Figures

(Figure 2.4) Shell bed with Neomiodon and Isognomon near the top of the Inverbrora Member. Lens cap 52mm.

(Figure 2.5) Sedimentary log of the Brora Coal Formation at locality 1.

(Figure 2.6) Sketch-map of the shoreline geology at localities 2 and 3.

(Figure 2.7) Log of the Doll Member of the Brora Coal Formation at locality 2 (key as for (Figure 2.5)).

(Figure 2.8) Exposure of the Brora Fault along the foreshore on the NW edge of locality 2. A, the fault is defined by a zone of increased cementation, view of outcrops of quartz-cemented and veined fault rock, and B, slickensided surfaces on landward face of outcrop at top of the beach.

(Figure 2.9) The Brora Arenaceous Formation at Strathsteven Cliff. Large-scale cross-bedding dipping seawards is seen in what is likely to be part of the Clynelish Quarry Sandstone Member.

(Figure 2.10) Sedimentary logs of the Clynelish Quarry Sandstone Member and Fascally Sandstone Member at localities 4 and 5. (Key as for (Figure 2.2).)

(Figure 2.11) Sedimentary log of the Brora Argillaceous Formation at locality 7. Key as for (Figure 2.2). P1, *Planolites*; Ch, *Chondrites*; Te, *Teichichnus*; Th, *Thalassinoides*; D, *Diplocraterion*.

(Figure 2.12) Belemnites (*Cylindroteuthis*) that are common in the Glauconitic Sandstone Member and adjacent strata.

(Figure 2.13) Locality map for localities 9 and 10, Ardlassie Point and estuary of the Brora River

(Figure 3.1) Location areas of itineraries 1 to 4 of Excursion 3.

(Figure 3.2) Basic stratigraphy of the Kimmeridgian section with approximate stratigraphic positions of localities described in the excursion.

(Figure 3.3) Cartoon showing origin of fauna and flora associated with the Helmsdale Boulder Beds.

(Figure 3.4) Reconstruction of the Helmsdale Fault zone in the early Kimmeridgian to show factors associated with the derivation of the Kintradwell Boulder Beds and the Allt na Cuile Sandstone.

(Figure 3.5) Locality map for itinerary 1, Kintradwell area.

(Figure 3.6) Photo and sketch plan of the intrusive sandstone dyke, Kintradwell (plan modified from Jonk, 2003).

(Figure 3.7) Rounded quartzose pebbles and a belemnite in boulder bed, Kintradwell. Coin 28mm.

(Figure 3.8) A Slump fold in pebbly boulder bed, Kintradwell. B Slide plane (at hammer head) beneath zone of deformed shale showing isoclinal folds, and overlain by a relatively undistorted sheet of sandstones and shale.

(Figure 3.9) Sandstone clast showing in situ disintegration within boulder bed, Kintradwell.

(Figure 3.10) Locality map for itinerary 2, Lothbeg area.

(Figure 3.11) Exposure of rock-fall breccias in Allt Choll.

(Figure 3.12) Allt na Cuille sandstones and interbedded shales in cliff at the Earl's Cut, Lothbeg.

(Figure 3.13) A Ammonite with tiny encrusting bivalves and an isolated fragment of *Gleichenites.* B Frond of cycad from carbonate concretion found loose on beach but probably derived from the mutabilis Zone shales.

(Figure 3.14) Features in Allt na Cuille Sandstone caused by fluidisation and injection of sand. Shore between localities 4 and 5, Lothbeg.

(Figure 3.15) Granulation seams in the Allt na Cuille Sandstone, Lothbeg.

(Figure 3.16) Locality map for itinerary 3, Portgower.

(Figure 3.17) Log of boulder bed section near Portgower with general trends in lithology and clast types (adapted from MacDonald (1985)).

(Figure 3.18) Cross-bedding in sandstone clast within boulder bed near Locality 1, Portgower, lens cap 52 mm

(Figure 3.19) The giant clast known as the 'Fallen Stack' showing near-vertical bedding; strata in foreground show general shallow easterly dip of shales and sandy boulder beds.

(Figure 3.20) Locality map for Itinerary 4, Helmsdale to Dun Glas.

(Figure 3.21) Reconstruction of the Helmsdale Fault zone in the late Kimmeridgian at the time of deposition of the Helmsdale Boulder Beds.

(Figure 3.22) Typical texture of Helmsdale Boulder Beds with Middle ORS flagstone clasts in a bioclastic matrix, locality 1, Helmsdale.

(Figure 3.23) Limestone clast in the Helmsdale Boulder Beds at locality 1 bored by the bivalve *Lithophaga,* together with example showing the shape of the bivalve crypt.

(Figure 3.24) Example of a boulder bed that wedges out rapidly away from the Helmsdale Fault, Helmsdale shore.

(Figure 3.25) Colony, 25 mm across, of the coral *Isastraea* from the boulder beds at Helmsdale. The colony was swept into deep water from its living position on a shallow shelf. It may have grown attached to rock on the shelf edge.

(Figure 3.26) View of Dun Glas from SW of the end of Allt Briste. The Helmsdale Fault is exposed on the beach below the granite buttress at the left of the picture, and passes through the col at the back of Dun Glas.

(Figure 3.27) Inclined rockfall breccia of Middle ORS flagstone clasts at Dun Glas, locality 9, Helmsdale excursion.

(Figure 4.1) Locality map for excursion 4, Ousdale area.

(Figure 4.2) Stratigraphic sections at Ousdale and Sarclet (see Excursion 5). Modified from Collins and Donovan (1977).

(Figure 4.3) Ousdale road cutting on the A9 (north end, southbound side) showing the junction between sheared granite and bedded arkose. (Locality now more overgrown with vegetation.)

(Figure 4.4) Log of part of the Ousdale Mudstones at locality 2.

(Figure 4.5) Sandstone beds with erosive bases within the Ousdale Mudstones. The upper bed has a coarse arkosic base. Ousdale Mudstone quarry, locality 2.

(Figure 4.6) Trace fossils from the Ousdale Mudstones at locality 2. The naming of arthropod trackways A–E is tentative, and follows the work of Carroll (1990) and Walker (1985). It is probable that all these trace fossils were made by arthropods. A. *Merostomichnites;* B. *Allocotichnus; C. Merostomichnites,* form with overlapping track series made by animal with at least six pairs of walking legs. D. *Danstaria;* E. *Tasmanadia*; F. *Rusophycus*, a coffee-bean shaped resting trace. G. *Cruziana*, a bilobed ribbon trace made by an animal ploughing through the surface. H. *Beaconichnus*, a double groove tramway-trace. I. *Diplocraterion*, a u-shaped burrow in plan and cross-section. Scale bars 1 cm long.

(Figure 4.7) Sketch reconstruction of depositional features associated with the Ousdale Arkose and Ousdale Mudstones. Eroding granite (G) supplies material for a fringe of arkose (A), and arkosic sheetflood deposits (S) that partly cover alluvial plain mudstones (M). Fluvial channel deposits (F) are sourced from more distant metamorphic basement (B) and hence carry a variety of lithic clasts.

(Figure 5.1) Summary of the characteristics of Lithological Associations A–D of Donovan (1980) which form the cyclic lacustrine facies of the Middle ORS of Caithness.

(Figure 5.2) Origin of fossil fish carcasses in deep lake laminite facies. Fish lived in rivers and shallow lake areas (A) where waters were oxygenated. Periodic mortalities due to salinity crisis, or deoxygenation caused by algal blooms, lake overturn or storm mixing, resulted in carcasses (B) drifting out into the lake where they eventually decayed (C) and sank through the thermocline to be preserved in the anoxic laminites of the deep lake (D). Modified from Trewin (1986).

(Figure 5.3) Locality map for Itinerary 5.1, Achanarras, Spital and Dirlot.

(Figure 5.4) Log of section at Achanarras Quarry. Modified from Trewin (1986).

(Figure 5.5) Section of base of siltstone bed resting on laminite. Siltstone bed contains rip-up clasts of laminite and the laminite consists of alternations of silt (dark) and dolomicrite (pale). The siltstone was emplaced by a turbidity current flowing downslope into the deep lake. The laminites deformed plastically beneath the turbidite; a compacted shrinkage crack produced the offsets in the lower part of the laminites in the photo. Scale bar 10 mm.

(Figure 5.6) Cut and acid-etched section showing the lamination typical of the central part of the Achanarras fish bed. White laminae are dolomitic. Scale bar 10 mm.

(Figure 5.7) Distribution of fish in the Achanarras fish bed, together with subdivision of the bed into six faunal units. Based on the positioning of over 1000 specimens by laminite-pattern matching. See Trewin (1986) for further details.

(Figure 5.8) Fish from the Achanarras fish bed at Achanarras Quarry. Note difference in scales. A. *Palaeospondylus gunni*; B. *Pterichthyodes milleri*; C. *Dipterus valenciennesi*; D. *Cheirolepis trailli*; E. *Coccosteus decipiens*; F. *Glyptolepis paucidens*; G. *Mesacanthus.*

(Figure 5.9) Map and sketch section at locality 4, Dirlot Castle (Modified from Donovan 1973).

(Figure 5.10) Domed stromatolite grown on the surface of a boulder of Moine schist from the Dirlot breccia; matrix contains flakes of stromatolite boken from the surfaces of other clasts. Coin 25mm.

(Figure 5.11) View downstream at the Devil's Pool, Dirlot Castle. The unconformity between Moine and Middle ORS is present in the cliff to the left, largely covered by vegetation.

(Figure 5.12) Locality map for Itinerary 5.2, John o' Groats area.

(Figure 5.13) Shore to the east of John o' Groats harbour, Red fluvial sandstones with thin-bedded greenish lacustrine strata that include the John o' Groats fish bed.

(Figure 5.14) Volcanic breccia in the volcanic neck at Ness of Duncansby, with Duncansby Head in the background.

(Figure 5.15) Fault gully giving access to locality 8. John o' Groats Sandstone Group on left and thin-bedded flagstones of Mey Subgroup on the right.

(Figure 5.16) The John o' Groats Sandstone at Locality 8, Duncansby Head.

(Figure 5.17) Cyclicity in the Lybster Subgroup at South Head, Wick. Lithological Association D in foreground and at top of quarry face (pale colour). Central part of face consists of grey to black Association C (see (Figure 5.18) and text).

(Figure 5.18) A Cut and acid-etched cross-section of typical sand-filled lenticular shrinkage cracks in Association C. B Sand/ mud couplets with shrinkage cracks enhanced by weathering in quarry face. C Orange weathering dolomitic beds and disruption features near base of quarry section. Lower Flagstone Group, South Head, Wick.

(Figure 5.19) Slide plane underlain by relatively undisturbed sandstones and overlain by folded and fractured strata. Cliff top exposure viewed from cliff ledge, locality 10, Sarclet. Further information in text.

(Figure 5.20) Deformation features in carbonate laminites of a fish bed at Brims Ness. Coin 27mm. from the organic-rich laminites during burial. The cyclic nature of the sequence can be examined on the foreshore at mid to low tide.

(Figure 5.21) *Osteolepis panderi.* A Reconstruction of lateral view, together with dorsal, lateral and ventral aspects of head (After Jarvik, 1948). B Well-preserved, articulated specimens of *O. panderi* from Cairnfield, near Thurso.

(Figure 5.22) Typical sand-filled lenticular shrinkage cracks from locality 12, Holborn Head Quarry.

(Figure 5.23) A Large sand-filled polygonal desiccation cracks formed due to subaerial exposure. B Current ripples formed in shallow water. Locality 13, Pennyland Shore, Thurso.

(Figure 5.24) Reconstruction of lateral view of head and thoracic region of *Millerosteus minor* (Miller) (after A. Desmond).

(Figure 5.25) Cross-bedded sandstones of mixed fluvial and aeolian origin. Promontary near isolated stack below building on cliff top, Thurso shore [ND 111 691].

(Figure 5.26) Locality map for Dunnet Head area, itinerary 5.3.

(Figure 5.27) Cliffs of fluvial cross-bedded red sandstones of the Upper ORS to the northwest of Dwarwick Pier. Locality 14.

(Figure 5.28) Soft sediment deformation in cross-bedded fluvial channel sandstones in Upper ORS to the SE of Dwarwick Pier. Locality 14.

(Figure 5.29) Locality map of the Red Point area, locality 17 (Modified from Donovan 1975).

(Figure 5.30) Red Point, basement margin features. Cross sections at points 1 and 2 and along line x–x^1 as shown on (Figure 5.29) (modified from Donovan, 1975).

(Figure 5.31) Exposure at Point 1, Locality 17, Red Point. Steeply dipping limestone mantles the basement and is overlain by breccia.

(Figure 5.32) Exposure at Point 2, Locality 17, Red Point. Rapid lateral transition from marginal breccia downslope into lacustrine flagstones.

(Figure 5.33) Gully at Point 4, Locality 17, Red Point. View to north of steep exhumed margin of basement hill of gneiss cut by granite veins at left of gully, and lacustrine flagstones in valley floor and on right.

(Figure 5.34) Locality map for Port Skerra and Baligill, localities 18 to 23.

(Figure 5.35) View to the west of Portskerra Bay from the track to the slipway. Knolls of Moine gneiss are draped by Old Red Sandstone.

(Figure 5.36) Banded and folded Moine gneiss in reef at the end of the slipway, Port Skerra.

(Figure 5.37) Unconformable contact between intensely jointed Moine gneiss and locally-derived Old Red Sandstone breccia. Near end of slipway, Port Skerra.

(Figure 5.38) Section at Locality 20, by the lime kilns. Shallowing-up section from lacustrine laminite at base of cliff to fluvial/ aeolian sandstones at top.

(Figure 5.39) Angular clasts of basement gneiss in limestone that drapes the gneiss surface. Locality 21, near An Dun.

(Figure 5.40) East-west section through the basement knoll at An Dun. Locality 22 (modified from Donovan, 1975).

(Figure 5.41) View of the cliff face below An Dun showing outcrop of gneiss beneath grey lacustrine limestone that drapes the steep gneiss surface.

(Figure 5.42) Locality map, Sandside Bay.

(Figure 5.43) Rippled sandstone overlying polygonal desiccation cracks. Bighouse Formation, Sandside Bay.

(Figure 5.44) Cliff exposure with bed of aeolian sandstone followed by rapid transition to laminated fish bed. Bighouse Formation, Sandside Bay.

(Figure 5.45) A Cross-bedded aeolian sandstone of the Fresgoe Sandstone Member near Sandside Harbour wall. B Lacustrine flagstones overlying truncated top of the aeolian Fresgoe Sandstone. East side of Sandside Bay, Locality 25.

(Figure 5.46) Section north of Sandside harbour with sandstone beds deposited by flash floods.

(Figure 5.47) *Thursius macrolepidotus.* Reconstruction (after Jarvik, 1948) and specimen from Sandside Bay.

(Figure 6.1) Locality map of Kildonan Burn area.

(Figure 6.2) Typical flakes of alluvial gold up to 3 mm in size, and panned from gravel in the Kildonan Burn at Baille an Or.

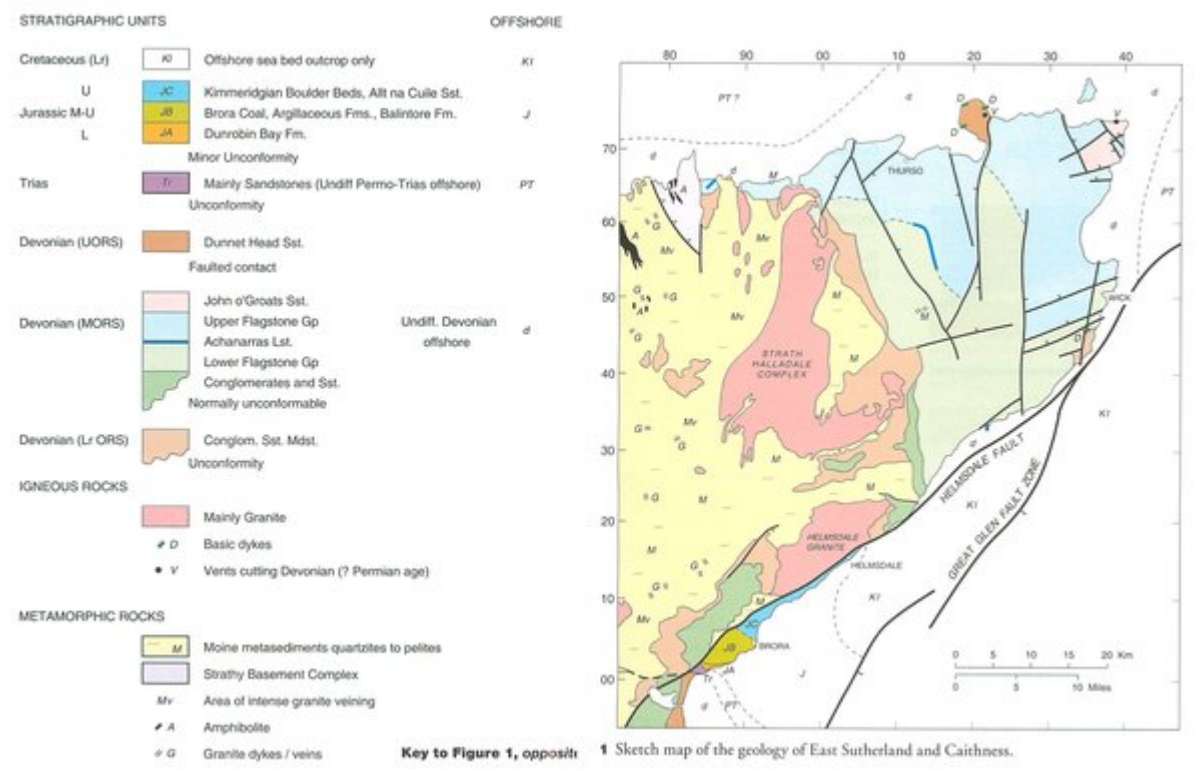
(Figure 6.3) Engraving of Baille an Or at the time of the 1869 gold rush. Reproduced from *The Illustrated London News,* May 29, 1869.

(Figure 6.4) Engraving of gold diggers working at Kildonnan in 1869. Reproduced from *The Illustrated London News,* May 29, 1869.

(Title page) Title page.

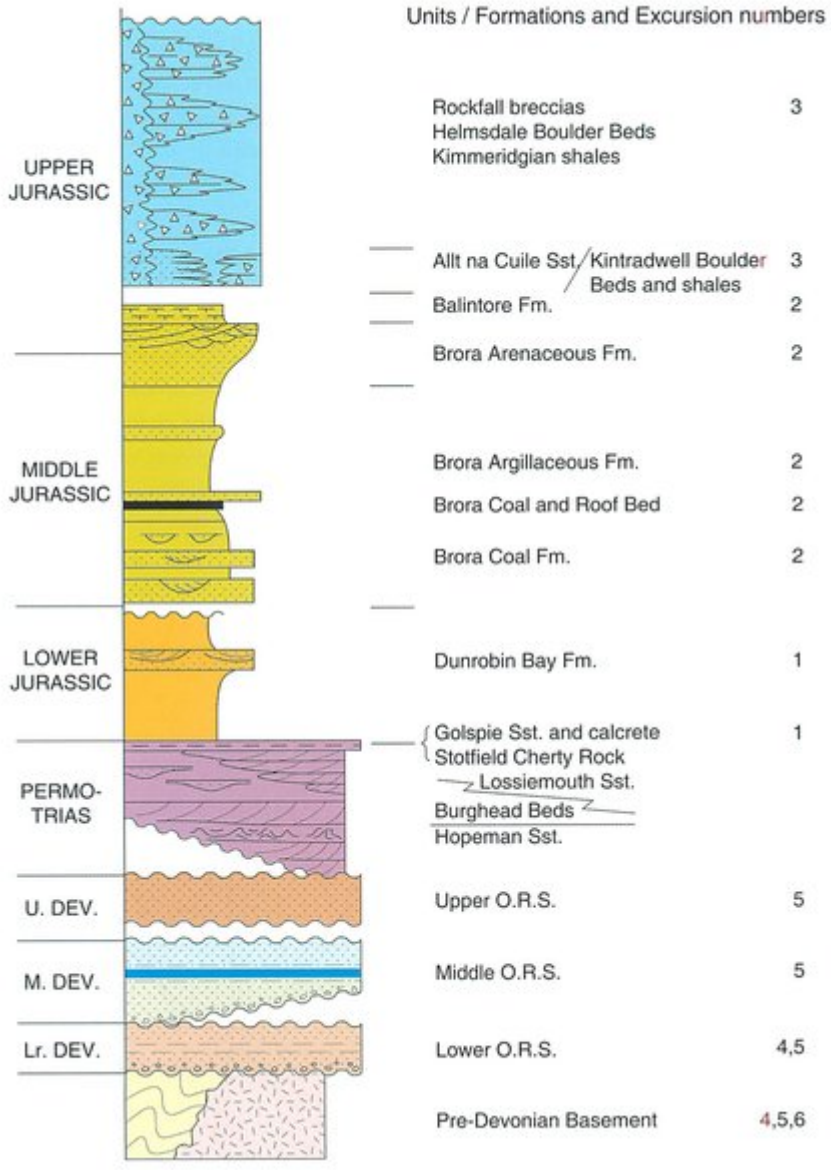
(Front cover) Front cover.

(Rear cover) Rear cover.



1 Sketch map of the geology of East Sutherland and Caithness.

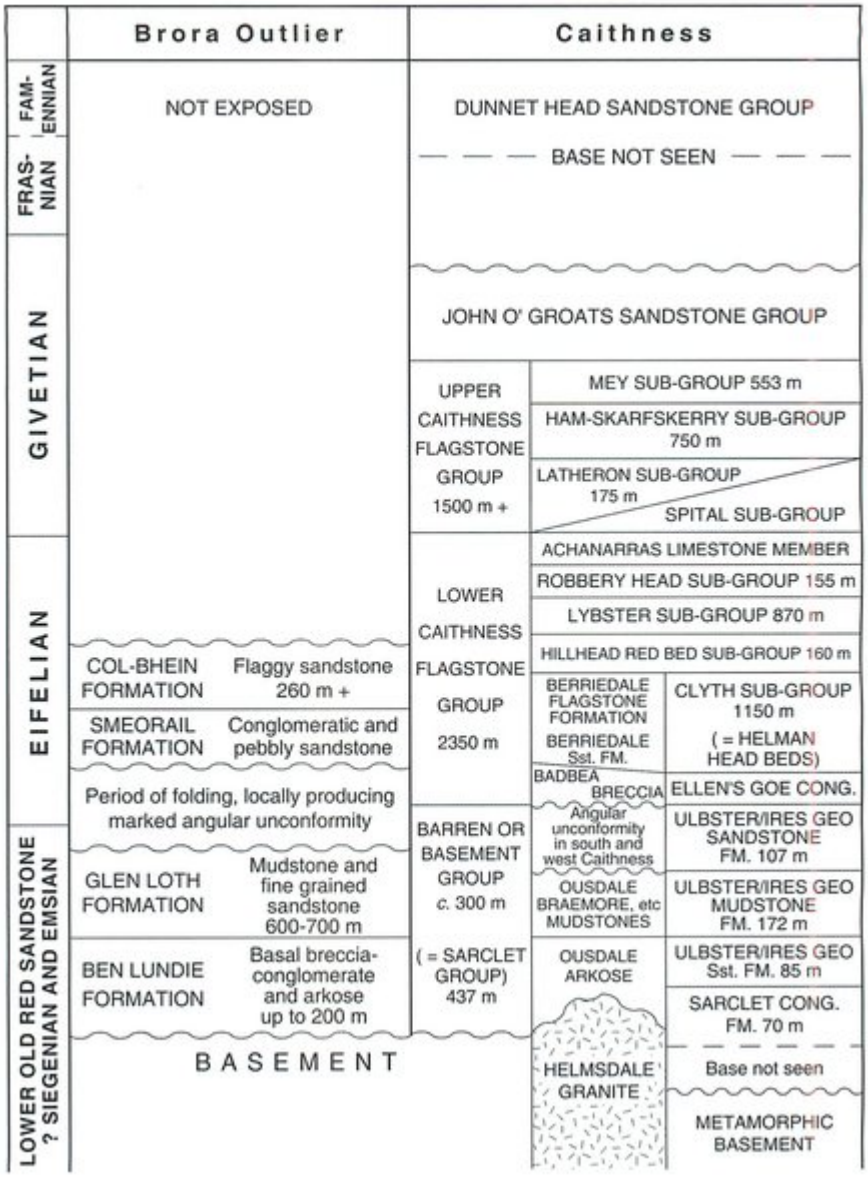
(Figure 1) Sketch map of the geology of East Sutherland and Caithness.



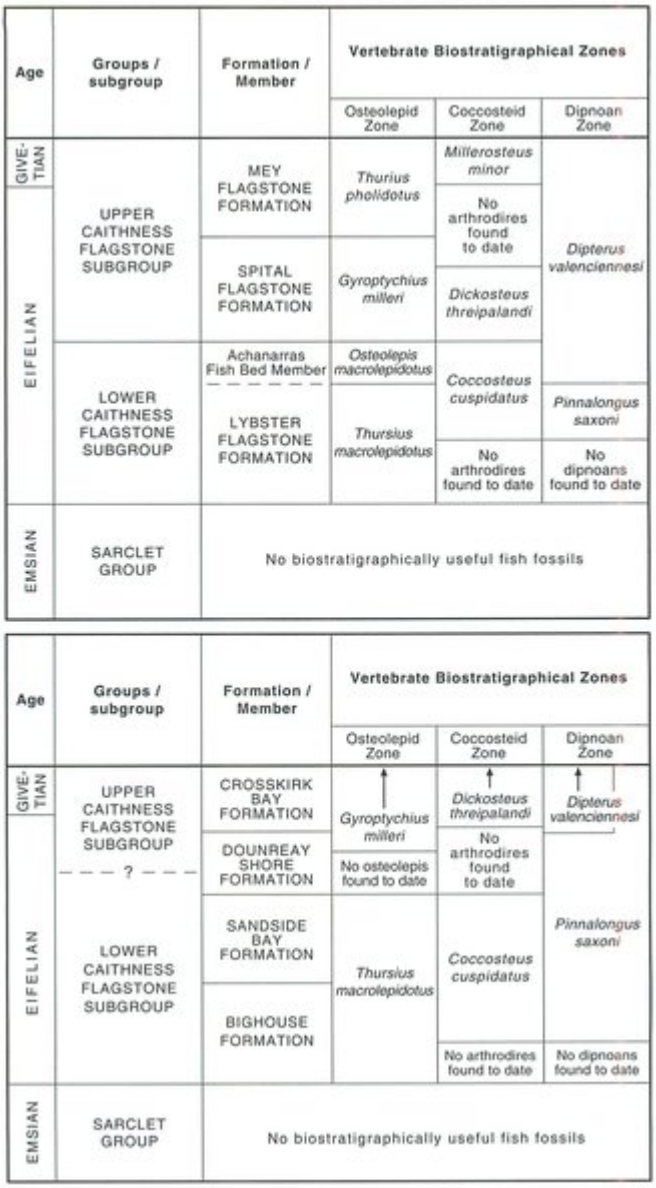
(Figure 2) Basic stratigraphic framework and relevant excursions.

From c. 400	Deposition of Lower Old Red Sandstone starting in Emsian, Initiation of Orcadian Basins. Uplift and erosion to expose Helmsdale Granite.
c. 420	Intrusion of Helmsdale Granite.
435 - 425	Scandian metamorphism deformation and nappe formation, ending with Moine Thrust movements and intrusion of undeformed Strath Halladale granite complex.
c. 470 - 440	Grampian metamorphic event, peak in mid Ordovician and including migmatites in East Sutherland. Inclusion of basement slices in Moine.
c. 820 - 870	Knoydartian orogeny seen on west coast of Scotland. Polyphase metamorphism and granite intrusion not proven in E. Sutherland, but some pre-Grampian event probable.
1000 - 900	Deposition of Moine sediments, mainly sandstones and shales, on metamorphic basement.

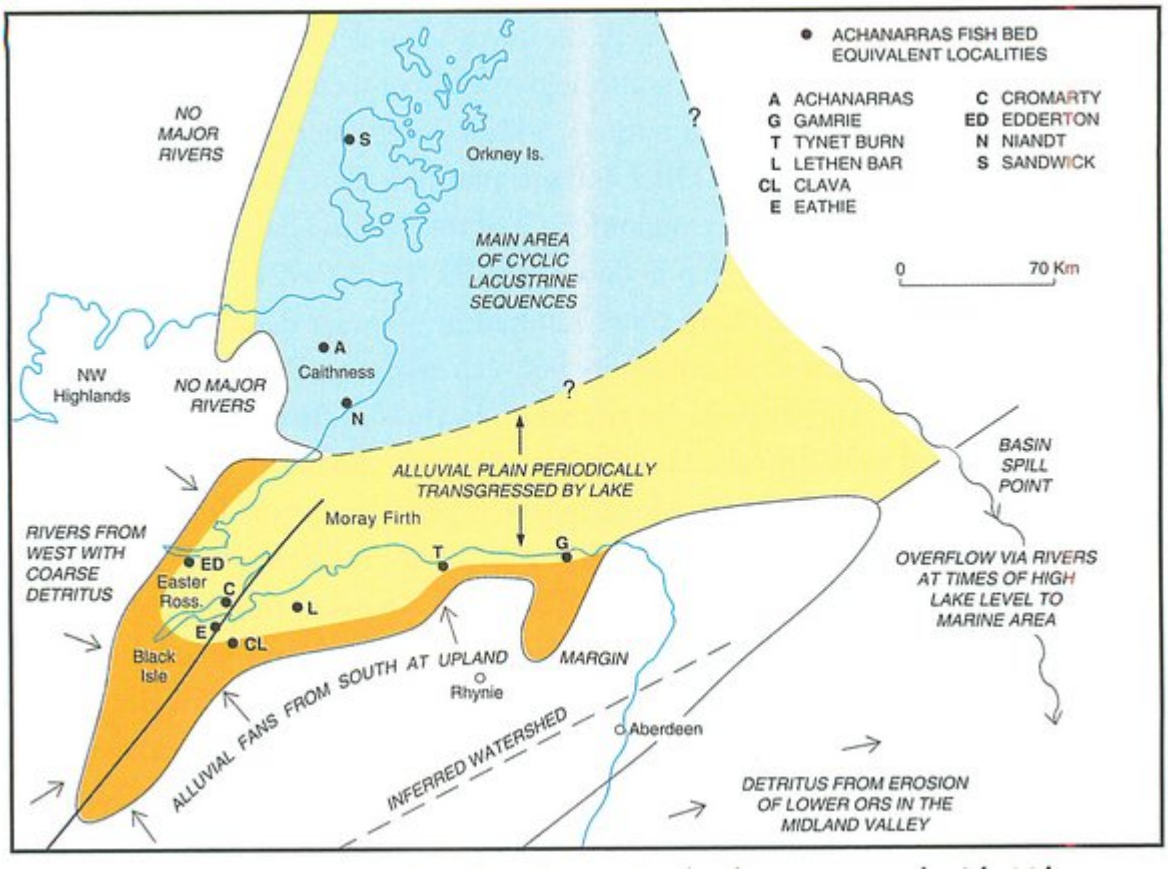
(Figure 3) Sequence of events in pre-Devonian basement. Summarised from Strachan et al. (2002) and Trewin and Rollin (2002).



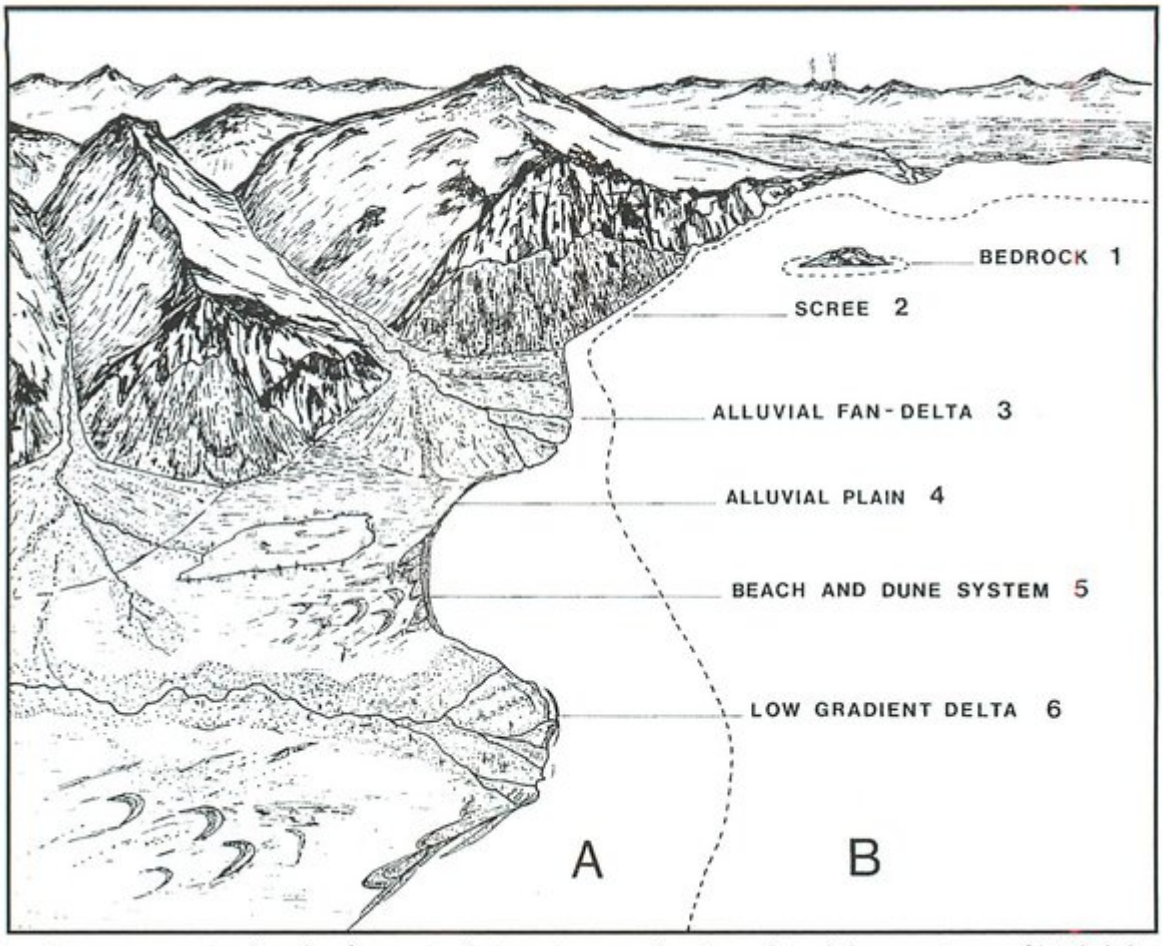
(Figure 4) Stratigraphic nomenclature for the Devonian in eastern and southern Caithness and the Brora region of Sutherland. Modified from Trewin and Thirlwall (2002).



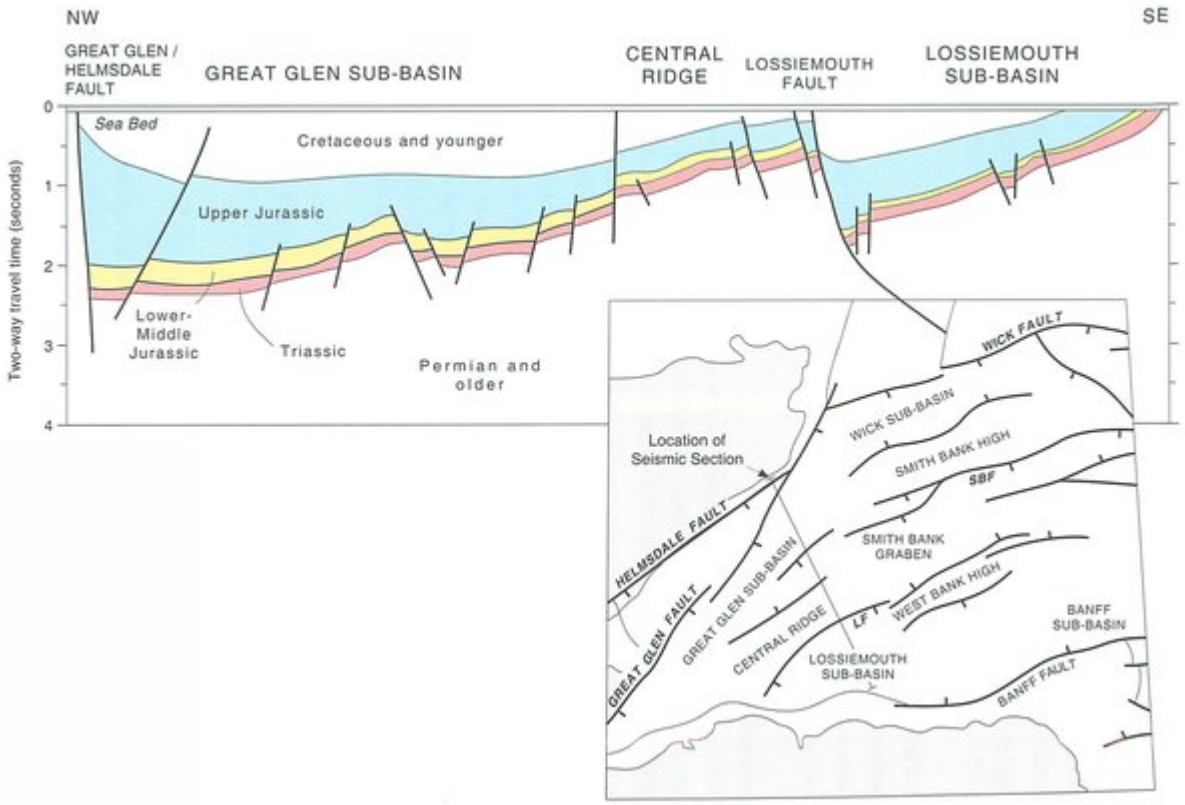
(Figure 5) Stratigraphic nomenclature for the Devonian in NW Caithness and the adjacent part of Sutherland showing correlation and fish faunas on either side of the Bridge of Forss Fault. (From British Geological Survey, 2005; Newman and den Blaauwen, 2008.)



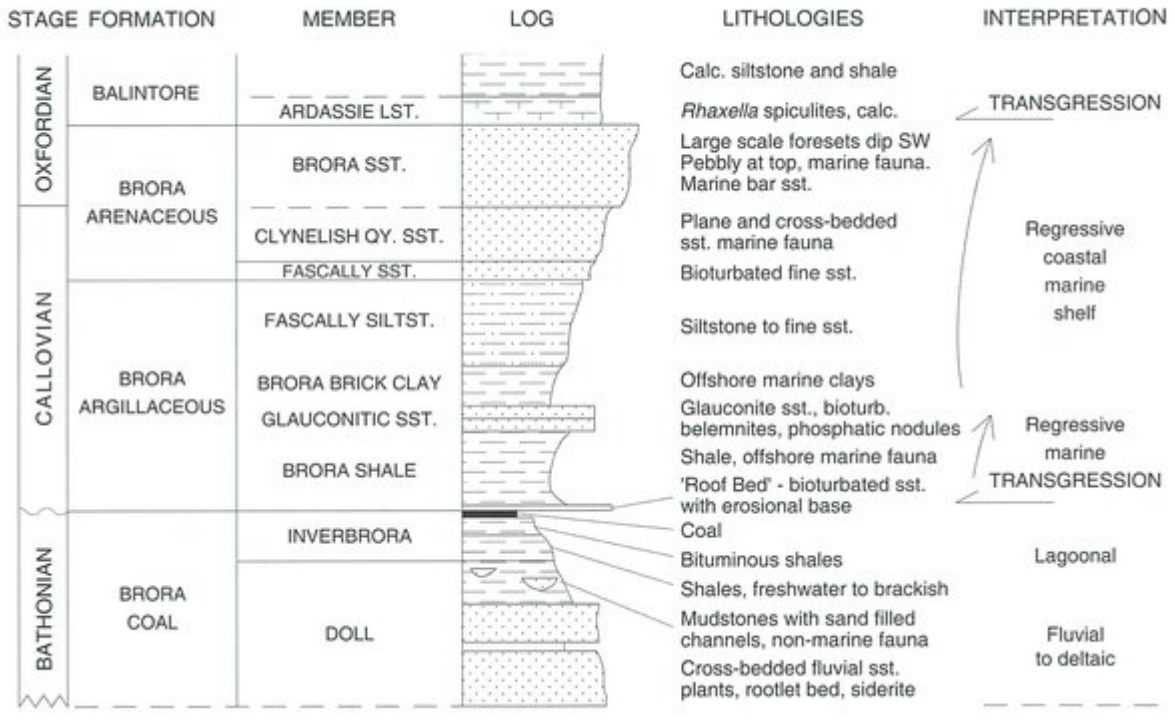
(Figure 6) Middle ORS palaeogeography of north-east Scotland reconstructed with 30 km post-Devonian dextral shift on the Great Glen Fault. Modified from Mykura (1991) and Hamilton and Trewin (1988).



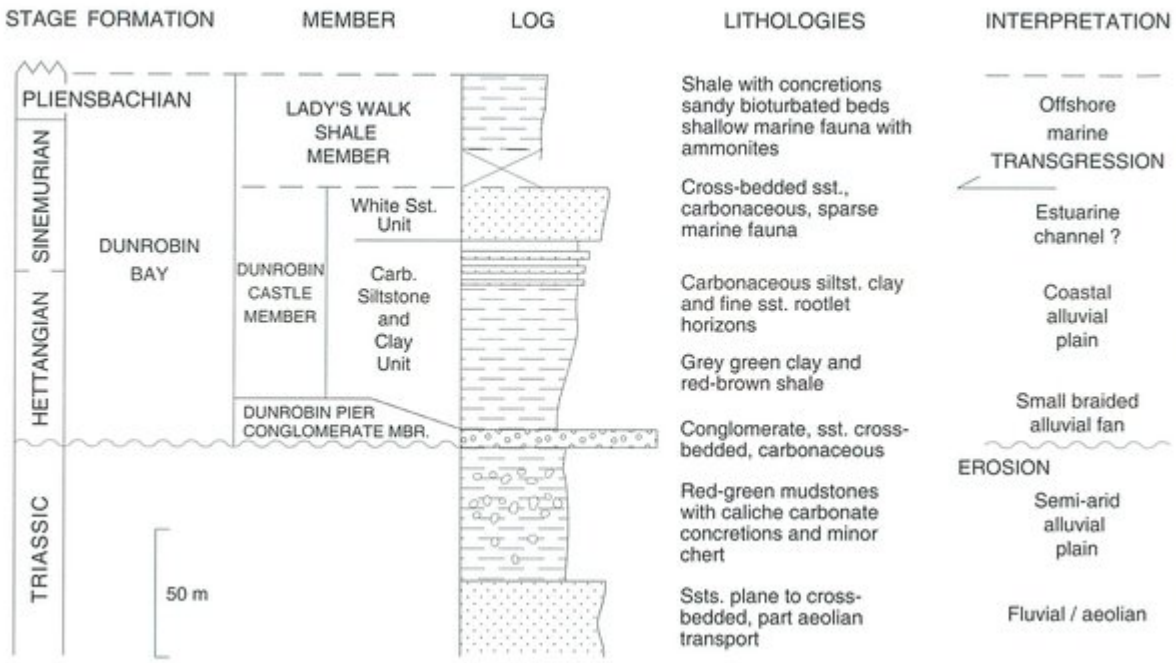
(Figure 7) Diagrammatic sketch of marginal situations to the Orcadian lake at a time of high lake level. Zone A represents shallow areas in which bottom conditions were oxygenated and area B the deeper lake where anoxic conditions existed beneath a thermocline. Modified from Trewin (1986).



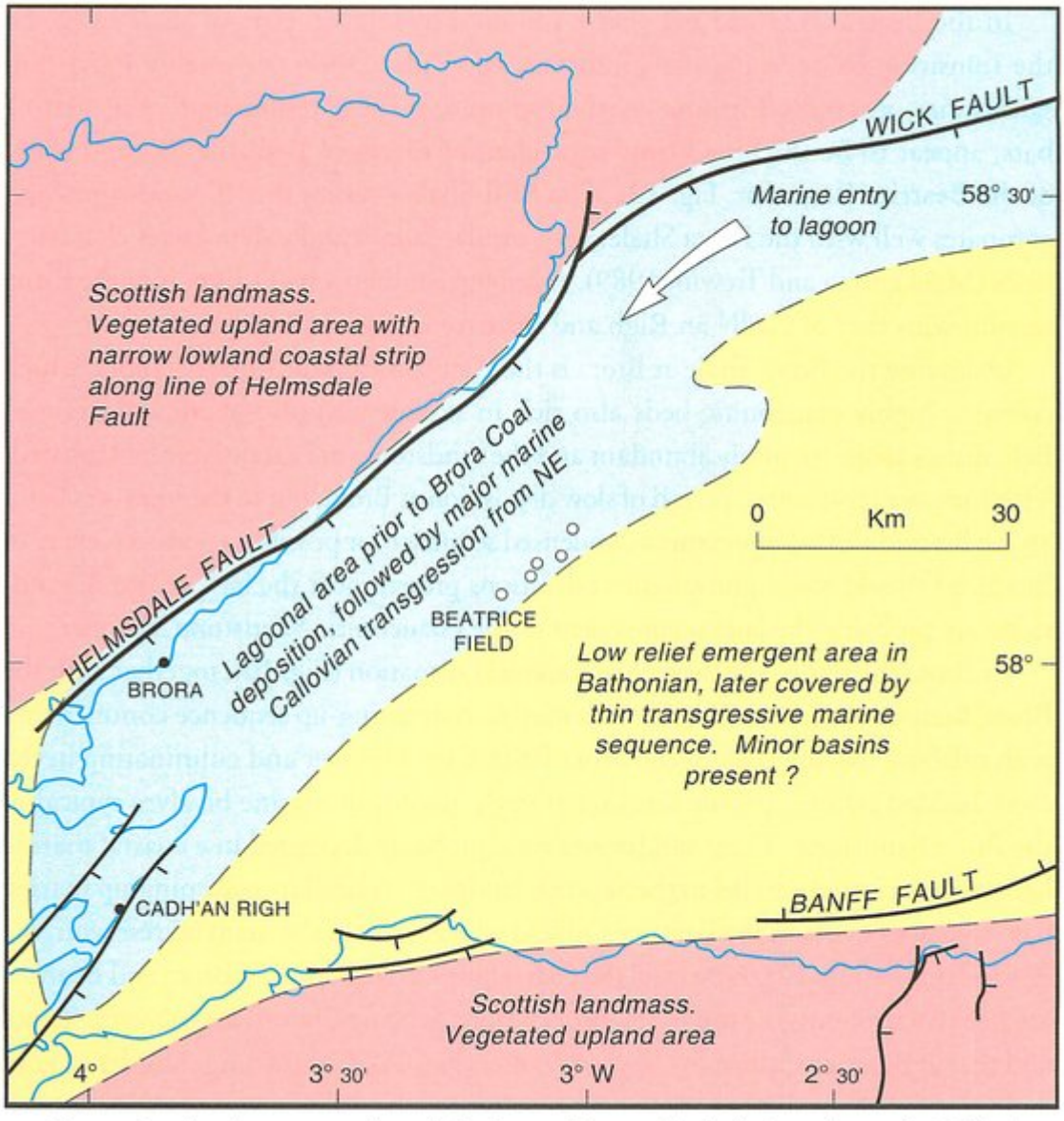
(Figure 8) Interpreted seismic cross-section of the Inner Moray Firth Basin (Modified from Andrews et al., 1990). Line of section shown on inset basic structural map of the basin.



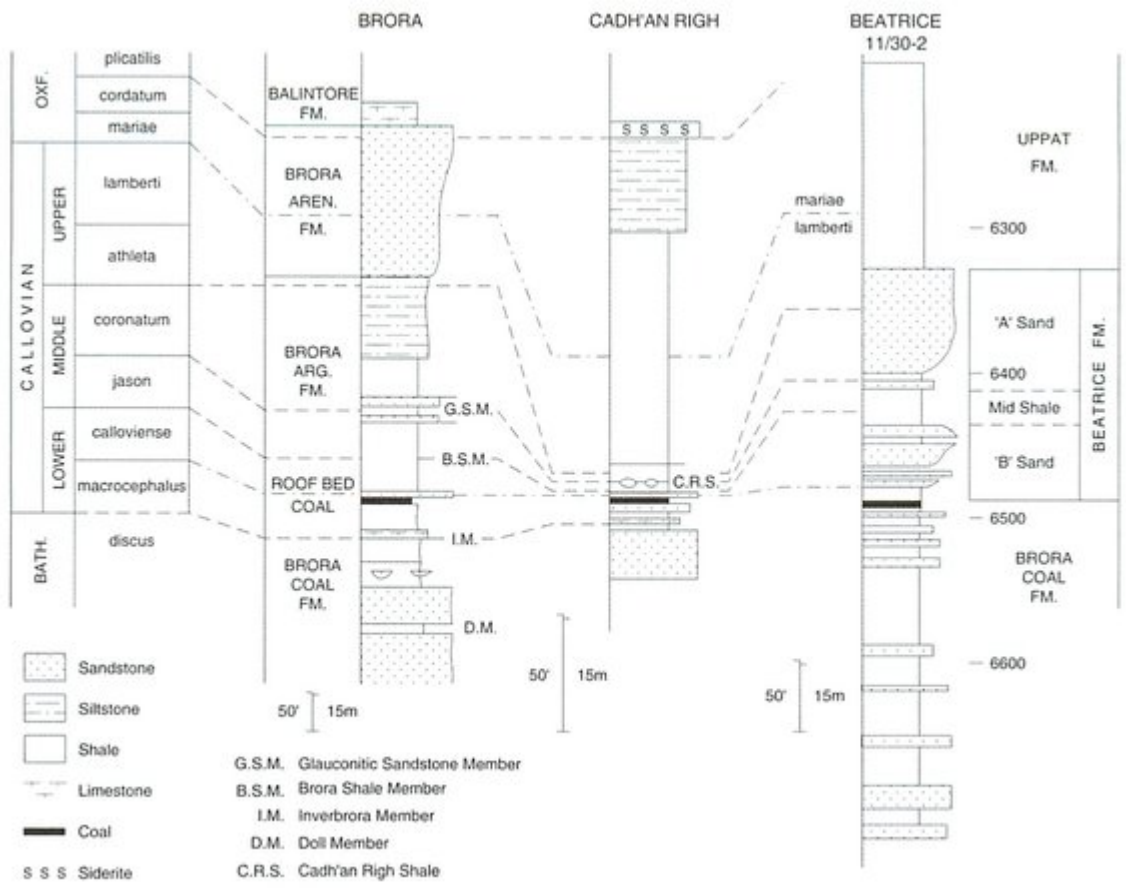
(Figure 9) Stratigraphy and lithofacies of the Triassic and Liassic rocks.



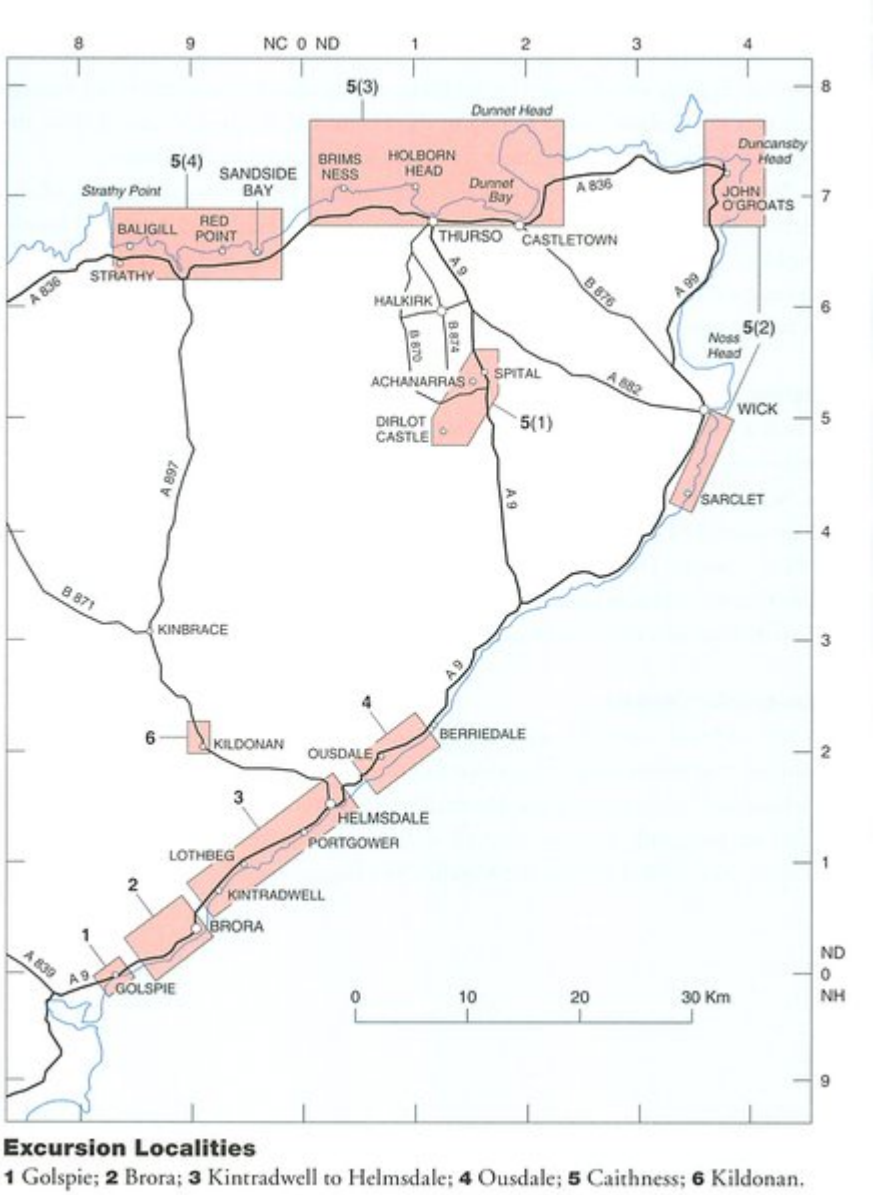
(Figure 10) Stratigraphy and lithofacies of the Bathonian and Oxfordian rocks.



(Figure 11) Generalised palaeogeography of the Inner Moray Firth during the early Caliovian, showing the probable extent of the lagoonal area (After MacLennan and Trewin 1989).



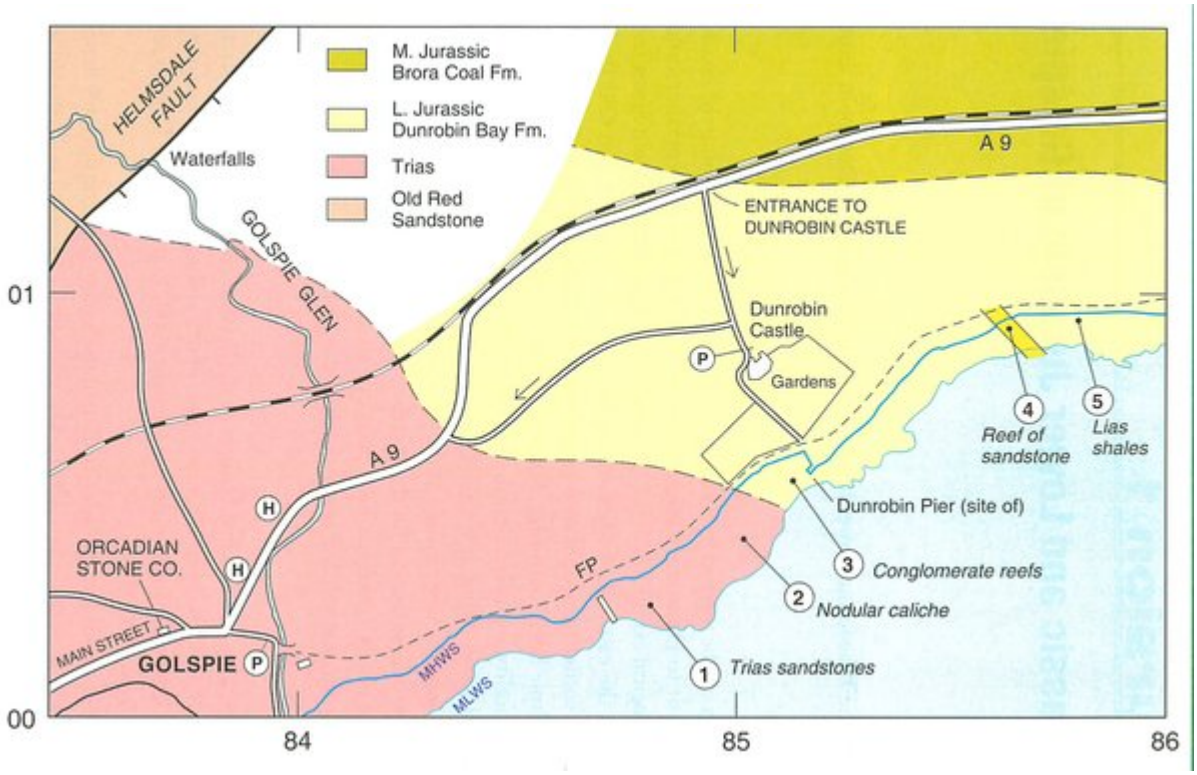
(Figure 12) Stratigraphic sections, nomenclature and correlations for the Callovian at three Inner Moray Firth Basin localities. Note variation in scales (Modified from MacLennan and Trewin 1989).



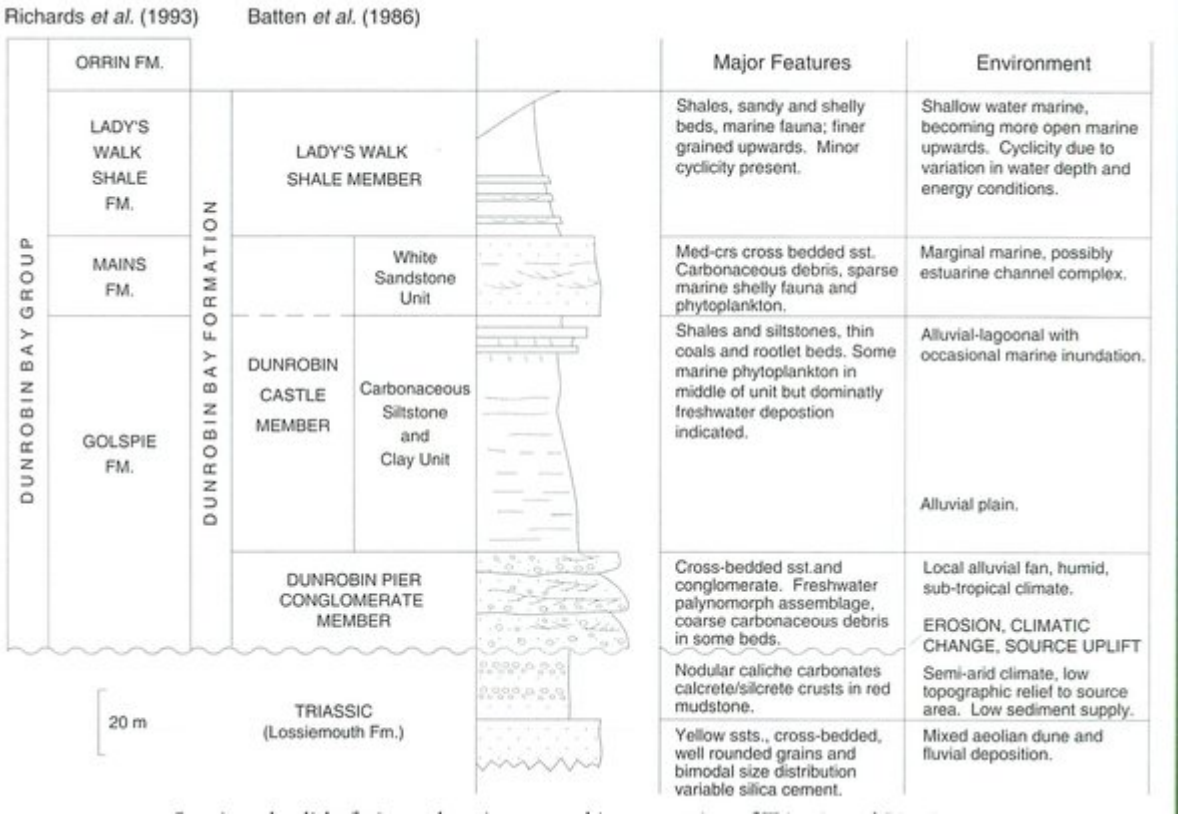
Excursion Localities

1 Golspie; **2** Brora; **3** Kintradwell to Helmsdale; **4** Ousdale; **5** Caithness; **6** Kildonan.

(Figure Unnumbered 1) Excursion localities 1 Golspie; 2 Brora; 3 Kintradwell to Helmsdale; 4 Ousdale; 5 Caithness; 6 Kildonan.

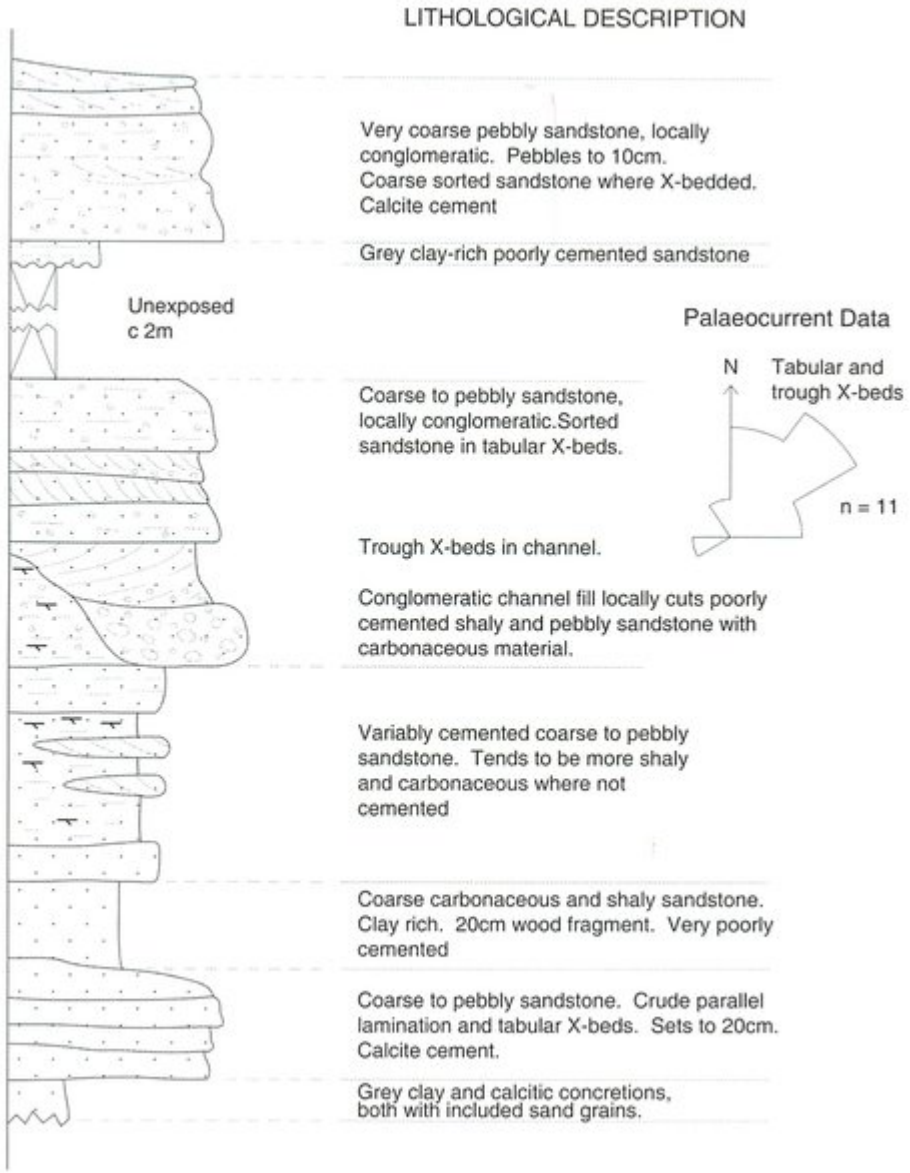


(Figure 1.1) Locality map Excursion 1.

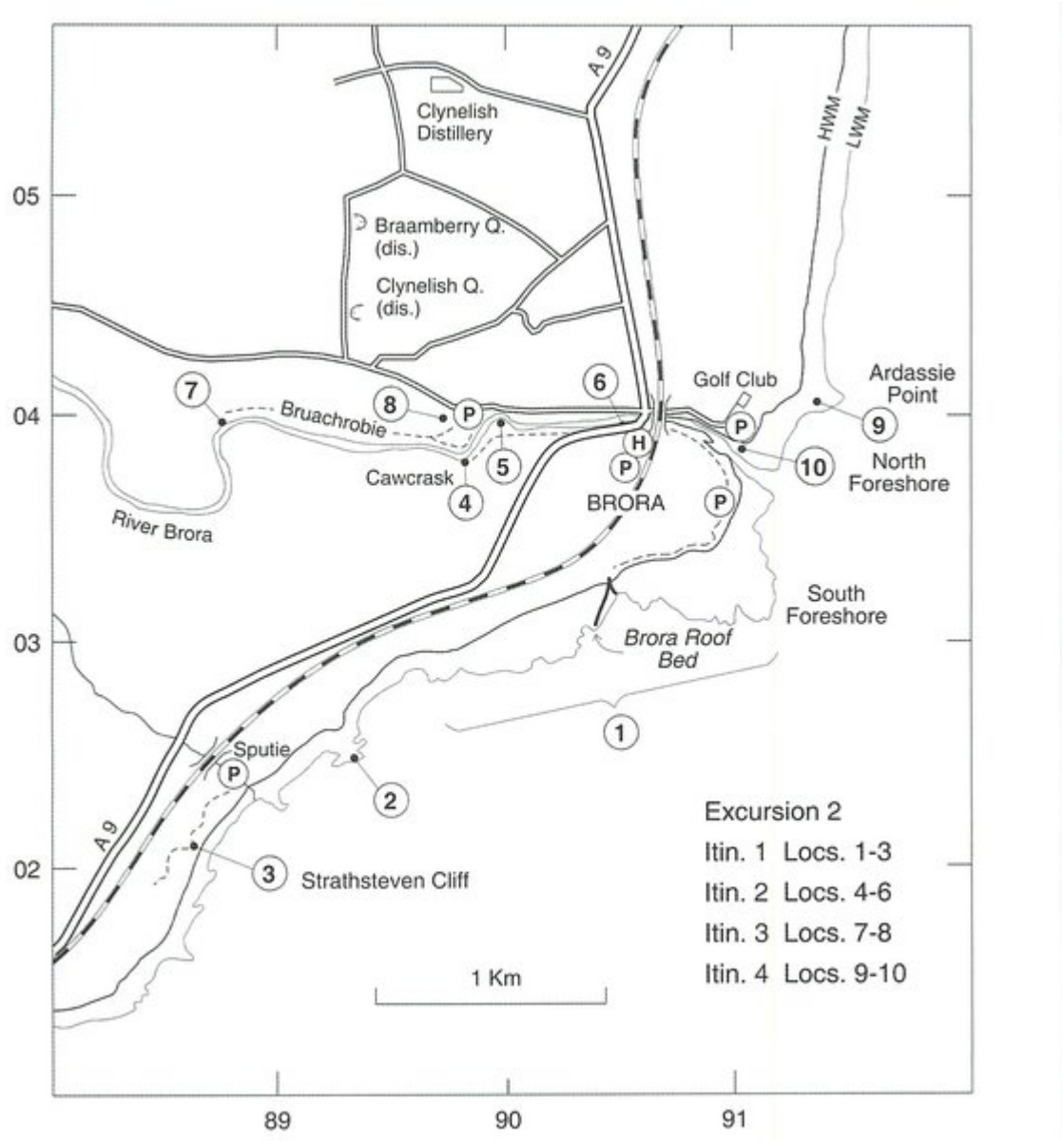


(Figure 1.2) Stratigraphy, lithofacies and environmental interpretation of Triassic and Liassic strata at Golspie (Modified from Batten et al. 1986).

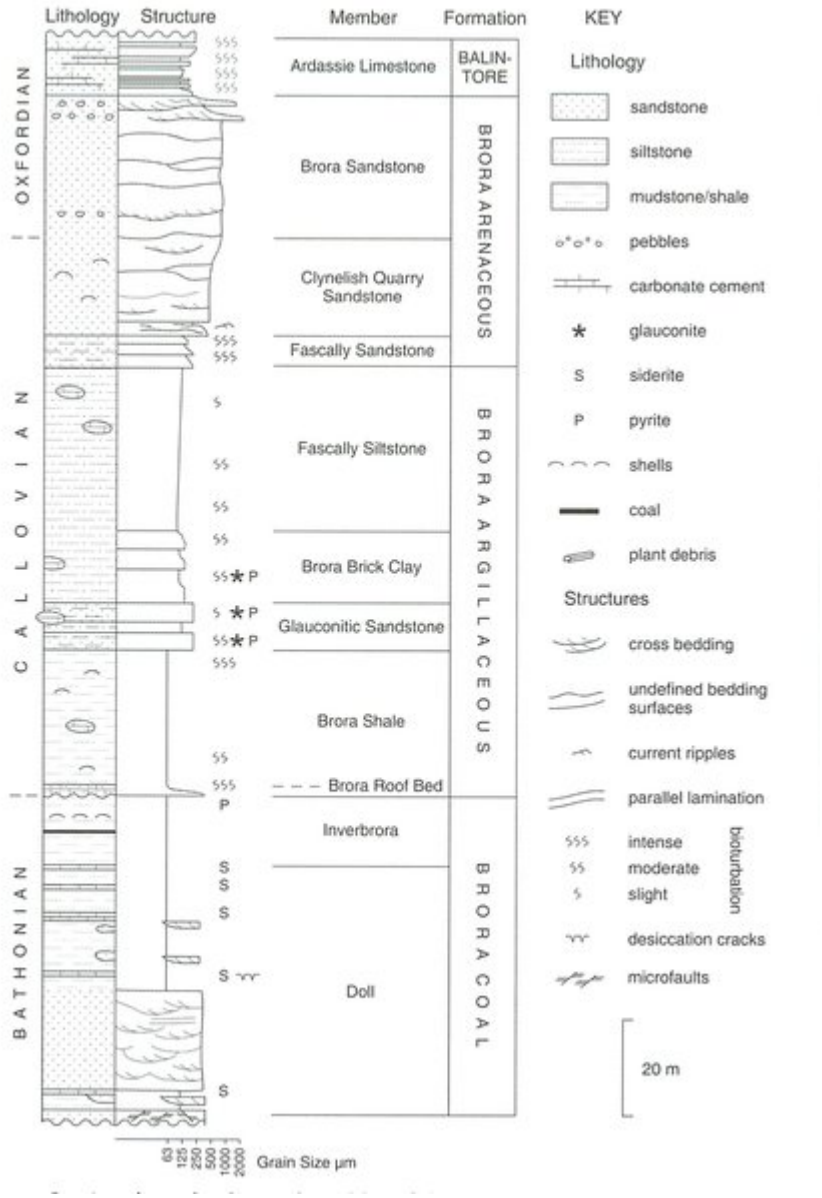
(Figure 1.3) Cut section of caliche limestone from the top of the Triassic section. Specimen from Golspie Glen.



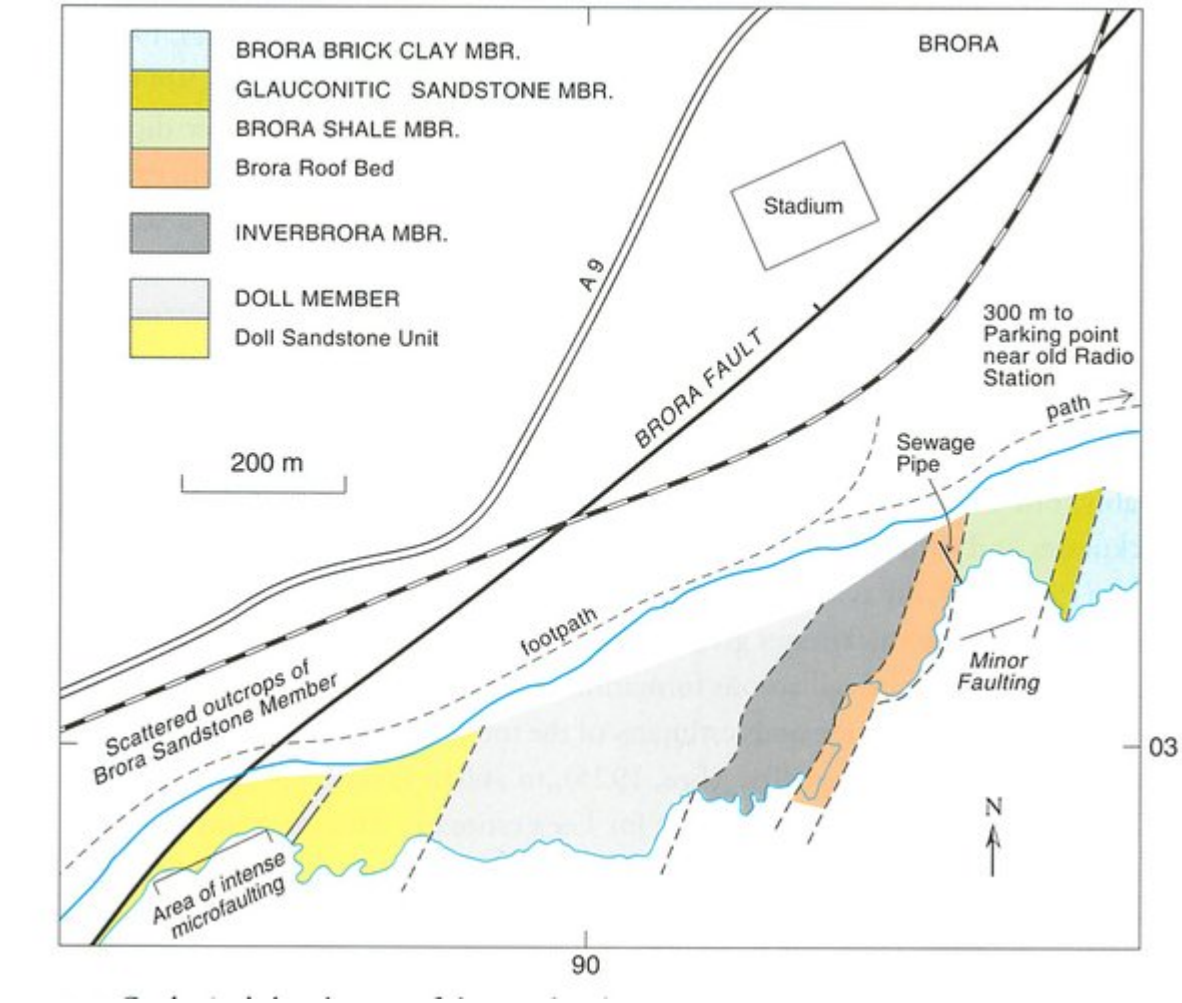
(Figure 1.4) Log of the Dunrobin Pier Conglomerate Member (Modified from Batten et al. 1986).



(Figure 2.1) General locality map of the Brora area.

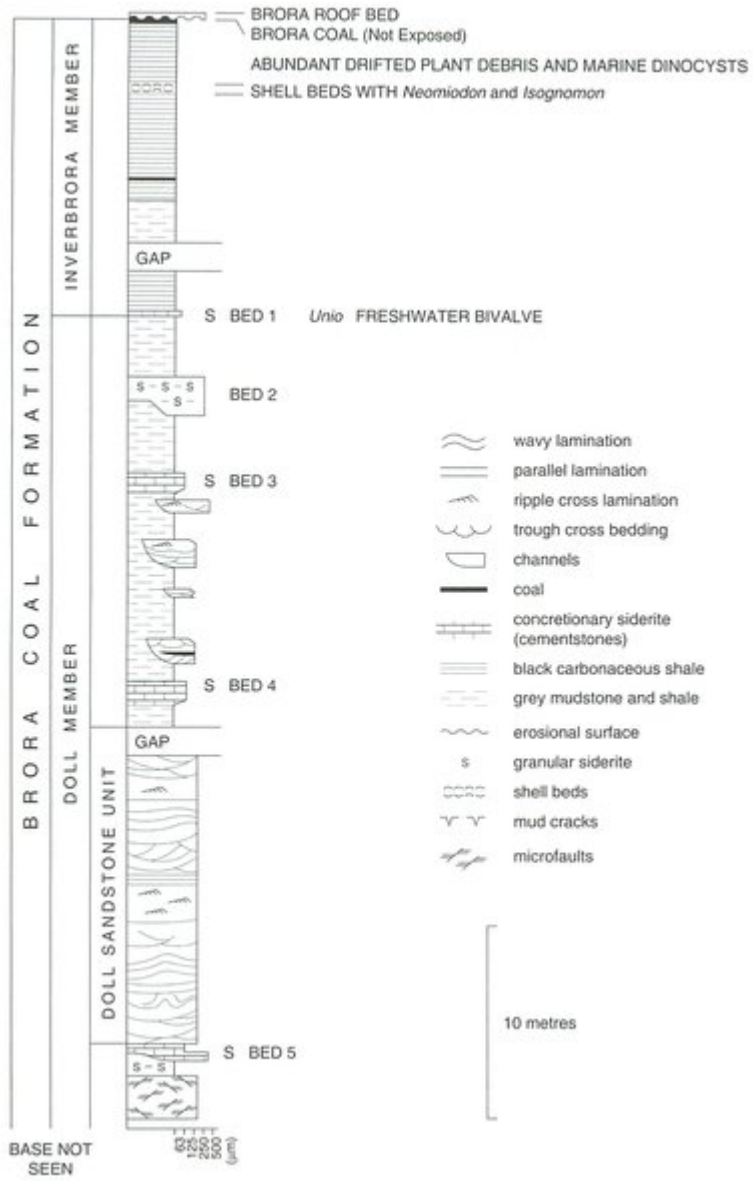


(Figure 2.2) Stratigraphy and sedimentological log of the Bathonian to Oxfordian section at Brora.

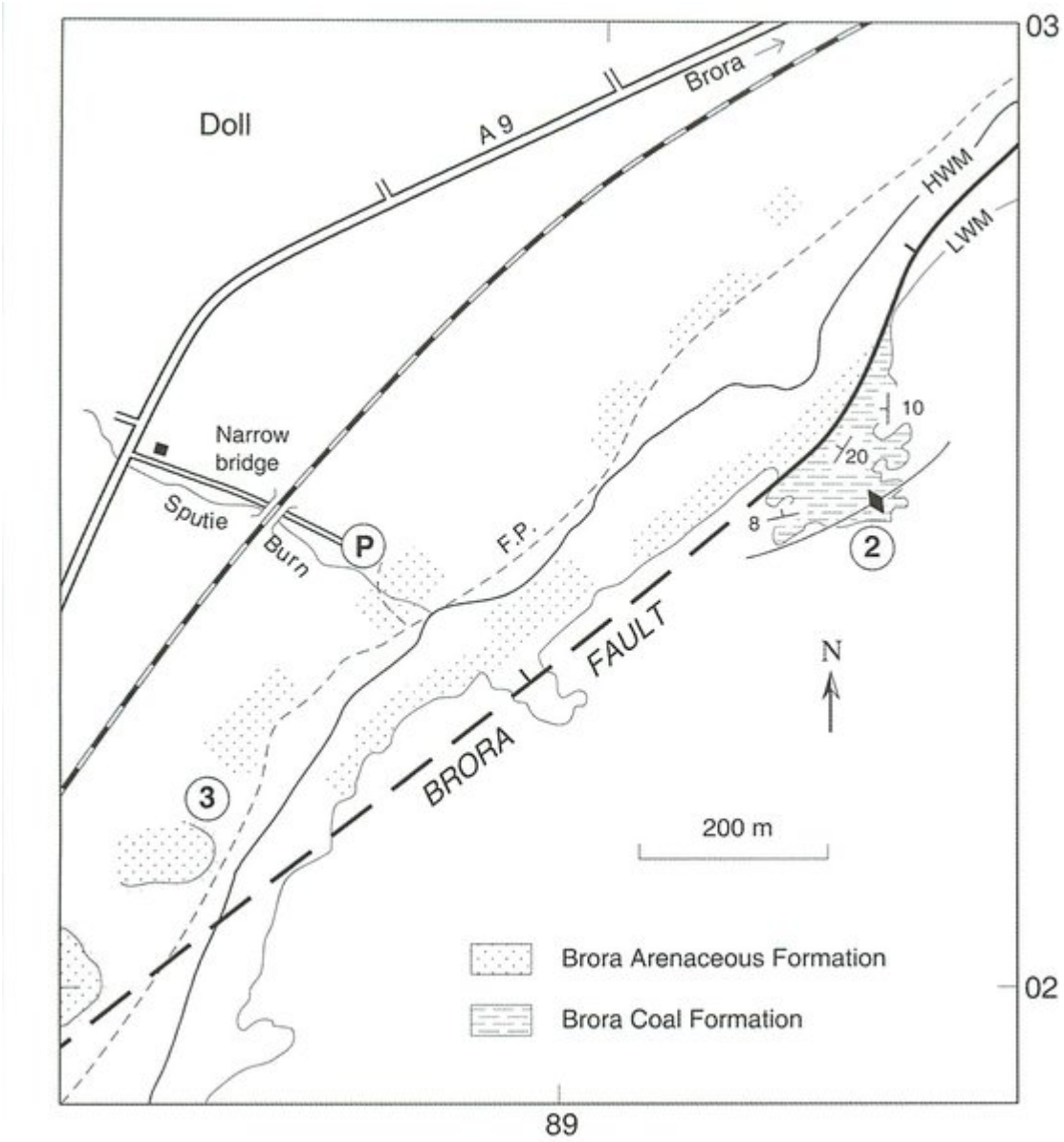


(Figure 2.3) Geological sketch map of the shore at locality 1

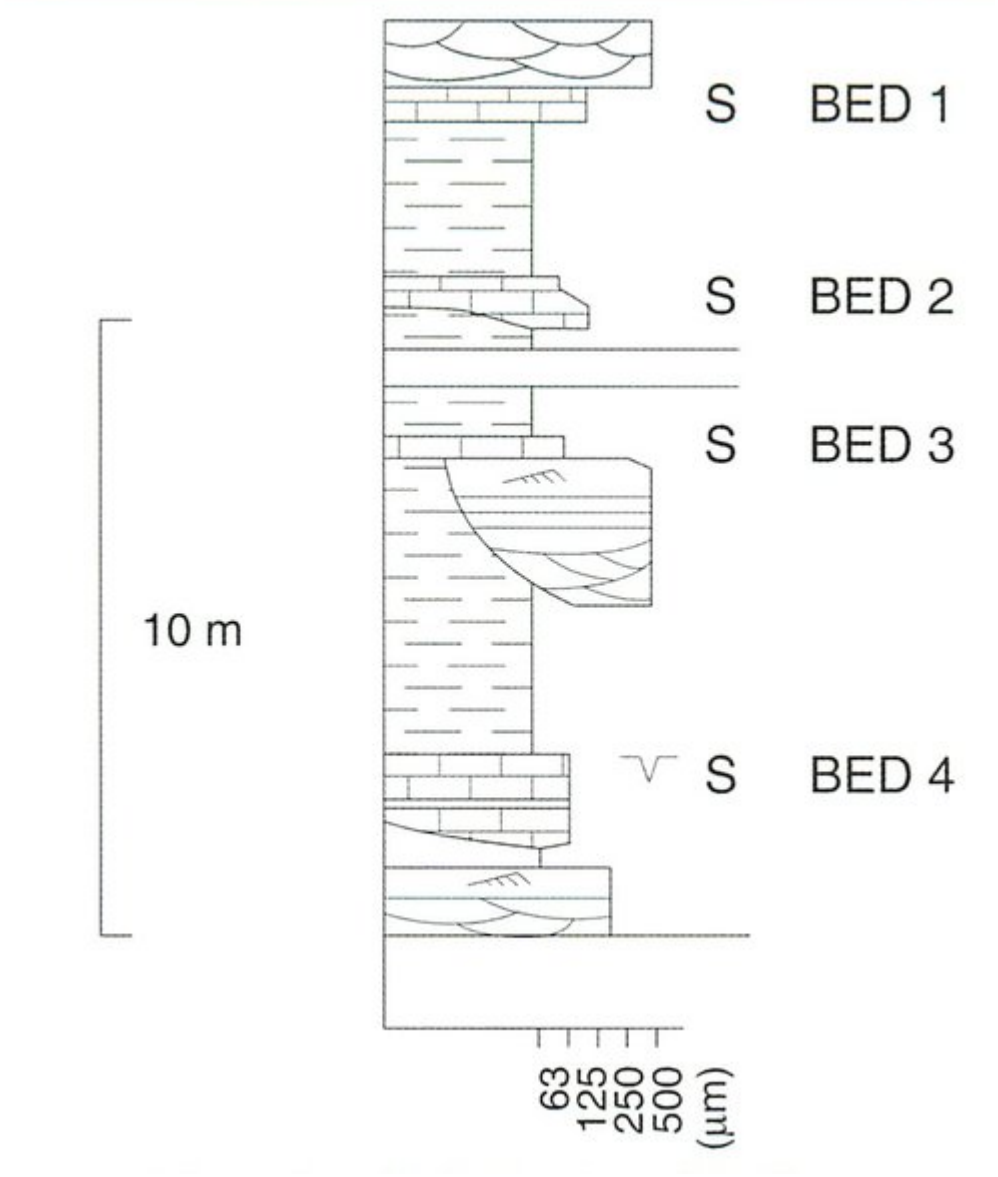
(Figure 2.4) Shell bed with Neomiodon and Isognomon near the top of the Inverbrora Member. Lens cap 52mm.



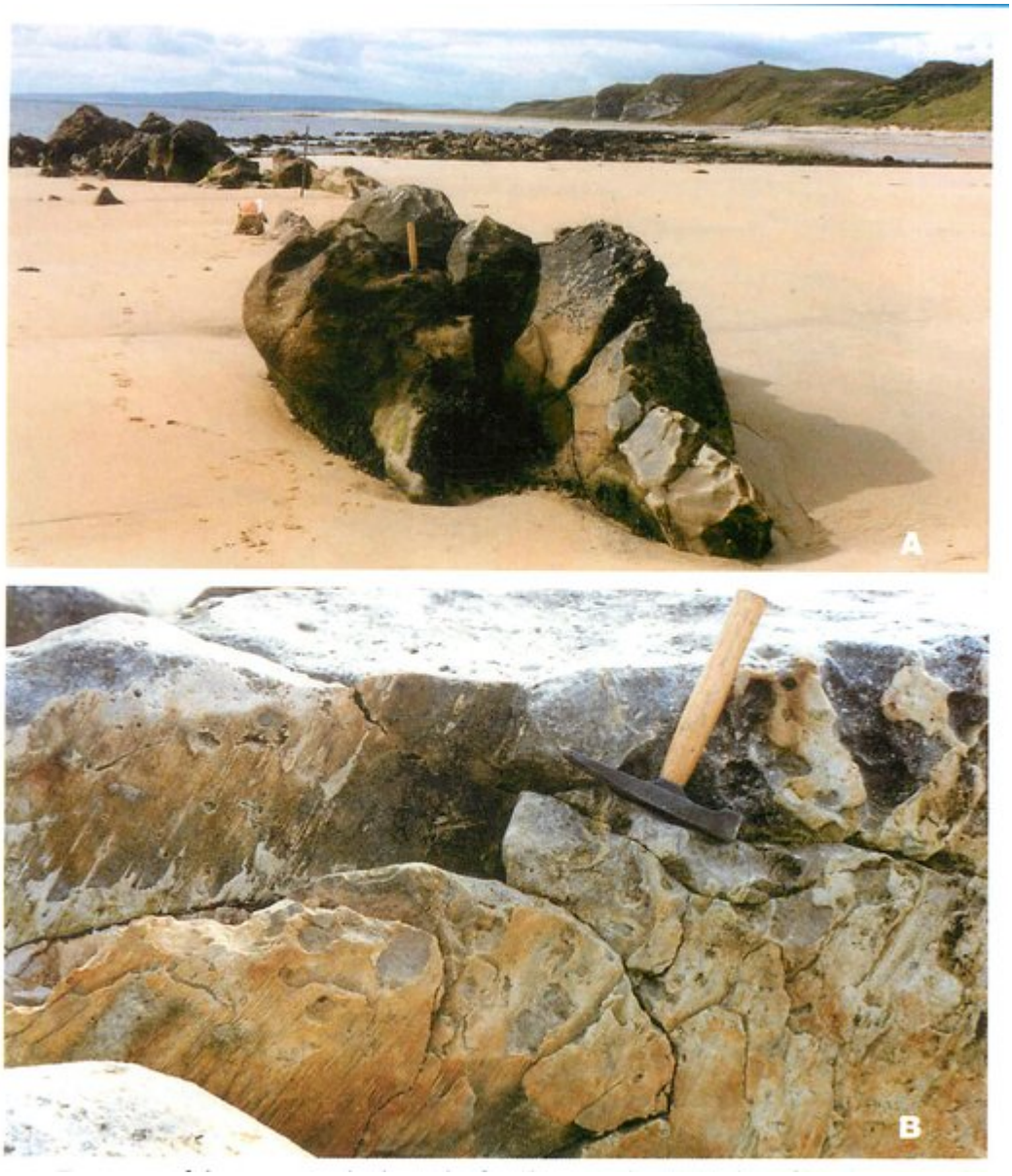
(Figure 2.5) Sedimentary log of the Brora Coal Formation at locality 1.



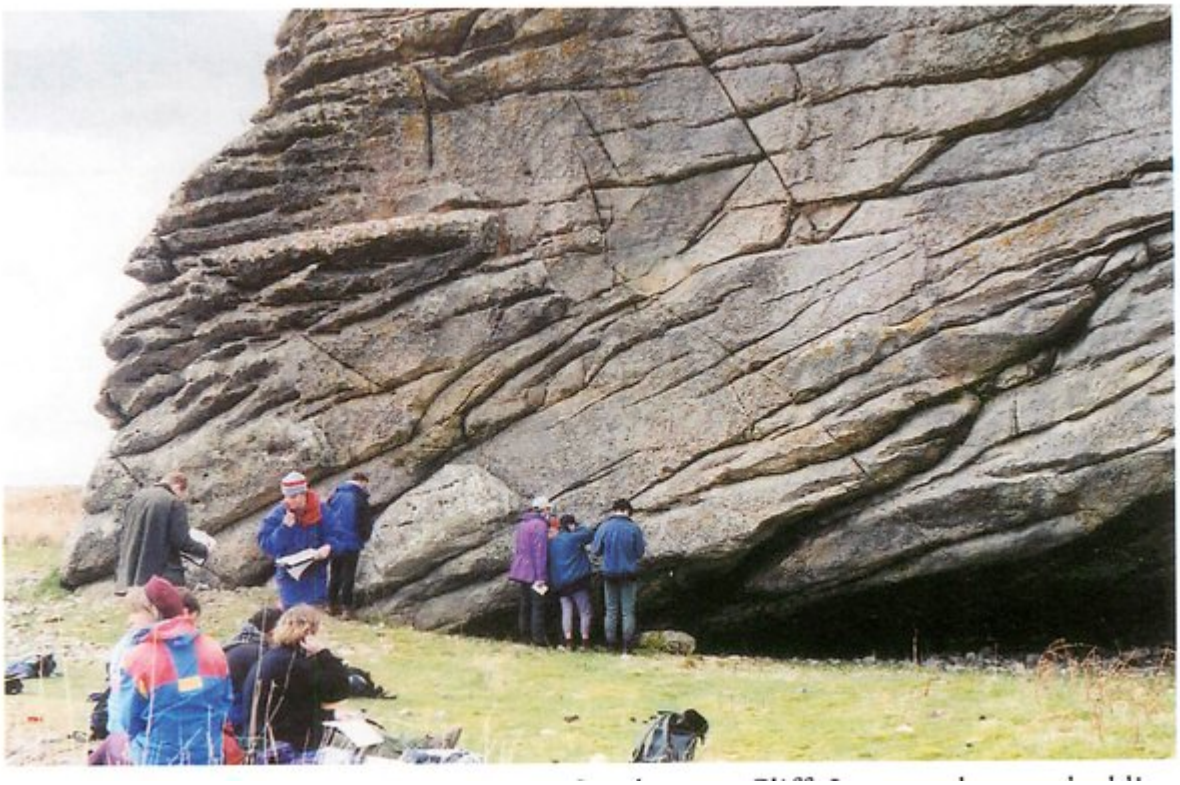
(Figure 2.6) Sketch-map of the shoreline geology at localities 2 and 3.



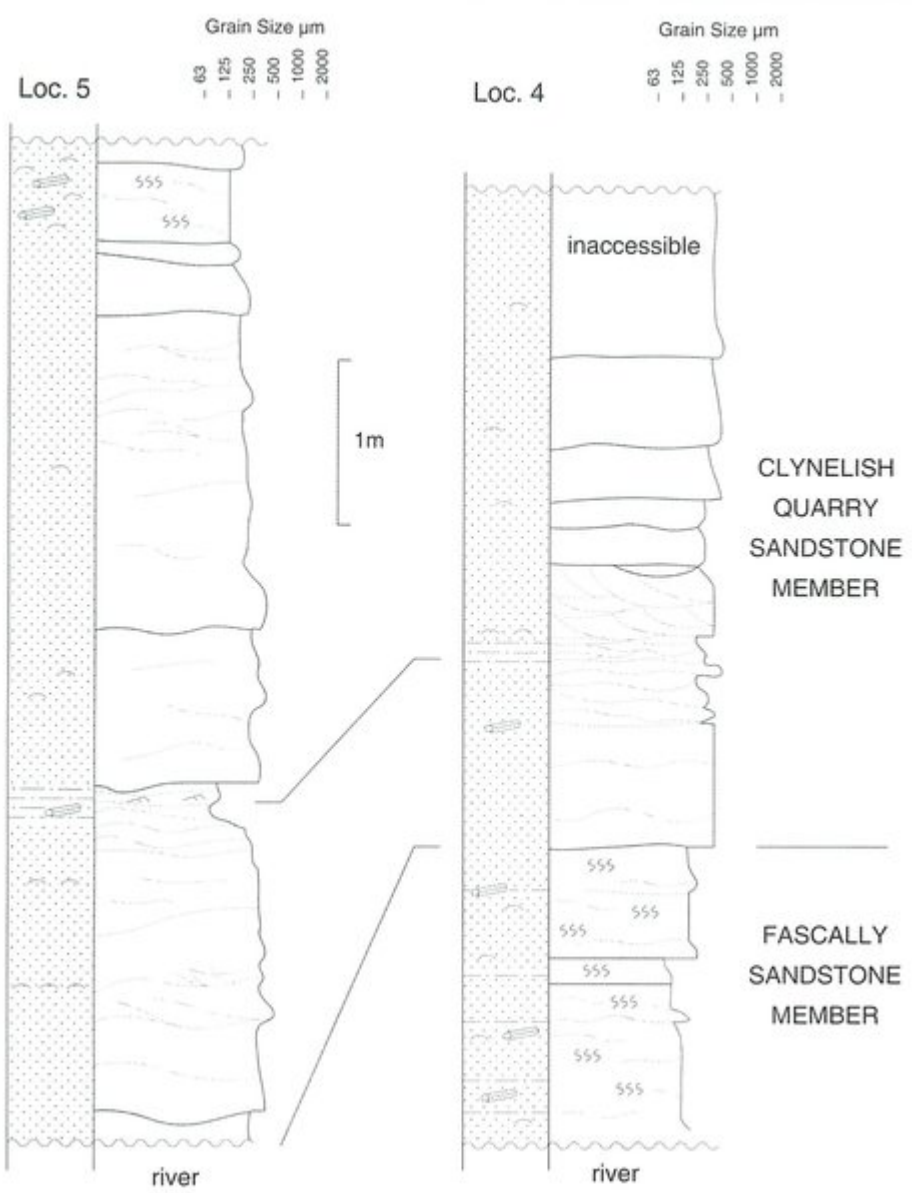
(Figure 2.7) Log of the Doll Member of the Brora Coal Formation at locality 2 (key as for (Figure 2.5)).



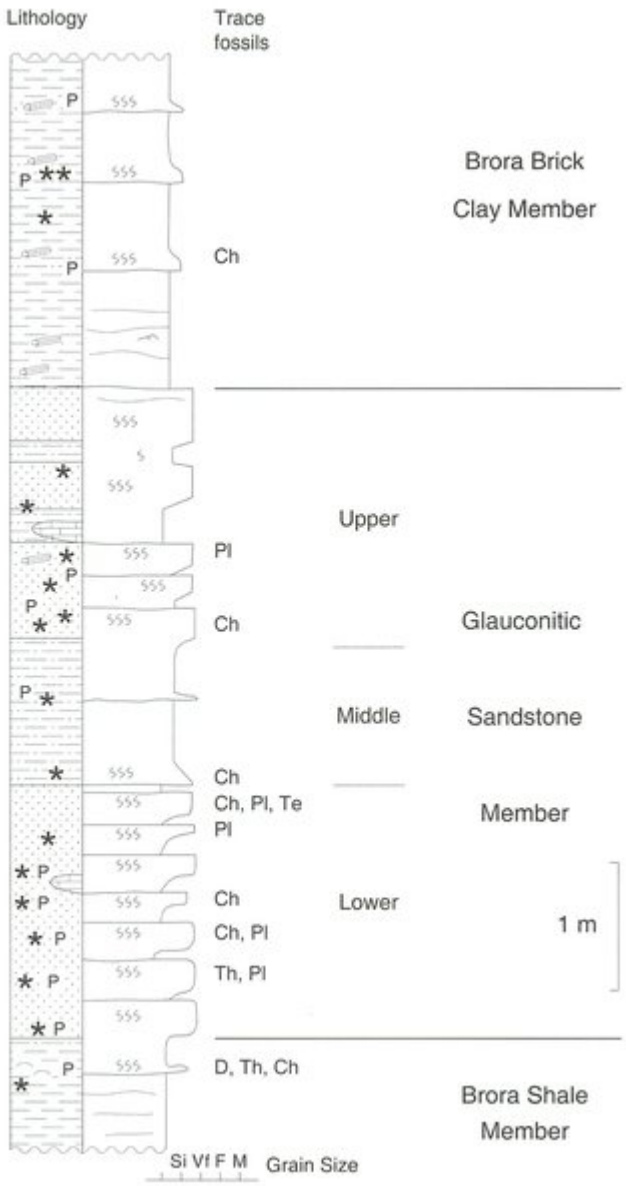
(Figure 2.8) Exposure of the Brora Fault along the foreshore on the NW edge of locality 2. A, the fault is defined by a zone of increased cementation, view of outcrops of quartz-cemented and veined fault rock, and B, slickensided surfaces on landward face of outcrop at top of the beach.



(Figure 2.9) The Brora Arenaceous Formation at Strathsteven Cliff. Large-scale cross-bedding dipping seawards is seen in what is likely to be part of the Clynelish Quarry Sandstone Member.

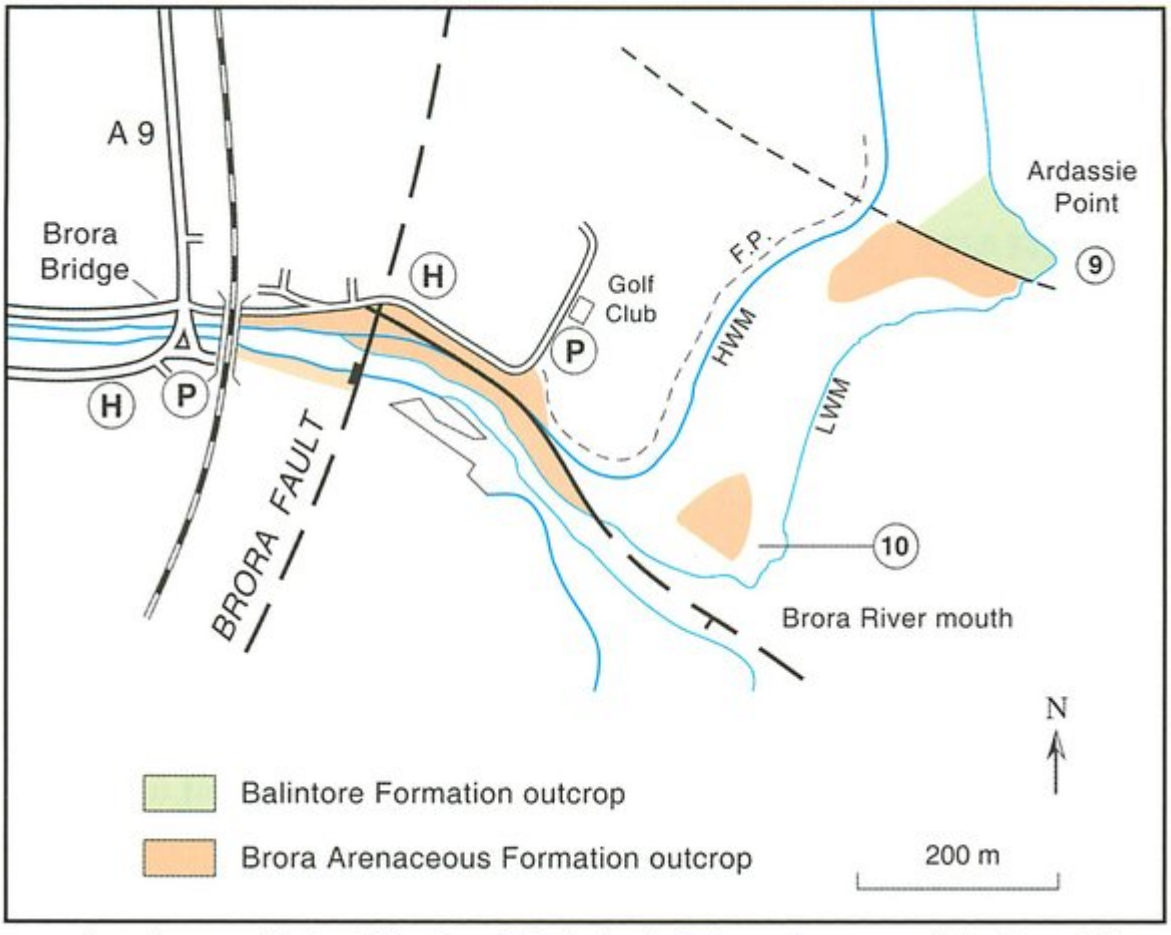


(Figure 2.10) Sedimentary logs of the Clynelish Quarry Sandstone Member and Fascally Sandstone Member at localities 4 and 5. (Key as for (Figure 2.2).)

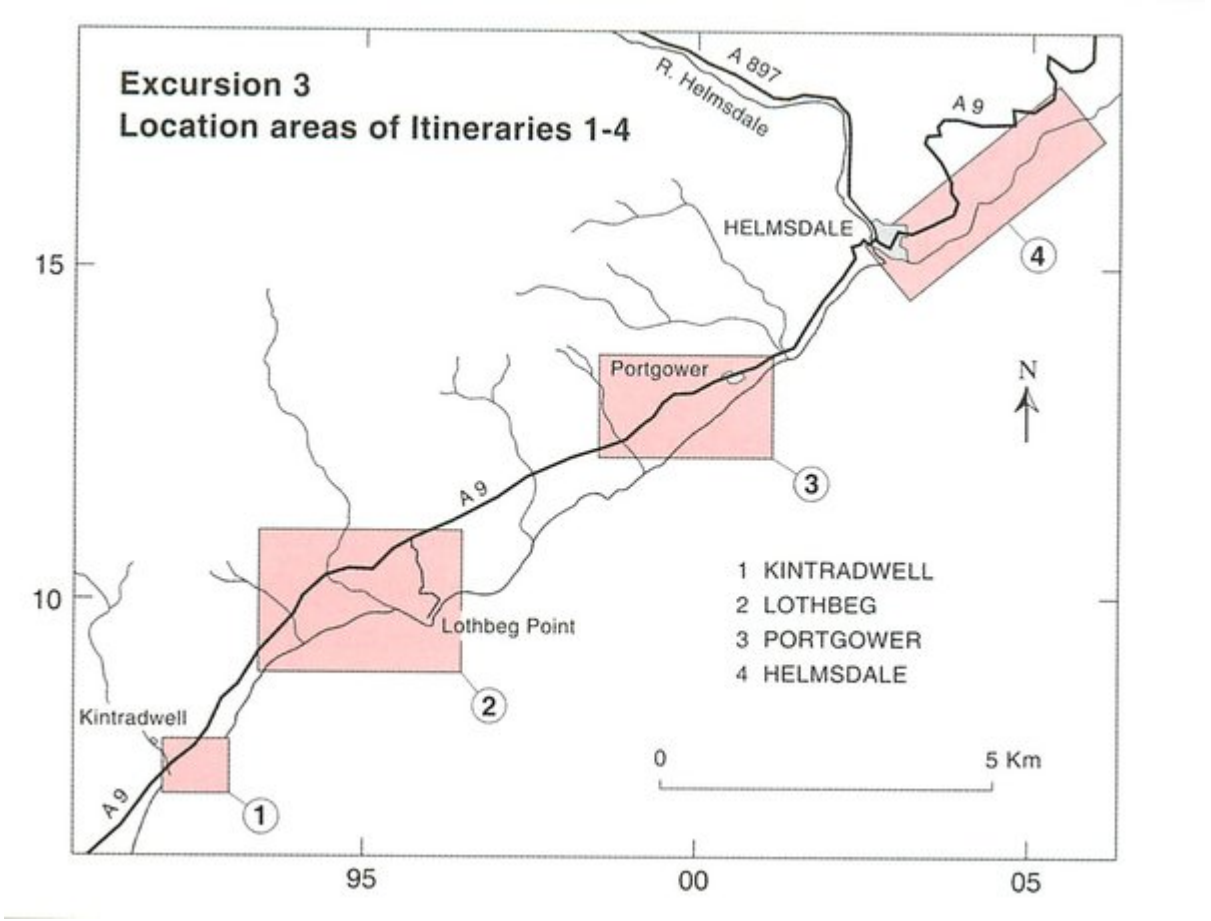


(Figure 2.11) Sedimentary log of the Brora Argillaceous Formation at locality 7. Key as for (Figure 2.2). P1, Planolites; Ch, Chondrites; Te, Teichichnus; Th, Thalassinoides; D, Diplocraterion.

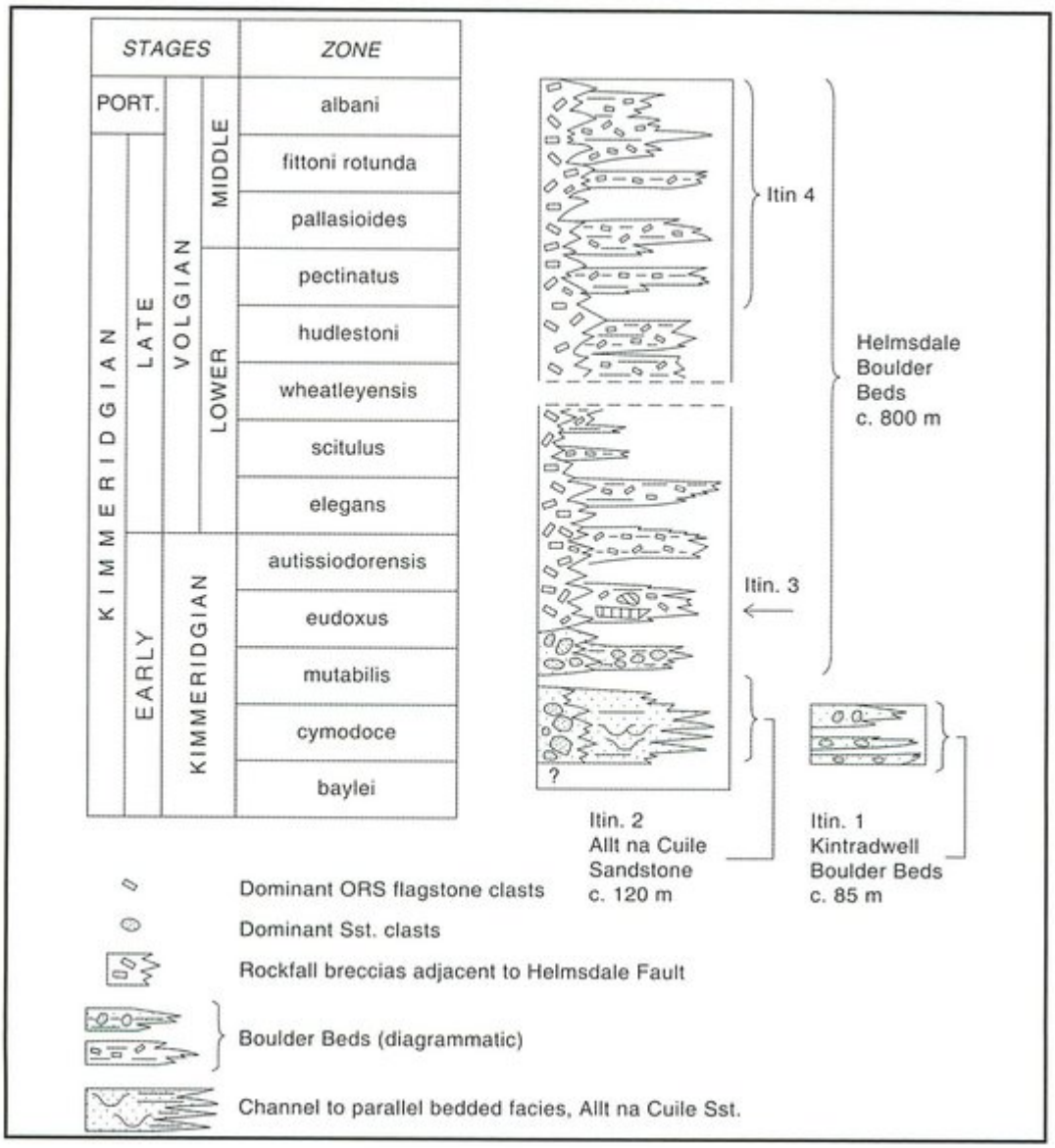
(Figure 2.12) Belemnites (Cylindroteuthis) that are common in the Glauconitic Sandstone Member and adjacent strata.



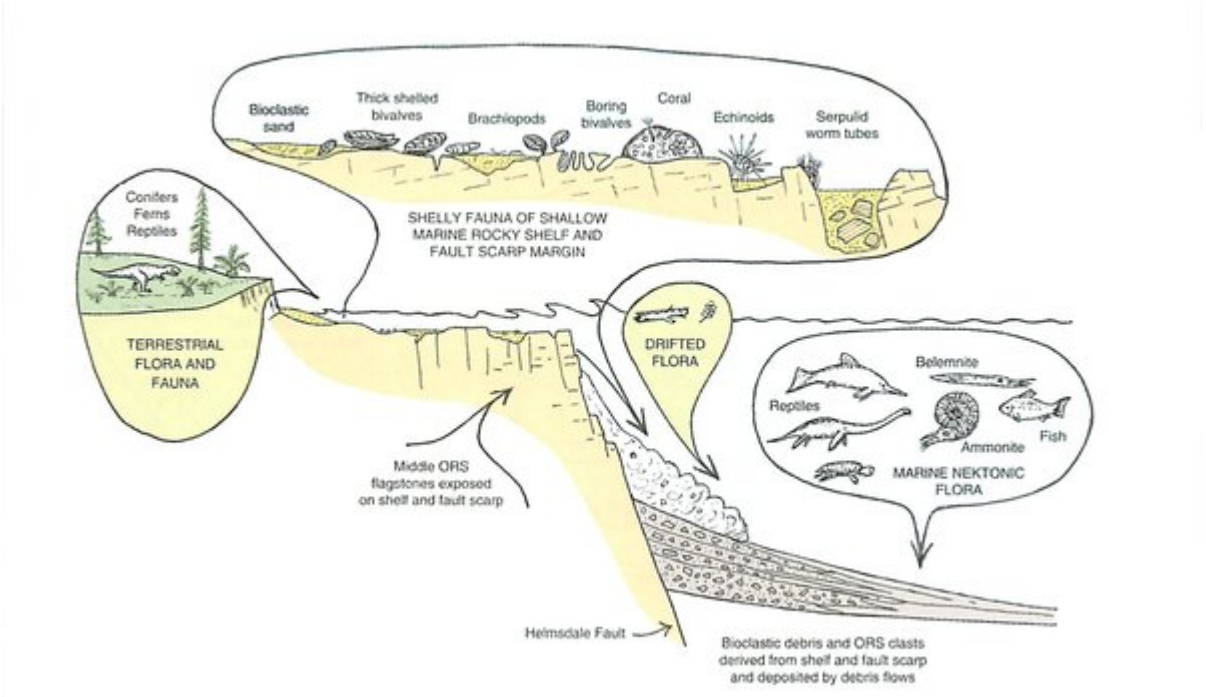
(Figure 2.13) Locality map for localities 9 and 10, Ardlassie Point and estuary of the Brora River



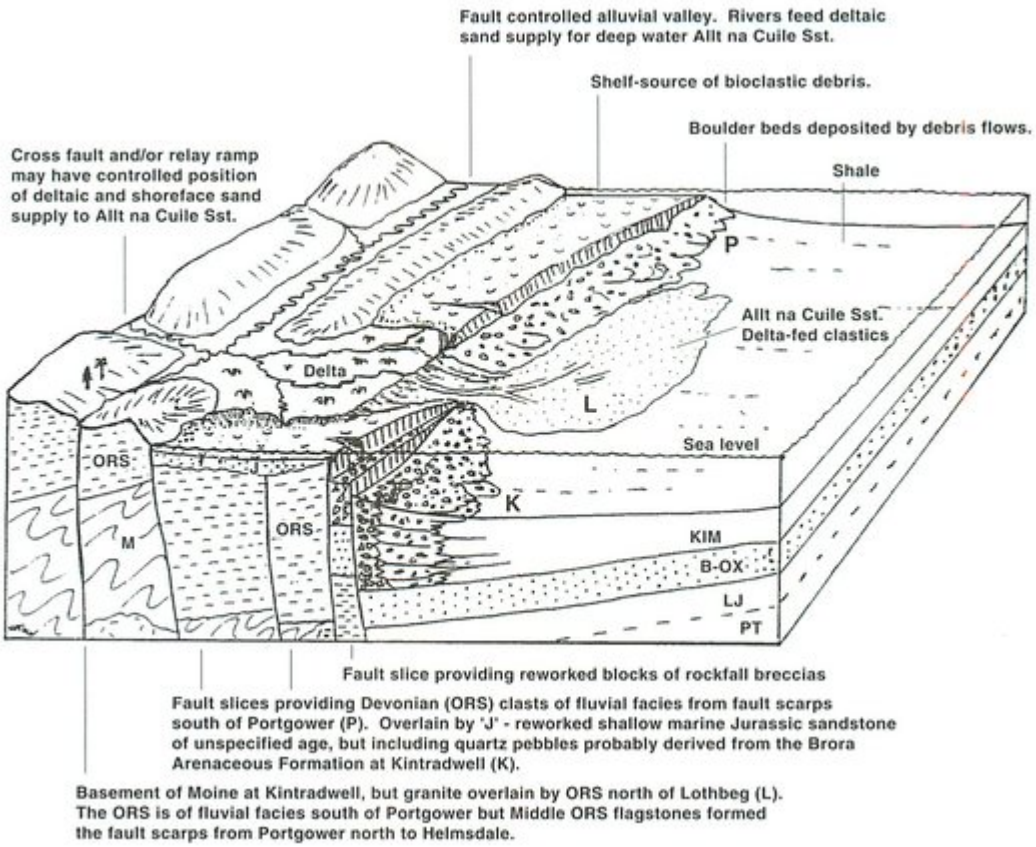
(Figure 3.1) Location areas of itineraries 1 to 4 of Excursion 3.



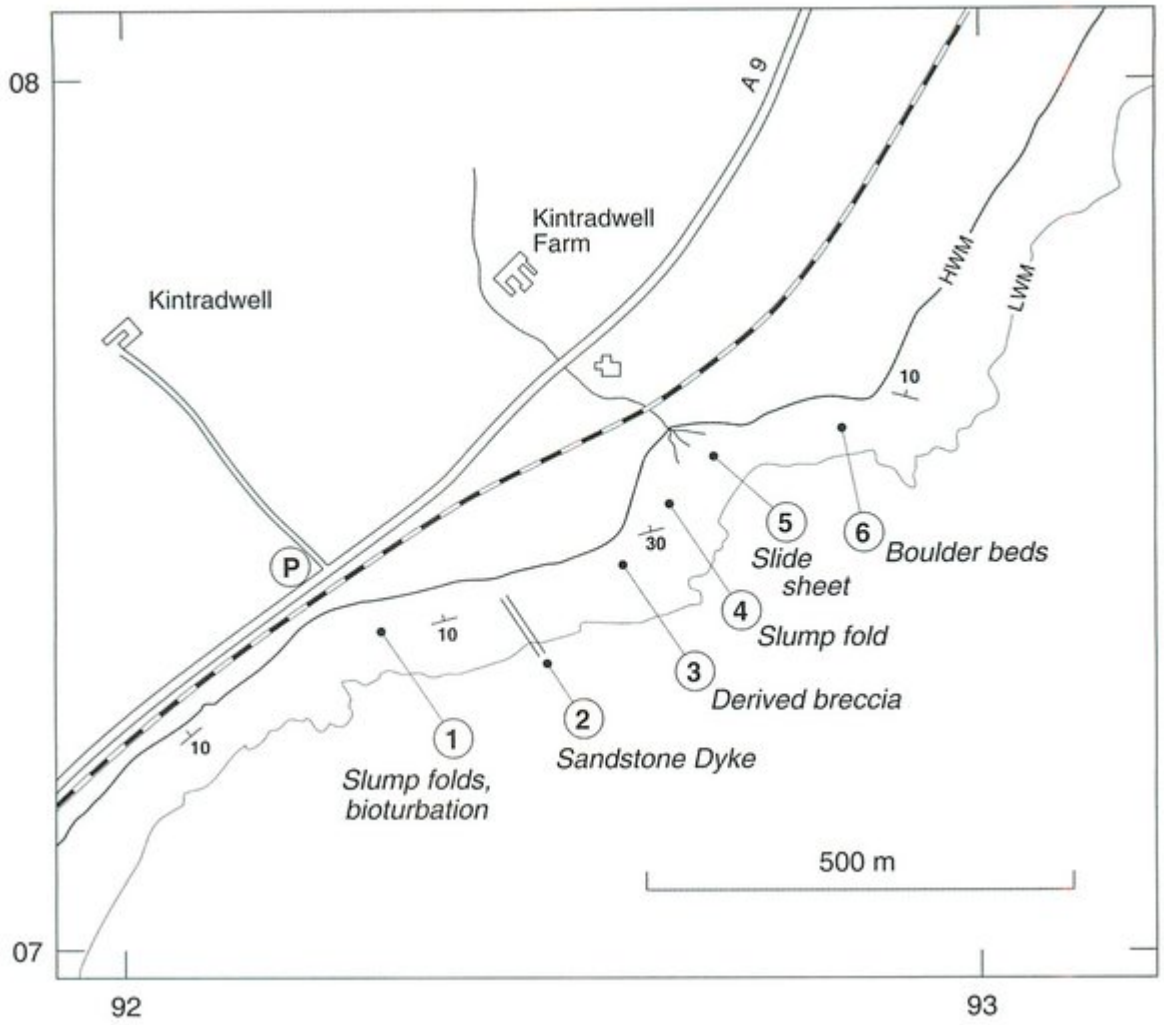
(Figure 3.2) Basic stratigraphy of the Kimmeridgian section with approximate stratigraphic positions of localities described in the excursion.



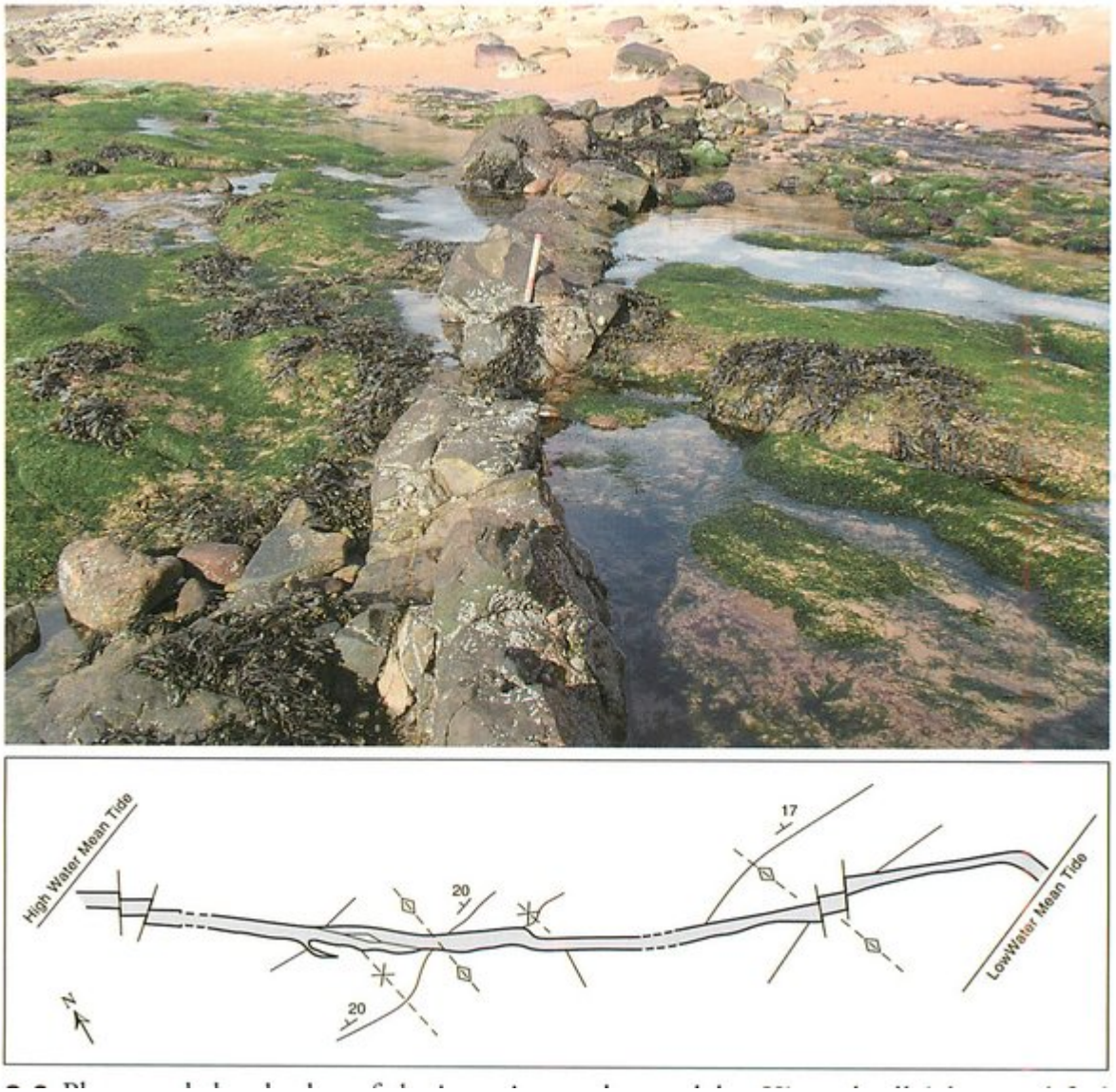
(Figure 3.3) Cartoon showing origin of fauna and flora associated with the Helmsdale Boulder Beds.



(Figure 3.4) Reconstruction of the Helmsdale Fault zone in the early Kimmeridgian to show factors associated with the derivation of the Kintradwell Boulder Beds and the Allt na Cuile Sandstone.

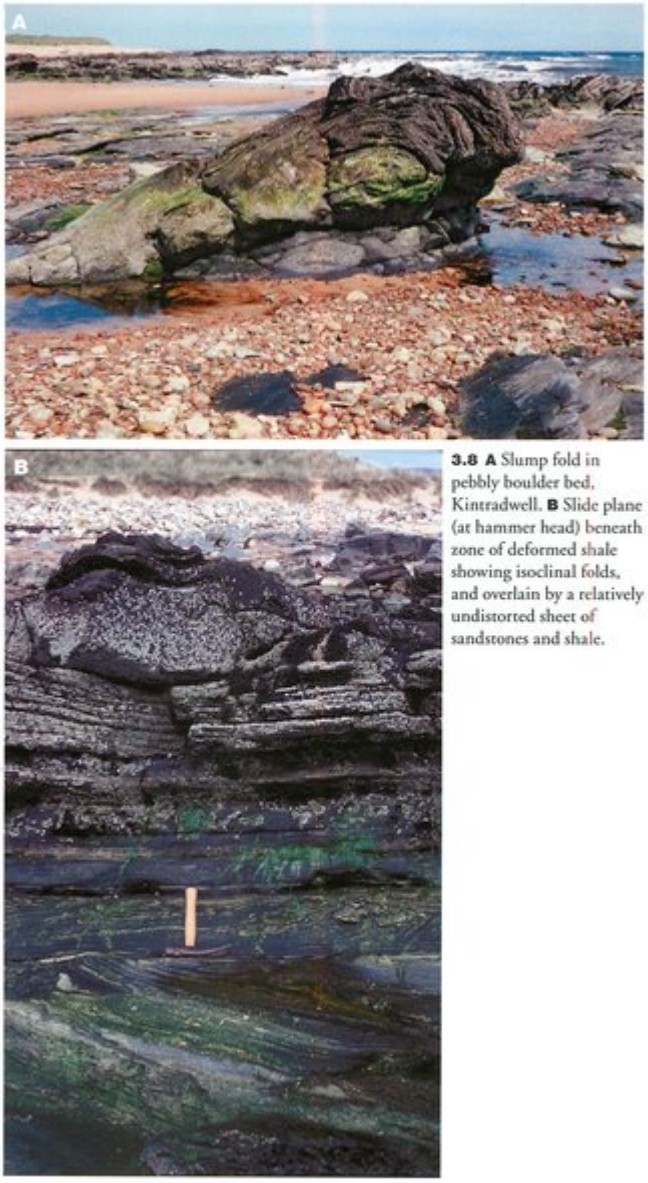


(Figure 3.5) Locality map for itinerary 1, Kintradwell area.



(Figure 3.6) Photo and sketch plan of the intrusive sandstone dyke, Kintradwell (plan modified from Jonk, 2003).

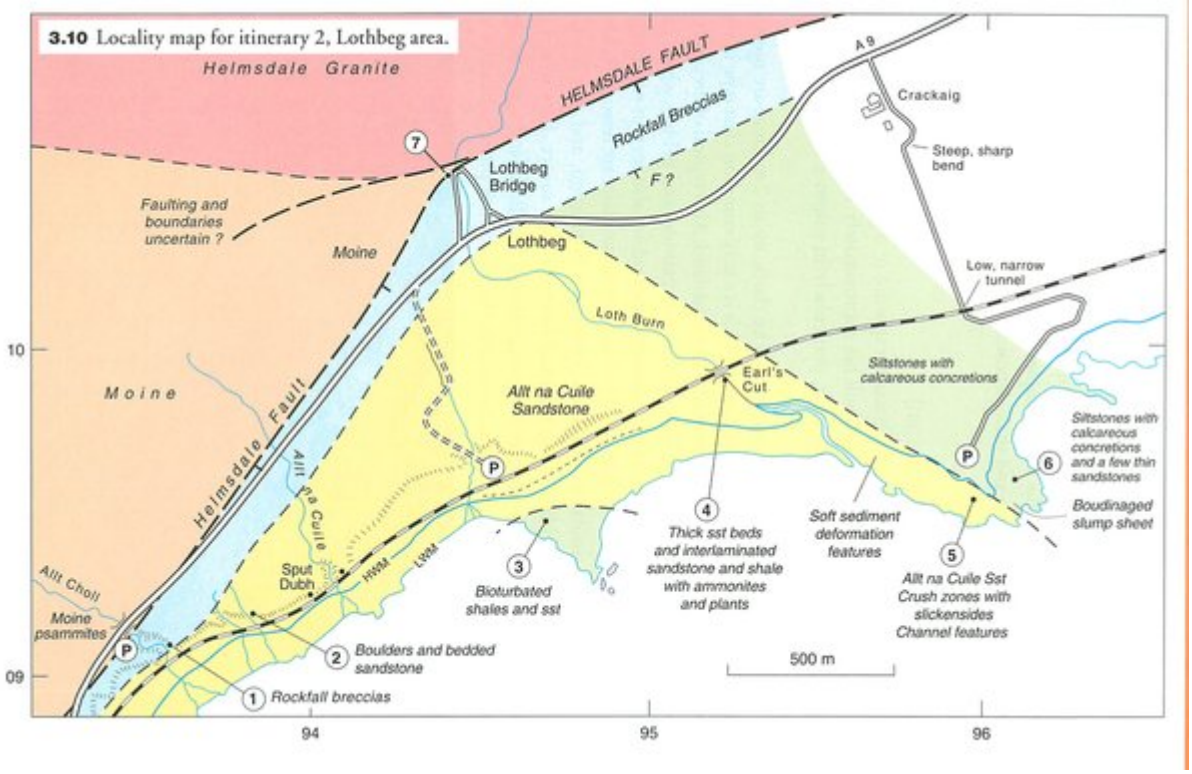
(Figure 3.7) Rounded quartzose pebbles and a belemnite in boulder bed, Kintradwell. Coin 28mm.



3.8 A Slump fold in pebbly boulder bed, Kintradwell. **B** Slide plane (at hammer head) beneath zone of deformed shale showing isoclinal folds, and overlain by a relatively undistorted sheet of sandstones and shale.

(Figure 3.8) A Slump fold in pebbly boulder bed, Kintradwell. B Slide plane (at hammer head) beneath zone of deformed shale showing isoclinal folds, and overlain by a relatively undistorted sheet of sandstones and shale.

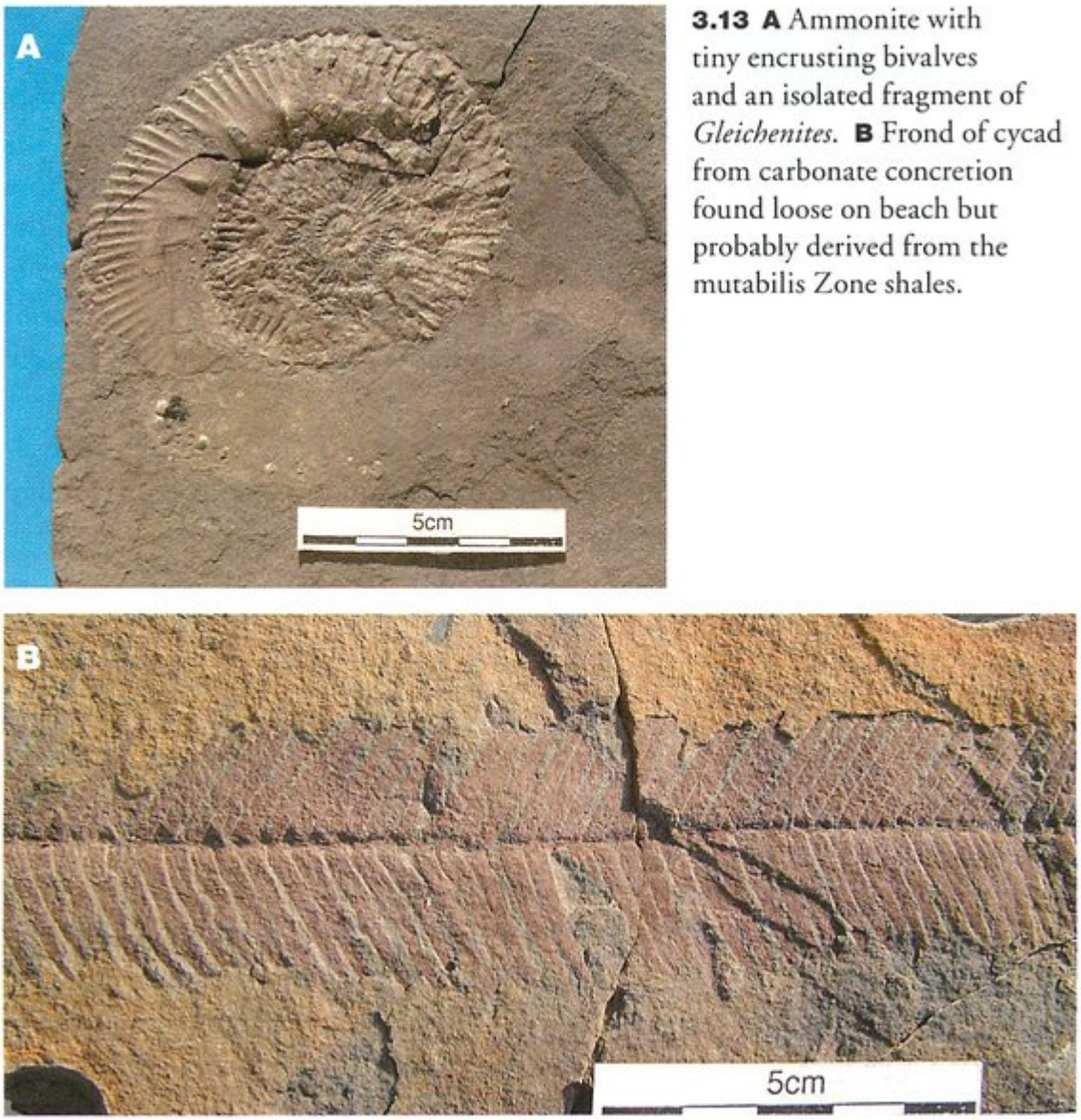
(Figure 3.9) Sandstone clast showing in situ disintegration within boulder bed, Kintradwell.



(Figure 3.10) Locality map for itinerary 2, Lothbeg area.

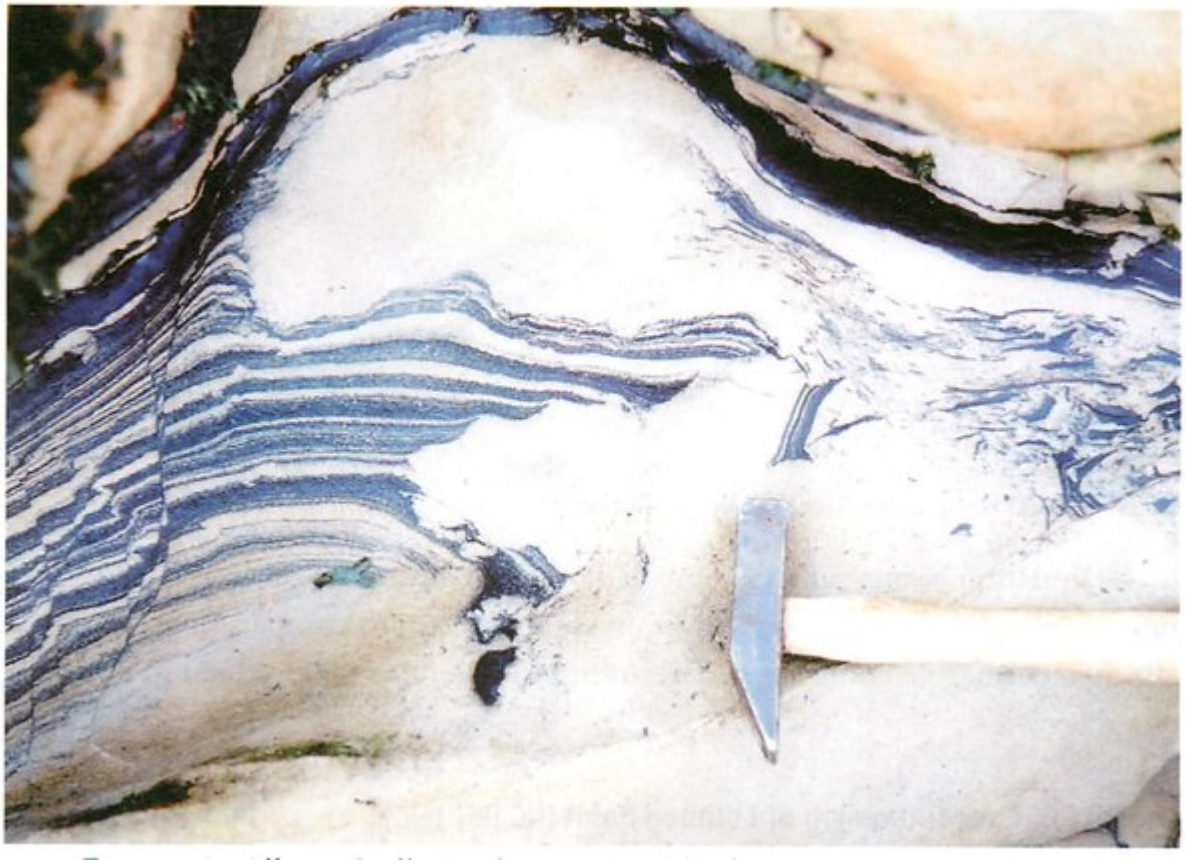
(Figure 3.11) Exposure of rock-fall breccias in Allt Choll.

(Figure 3.12) Allt na Cuille sandstones and interbedded shales in cliff at the Earl's Cut, Lothbeg.



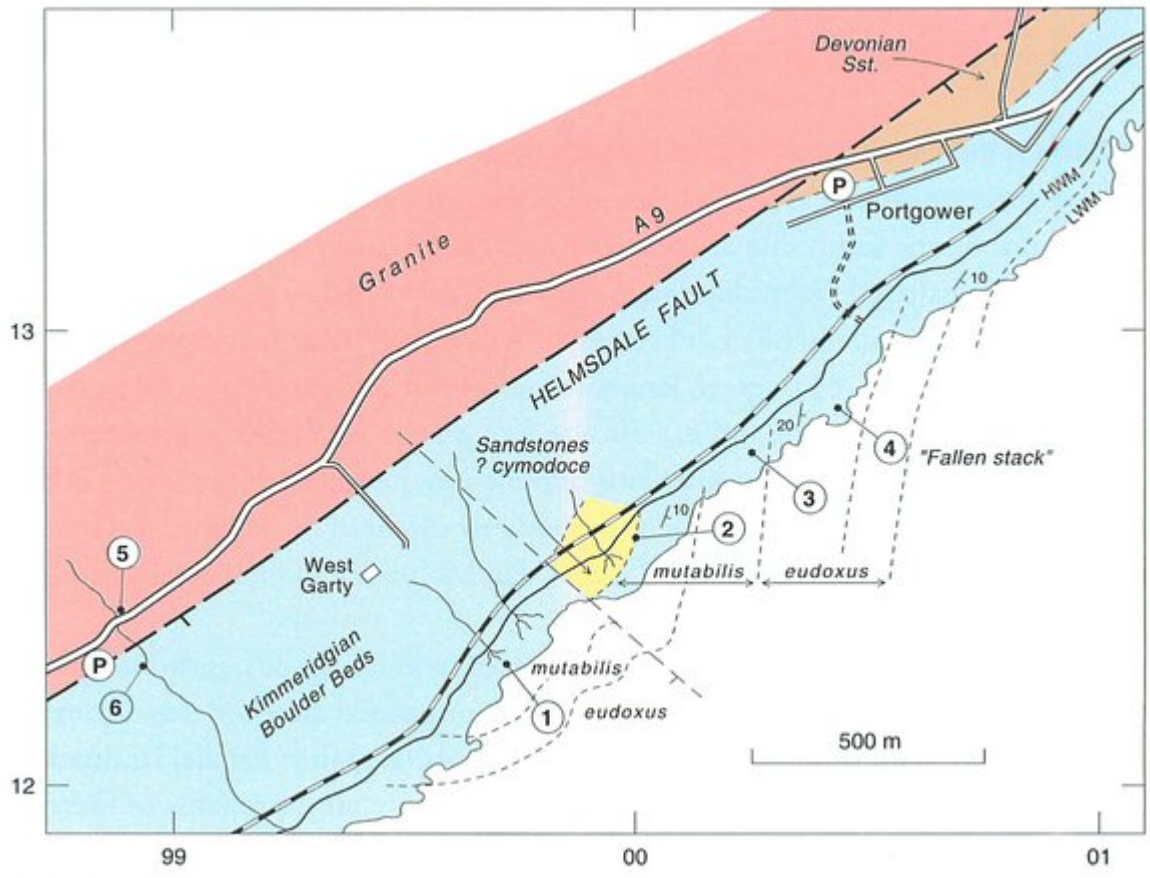
3.13 A Ammonite with tiny encrusting bivalves and an isolated fragment of *Gleichenites*. **B** Frond of cycad from carbonate concretion found loose on beach but probably derived from the mutabilis Zone shales.

(Figure 3.13) A Ammonite with tiny encrusting bivalves and an isolated fragment of Gleichenites. B Frond of cycad from carbonate concretion found loose on beach but probably derived from the mutabilis Zone shales.

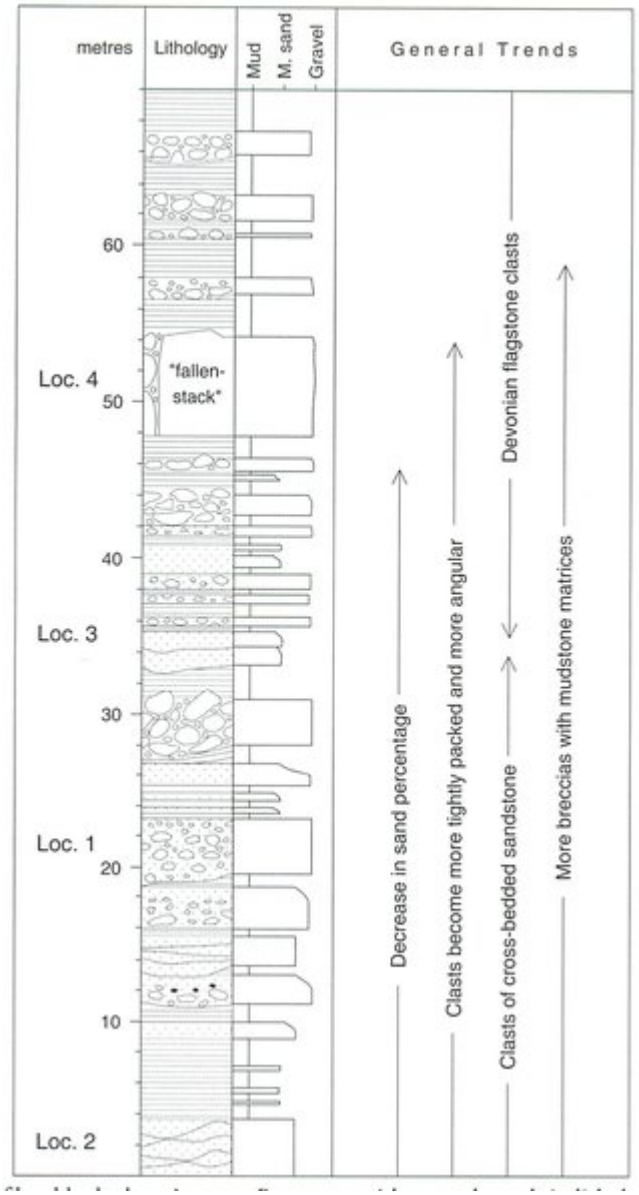


(Figure 3.14) Features in Allt na Cuille Sandstone caused by fluidisation and injection of sand. Shore between localities 4 and 5, Lothbeg.

(Figure 3.15) Granulation seams in the Allt na Cuille Sandstone, Lothbeg.

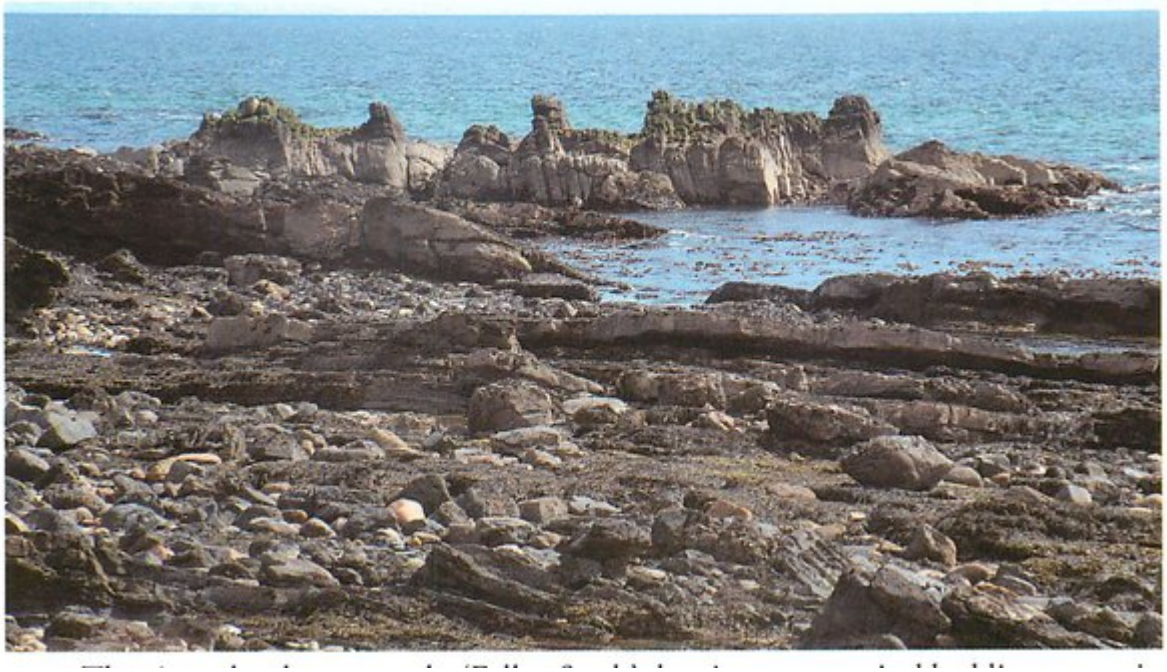


(Figure 3.16) Locality map for itinerary 3, Portgower.

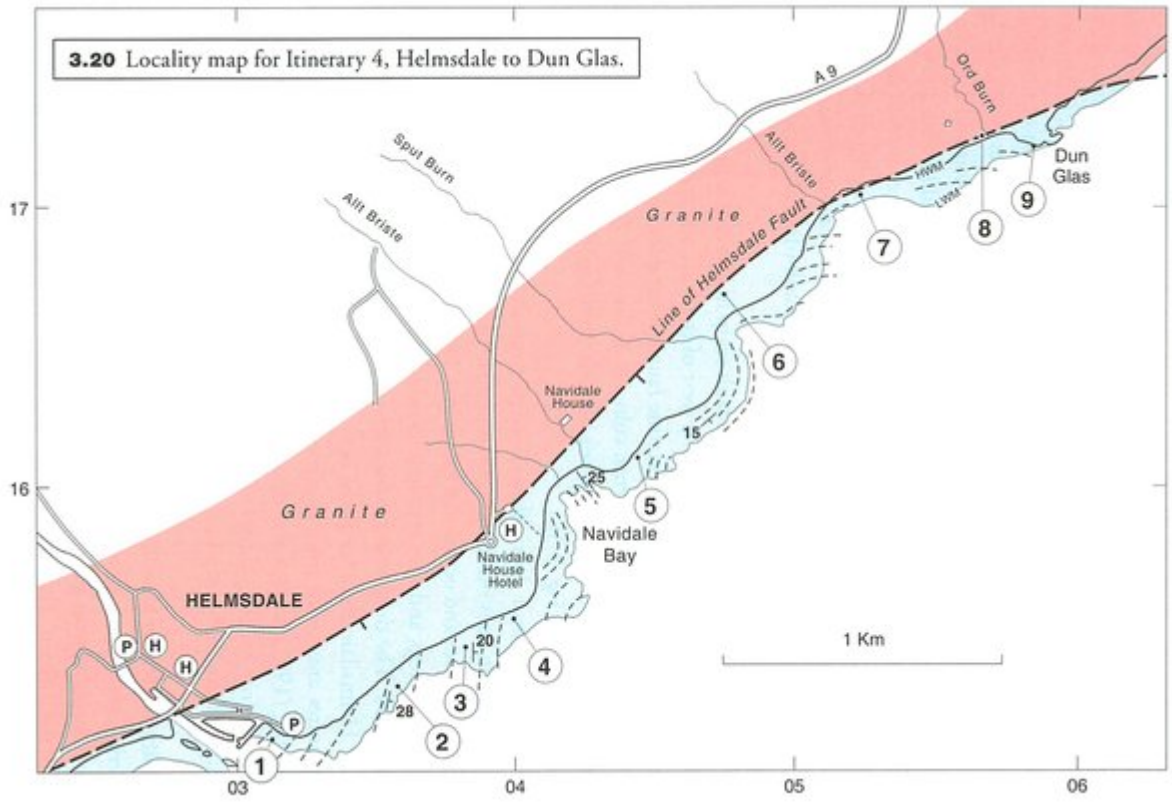


(Figure 3.17) Log of boulder bed section near Portgower with general trends in lithology and clast types (adapted from MacDonald (1985)).

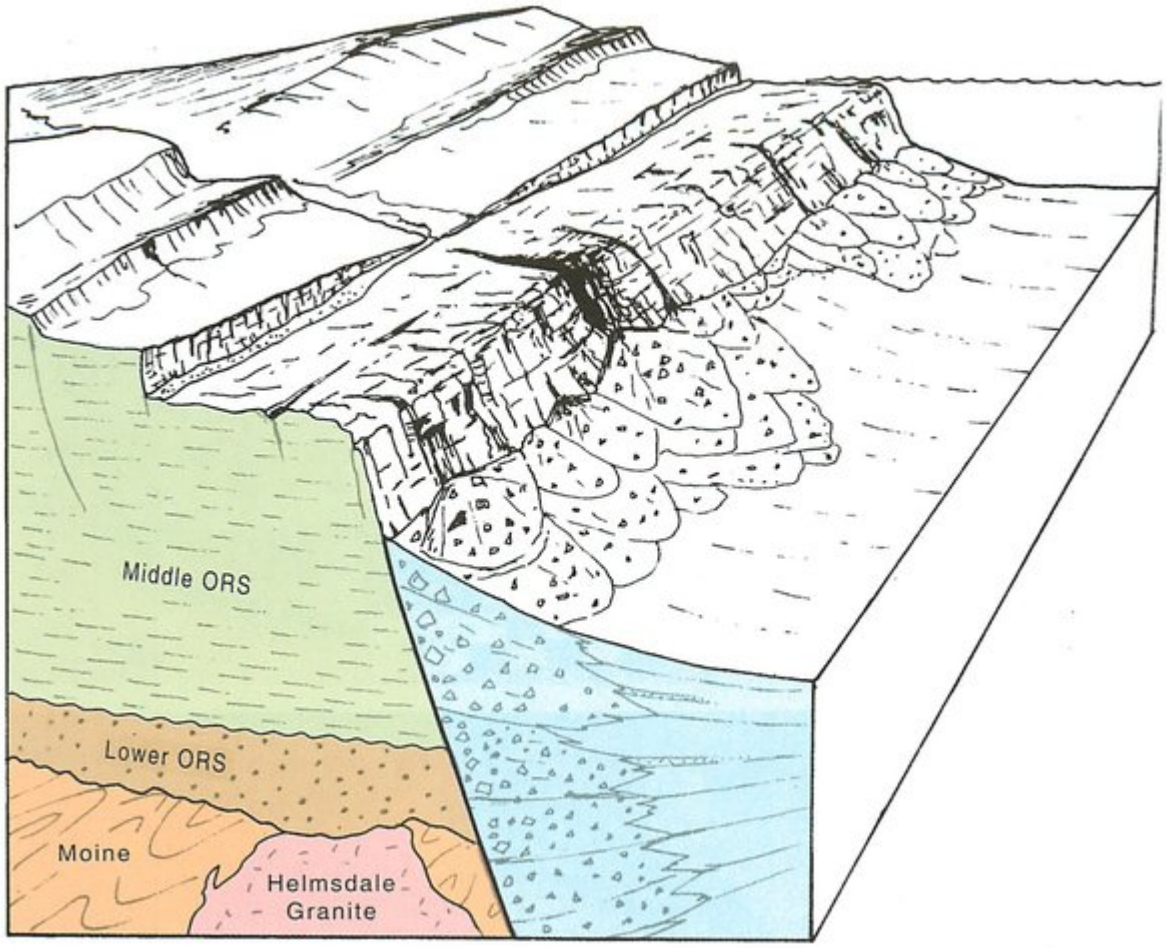
(Figure 3.18) Cross-bedding in sandstone clast within boulder bed near Locality 1, Portgower, lens cap 52 mm



(Figure 3.19) The giant clast known as the 'Fallen Stack' showing near-vertical bedding; strata in foreground show general shallow easterly dip of shales and sandy boulder beds.



(Figure 3.20) Locality map for Itinerary 4, Helmsdale to Dun Glas.



(Figure 3.21) Reconstruction of the Helmsdale Fault zone in the late Kimmeridgian at the time of deposition of the Helmsdale Boulder Beds.

(Figure 3.22) Typical texture of Helmsdale Boulder Beds with Middle ORS flagstone clasts in a bioclastic matrix, locality 1, Helmsdale.

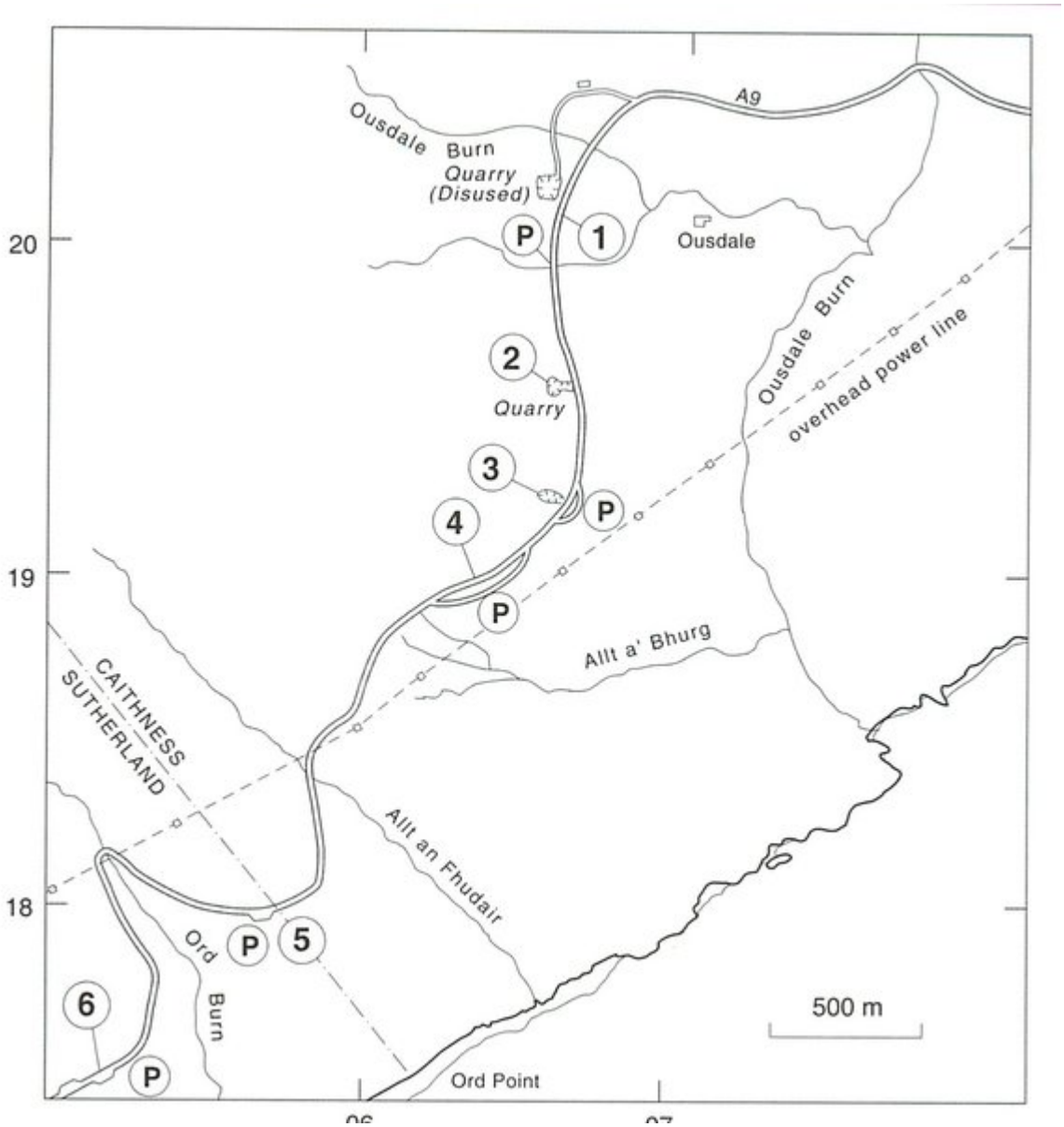
(Figure 3.23) Limestone clast in the Helmsdale Boulder Beds at locality 1 bored by the bivalve Lithophaga, together with example showing the shape of the bivalve crypt.

(Figure 3.24) Example of a boulder bed that wedges out rapidly away from the Helmsdale Fault, Helmsdale shore.

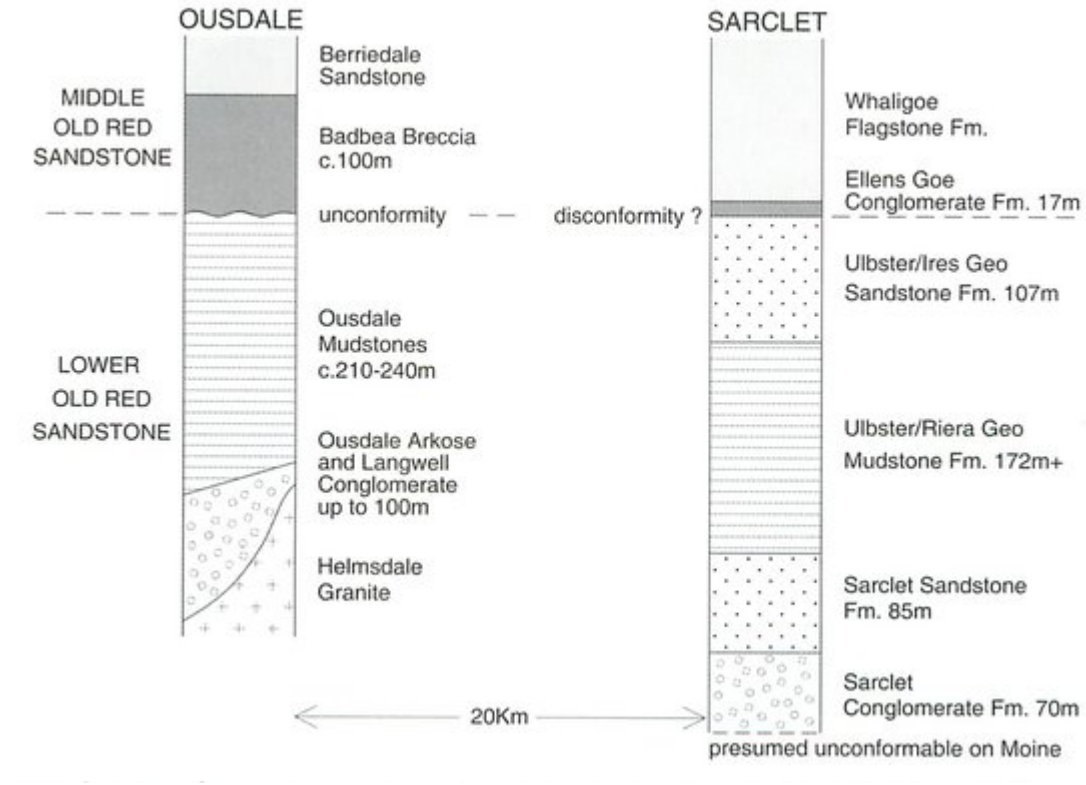
(Figure 3.25) Colony, 25 mm across, of the coral Isastraea from the boulder beds at Helmsdale. The colony was swept into deep water from its living position on a shallow shelf. It may have grown attached to rock on the shelf edge.

(Figure 3.26) View of Dun Glas from SW of the end of Allt Briste. The Helmsdale Fault is exposed on the beach below the granite buttress at the left of the picture, and passes through the col at the back of Dun Glas.

(Figure 3.27) Inclined rockfall breccia of Middle ORS flagstone clasts at Dun Glas, locality 9, Helmsdale excursion.

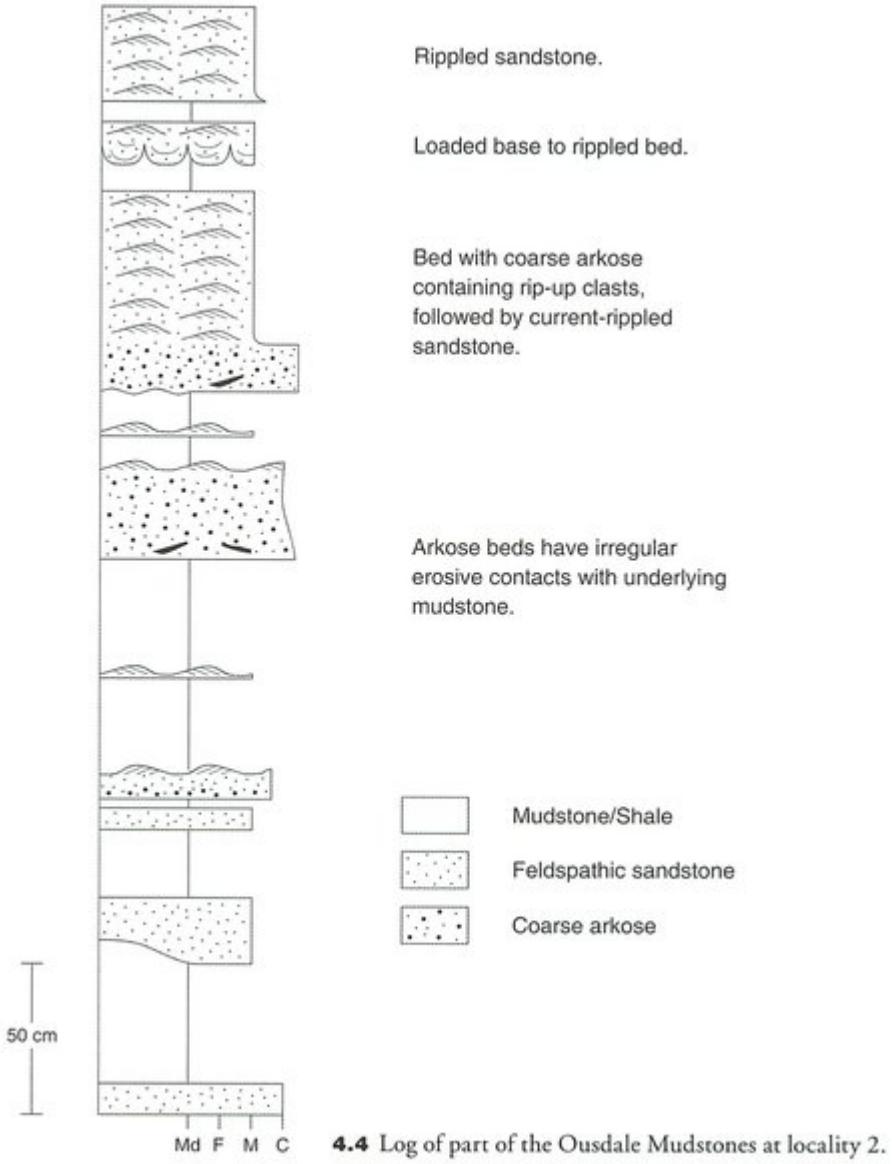


(Figure 4.1) Locality map for excursion 4, Ousdale area.



(Figure 4.2) Stratigraphic sections at Ousdale and Sarclet (see Excursion 5). Modified from Collins and Donovan (1977).

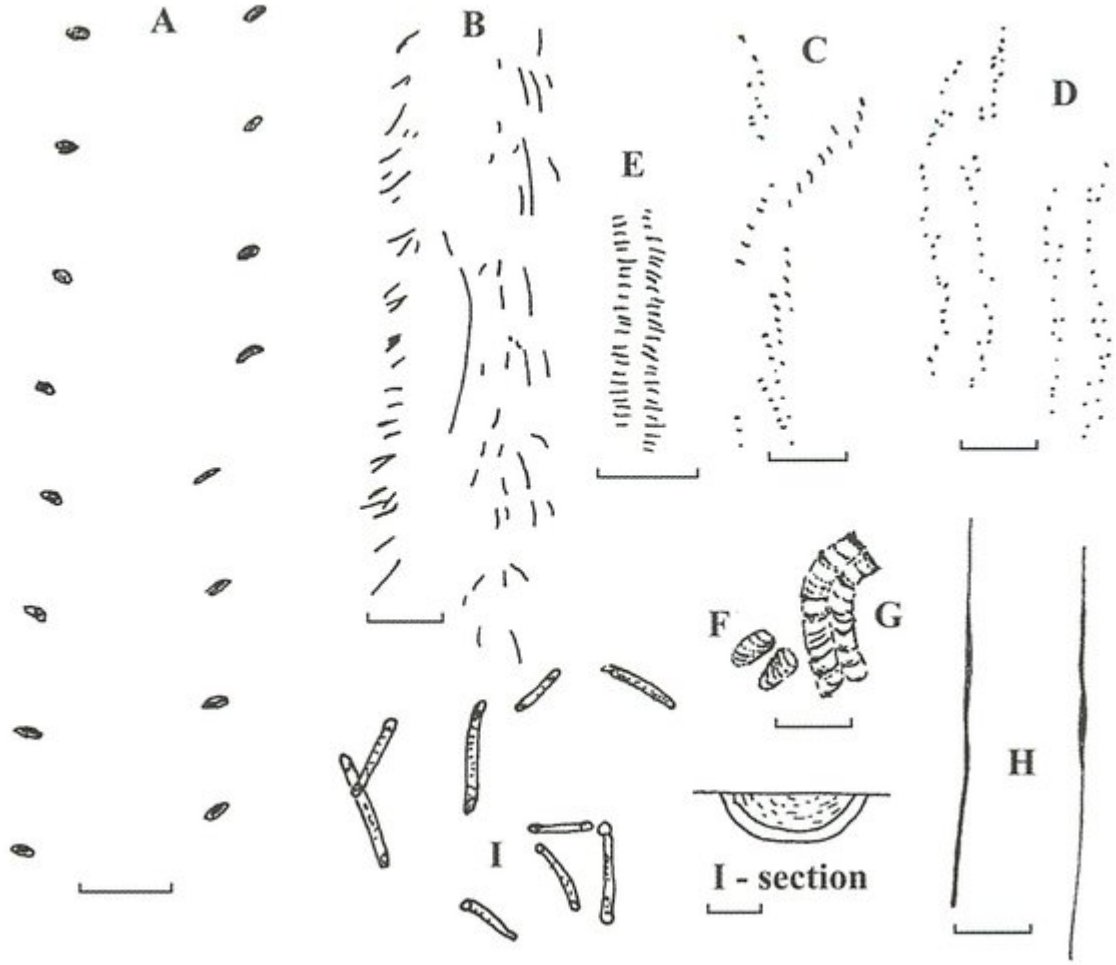
(Figure 4.3) Ousdale road cutting on the A9 (north end, southbound side) showing the junction between sheared granite and bedded arkose. (Locality now more overgrown with vegetation.)



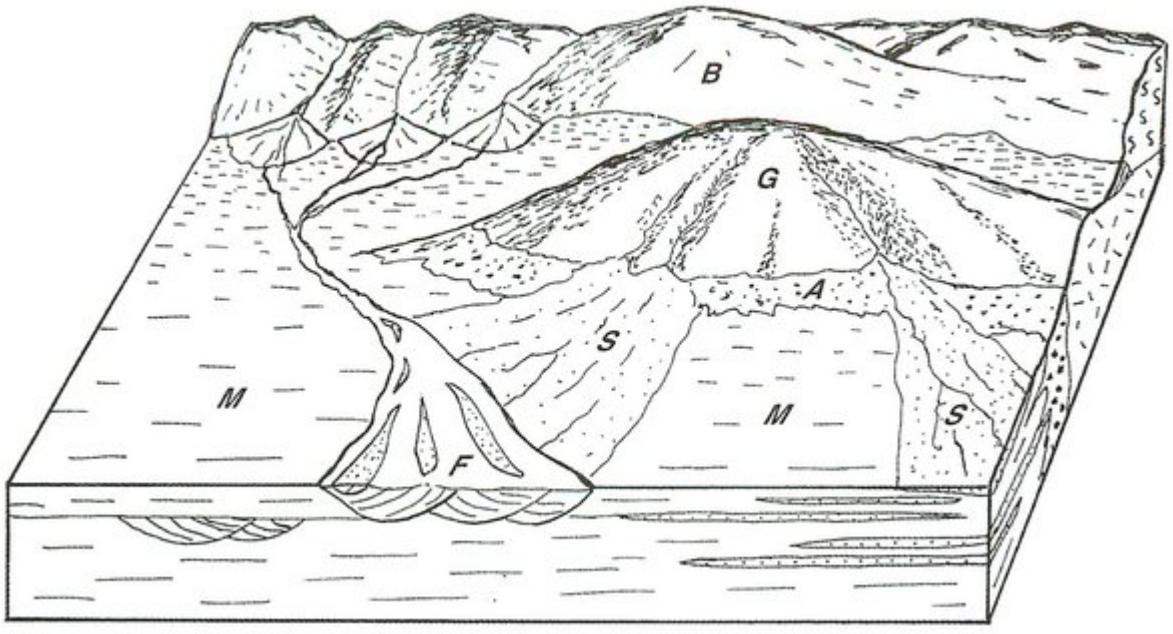
4.4 Log of part of the Ousdale Mudstones at locality 2.

(Figure 4.4) Log of part of the Ousdale Mudstones at locality 2.

(Figure 4.5) Sandstone beds with erosive bases within the Ousdale Mudstones. The upper bed has a coarse arkosic base. Ousdale Mudstone quarry, locality 2.

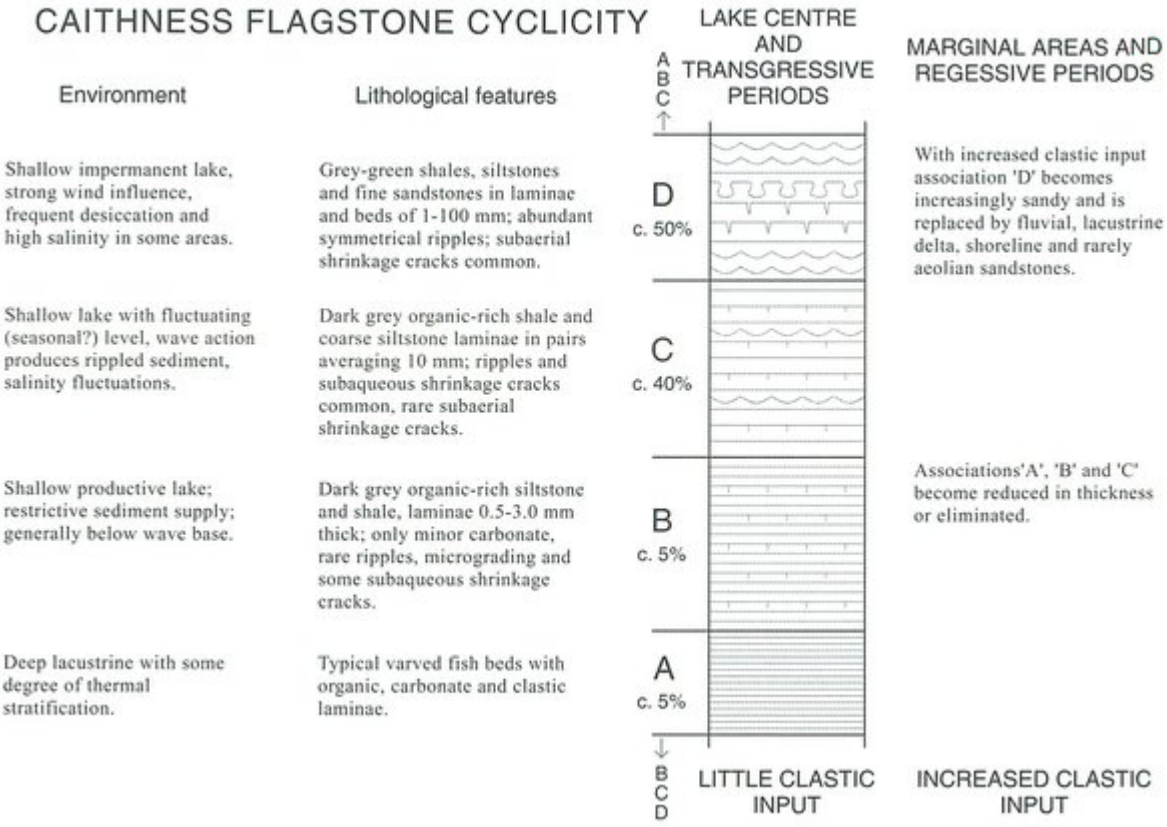


(Figure 4.6) Trace fossils from the Ousdale Mudstones at locality 2. The naming of arthropod trackways A–E is tentative, and follows the work of Carroll (1990) and Walker (1985). It is probable that all these trace fossils were made by arthropods. A. Merostomichnites; B. Allocotichnus; C. Merostomichnites, form with overlapping track series made by animal with at least six pairs of walking legs. D. Danstaria; E. Tasmanadia; F. Rusophycus, a coffee-bean shaped resting trace. G. Cruziana, a bilobed ribbon trace made by an animal ploughing through the surface. H. Beaconichnus, a double groove tramway-trace. I. Diplocraterion, a u-shaped burrow in plan and cross-section. Scale bars 1 cm long.

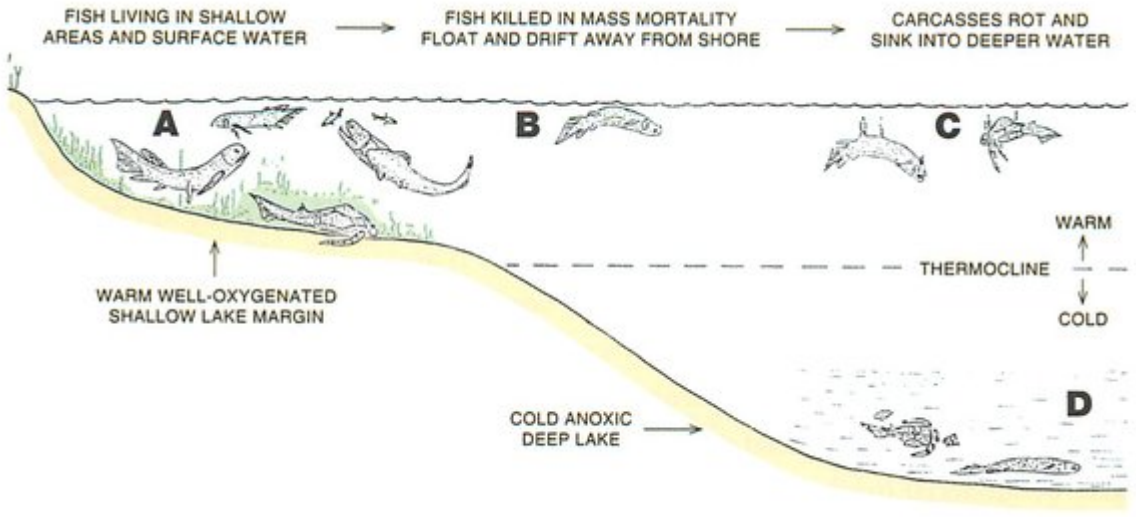


(Figure 4.7) Sketch reconstruction of depositional features associated with the Ousdale Arkose and Ousdale Mudstones. Eroding granite (G) supplies material for a fringe of arkose (A), and arkosic sheetflood deposits (S) that partly cover

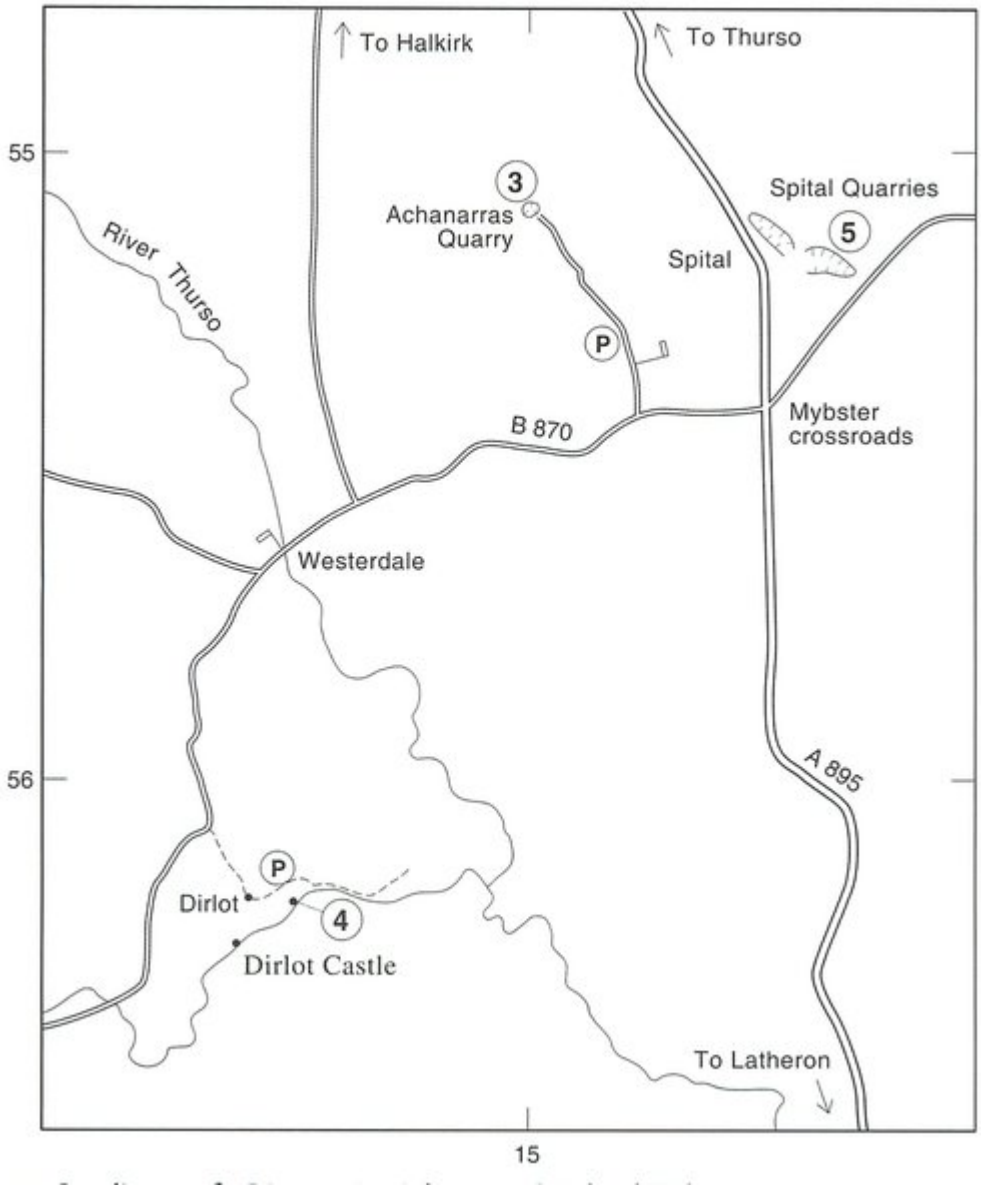
alluvial plain mudstones (M). Fluvial channel deposits (F) are sourced from more distant metamorphic basement (B) and hence carry a variety of lithic clasts.



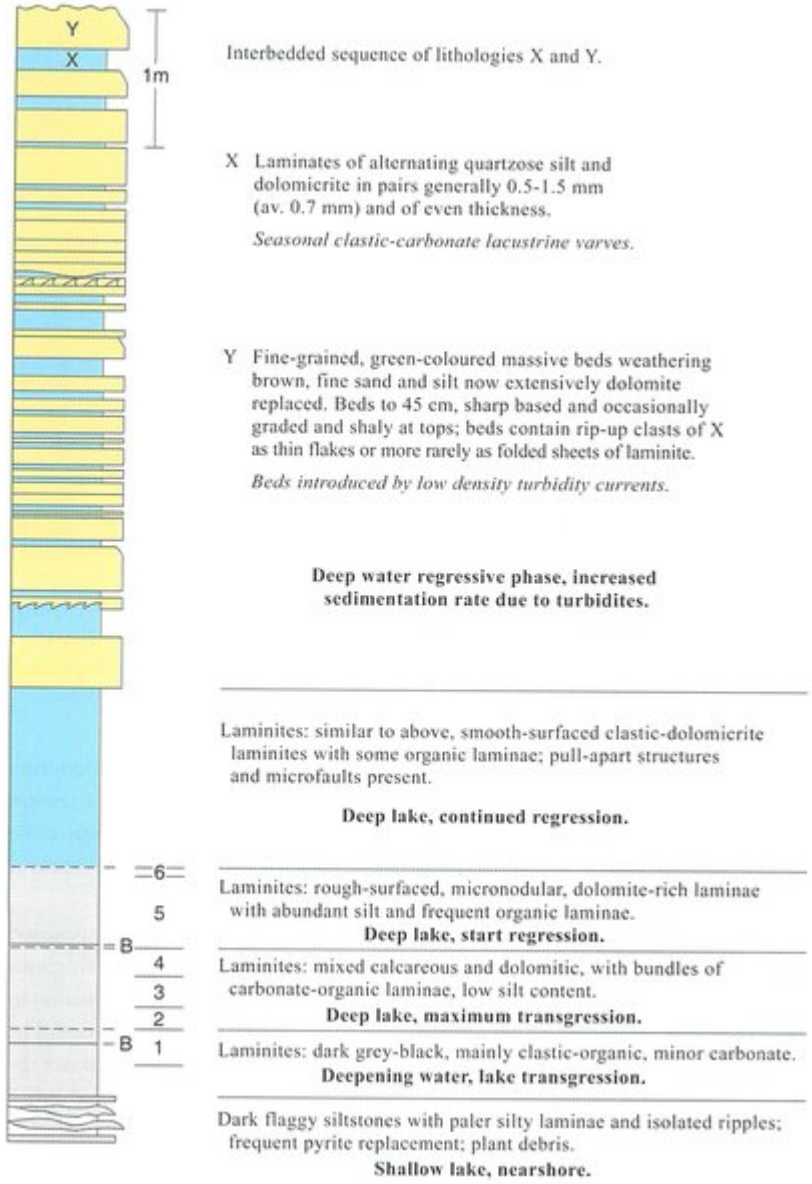
(Figure 5.1) Summary of the characteristics of Lithological Associations A–D of Donovan (1980) which form the cyclic lacustrine facies of the Middle ORS of Caithness.



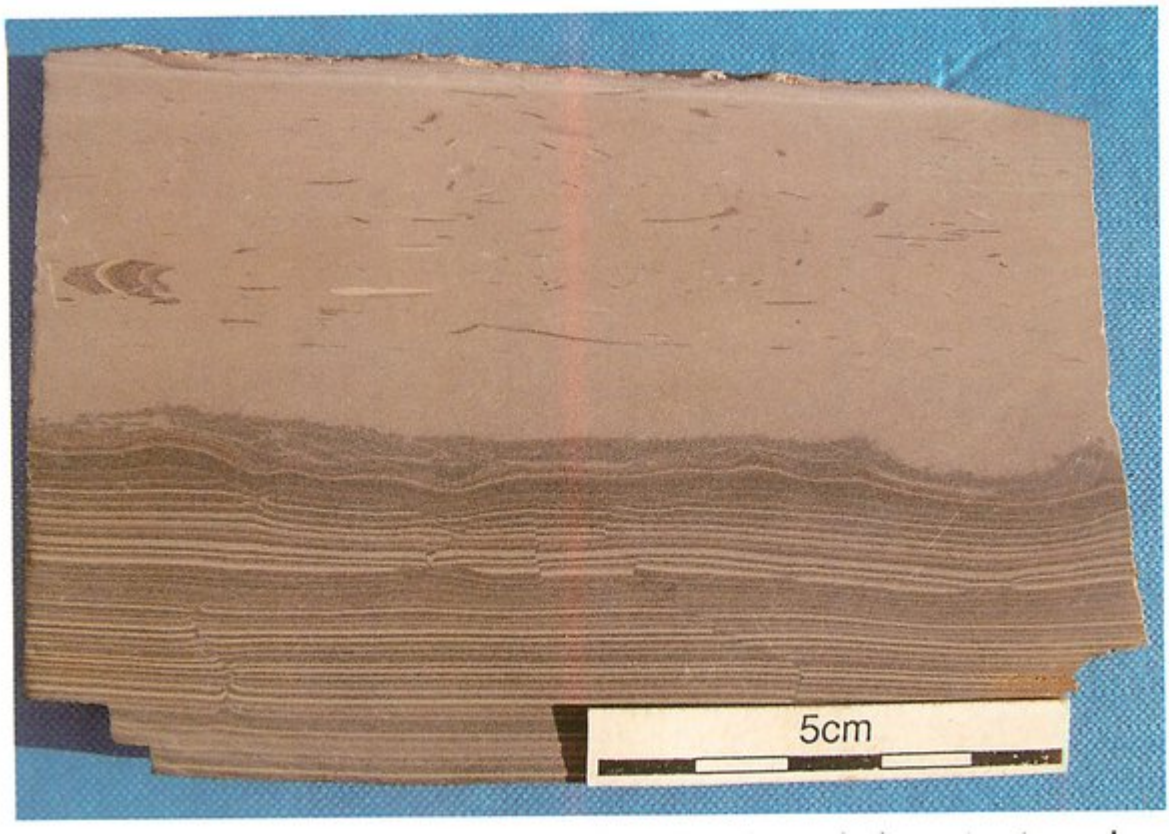
(Figure 5.2) Origin of fossil fish carcasses in deep lake laminite facies. Fish lived in rivers and shallow lake areas (A) where waters were oxygenated. Periodic mortalities due to salinity crisis, or deoxygenation caused by algal blooms, lake overturn or storm mixing, resulted in carcasses (B) drifting out into the lake where they eventually decayed (C) and sank through the thermocline to be preserved in the anoxic laminites of the deep lake (D). Modified from Trewin (1986).



(Figure 5.3) Locality map for Itinerary 5.1, Achanarras, Spital and Dirlot.

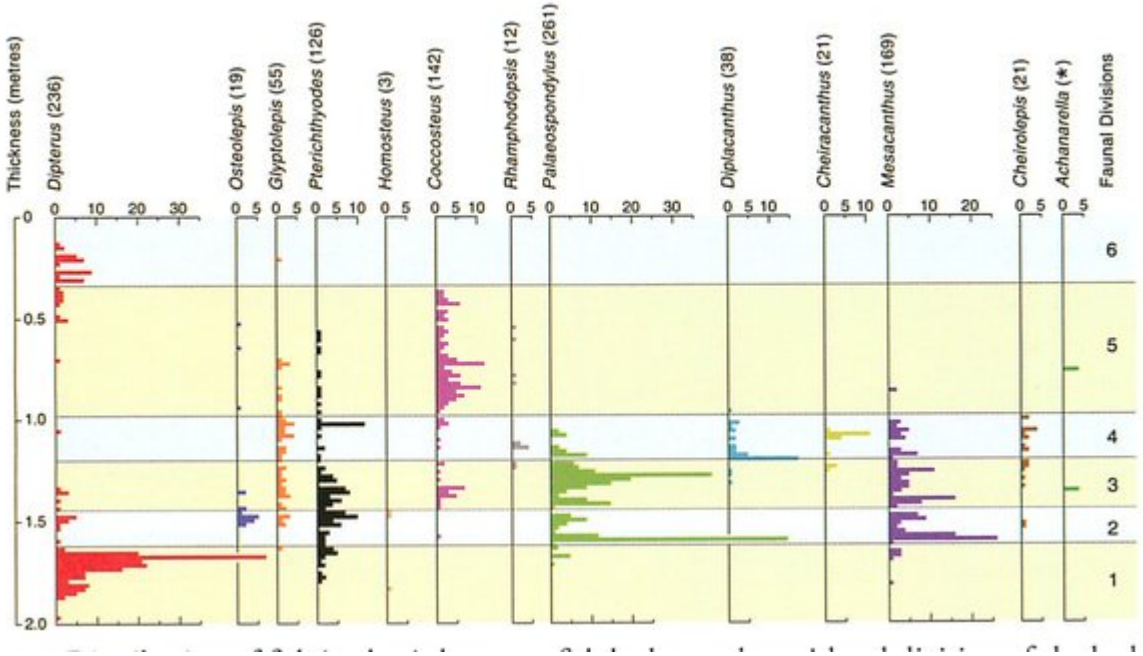


(Figure 5.4) Log of section at Achanarras Quarry. Modified from Trewin (1986).

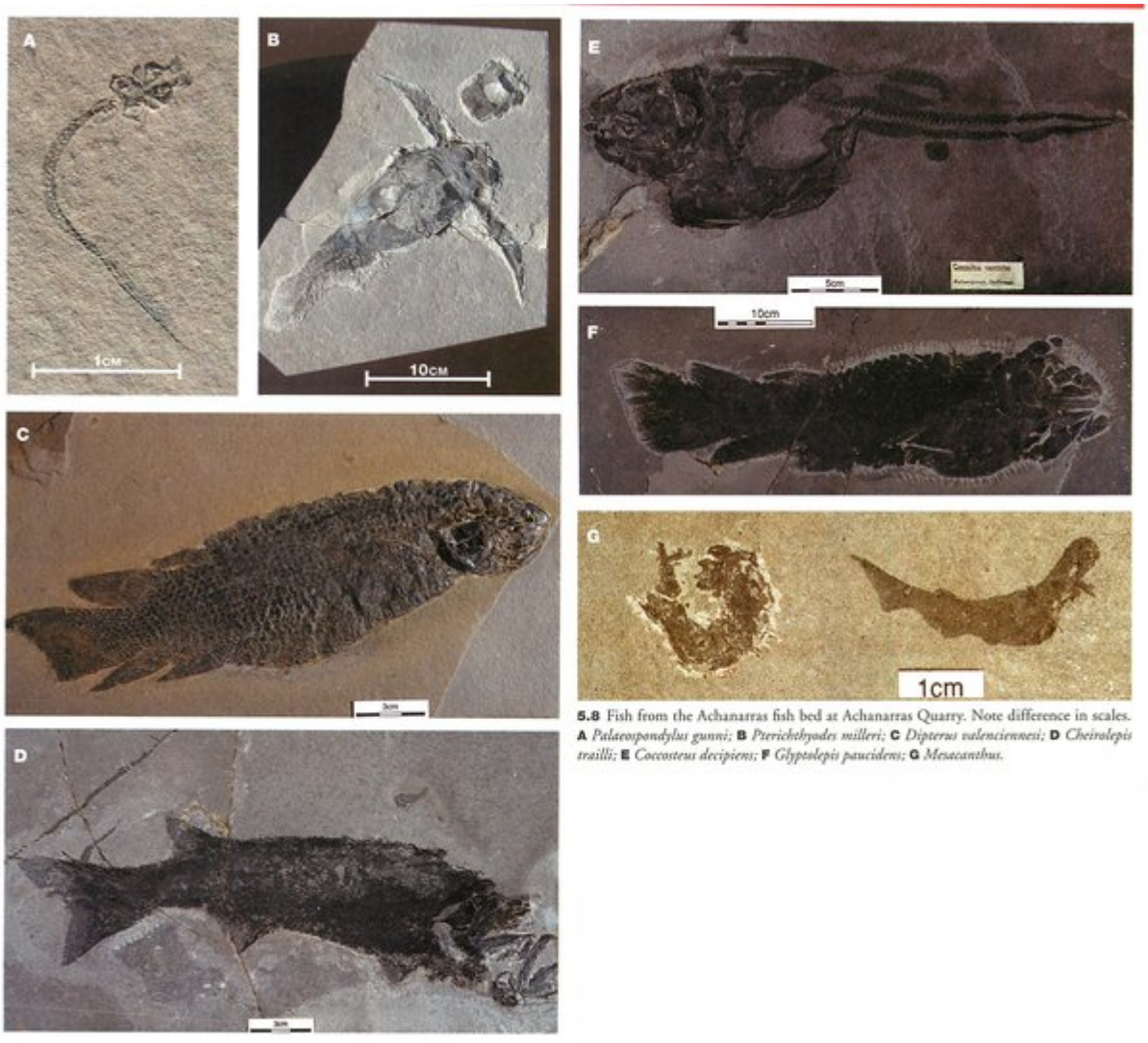


(Figure 5.5) Section of base of siltstone bed resting on laminite. Siltstone bed contains rip-up clasts of laminite and the laminite consists of alternations of silt (dark) and dolomicrite (pale). The siltstone was emplaced by a turbidity current flowing downslope into the deep lake. The laminites deformed plastically beneath the turbidite; a compacted shrinkage crack produced the offsets in the lower part of the laminites in the photo. Scale bar 10 mm.

(Figure 5.6) Cut and acid-etched section showing the lamination typical of the central part of the Achanarras fish bed. White laminae are dolomitic. Scale bar 10 mm.

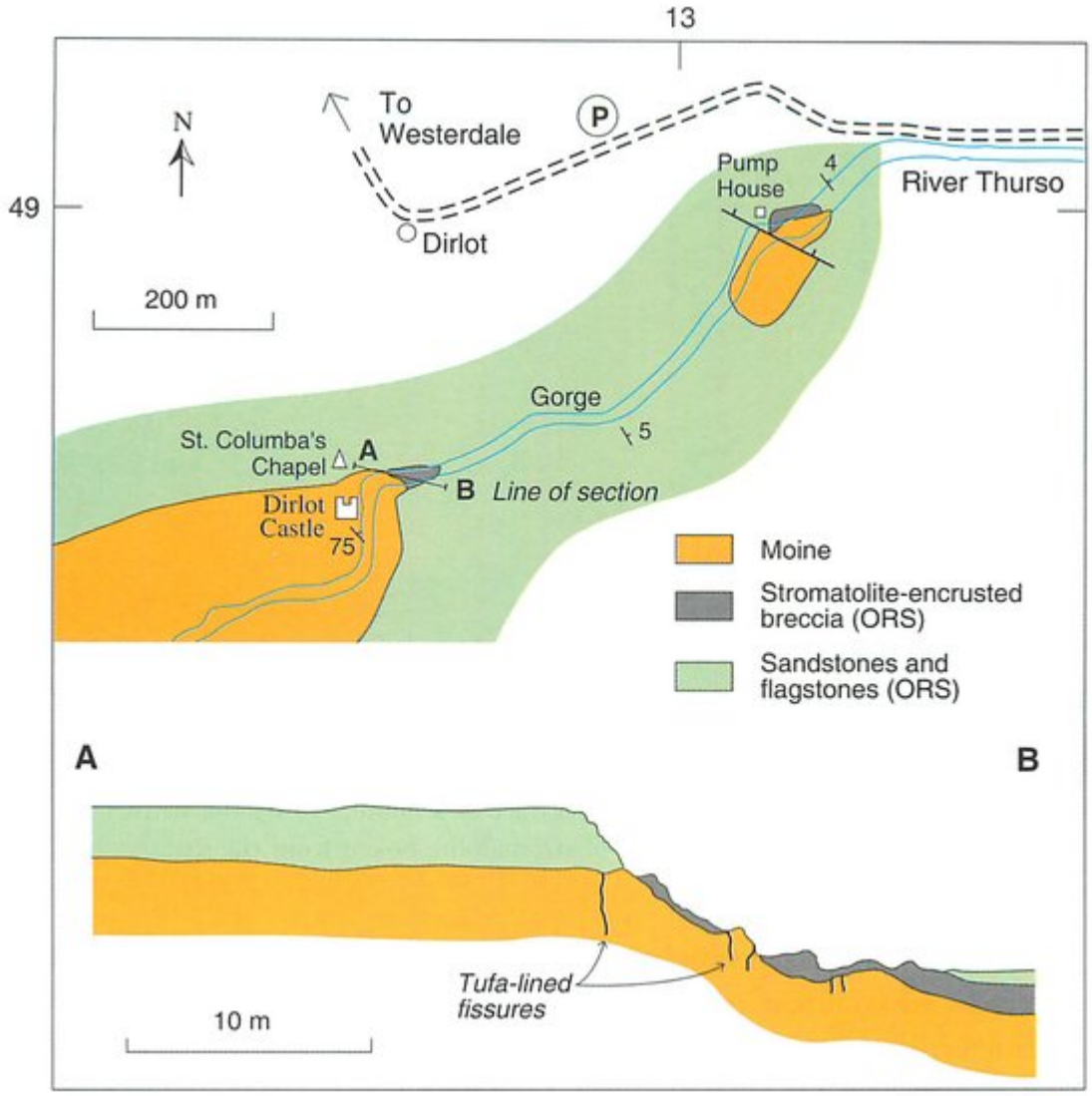


(Figure 5.7) Distribution of fish in the Achanarras fish bed, together with subdivision of the bed into six faunal units. Based on the positioning of over 1000 specimens by laminite-pattern matching. See Trewin (1986) for further details.



5.8 Fish from the Achanarras fish bed at Achanarras Quarry. Note difference in scales. **A** *Palaeospondylus gunni*; **B** *Pterichthyodes milleri*; **C** *Dipterus valenciennesi*; **D** *Cheirolepis trailli*; **E** *Coccosteus decipiens*; **F** *Glyptolepis paucidens*; **G** *Mesacanthus*.

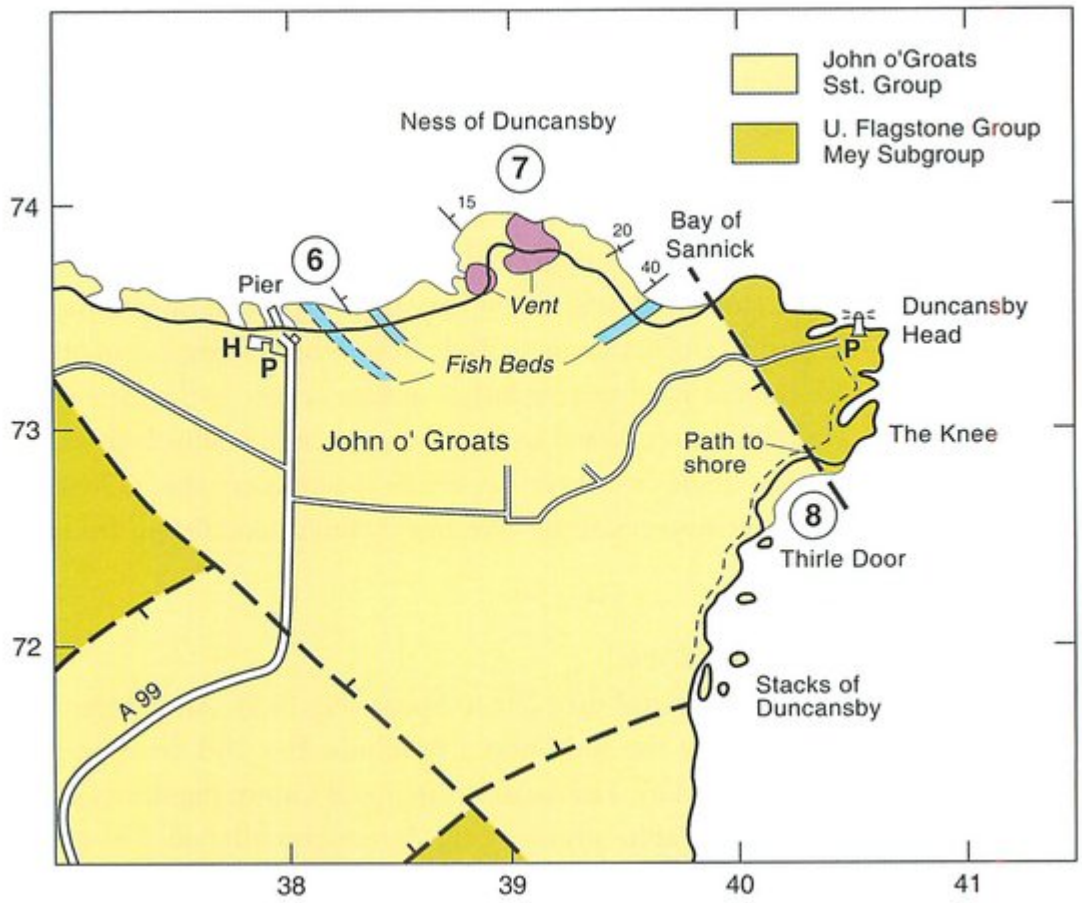
(Figure 5.8) Fish from the Achanarras fish bed at Achanarras Quarry. Note difference in scales. A. Palaeospondylus gunni; B. Pterichthyodes milleri; C. Dipterus valenciennesi; D. Cheirolepis trailli; E. Coccosteus decipiens; F. Glyptolepis paucidens; G. Mesacanthus.



(Figure 5.9) Map and sketch section at locality 4, Dirlot Castle (Modified from Donovan 1973).

(Figure 5.10) Domed stromatolite grown on the surface of a boulder of Moine schist from the Dirlot breccia; matrix contains flakes of stromatolite boken from the surfaces of other clasts. Coin 25mm.

(Figure 5.11) View downstream at the Devil's Pool, Dirlot Castle. The unconformity between Moine and Middle ORS is present in the cliff to the left, largely covered by vegetation.

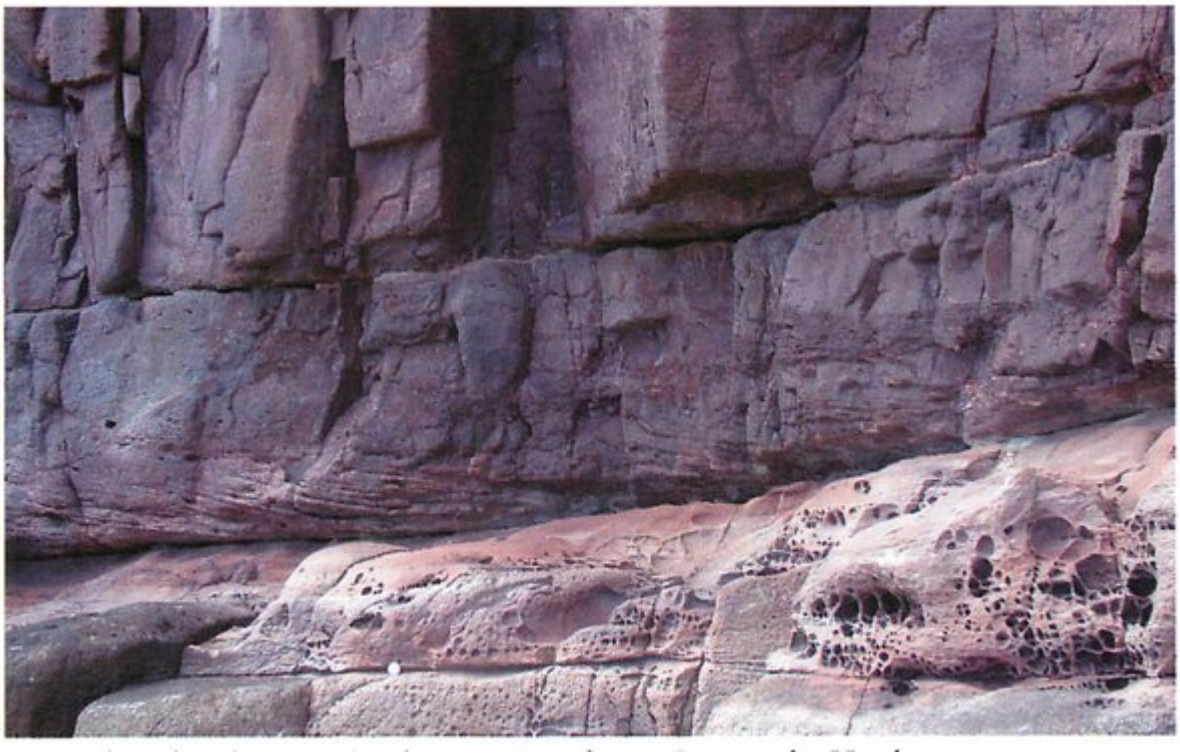


(Figure 5.12) Locality map for Itinerary 5.2, John o' Groats area.

(Figure 5.13) Shore to the east of John o' Groats harbour, Red fluvial sandstones with thin-bedded greenish lacustrine strata that include the John o' Groats fish bed.

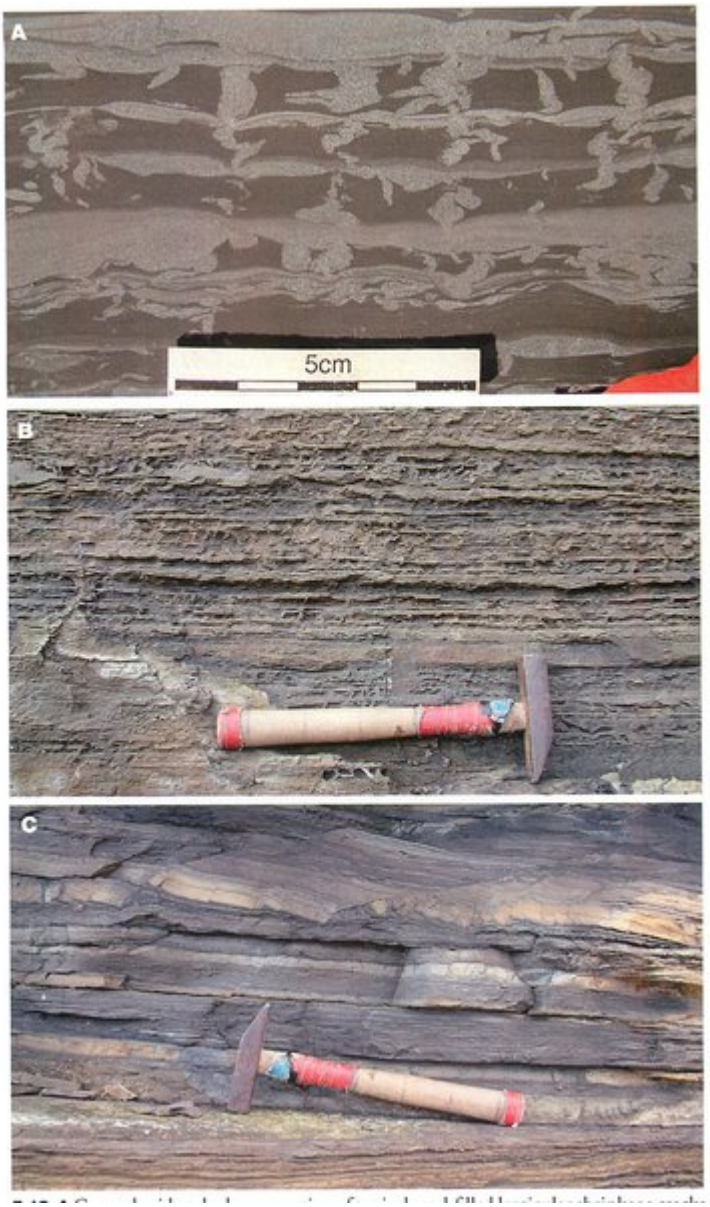
(Figure 5.14) Volcanic breccia in the volcanic neck at Ness of Duncansby, with Duncansby Head in the background.

(Figure 5.15) Fault gully giving access to locality 8. John o' Groats Sandstone Group on left and thin-bedded flagstones of Mey Subgroup on the right.



(Figure 5.16) The John o' Groats Sandstone at Locality 8, Duncansby Head.

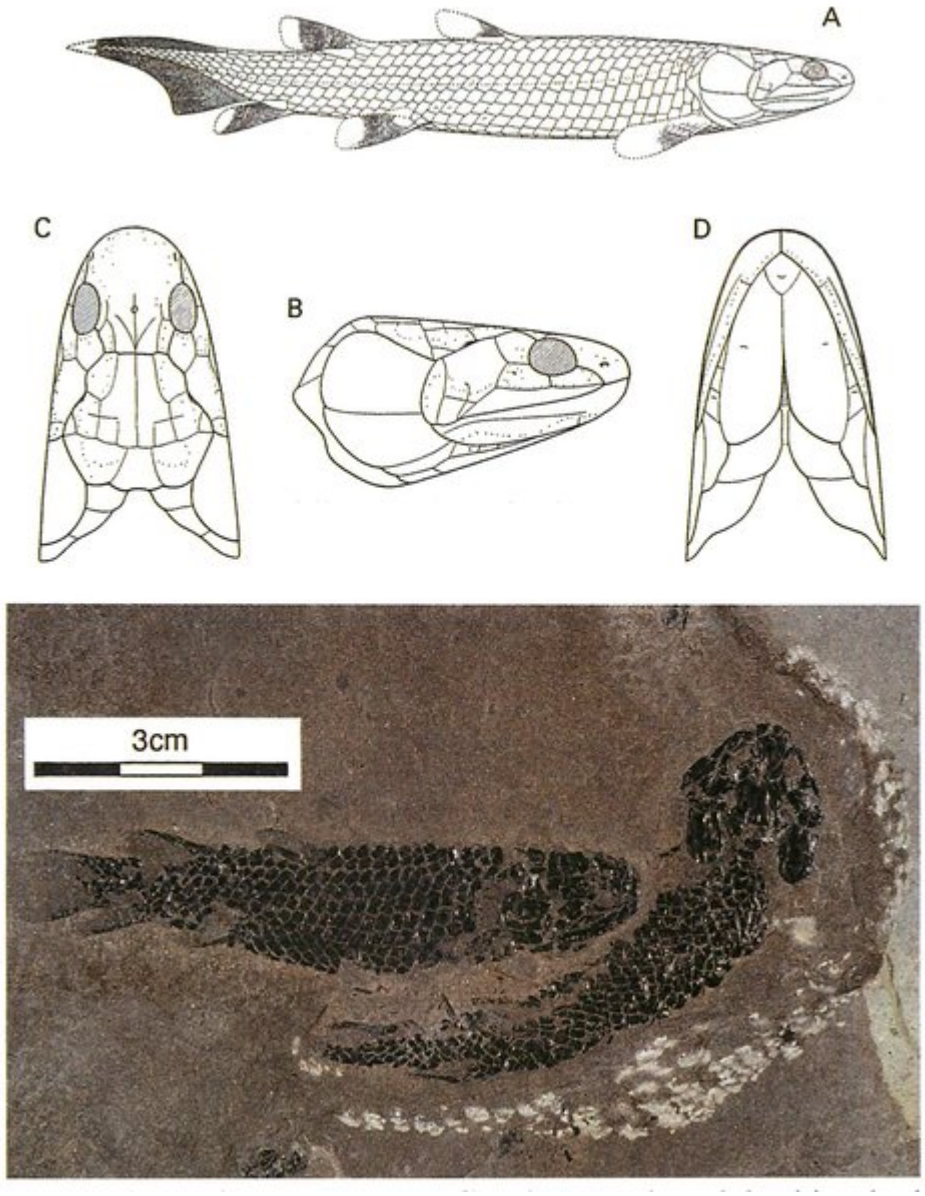
(Figure 5.17) Cyclicity in the Lybster Subgroup at South Head, Wick. Lithological Association D in foreground and at top of quarry face (pale colour). Central part of face consists of grey to black Association C (see (Figure 5.18) and text).



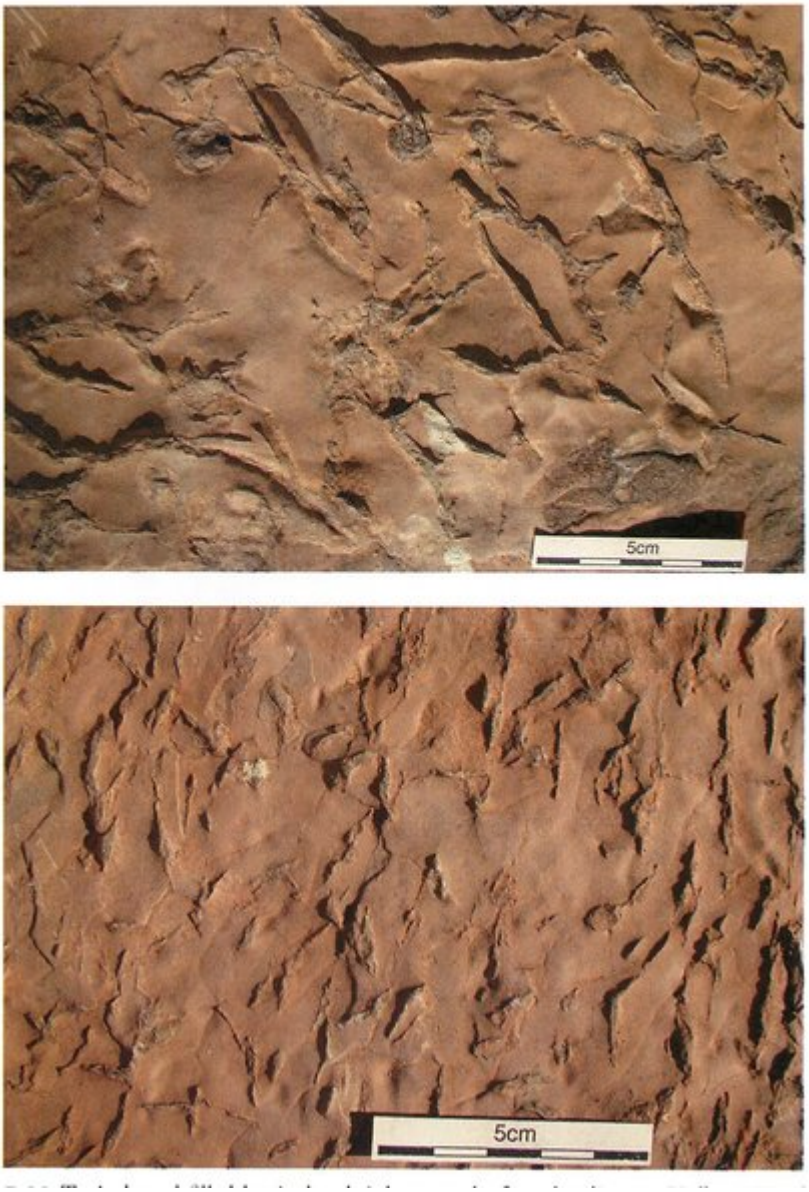
(Figure 5.18) A Cut and acid-etched cross-section of typical sand-filled lenticular shrinkage cracks in Association C. B Sand/ mud couplets with shrinkage cracks enhanced by weathering in quarry face. C Orange weathering dolomitic beds and disruption features near base of quarry section. Lower Flagstone Group, South Head, Wick.

(Figure 5.19) Slide plane underlain by relatively undisturbed sandstones and overlain by folded and fractured strata. Cliff top exposure viewed from cliff ledge, locality 10, Sarclet. Further information in text.

(Figure 5.20) Deformation features in carbonate laminites of a fish bed at Brims Ness. Coin 27mm. from the organic-rich laminites during burial. The cyclic nature of the sequence can be examined on the foreshore at mid to low tide.

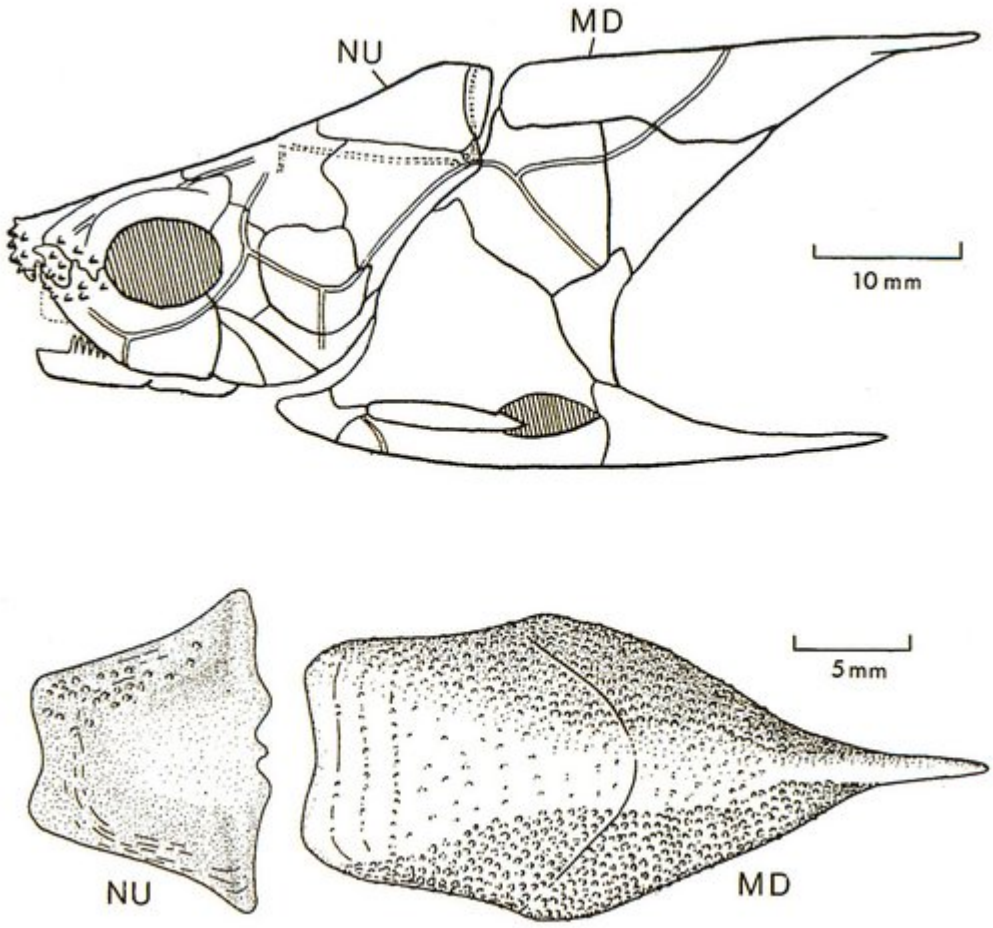


(Figure 5.21) Osteolepis panderi. A Reconstruction of lateral view, together with dorsal, lateral and ventral aspects of head (After Jarvik, 1948). B Well-preserved, articulated specimens of O. panderi from Cairnfield, near Thurso.



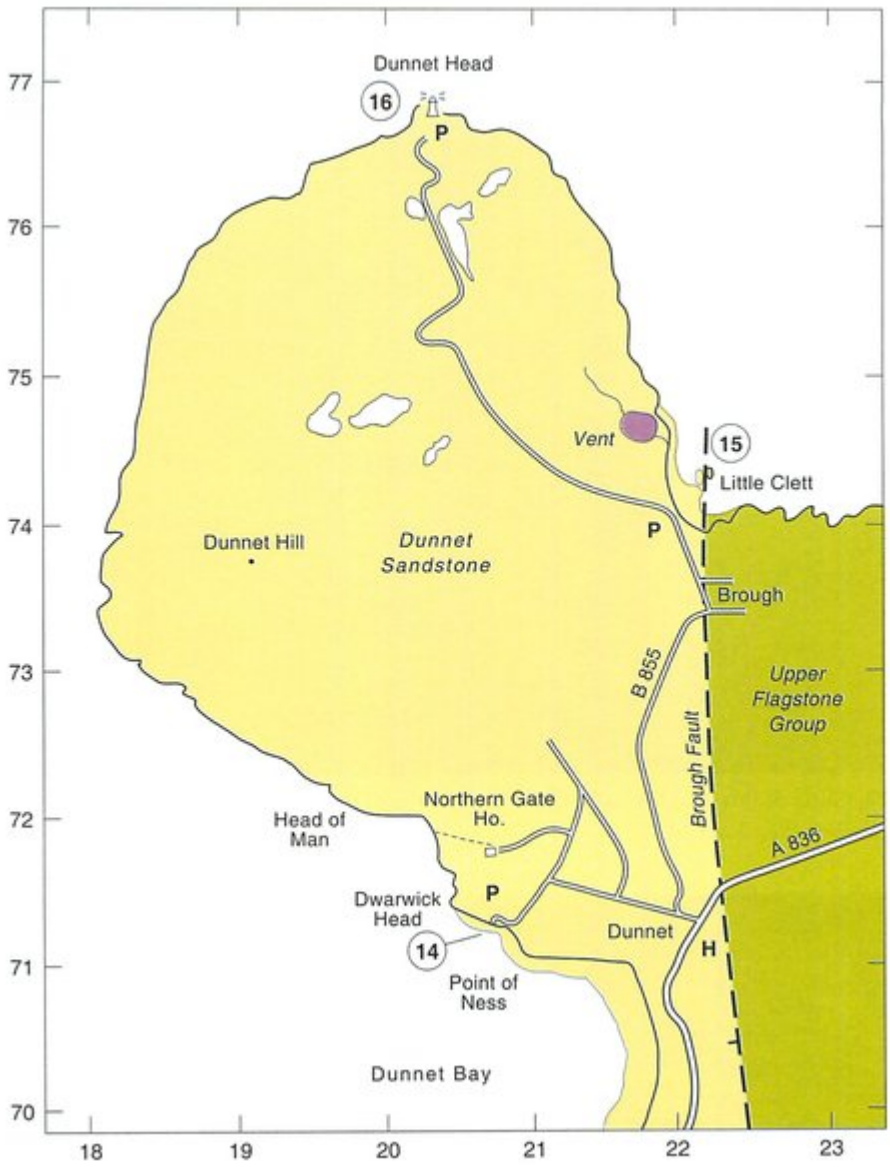
(Figure 5.22) Typical sand-filled lenticular shrinkage cracks from locality 12, Holborn Head Quarry.

(Figure 5.23) A Large sand-filled polygonal desiccation cracks formed due to subaerial exposure. B Current ripples formed in shallow water. Locality 13, Pennyland Shore, Thurso.



(Figure 5.24) Reconstruction of lateral view of head and thoracic region of Millerosteus minor (Miller) (after A. Desmond).

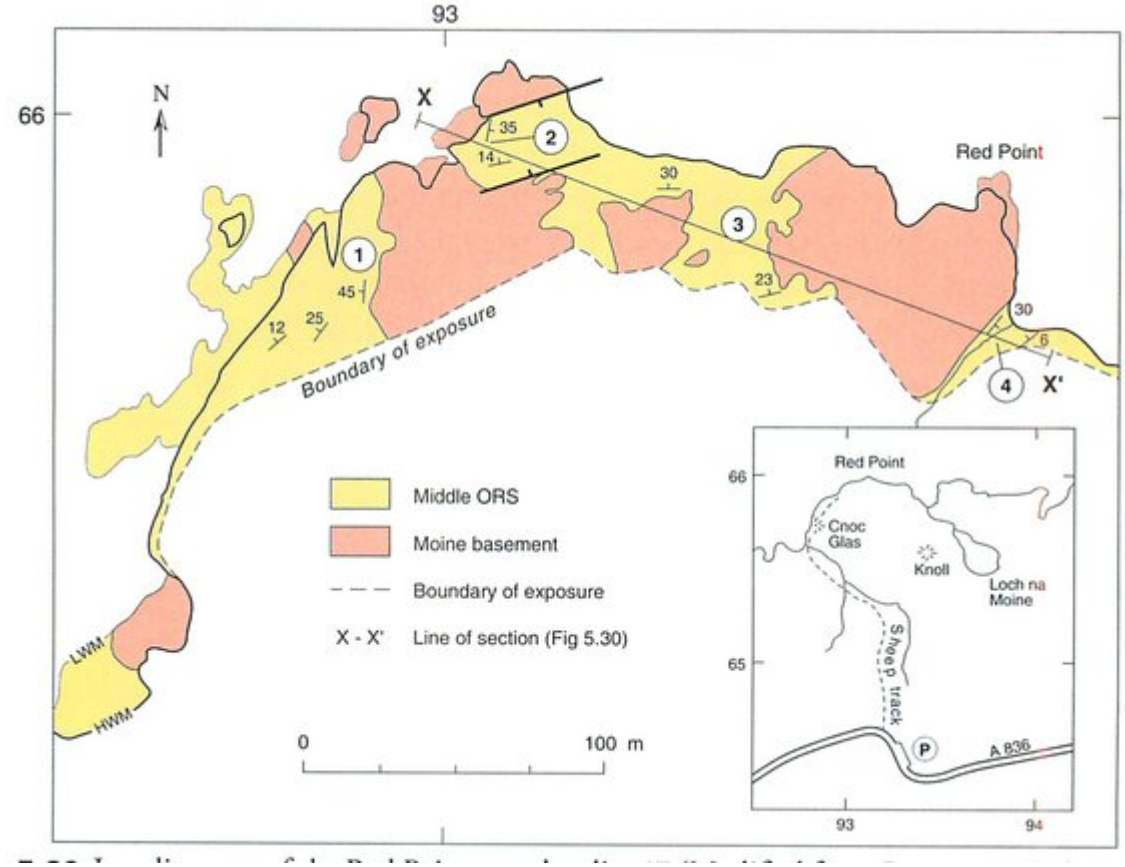
(Figure 5.25) Cross-bedded sandstones of mixed fluvial and aeolian origin. Promontary near isolated stack below building on cliff top, Thurso shore [ND 111 691].



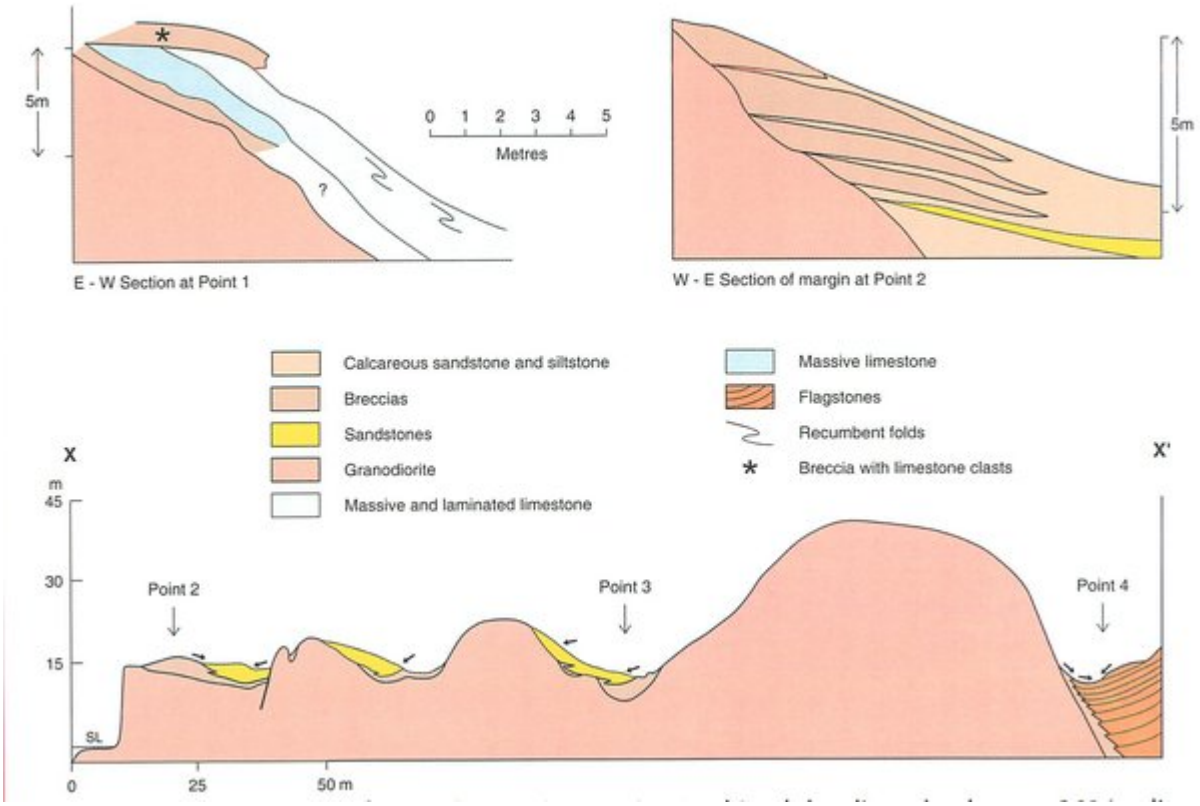
(Figure 5.26) Locality map for Dunnet Head area, itinerary 5.3.

(Figure 5.27) Cliffs of fluvial cross-bedded red sandstones of the Upper ORS to the northwest of Dwarwick Pier. Locality 14.

(Figure 5.28) Soft sediment deformation in cross-bedded fluvial channel sandstones in Upper ORS to the SE of Dwarwick Pier. Locality 14.

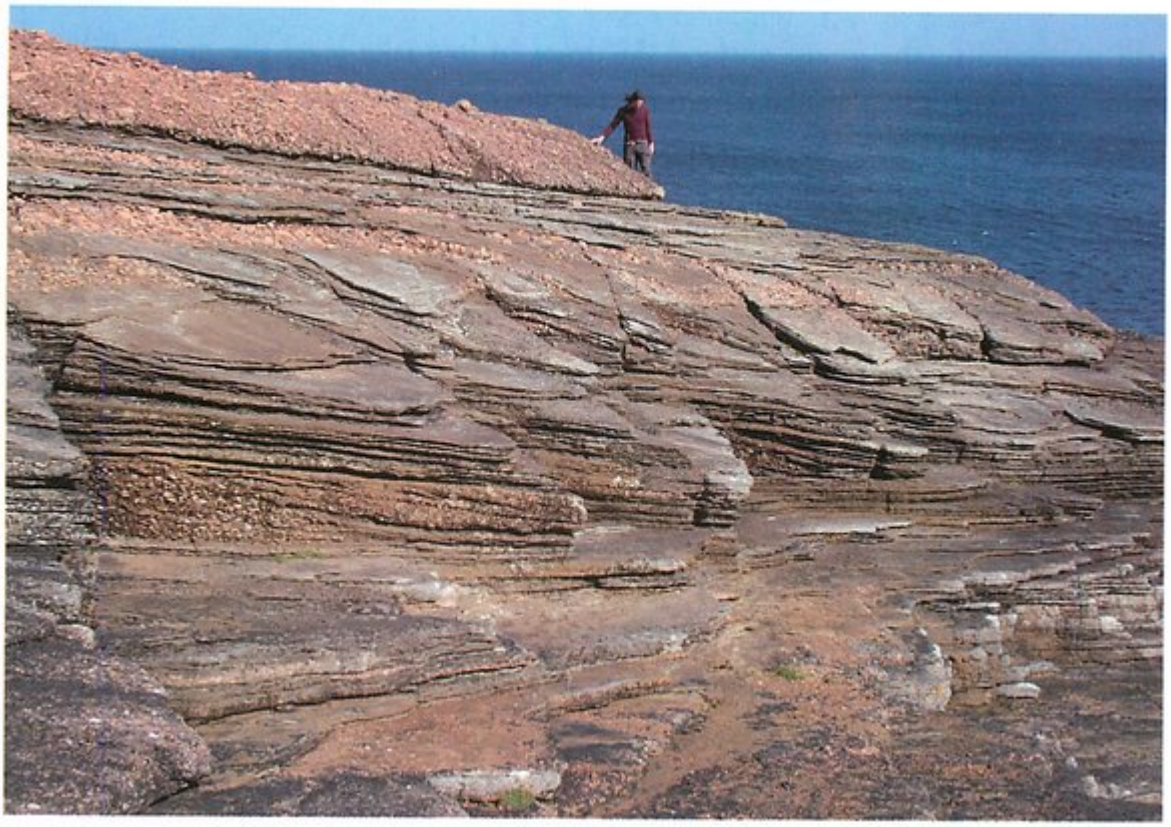


(Figure 5.29) Locality map of the Red Point area, locality 17 (Modified from Donovan 1975).

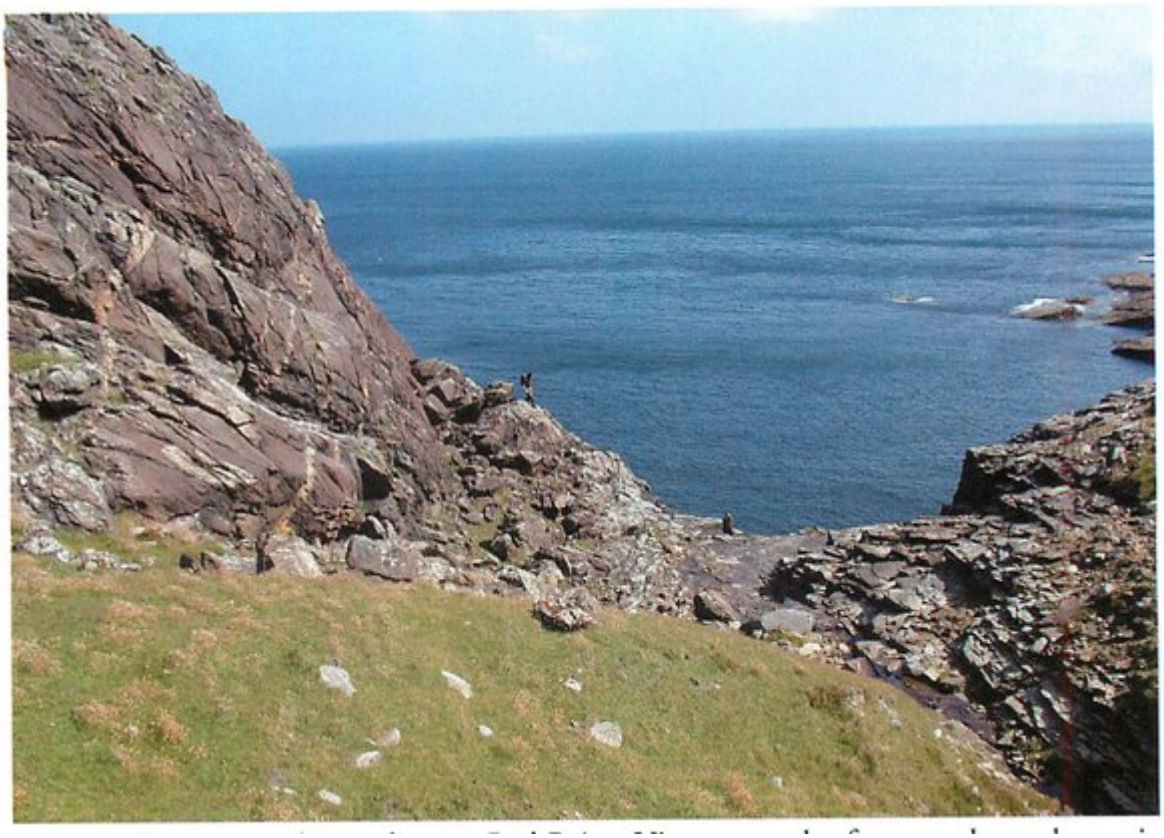


(Figure 5.30) Red Point, basement margin features. Cross sections at points 1 and 2 and along line x–x[1] as shown on (Figure 5.29) (modified from Donovan, 1975).

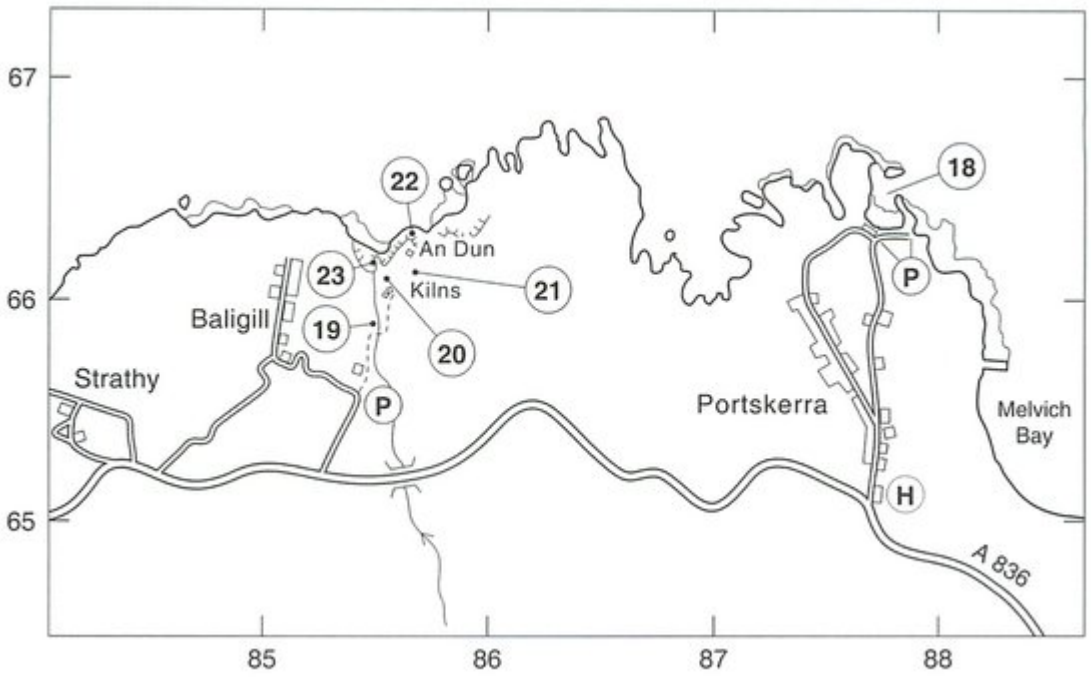
(Figure 5.31) Exposure at Point 1, Locality 17, Red Point. Steeply dipping limestone mantles the basement and is overlain by breccia.



(Figure 5.32) Exposure at Point 2, Locality 17, Red Point. Rapid lateral transition from marginal breccia downslope into lacustrine flagstones.



(Figure 5.33) Gully at Point 4, Locality 17, Red Point. View to north of steep exhumed margin of basement hill of gneiss cut by granite veins at left of gully, and lacustrine flagstones in valley floor and on right.



(Figure 5.34) Locality map for Port Skerra and Baligill, localities 18 to 23.

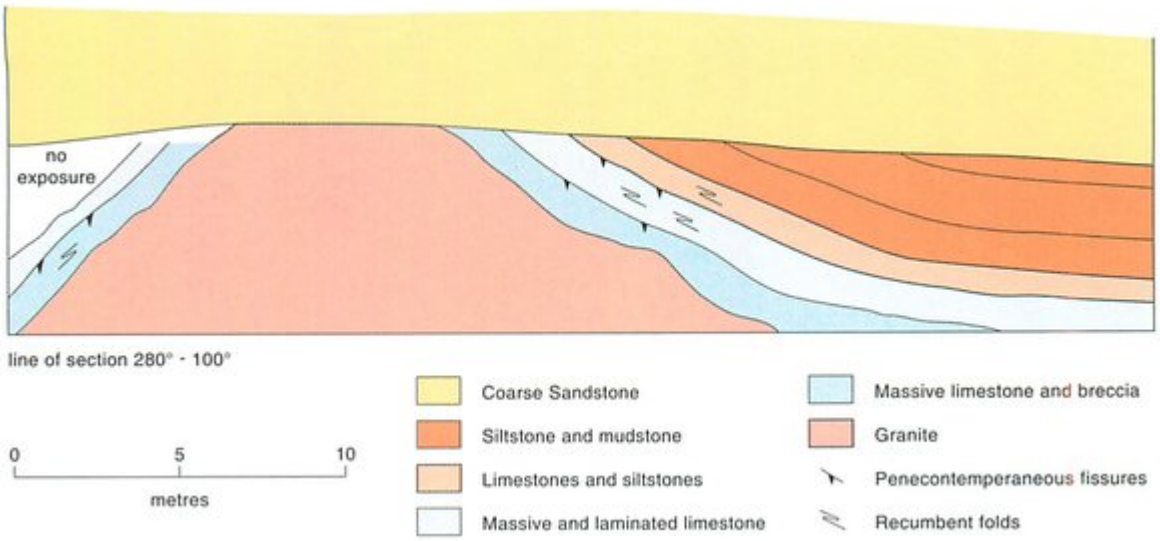
(Figure 5.35) View to the west of Portskerra Bay from the track to the slipway. Knolls of Moine gneiss are draped by Old Red Sandstone.

(Figure 5.36) Banded and folded Moine gneiss in reef at the end of the slipway, Port Skerra.

(Figure 5.37) Unconformable contact between intensely jointed Moine gneiss and locally-derived Old Red Sandstone breccia. Near end of slipway, Port Skerra.

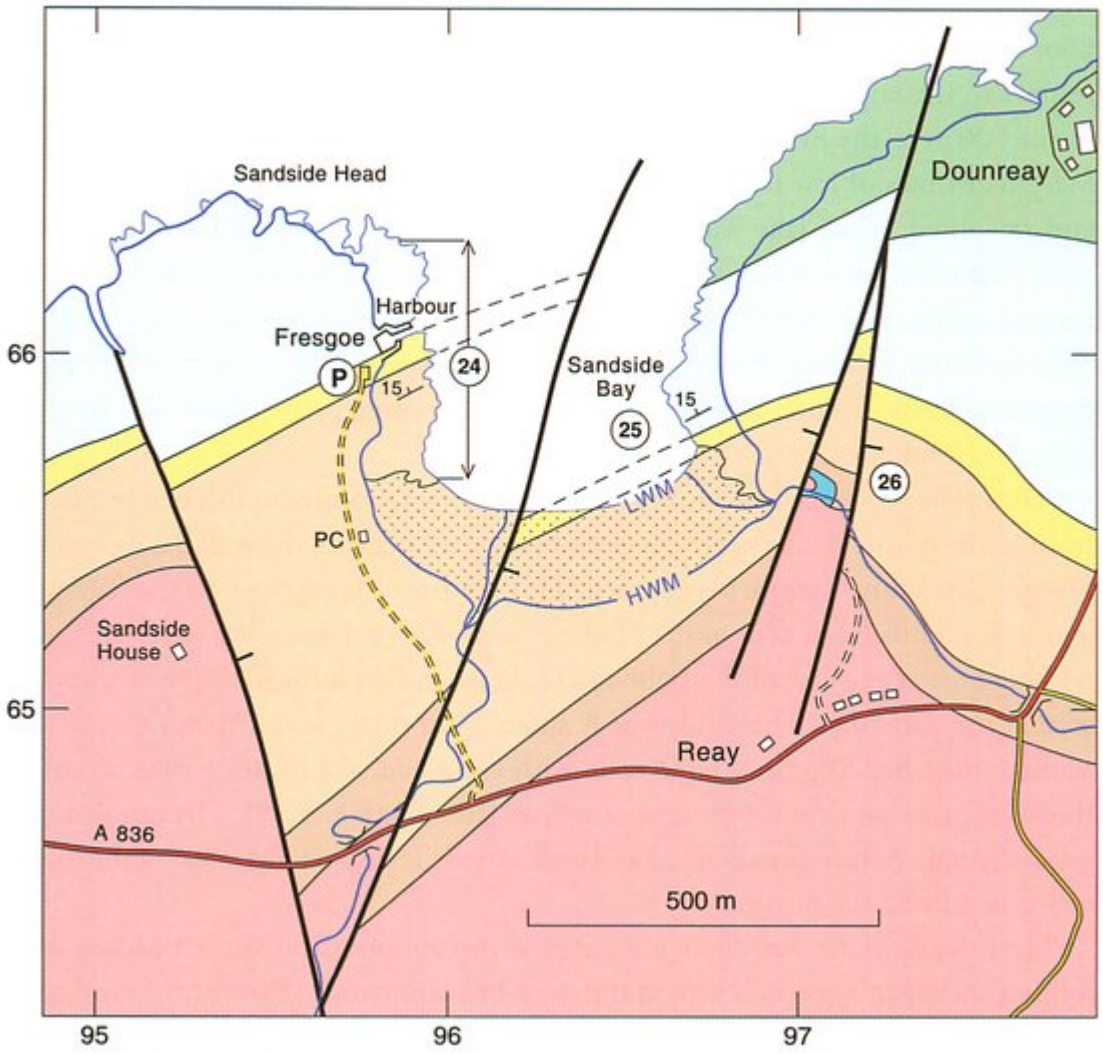
(Figure 5.38) Section at Locality 20, by the lime kilns. Shallowing-up section from lacustrine laminite at base of cliff to fluvial/ aeolian sandstones at top.

(Figure 5.39) Angular clasts of basement gneiss in limestone that drapes the gneiss surface. Locality 21, near An Dun.



(Figure 5.40) East-west section through the basement knoll at An Dun. Locality 22 (modified from Donovan, 1975).

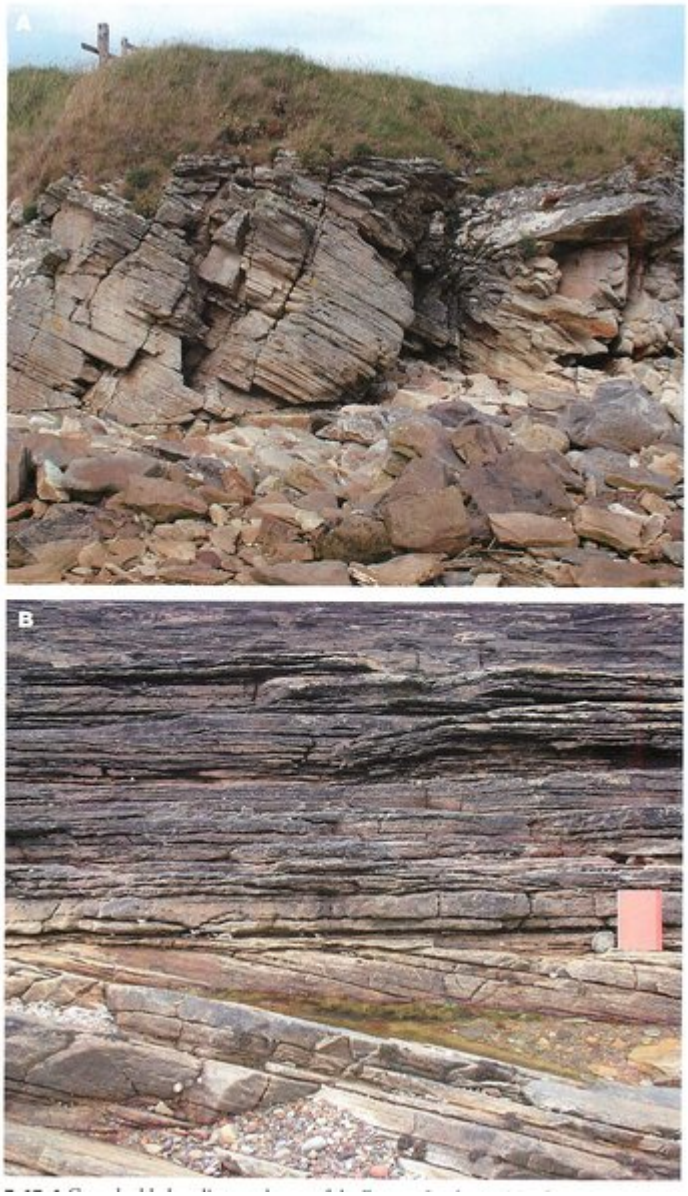
(Figure 5.41) View of the cliff face below An Dun showing outcrop of gneiss beneath grey lacustrine limestone that drapes the steep gneiss surface.



(Figure 5.42) Locality map, Sandside Bay.

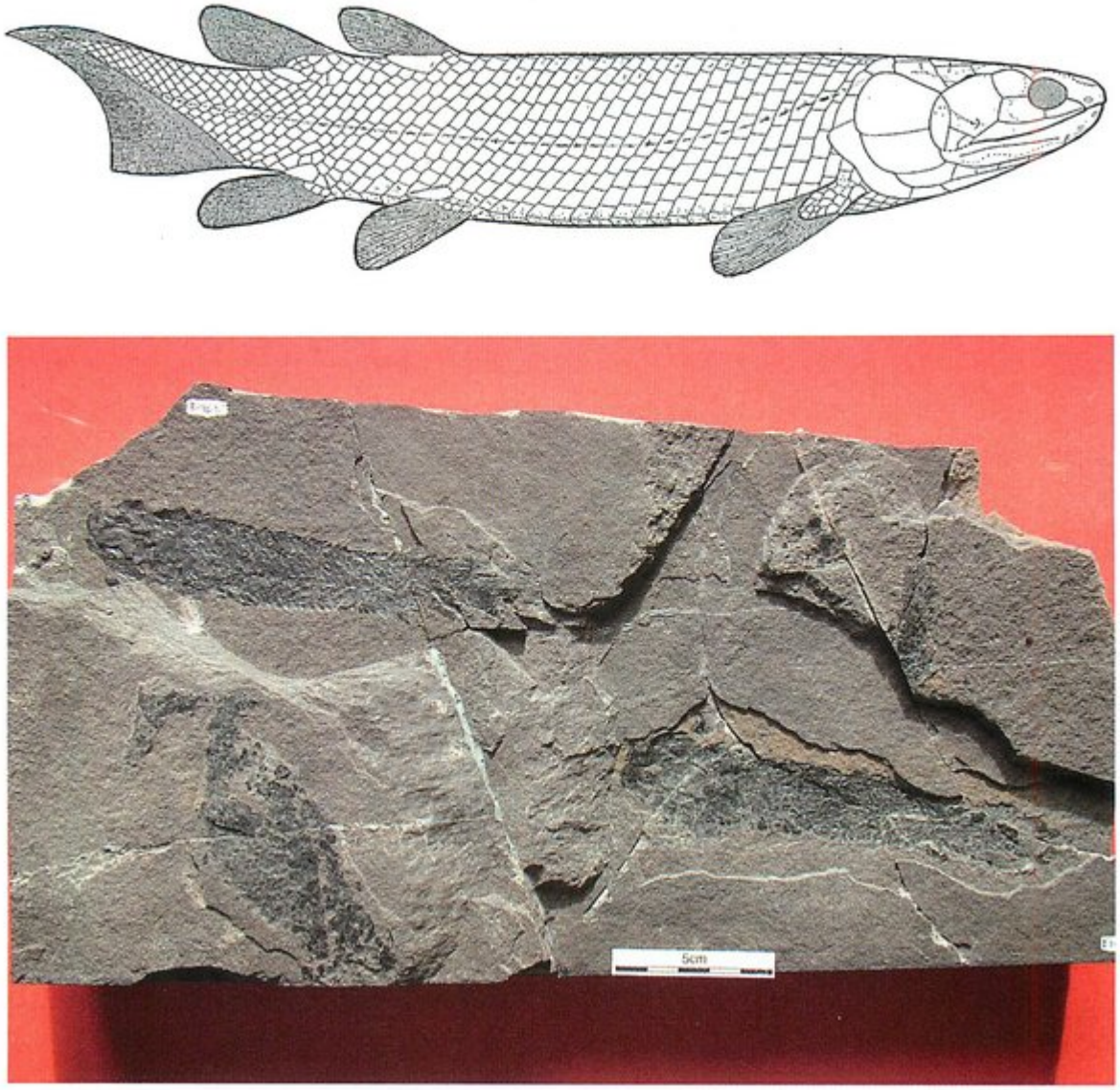
(Figure 5.43) Rippled sandstone overlying polygonal desiccation cracks. Bighouse Formation, Sandside Bay.

(Figure 5.44) Cliff exposure with bed of aeolian sandstone followed by rapid transition to laminated fish bed. Bighouse Formation, Sandside Bay.

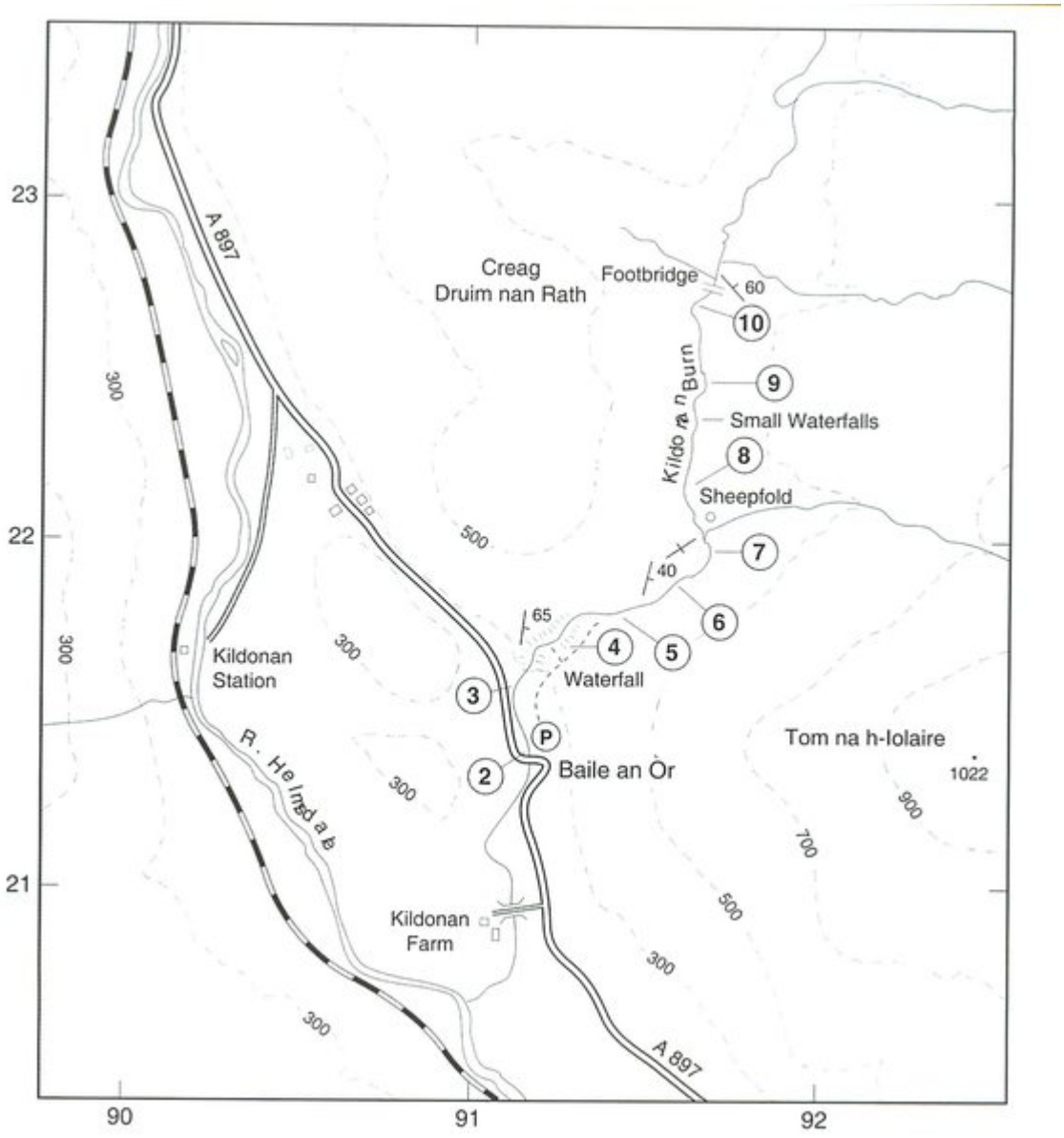


(Figure 5.45) A Cross-bedded aeolian sandstone of the Fresgoe Sandstone Member near Sandside Harbour wall. B Lacustrine flagstones overlying truncated top of the aeolian Fresgoe Sandstone. East side of Sandside Bay, Locality 25.

(Figure 5.46) Section north of Sandside harbour with sandstone beds deposited by flash floods.

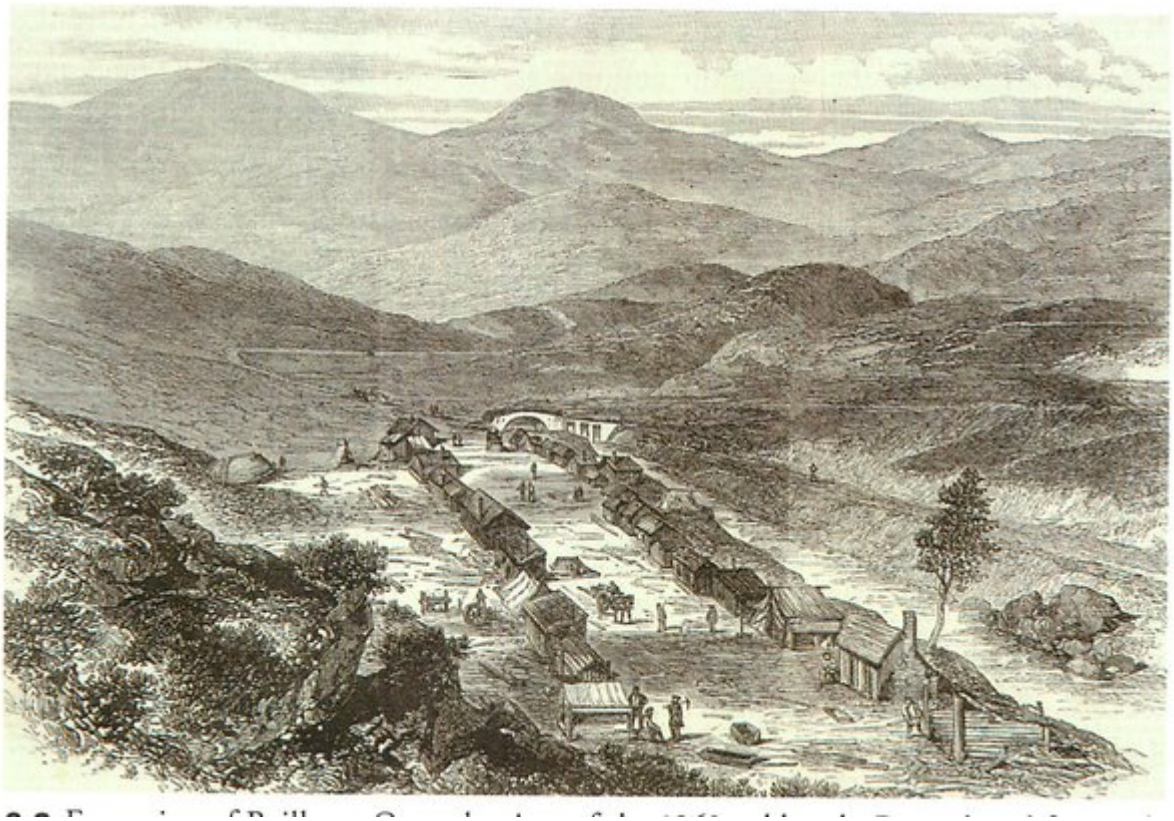


(Figure 5.47) Thursius macrolepidotus. Reconstruction (after Jarvik, 1948) and specimen from Sandside Bay.

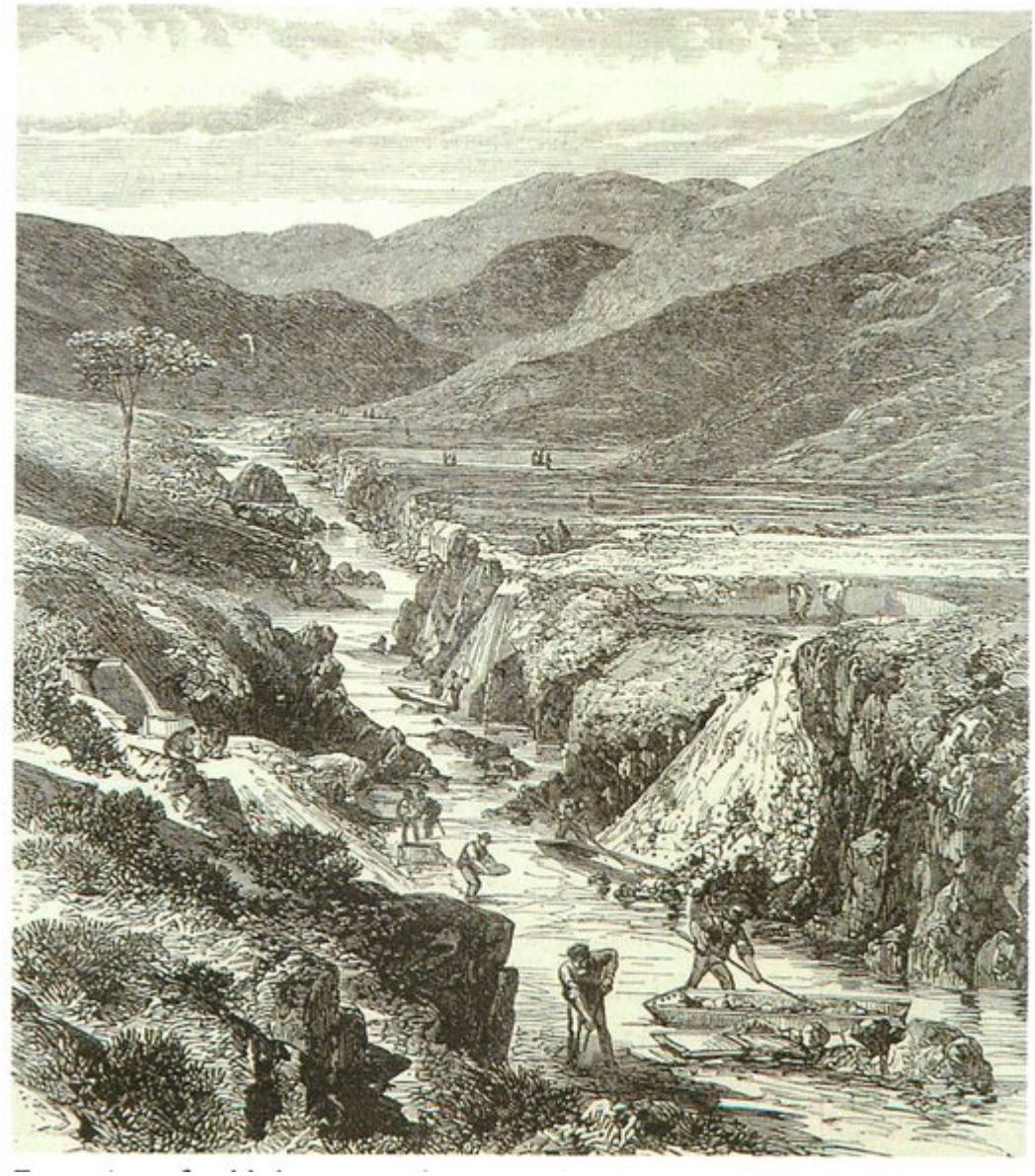


(Figure 6.1) Locality map of Kildonan Burn area.

(Figure 6.2) Typical flakes of alluvial gold up to 3 mm in size, and panned from gravel in the Kildonan Burn at Baille an Or.



(Figure 6.3) Engraving of Baille an Or at the time of the 1869 gold rush. Reproduced from The Illustrated London News, May 29, 1869.



(Figure 6.4) Engraving of gold diggers working at Kildonnan in 1869. Reproduced from The Illustrated London News, May 29, 1869.

Aberdeen Geological Society

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Second Edition

Edited by

N. H. Trewin and A. Hurst

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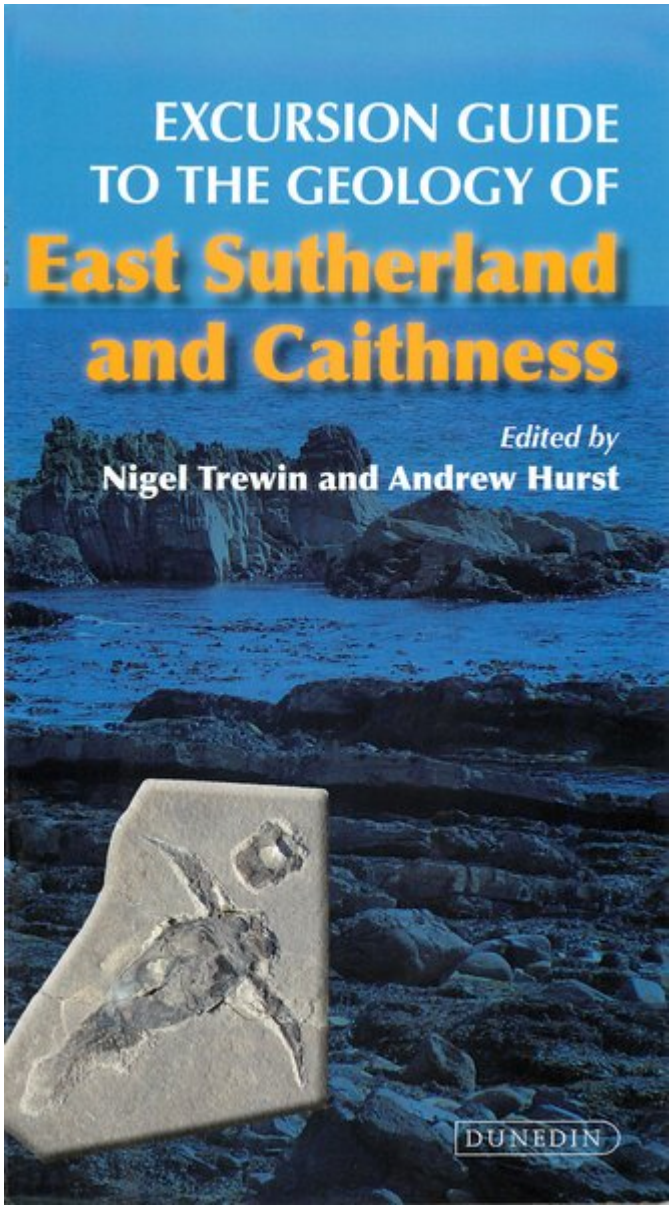
(Title page) Title page.



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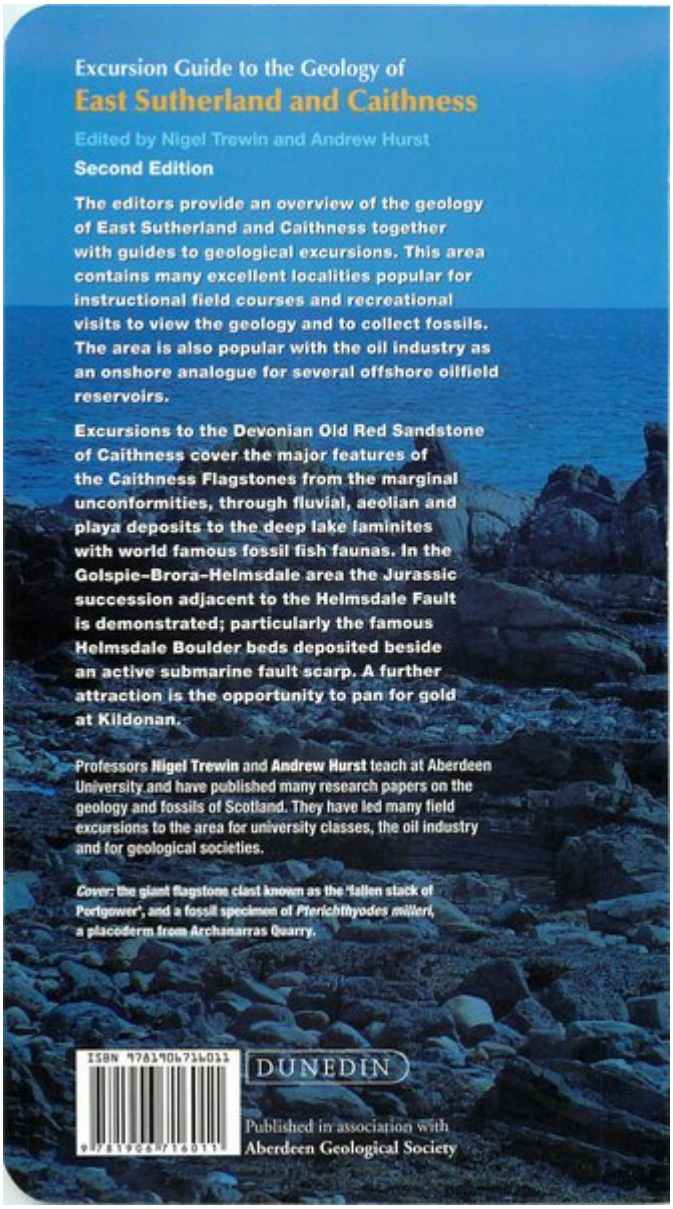

(Rear cover) Rear cover.