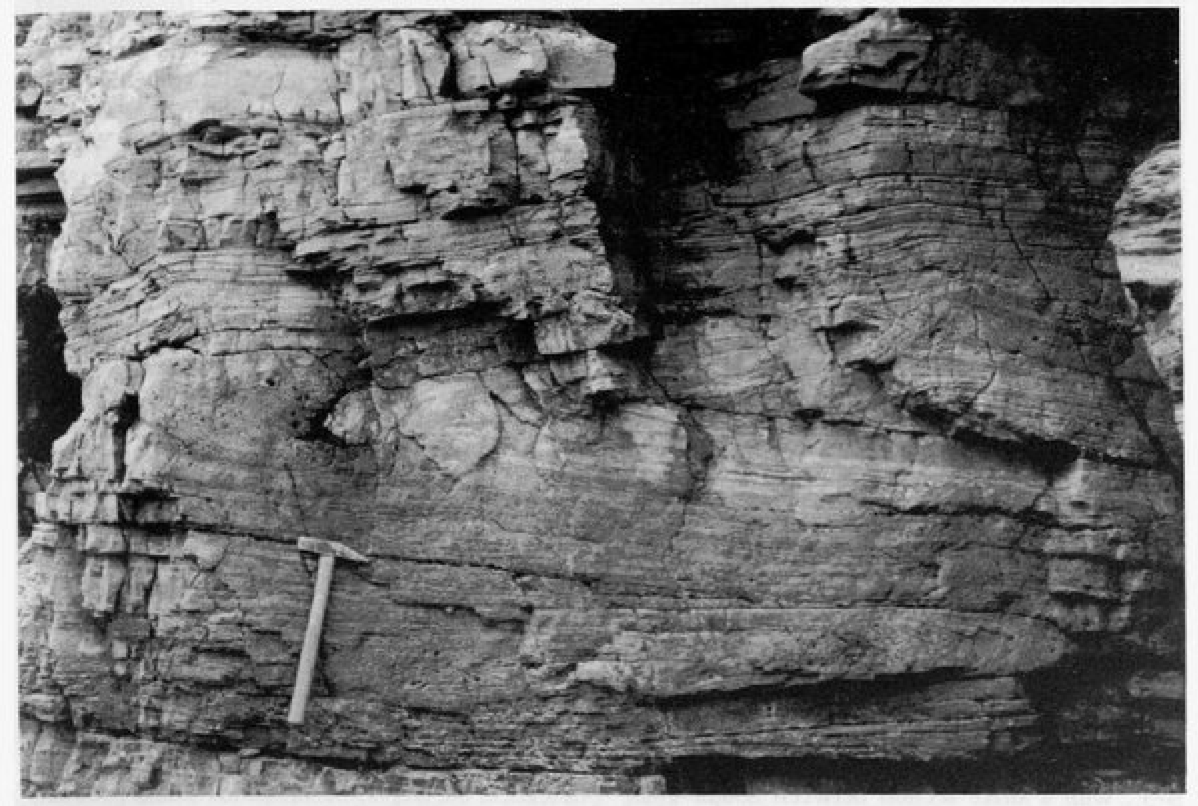
(Figure 3.13) Foundered strata of the lower part of the Concretionary Limestone Formation, showing massive dedolomitized collapse-breccias sharply overlain by slightly to severely collapse-brecciated dolomite and limestone; late-stage breccia-gashes (or collapse-pipes) cut the latter. The residue of 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).



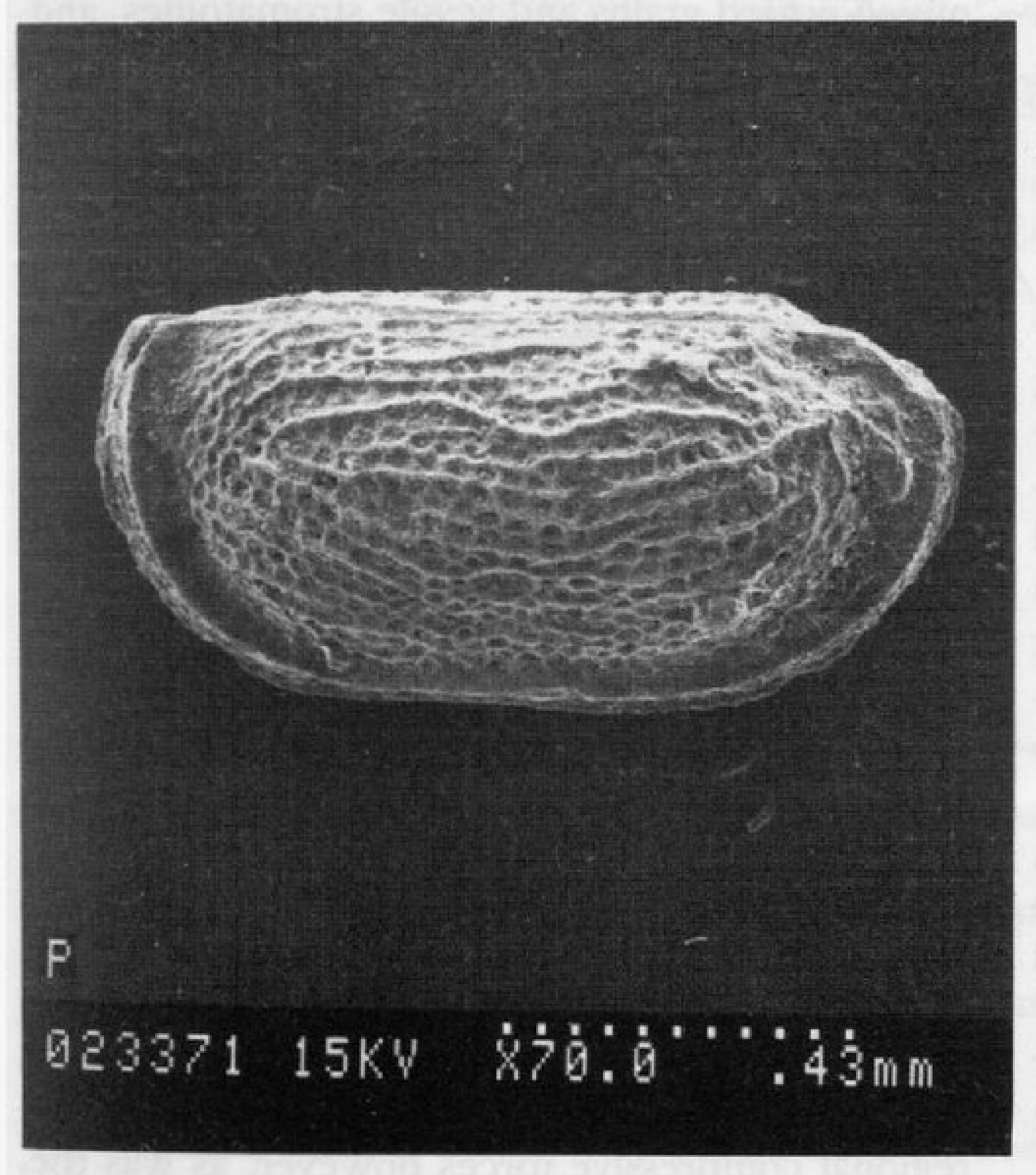
(Figure 3.14) The Marsden Rock to Lizard Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.



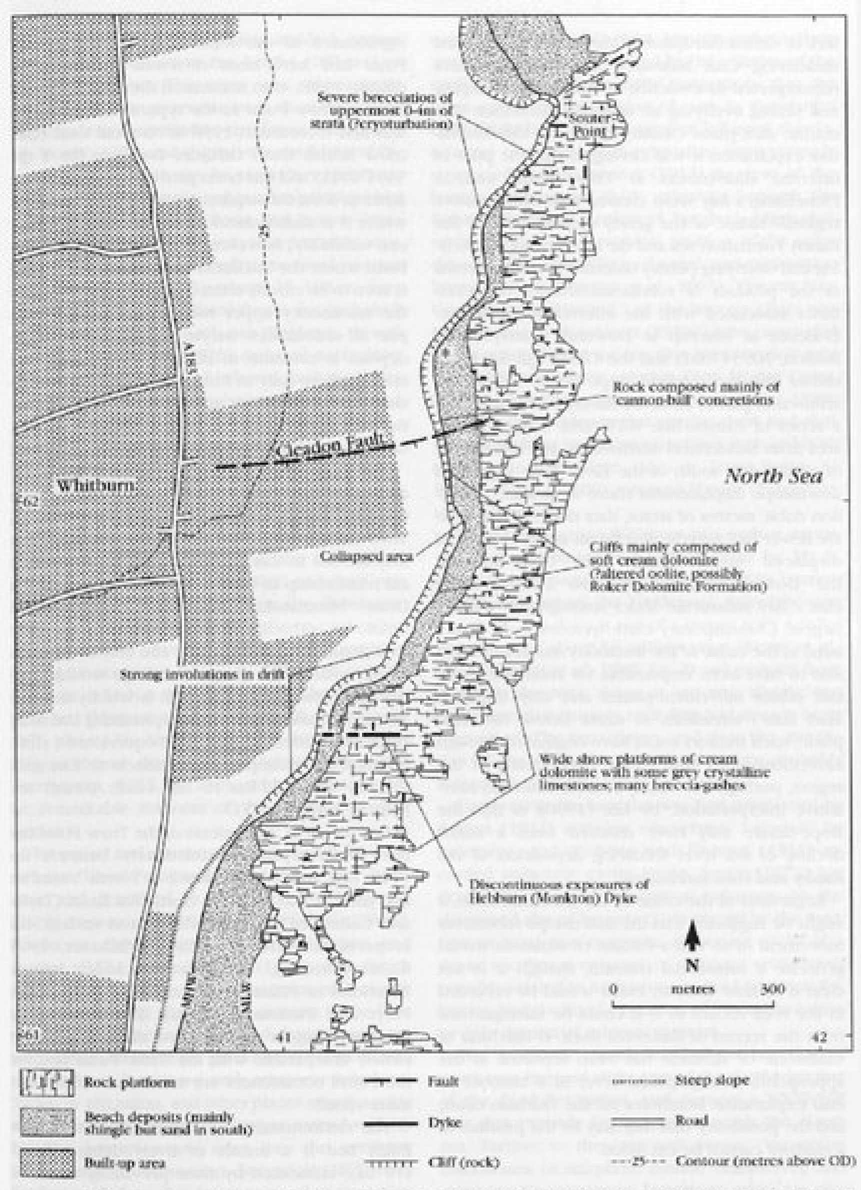
(Figure 3.15) The Lizard Point to Souter Point sector, showing the main features of geological interest. All exposed solid strata are of the Concretionary Limestone Formation. For further details of strata see British Geological Survey 1:10,560 Sheet NZ 46 SW.



(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.