Excursion 5 The Old Red Sandstone of Caithness

N. H. Trewin

General purpose

Localities have been selected to illustrate the variety of features of the Old Red Sandstone (ORS) of the Caithness area of the Orcadian Basin. Each itinerary would make a suitable day excursion given favourable tides, thus the localities have been arranged geographically rather than with regard to stratigraphic order. General areas of the four itineraries are shown on the Excursion Planner map.

Major features of the itineraries are listed below.

Itinerary 5.1

Locality 1 Badbea. Basal Middle ORS breccia.

Locality 2 Berriedale. Berriedale Sandstone.

Locality 3 Achanarras Quarry. Achanarras fish bed.

Locality 4 Dirlot. Middle ORS/basement unconformity.

Locality 5 Spiral Quarry. Middle ORS Spiral Group.

Itinerary 5.2

Locality 6–8 John o' Groats area. John o' Groats Sst., Duncansby volcanic vent.

Locality 9 South Head, Wick. Middle. ORS: Lower Flagstone Group cycles.

Locality 10 Sarclet. Lower ORS Sarclet Group.

Itinerary 5.3

Locality 11 Brims Ness. Upper Flagstone Group cycles.

Locality 12 Holborn Head Quarry. Upper Flagstone Group fish bed.

Locality 13 Pennyland Shore, Thurso. Upper Flagstone Group cycles.

Locality 14–16 Dunnet Head. Upper ORS, Dunnet Sandstone and vent.

Itinerary 5.4

Locality 17 Red Point. Unconformity ORS/basement.

Locality 18 Port Skerra. Unconformity ORS/basement.

Locality 19–23 Baligill. Basin margin deposits.

Locality 24–5 Sandside Bay. Aeolian sandstone within lacustrine flagstones.

General access

The localities are generally accessible by car or minibus combined with short walks often on boulder strewn shores, cliff tops and in quarries. Care must be taken at all times, but especially in wet weather when grass on cliff edges and rocks on the shore are very slippery.

Larger vehicles should check access and turning opportunities on minor roads to the coast and to quarries, and a little more walking will be required. Permission should be obtained to cross farmland to reach localities.

Introduction

The localities chosen from the extensive exposures of Caithness illustrate the main features of the Lower, Middle and Upper ORS in the area. The stratigraphic framework has been presented in the Geological History section of this guide. Lower ORS near Helmsdale is covered in Excursion 4 and the Lower ORS at Sarclet in this excursion (Locality 10). Upper ORS is only seen at Dunnet (Lots. 14–16) where it is dominantly of fluvial origin but shows considerable aeolian influence. The main interest of the area lies in the Caithness Flagstone Groups and John o' Groats Sandstone Group of the Middle ORS. The general sedimentological features of this cyclic sequence are introduced below, but the visitor will find that in the field there is great variety within the cycles displayed at Brims Ness (Locality 11), Pennyland Shore (Locality 13), South Head, Wick (Locality 9), Sandside Bay (Locality 24) and Achanarras Quarry (Locality 3). This variety reflects variations in rate and mechanism of sediment supply, subsidence, carbonate production and water depth and its chemistry. In some parts of the sequence permanent lake conditions were predominant, in others ephemeral playa lakes were usual.

The Middle ORS Flagstone Groups of Caithness and Orkney form part of a thick (c.4 km aggregate thickness) Middle Devonian sedimentary fill of this part of the Devonian Orcadian Basin (Donovan *et al.,* 1974). In its broadest interpretation the 'Orcadian Basin' extended from the southern shores of the present Moray Firth through Caithness and Orkney to Shetland and Norway. In reality a great number of smaller sub-basins are present within the area with varying proportions of Lower, Middle, and Upper ORS in their fills. For further general details see the Geological History section of this guide and Trewin and Thirlwall (2002).

The flagstones are the deposits of a large ephemeral lake, the extent of which was controlled by climatic fluctuations (Hamilton and Trewin, 1988; Andrews, 2008). The resulting sedimentary deposits are cyclic in nature (Figure 5.1), and a range of conditions from deep to shallow lake and exposed playa surface are represented. The Associations A–D of Donovan (1980) are used in this guide (Figure 5.1) as they describe the lithologies and sedimentary structures/features seen in the field. However, this is a simplification of Donovan's scheme, and there is great deal of variation within the described Associations.

The fish beds (Association A) were deposited during the deep lake phase when water depths as great as 80 m may have been achieved (Hamilton and Trewin, 1988). The fish bed lithology is a finely laminated siltstone with clastic, carbonate and organic laminae. These deposits have been interpreted as varved sediments with an annual climatic control (Rayner, 1963; Donovan, 1980). Clastic laminae represent input from rivers in a rainy season; the carbonate laminae were deposited in the dry, warm season (summer) due to photosynthetic activity of phytoplankton in the lake, and the organic laminae represent the annual decay of the phytoplankton (autumn). Other mechanisms could have introduced clastic laminae into the lake, for example, dust storms passing over the lake (Trewin, 1991), but in general it is considered that the millimetre-scale lamination represents annual varves.

The fish found preserved in the laminites of the Achanarras fish bed (Locality 3) include shallow-water bottom-dwelling forms such as *Pterichthyodes* which clearly drifted out into the lake as dead carcasses prior to sinking into deep anoxic water where they were preserved (Figure 5.2). Since all fish appear to be affected, including carnivores such as *Coccosteus* and *Glyptolepis,* it is thought that mass-mortality events were responsible. This interpretation is supported by the occurrence of fish concentrations on specific lamination planes within the fish beds (Trewin, 1985, 1986).

Causes of mass mortalities might have been de-oxygenation events caused by algal blooms, or storms mixing anoxic water from the deep lake with the oxygenated surface waters or stirring up deoxygenated mud. Extreme water temperatures during hot weather can also cause mass mortalities of fish in rivers and lakes. Evidence from isotopic studies and carbon/sulphur ratios (Hamilton and Trewin, 1988) indicate that salinity in the lake was variable, and that salinity crises might have been the cause of mortalities. Disarticulation of fish carcasses is related to environmental energy and hence water depth.

The Achanarras fish bed at Achanarras Quarry has yielded fish of some 15 genera of which three can be considered abundant (*Dipterus, Palaeospondylus, Mesacanthus*) and two others relatively common (*Coccosteus, Pterichthyodes*). These five genera make up 85% of the population (Trewin, 1986). Other fish beds are seen at Holborn Head (Locality 12), Pennyland Shore (Locality 13), John o' Groats (Locality 6) and Sandside Bay (Locality 24). Further details of fauna are included in the Achanarras excursion (Locality 3).

Immediately above the fish bed laminites beds of silt to fine sand are present at Achanarras, the sediment being transported into the deep lake by turbidity currents derived from the basin margin. However turbidites are only associated with a few of the cycles.

The fine laminites of the fish bed grade upwards into Association B which comprises organic-rich shale and siltstone with laminae generally less than 5 mm thick. Silt laminae may be graded and were probably introduced as very weak density flows. Ripples and subaqueous shrinkage cracks are only rarely found. With increased shallowing of the lake the laminae become thicker, so that Association C comprises sand/shale couplets averaging 10 mm in thickness. The shale is generally grey, and ripples and subaqueous shrinkage cracks are common and may reflect changing salinity (Donovan and Foster, 1972).

Association D represents shallow, ephemeral lake conditions as shown by the numerous polygonal desiccation crack horizons together with ripples of very shallow water origin. The shales are generally green in colour and lack organic matter due to oxidising conditions during deposition. Within this facies, sandstones of fluvial, lacustrine delta, shoreline and aeolian origin have been recognised. Near the lake margins (e.g. Red Point (Locality 17) and Port Skerra (Locality 18)) the sediments of Associations A, B and C become interbedded with conglomerates and sandstones of fluvial and shoreline origin, and at Dirlot Castle (Locality 4) a rocky lake shore with stromatolites is preserved against an inlier of Moine metamorphics (Donovan, 1973).

An alternative interpretation of Associations B and C, based largely on the sections at South Head, Wick (Locality 9) has been given by Rogers and Astin (1991) and Astin and Rogers (1991). They consider that there is a complete gradation between the lenticular (subaqueous) sand-filled cracks and the typical polygonal cracks representing subaerial exposure. They conclude that the lenticular cracks were also of subaerial origin and that they were initiated on evaporitic gypsum crystals within the sediment surface. The sand fill of the cracks is considered to have been wind-blown over the dry playa lake floor.

Whilst there are examples of sand-filled pseudomorphs, possibly after gypsum, and even rare hopper-shaped pseudomorphs after halite, the majority of cracks do not resemble gypsum crystal shapes. I prefer (Trewin, 1992) a subaqueous origin for the majority of these cracks, since they are highly compacted (indicating highly water-charged sediment rather than dried mud). The organic matter within the sediment was not oxidised by exposure, and the micaceous fine-sand fill of the cracks is not typical of aeolian transported material. Furthermore, since the horizons with lenticular cracks are repeated hundreds of times in sequence and each extends only a few centimetres in depth, it is difficult to imagine such regular and similar desiccation events. If the Astin and Rogers model is appropriate, desiccation of the lake floor was a much more frequent event than in the Donovan model which is preferred in this guide.

Further details of the fish are contained in the guide by Saxon (1975), the leaflet 'Fossil fishes of Caithness' produced by the Caithness Fossil Group, which can be found at tourist outlets, and academic papers referenced in this guide. When visiting localities in the area please remember that most of the fish-bearing localities are designated as 'Sites of Special Scientific Interest' (SSSI). Outcrops must not be hammered and bedrock must not be disturbed. At Achanarras Quarry material is found by searching the waste tips. Parts of the tips are regularly excavated by Scottish Natural Heritage to provide material for collectors to examine. At all times follow the Scottish Fossil Code, and report any unusual finds. Two new fish genera (*Cornovichthys, Actinolepis*)and a new arthropod (*Achanarraspis*)have been described from Achanarras in the past 10 years, showing that valuable contributions to science can be made by collectors when interesting finds are reported.

Itinerary 5.1 Old Red Sandstone of Achanarras Quarry and the Unconformity at Dirlot Castle

Purpose

To examine the fauna and sedimentary features of the classic Middle ORS fish bed locality at Achanarras Quarry, and to demonstrate the Middle ORS unconformity on Moine gneisses at Dirlot Castle where stromatolite coated breccias overlie the unconformity. Roadside exposures of basal Middle ORS breccias and sandstones north of Helmsdale can be briefly examined on the journey if the party is staying at Helmsdale. Alternatively localities 1 and 2 can be added to Excursion 4 (Ousdale).

Access

From Helmsdale drive north on the A9 visiting localities 1 and 2 if desired. Proceed as far as Latheron where the A9 forks left towards Thurso (Note that on older maps the A9 is the right fork to Wick, now renumbered A99). At Mybster crossroads turn left (Figure 5.3) and after 1 km at [ND 158 528] turn right on the track beside a plantation to Achanarras Quarry (Locality 3). Vehicles should be left at the designated parking area at the end of the plantation. Follow the 'timeline' up the track past the disused croft at [ND 153 540] to the quarry. Take care to close gates on this track. The other localities are situated near roads with easy access.

Locality 1. Badbea [ND 085 205]

The base of the Middle ORS is marked by the Badbea Breccia that rests uncon-formably on the Lower ORS in the Ousdale area. Examples of the breccia can be examined in small outcrops along the signposted path to Badbea historical village from the lay-by on the A9. The road cutting 200 m to the north of the lay-by also exposes this breccia. The rock contains material ranging from sand to gravel size. Most of the material consists of angular grains of intrusive acid igneous rocks and much is interpreted as having been derived from the Helmsdale Granite. Some clasts are rounded, and these tend to be pebbles of metamorphic quartzites that have a longer transport history.

Locality 2. Berriedale Cutting [ND 095 210]

The next road cutting on the journey north is 1 km beyond the Badbea cutting shortly after the power lines cross the road. Park on the right before entering the cutting. The cutting exposes Middle ORS Berriedale Sandstones. The sandstones are generally medium-grained, red and arkosic. Laminae of coarser granitic debris are also present and the Helmsdale Granite is a probable source. The sandstones occur in beds up to 1 m thick, but are generally around 0.5 m. Very little interbedded shale is present and the beds are almost exclusively parallel laminated, the lamination being due to grain-size variations. Beds appear to have been deposited rapidly, possibly as overbank deposits from large floods or as sheetflood deposits.

Locality 3. Achanarras Quarry [ND 150 544]

Follow the instructions given above in 'access' and enter this disused quarry which is situated in an exposed position on Achanarras Hill. This quarry was opened in about 1870 as a farm quarry, and was later worked by the Thurso Flagstone Company in the first decade of the 20th century. In 1959–61 it was worked for roofing slates, and minor working took place around 1970 (MacFadyen, 1992). The fish bed was first exposed in 1891 and the fauna became well known, attracting workers such as R.H. Traquair, D.M.S. Watson, E.I. White and T.S. Westoll. The fish bed succession and lamination was first studied by Rayner (1963) who proposed that the lamination represented annual varves. The quarry was drained by means of a siphon in 1980 for a study of the sedimentology and fish distribution within the bed (Trewin, 1986).

The old quarry buildings were taken down recently for safety reasons, and remains of old bogies and rails used to push waste from the quarry to the tips were removed. There is now a shelter for visitors that was opened in 2008, together with interpretation boards illustrating the mode of preservation of the fish, and providing illustrations of the fossil fish together with reconstruction drawings. Under normal circumstances the quarry is flooded and the fish bed outcrop is mainly under water, but exposures (not to be hammered or disturbed) may be visible at the north of the quarry. The exposed quarry face consists of laminated siltstones with clastic and dolomitic laminae on a millimetre scale, which are interbedded with siltstone beds up to 45 cm thick. The main features of the succession in the quarry are summarised in (Figure 5.4). The siltstones (Figure 5.5) contain rip-up clasts of the laminites, have sharp erosive bases and graded tops. These beds are interpreted as turbidity current deposits of a deep lake phase and were derived from the NW (Hamilton and Trewin, 1985). Fish are not present, or possibly very rare, in this part of the succession, but a few drifted plant fragments are found.

The interbedded laminites of dolomicrite and quartzose silt are interpreted as seasonal varves. By counting these varves it is estimated that a turbidity current event took place on average every 70 years. At some levels bedding surfaces of the laminite above the fish bed display patterns of lenticular or arcuate cracks. In cross section minor laminar displacement is seen across the cracks. These features appear to be compacted subaqueous shrinkage cracks. The origin of these and similar cracks is discussed in the introduction to this excursion and in notes on locality 9.

The fish bed laminated siltstones are very variable in texture and composition (Figure 5.6). Individual laminae and groups of laminae are continuous throughout the quarry area, thus fish-bearing slabs can be matched to their original position in the fish bed by comparison with a collected rock section of the entire fish bed. The results of positioning over 1,000 fish are shown in (Figure 5.7), which illustrates the distribution of fish within the fish bed. Details of this study have been published elsewhere (Trewin, 1986) but the major points that influence collecting in the quarry are given here. The lungfish *Dipterus* (Figure 5.8) is common and best preserved at the base of the fish bed (Faunal Division 1) in dark, smooth, finely laminated siltstones which split easily into thin sheets. *Dipterus* is abundant on some lamination planes that represent mass mortalities of fish. A second concentration of *Dipterus* at the top of the fish bed (Faunal Division 6) occurs in coarser textured, dolomitic laminites where the fish are not so well preserved. This fish appears to have been the first to colonise the lake and the last survivor, and was probably the most tolerant of adverse conditions of oxygenation and salinity.

The central part of the fish bed (Faunal Divisions 2, 3 and 4) contains fine-grained calcareous laminites and some bundles of coarse dolomitic laminae. The greatest variety of fish occurs here, and *Palaeospondylus, Mesacanthus* and *Pterichthyodes* (Figure 5.8) are the genera most likely to be seen. *Pterichthyodes was* a bottom-dwelling fish with a ventrally situated mouth, and eyes on the dorsal surface. This fish was first described from Cromarty by Hugh Miller (1841) in *The Old Red Sandstone,* a book that inspired many people to study geology and the fossil fishes of northern Scotland. Carcasses of *Pterichthyodes* frequently disintegrated due to decay during transport and are preserved incomplete. *Mesacanthus* and *Palaeospondylus* are frequently found together, probably because they are of similar size and carcasses drifted to the same areas. The small acanthodian *Mesacanthus* may have been a shoal fish, feeding on small organisms and phytoplankton. *Palaeospondylus* is only common at Achanarras and despite much speculation there is no agreement on the relationship of this vertebrate to other Devonian forms. It has been suggested that it is a larval form, and *Dipterus* is favoured as the adult form by Thomson *et al.* (2003), but Newman and den Blaauwen (2008) provide information to the contrary. *Coccosteus* and *Osteolepis* have also been suggested as the adult form, but supporting evidence is lacking. However, the distribution *of Palaeospondylus* through the fish bed ((Figure 5.7)) does not show any obvious associations with other fish, and it is likely that this fish was a chance introduction to the lake along with the other genera, and for any clues to its origin, one must look elsewhere. The larger acanthodians, species of *Diplacanthus* and *Cheiracanthus,* and the actinopterigian *Cheirolepis* also occur in the central part of the fish bed but are scarce. They are mainly represented by full-grown specimens that probably migrated into the lake in the adult state. Scarce but large *Dipterus* also occur in this part of the fish bed. The largest predator present is *Glyptolepis,* which grew to over a metre in length and was capable of swallowing full-grown individuals of all the other species present. One *Glyptolepis* has been found, which died trying to swallow a smaller individual of its own kind, and another contained a *Coccosteus. Glyptolepis,* with a concentration of fins in the caudal region, was probably a lurking predator similar in habit to the modern pike.

One feature of the preservation in parts of the fish bed is that soft tissues are preserved as dark carbonaceous shadows. A few *Coccosteus* specimens show skin outlines over the dorsal fin, and the agnathans are similarly preserved. *Achanarella* (Newman, 2002) is abundant on at least two bedding surfaces, but *Cornovichthys* (Newman and Trewin, 2001) is only known from two specimens. Careful examination is required to spot these fish. The coarser laminites towards the top of the fish bed in Faunal Division 5 have a rough surface texture due to the micronodular nature of the dolomite present. The predatory arthrodire *Coccosteus* (Figure 5.8) is most frequent at this level.

Underlying the fish bed are flaggy siltstones with isolated ripples and moderately abundant plant debris. This part of the sequence is not likely to be visible unless the lake level in the quarry is exceptionally low and the lower bench of the quarry working is visible. These rocks were deposited in shallow water at the start of the major lake transgression which resulted in deposition of the overlying fish bed lam-Mites in deep water (Figure 5.4).

Collecting

Fish fossils are found by searching in the tips of quarry waste and carefully splitting likely blocks of the fish bed laminates. Many people visit the quarry and good specimens are rarely found by wandering about looking at surface material. Before you start searching, take time to look at the illustrations of fossils in the display at the shelter: it is easier to find something when you know what you are looking for. On finding a specimen do not attempt to trim the slab and risk a breakage; have it sawn to shape later and prepare the fish carefully with a small hammer and chisel, mechanical engraver, or air-abrasive method. Broken material can be carefully repaired and glued back together. The material is not suitable for acid preparation. Do not take duplicate material you do not need, and leave unwanted material at the shelter for others. Any exceptional finds of new or rare genera (see (Figure 5.7)) should be notified to the Royal Museum of Scotland, a local museum or University museum curator. One surprising absentee from the faunal list is *Gyroptychius,* which is common in the equivalent Sandwick fish bed in Orkney; please report any finds of this fish, or other unusual specimens.

Locality 4. Dirlot [ND 131 490]

From Achanarras quarry return to the B870 and turn right to Westerdale. Cross the River Thurso at Westerdale and continue straight along the minor road. After a mile take the track to the left through the abandoned sand and gravel quarry. Continue a further hundred metres past Dirlot and park off the road at a small overgrown sand quarry (Figure 5.9). Walk across the field towards a ruin on the far side of the Thurso River and find the small pumphouse at [ND 131 490]. The Thurso River is a famous salmon fishing river and parties should give priority to fishermen at this locality.

Immediately downstream of the pumphouse there are exposures of breccias which rest on a small inlier of Moine schists (Figure 5.9). Upstream, gently dipping flagstones of the Middle ORS form the side of the gorge. The breccias which overlie the unconformity contain clasts from pebble to boulder size, some of which are coated with algal stromatolite (Donovan, 1973). The stromatolite coatings vary from thin (1–10 mm) rusty brown ferroan dolomicrite coats on smaller clasts, with larger clasts coatings up to 10 cm thick which show laterally linked hemispheroids 5–15 mm in diameter of algal or cyanobacterial origin (Figure 5.10). Flakes of stromatolite material also occur in the matrix of the breccia. Towards the top of the exposed breccia a sandy matrix is present and the clasts are not coated by stromatolite.

Upstream from the pumphouse the river generally follows the strike of the ORS flagstones, which here consist of fine-grained sandstones in beds generally less than 20 cm thick, interbedded with laminated shale and siltstone. Subaqueous shrinkage cracks are common and polygonal desiccation cracks are also present. The sandstones display parallel and ripple lamination and some loading features. These deposits formed in a shallow lake phase (see Introduction).

Unless the river is very low it is not possible to follow the bank of the river through the gorge, and it is easiest to walk along the gorge top and round the back of the old churchyard and St Columba's Chapel and descend to the river pool (The Devil's Pool) at Dirlot Castle [ND 125 485] (Figure 5.11). The castle rock and outcrops beneath the churchyard wall are of Moine metamorphic rocks. Semi-pelites with gneissose banding defined by micas are prominent and quartz segregation veins are present. The foliation dip is generally steep, but a few folds with sub-horizontal axes are present.

Ptygmatic folding is seen in quartz veins within the folds. Veins of aplite have intruded the gneisses and cut the foliation.

Immediately downstream of the churchyard wall over the deep pool the unconformity suface can be seen about two-thirds of the way up the face of the gorge. The surface is sub-horizontal and is overlain by about 0.6 m of conglomeratic sandstone with both angular and rounded pebbles. Sandstones with low-angle cross-bedding overlie the conglomerate.

Donovan (1973) described a network of tufa-coated fissures up to 2 m deep in the Moine schists beneath the unconformity surface. Return via the cliff top and scramble down to the riverside at the downstream end of the cliff beside the tail of the pool. The unconformity surface dips more steeply eastwards and a coarse breccia is present, apparently banked against the sloping unconformity surface. Stromatolite coatings are again present on pebbles and boulders in this breccia.

The general environment of the tufa-coated fissures and stromatolite-coated breccias is consistent with an origin as beach or scree deposits fringing a lacustrine shore. The small inliers of Moine at Dirlot were small islands within the lake area. Stromatolite coatings formed in shallow lake waters subject to seasonal changes in water level, salinity, carbonate content and temperature; coatings are thickest on the largest, most stable clasts, which were not moved by wave action on the shoreline. Wave action and/or desiccation was probably responsible for breaking coatings from local surfaces to provide the stromatolite flakes present in the breccia matrix.

Donovan (1973) discussed the origin of the tufa-lined fissures in the Moine and considered that the laminated tufas might have been deposited by umbrophile algae. However, the sparite cements are more likely to have been inorganic in origin, formed as beachrock cement from wave splash, capillary action or the interaction of local fresh, weakly acidic groundwater with the warmer, more saline lake waters. Grey sandstones with low angle cross-bedding overlie the breccias which Donovan (1973) associated with the invasion of the lake area by fluvial conditions from the west.

Locality 5. Spital Quarry [ND 171 541]

Return to Mybster Crossroads and turn left to Spital (Figure 5.3). After 1 km turn right off the A895 in Spital at the bend near a telephone box and drive into the quarry of A. & D. Sutherland Ltd. The quarry is in Spital Group flagstones of the Middle ORS, which lie stratigraphically above the Achanarras fish bed. The quarry is worked for roadstone, bulk aggregates and flagstones which are prepared at the quarry. Permission to visit should be obtained from the quarry office.

Lithologies are mainly laminated dolomitic siltstone. Lamination is on a millimetre to centimetre scale and is extremely regular. The surfaces of flagstones show excellent examples of subaqueous shrinkage cracks and small (1–4 mm) bumps which are due to micronodular dolomite. Fossils are very scarce at this locality, but *Dipterus, Dickosteus thrieplandi* and *Trewinia magnifica* (Janvier and Newman, 2005) have been recorded.

Itinerary 5.2 Old Red Sandstone of John o' Groats, Wick and Sarclet

John o' Groats

Purpose

To examine the John o' Groats Sandstone Group at the top of the Middle ORS succession, and see the volcanic vent at Duncansby Ness.

Access

The localities (Figure 5.12) can all be visited on foot (8 km walk) from the car and coach park at the end of A99 at John o' Groats, or the excursion can be split in two and transport (car or coach) taken to the parking area at Duncansby Head via the turning off the A99 opposite John o' Groats post office. Binoculars for geology (and the birds) are useful at

Duncansby Head. Low tide is required for the John o' Groats foreshore.

Locality 6. John o' Groats [ND 380 735]

Park in the tourist car park, walk past the 'Last House' and examine the rocks immediately east of the harbour. Red sandstones dominate in beds up to 50 cm thick that display trough and planar cross-bedding, parallel lamination with primary current lineation and ripple lamination. Soft-sediment deformation features caused by water escape are frequent. These rocks are of fluvial origin and formed on a low angle, broad alluvial fan characterised by shallow channels. Further details of these rocks and comparisons with the equivalent Eday Group in Orkney are found in Astin (1985).

Periodically the alluvial fan was transgressed by lake waters, and lacustrine sediments were deposited. Some 100 m east of the harbour green to grey thin-bedded sediments represent ephemeral lake conditions and display numerous polygonal desiccation cracks, beds with wave and current ripples, and lenticular cracks of subaqueous origin (Figure 5.13). Thin developments of dark grey laminated siltstone with pale concretionary carbonate record periods of permanent, deeper lacustrine conditions, and several of these units contain fish remains, usually as scattered fragments. One bed is the John o' Groats fish bed that has yielded *Tristichopterus alatus, Pentlandia macroptera, Microbrachius dicki* and *Watsonosteus fletti,* a fauna also typical of the Eday Group of Orkney. The fish beds are truncated by a fault and are only visible low on the shore.

Continue along the shore, noting the variety of sedimentary structures in the red fluvial sandstones and grey-green lacustrine strata. Approximately 200 m west from the concrete breakwater a lacustrine unit also contains laminites in which fish scales may be seen.

Locality 7. Ness of Duncansby [ND 390 739]

Continue along the shore to the western side of the Ness of Duncansby (Figure 5.12) where a small vent is exposed on the shore; the vent rocks form irregular black reefs near high tide mark. The vent agglomerate includes numerous baked sandstone fragments, but there is little evidence of alteration of the surrounding sandstones. Proceed around the Ness, noting another intercalation of grey-green strata of lacus-trine origin in the red fluvial sandstones, and locate exposures of the larger vent. Here, the vent material is a nepheline basalt tuff (Figure 5.14) which contains crystals of augite and biotite together with fine-grained ultrabasic rocks which might be bombs. Country-rock clasts are dominantly sandstone but also include granites and metamorphic rocks brought up the vent from underlying basement. Dykes and intrusions of nepheline-basalt cut the agglomerate. A K–Ar date of 255 Ma on the nepheline-basalt supports a Permian age for the vent. It is not known if the two exposure areas of vent rocks represent a single vent or two discrete vents.

From here one can return to John o' Groats or continue into Bay of Sannick [ND 397 735] to examine the sandstones on the eastern limb of the gentle syncline that forms the Ness. At Bay of Sannick dip increases to 40° from the usual 10–20°, and in the bay, at low tide, a lacustrine unit with dark grey laminites can be seen, which is possibly the equivalent of the John o' Groats fish bed. If continuing the excursion on foot, walk to the car park by the lighthouse on Duncansby Head; alternatively return to John o' Groats and drive to the lighthouse.

Locality 8. Duncansby Head [ND 405 735]

From the lighthouse car park take the path towards Duncansby Stacks. The cliffs of Duncansby Head are formed of the Mey Subgroup which is faulted against the John o' Groats Sandstone Group. Walk round the ends of the geos (narrow inlets in cliff) and observe the generally thin-bedded nature of the Mey Subgroup and their grey-green colouration. Numerous seabirds nest on the ledges, providing whitewash and a characteristic aroma in spring and summer. Beyond The Knee' a path leads to the beach from a metal gate in the fence [ND 403 727]. The path utilises a gully eroded along the fault separating the Mey Subgroup from the John o' Groats Sandstone (Figure 5.15). On the foreshore at the foot of the gully (low tide required) the fractured rocks of the fault zone can be observed. Most geos are eroded along faults or shatter zones in the rocks that form weaknesses exploited by the erosive power of the sea.

Here, the John o' Groats Sandstone (Figure 5.16) lacks lacustrine intervals, and high-energy fluvial deposits with trough and planar cross-beds and low angle planar bedding with primary current lineation are seen. Rip-up mud clasts are frequent in channel bases, and beds up to 1 m thick wedge out laterally within 10 m. A broad cyclicity is seen at the southern end of the bay with cross-bedded sandstones on a sharp erosive base grading up into thinner-bedded parallel and ripple laminated sandstones. If the tide is low it is possible to clamber to Thirle Door, through which there is a good view of the Duncansby Stacks, and also of cycles in the sandstones of the main cliff.

Return to the path out of the bay and walk south along the cliff top for views of the Duncansby Stacks. Lateral variation in the bedding of the sandstones of the stacks can be observed with binoculars. Beds are generally laterally continuous and seldom greater than 1 m thick, possibly indicative of rapid lateral migration of small shallow river channels on the alluvial fan surface.

South Head, Wick

Purpose

Examination of cycles of the Lybster Subgroup of the Lower Flagstone Group. Sedimentary structures are well displayed in the walls of disused coastal quarries.

Access

Follow signs to the Castle of Old Wick from the A99 about 600 m south of the bridge over the Wick River in the centre of Wick. Pass the coastguard station and follow the coastal road to the parking area at the end of the road.

Locality 9. South Head, Wick [ND 373 492]

The cliff has been extensively quarried and the old quarry faces show good detail of the sedimentary structures of the flagstones. Several cycles, typical of the Lybster Subgroup, are exposed between the parking area and the coastguard station. The sloping quarry floors are very slippery when wet and care is required. The flagstone cycles here are dominated by the C Association of Donovan (1980) with thinner sequences of Associations A, B and D (Figure 1).

In the quarry below the parking area (Figure 5.17) the cyclicity is picked out well by colour changes. The quarry floor marks the top of a development of D, which is pale grey to green with whitish sandstone beds. This passes up into dolomitic, orange-weathering C Association, seen at the base of the quarry face. The grey central part of the quarry face is also C, and water was deepest during deposition of this part of this cycle, but there are no fish bed laminites present. The succession then passes back into orange dolomitic strata and a pale band of D forms the top of the face. Near the entrance to the quarry there are good weathered exposures, below the main quarry floor level where ripples, polygonal desiccation cracks, and loading features can be seen in D. Above the quarry floor are exposures of laminated mudstone and fine sandstone with extensive development of subaqueous shrinkage cracks which are strongly compacted (Figure 5.18). Brown-weathering dolostone beds up to a few centimetres thick show pull-apart features, and also repetition by low angle thrusts (Figure 5.18). The dolostones were lithified early in diagenesis and behaved as competent layers, whilst the shales deformed plastically.

The grey, central part of the quarry face shows an excellent section in 'C' Association flagstones with hundreds of mudstone-fine sandstone couplets on a centimetre scale. The base of each sandstone bed is sharp, and sandstone fills underlying lenticular cracks which have been strongly deformed during compaction (Figure 5.18). The tops of the sandstone beds may be sharp or grade rapidly to mudstone. The sandstone laminae are micaceous and contain pyrite; the dark colour of the mudstone is due to the preservation of organic matter. The origin of the lenticular sand-filled cracks was assigned to subaqueous shrinkage of the mud due to salinity changes (Donovan and Foster, 1972), and rare examples of hopper-shaped crystal pseudomorphs after halite are present indicating that brines were present. Rogers and Astin (1991), and Astin and Rogers (1991) argued that the cracks were subaerial in origin and were filled by wind-blown sand. However, the grain-size, sorting, mineral composition and ripple style support deposition in water. The author concurs with Donovan (1980) and favours a subaqueous origin for the great majority of the lenticular cracks (Trewin, 1992). Futhermore the rocks in question were formed during what is interpreted as the deepest water part of this cycle. In the next quarry to the north at Trinkie swimming pool, a fish-bed laminite (A Association) is exposed in the cliff. The laminite is carbonate-rich, and only rare fish scales have been seen. The laminite grades above and below into thin developments of B Association laminites with a few subaqueous shrinkage cracks. Veins of carbonate and hydrocarbon cut the organic-rich laminites. The transition from D Association of the Trinkie quarry floor to the deep lacustrine laminites takes place very rapidly, showing that there was little sedimentation during lake transgression. A much greater thickness was deposited during the regressive phase of sedimentation as material was eroded from the lake margins and transported towards the lake depocentre.

Proceed north from Trinkie, and in the next quarried area examples of the C and D Associations of Donovan (1980) can be seen with wave ripple-marked surfaces and polygonal desiccation cracks. At this locality, cross-sections of sand-filled cracks which resemble gypsum pseudomorphs can be seen, but many cracks have no resemblance to such pseudomorphs. A great variety of lenticular, polygonal and mixed pattern cracks can be seen at this locality. Horizons already bearing lenticular cracks appear to have been exposed, either causing the lenticular cracks to control polygonal patterns, or to have large desiccation polygons superimposed on the lenticular crack systems.

Sarclet

Purpose

To examine the Sarclet Group of the Lower Old Red Sandstone and structural deformation features.

Access

Turn off the A99 in Thrumster at the signpost to Sarclet, and drive to the end of the road, taking a left fork on the way. At the end of the road there is parking room for a few cars on grass, and a small bus could be turned, traffic permitting. Do not block access to the new houses.

Locality 10. Sarclet [ND 351 433]

From the car park area a rocky cliff top can be seen some 500 m to the north, and cliff top exposures of the Sarclet Sandstone Formation can be examined from the north side of the harbour to this point. The sandstones are fully quartz cemented and extensively fractured, possibly due to the proximity of the convergence of the Helmsdale, Great Glen and Wick fault systems immediately offshore at this point. The sandstones are medium-grained and cross-bedding and parallel lamination are present in generally parallel-sided beds up to 50 cm thick.

Several directions of fracturing are present, and the directions vary locally in the Sarclet area. Fracture zones are associated with folds, one prominent syncline plunging to 020°. Other structural features are related to low-angle dislocations overlain by folded and truncated strata. A good example (Figure 5.19) is exposed in the cliff face below the clifftop exposure visible from the car park. A sheet of disrupted strata rests on an undulating sub-horizontal slide plane which is roughly parallel to the underlying bedding. The cliffs are accessible with care at this point and the dislocation plane can be examined. The rocks below are normally bedded and relatively undisturbed, but those above are highly fractured and have numerous quartz veins a few millimetres wide. The rocks were certainly well cemented when the structure developed.

To the north of this locality a fault terminates the exposure of Sarclet Sandstone, and the Riera Geo Mudstone Formation occurs to the north in vertical cliffs which are crowded with nesting seabirds in spring and summer.

Return to the harbour and follow the track down into the bay. The quarried cliff on the north side has hard, parallel-bedded sandstone with internal structures which include wispy lamination defined by thin irregular mud laminae which resemble adhesion ripples, and also sorted laminae of coarse rounded sand grains with grain-size variation on a laminar scale. Deposition was probably affected by aeolian processes.

Viewed from the south side of the bay, large-scale low-angle dislocations are apparent in the cliffs at the seaward end of the north side of the bay. Proceed carefully up a cliff path out of the bay on the south side and walk south along the cliff top. Exposures here show the downward transition to the Sarclet Conglomerate Formation. The Formation comprises alternating conglomerate and pebbly sandstone units. The clasts are up to 30 cm diameter and are composed of granite, schist, quartzite and notably basalt and andesite, indicative of a nearby area of possibly contemporaneous volcanism. The conglomerates are in general poorly sorted, and the clasts mainly subrounded. Deposition was probably by braided streams in an alluvial fan environment. The rocks are extensively fractured, with fractures being more closely spaced in the thinner-bedded units. Return to the starting point along the cliff top path.

Itinerary 5.3 Old Red Sandstone of Brims Ness to Dunnet Head

Brims Ness

Purpose

To examine the cycles of the Upper Flagstone Group of the Middle ORS.

Access

Turn off the A836 three miles west of Thurso at [ND 057 695] beside a bungalow and follow the single track road (no turning place for bus) towards the large farm building beside the ruined Brims Castle above Port of Brims. Drive through the farmyard, go through a gate to the right to the cliff-top parking area. The section can be examined starting in the small bay in front of the parking area, and heading west along the coast.

Locality 11. Brims Ness [ND 040 715]

The lithologies present are typical of the Upper Flagstone Group. On BGS Sheet 115E the strata at Brims Ness are mapped as Latheron Sub-Group. Recent revision of the stratigraphic nomenclature and fish faunas to the west of the Bridge of Forss Fault (BGS Dounreay sheet (2005) and Newman and den Blaauwen (2007) place these strata in the Crosskirk Bay Formation. The presence of *Dickosteus* indicates that they can be correlated with the Spital Flagstone Formation to the east of the fault (see (Figure 4) in Introduction). The succession comprises cycles averaging 6.5 m in thickness. Donovan (1980) recognised 14 cycles of which 8 contain carbonate laminite (fish bed') members, but not all of those contain fish. The cycles represent episodes of lake transgression and regression. In the terminology of Donovan (see (Figure 5.1)), DCABCD sequences represent major transgression–regression episodes and DCBCB and DCD sequences less severe transgression and regression. This section was analysed by Hamilton (1986) who by using frequency analysis, and assuming a rate of deposition of 0.28 mm/yr from average varve thickness, produced two prominent peaks corresponding to periods of 22.5 and 88 Kyr. It is implied that climatic cycling associated with Milankovich periodicities was responsible for lake transgression and regression.

On the shore in the bay below the ruined building, flagstones have typical lenticular cracks, here associated with high concentrations of pyrite. Sulphate values in the lake were variable, probably caused by periodic evaporitic concentration of salts (Hamilton and Trewin, 1988). The cliffs on the west side of the inlet show a transition to 'D' facies with numerous wave-rippled sandstone surfaces.

Proceed towards the point and examine the numerous blocks of carbonate laminite which occur at the top of the beach. The rock weathers pale grey but it is dark grey on fresh surfaces. The lamination represents alteration of carbonate (calcite and dolomite) and organic laminae. Microstylolites have developed along some organic laminae and the rock is exceptionally hard and difficult to split. Lenticular chert nodules up to 1 cm thick occur in some fish beds and larger vertically oriented nodules, similar to those described by Parnell (1986) from Orkney, are also present. Fish are present including *Dickosteus thrieplandi, Gyroptychius milleri, Mesacanthus, Diplacanthus, Homosteus* and the dipnoan *Pinnalongus saxoni* for which this is the type locality (Newman and den Blaauwen, 2007, and see Locality 24 below). The scales are bituminised and tend to part from the matrix when exposed. Disruption features in the laminites include bedding parallel, soft-sediment deformation features and later conjugate folds and fractures; the latter frequently containing calcite and black hydrocarbon residues (Figure 5.20). These residues are the remnants of oil formed

Continue past the cemetery wall to the start of sea cliffs. Here, the dip flattens into a small faulted syncline flanked by an anticline with the axis trending N–S. The crest of the anticline is faulted and fractured in the upper part of the beach, and the steeply dipping strata form a ridge on the beach; on the lower shore this structure grades into an unfaulted northward-plunging anticline.

Return to Brims Castle and examine the exposures in Brims Harbour. The NNE–SSW Bridge of Forss Fault passes through the harbour and the rocks are extensively shattered over a wide zone by numerous minor faults. Further from the fault, granulation seams are common in the sandstone and nodular cements of dolomite are present. The strata east of the fault are similar to those of the Thurso shore (Locality 13), and a fish bed exposed 250 m east of the fault contains *Millerosteus minor,* confirming the general correlation.

Holborn Head Quarry

Purpose

To observe features of the sand-poor Upper Flagstone Group lacustrine facies and an associated fish bed rich in *Osteolepis panderi.* This fish bed forms a marker band within the Upper Flagstone Group, and has also been found at Lythmore, Skinnet, and in Cairnfield Quarry (Weydale). This fish bed lies at the top of the Latheron/ Spital 'subgroups', and thus modifications to the existing geological maps (BGS sheets 116W and 115E) are required and are in progress using new information on the fish faunas. This illustrates the difficulty in mapping the Caithness flagstones in the poorly exposed interior of Caithness.

Access

From the A836/A9 junction at the western side of Thurso take the A9 to Scrabster. After about 1 km, before reaching the harbour, turn left on the Scrabster Housing access road. Follow the road round to the right and turn left into St Clair Avenue. Park at Scrabster Hall (green building) at the end of the metalled road by the football field. It is a brisk 20 minute walk up the track to the quarry, which is situated on the cliff edge. The track has a left fork just before the quarry, but keep straight on to enter the quarry. Note that this is a cliff-top quarry, and much of the waste was pushed over the cliff edge into the sea. The cliff edge is dangerous and should be avoided; the cliff is vertical to overhanging with a drop of about 100m to the sea. The quarry had been abandoned for many years but working has been resumed on a small scale.

Locality 12. Holburn Head Quarry [ND 080 710]

The floor of the quarry is a bedding surface which dips gently seaward towards the cliff top.

The fish bed lies below the main quarry floor but is exposed in one area near the quarry entrance where numerous fish fragments can be found. The fish bed is a carbonate/organic laminite in which the carbonate is a micritic mix of ferroan dolomite and calcite with a micronodular texture. Bundles of dolomitic laminae occur and are the host laminae for abundant *Osteolepis panderi* (Figure 5.21) which died in mass mortalities (Hamilton and Trewin, 1994). The fish carcasses have variable states of disarticulation, with the most highly disarticulated material occurring in the silty upper and lower parts of the bed and the better articulated material in the central, carbonate-rich, part of the bed. The degree of disarticulation increases with increase in depositional energy of the environment, which in turn reflects water depth. Apart from the abundant *Osteolepis panderi,* other fish recorded from this fish bed (various localities) are *Thursius, Mesacanthus peachi, Dipterus valenciennesi, Homosteus* and *Cheiracanthus.*

The strata overlying the fish bed in the quarry comprise 5 m of thin-bedded, dominantly grey-weathering flagstones of lacustrine origin which are laminated on a millimetre scale with micronodular calcareous laminae and silt to fine sand laminae. A few beds of fine sandstone up to 5 cm thick with ripple lamination are present. These are slightly lenticular and erode up to 1 cm into the underlying laminae. The most abundant structures are lenticular sand-filled shrinkage cracks (Figure 5.22). In the tip material nicely weathered examples of a variety of forms of shrinkage cracks can be found, and there are also examples of small sand-filled crystal pseudomorphs (possibly after gypsum).

Pennyland Shore, Thurso

Purpose

To examine typical cycles of the Mey Subgroup of the Upper Caithness Flagstone Group. This section shows a higher proportion of sandstone and more evidence of subaerial exposure than at Brims Ness. Stratigraphically this section lies in the *Millerosteus* fish zone and is younger than the section at Brims Ness (Figure 5 in Introduction).

Access

The section is exposed on the shore and in cliffs to the west of Thurso beach, and adjacent to the Camping Site. Cars can be parked on the road beside the beach, but coaches are advised to stop near Thurso Caravan Site, from where the party can follow the cliff-top path and steps to the sandy beach. The eastern part of the section requires low tide. There are several access paths to the section, but take care not to be cut off on a rising tide. The rocks on the wave-cut platform are very slippery when wet.

Locality 13. Pennyland Shore, Thurso [ND 114 687] to [ND 108 692]

The Mey Subgroup cycles exposed in this section show a dominance of Association D of Donovan (1980) when compared with those at Brims Ness. The succession is sandier and has less carbonate. The fish beds have fine lamination restricted to the central parts of the beds and fish (*Millerosteus minor*)are generally disarticulated. Fluctuations in lake depth are represented by rapid transitions from Association A (fish beds) to D. (exposed playa lake), with only weak development of Associations B and C.

At the eastern end of the section, immediately west of the concreted sea defences, thin-bedded grey-green strata of cemented fine sandstone and green shale display excellent examples of both polygonal and lenticular cracks. Both wave and current ripples are present and sandstone beds frequently have internal loading features which form 'pseudonodule' beds. Small-scale trough cross-bedding with sets to 10 cm is also present. The environment was one of frequent exposure with sand transported by currents in ripple sheets, and intermittent shallow water cover in which wave ripples formed.

Between the rock tip with the 'Danger' notice and the concreted cliff steps there are examples of surfaces encrusted by stromatolitic algal sheets and domes. In one case the stromatolites, which weather orange-brown, have colonised a desiccated surface following flooding, and stromatolite growth is clearly related to the desiccation crack morphology.

Below the steps with railings on the landward side of a fault, a grey laminated siltstone fish bed is exposed — but is covered at about half tide. Fish material is dis-articulated and widely scattered, probably by current activity, and the typical fine lamination of the fish beds is only poorly developed. The fish bed is cut by thin sandstone dykes, which have compaction features and were thus emplaced prior to the completion of compaction of the fish bed. The strata above the fish bed show a regressive lake sequence, passing up into green sandstone and mudstone with polygonal desiccation cracks.

Continue along the shore, noting the cyclic nature of the sequence. In the second prominent gully past the concreted steps, and on the foreshore, excellent examples of polygonal desiccation cracks are seen in plan and section (Figure 5.23). In the west wall of the gully a lenticular current-rippled sandstone bed 13 m wide and up to 15 cm thick is exposed in cross section. This is one of several examples of wide, shallow channels with erosive bases, and filled by a single flood event.

Near the point, about 100m east of a low cliff with access path, another fish bed with *Millerosteus* (Figure 5.24) is exposed. The fish are generally disarticulated, but characteristic plates can be recognised. Sandstone dykes also affect this bed, show only minor compactional features, and are related to joint patterns.

Discrete cross-bedded sandstone units up to 4 m thick occur towards the top of the Mey Subgroup section, and are well exposed in the promontory east of the isolated stack on the seashore. The sandstones are fine- to medium-grained and show a variety of cross-bedding and lamination features (Figure 5.25). The base of the sandstone includes typical fluvial trough cross-bedding with abundant rip-up dasts of green shale. However, parts of the sandstone consist of low-angle cross-bedding with reactivation features. The sandstone is well sorted and mica-poor, and is finely laminated on a millimetre scale. Granule lags containing well-rounded coarse sand grains occur at the base of some cross-bed sets, and examples of upward-coarsening laminae typical of aeolian ripples are present. Lenticular cross-sections of grain flows are also present. It is probable that the sand bodies were formed by local aeolian reworking of fluvially deposited sands as small dunes and aeolian rippled sandsheets. The sandstones retain some porosity, and there is irregular dark staining by hydrocarbon residues indicating that oil migrated into these sandstones during burial.

At the end of the section the sandstone below the pill box at the west end of a bay with tank traps is similar to that described above with both fluvial and aeolian features present. Pyrite nodules are common in greenish sandstone at this point.

Dunnet

Purpose

Examination of the Upper ORS Dunnet Sandstone of Dwarwick and Brough, deformation associated with the Brough Fault, and exposures of vent fill.

Access

The most easily accessible localities are situated at the north end of Dunnet Bay near Dwarwick Pier, and on the shore north of the small landing place at Brough opposite Little Clett (Figure 5.26). Exposures in vertical cliffs can be viewed from the most northerly point of the Scottish Mainland at Dunnet Head. Low tide is required to complete the shore section at Brough, but some exposure at Dwarwick can be seen at all states of the tide. Take the B855 off the A836 in Dunnet Village, the minor road to Dwarwick Pier is not advised for coaches.

Locality 14. Dwarwick Pier [ND 207 713] Head of Man Bay [ND 203 719]

From the B855 turn off in Dunnet, continue for about 100m and carry straight on along the minor road where the B855 bears to the right, and follow signs to Dwarwick Pier where vehicles can be parked.

The bay between Dwarwick Head and Head of Man also contains good exposures of the Dunnet Sandstone, and effects of faulting can be seen. To reach this bay follow the road back from Dwarwick and carry straight on having passed the museum (Mary Ann's Cottage), keep to the left and stop at the drive entrance to the large white house (marked on some maps as 'Northern Gate Ho.', but it is not a hotel and parking here is not suitable for coaches). Take the footpath passing to the north of the house which leads down to the beach. Low to half tide is required.

The cliffs NW of Dwarwick Pier (Figure 5.27) display typical fluvial sandstones of the Upper ORS. Red to buff-coloured, medium- to coarse-grained, quartzose sandstones in beds up to a metre thick are typical. The dominant structure is trough cross-bedding, which frequently has soft sediment deformation features towards the tops of beds. Abundant red and green mudstone clasts, both angular and rounded, are concentrated at the bases of troughs. Low-angle bedding with millimetre-scale lamination displays primary current lineation, and planar cross-bedding is also present. Colour variations in the sandstone represent variable oxidation states of iron and differential erosion accentuates variations in cementation. Cementation is dominantly by quartz overgrowths on quartz grains.

The depositional environment was one of braided fluvial channels, probably on a low-angle alluvial fan. Rapid lateral migration of channels and consequent sediment reworking prevented mudstone preservation except in the form of rip-up clasts of dried mud incorporated into channels. General transport direction was to the NE (McAlpine, 1977). To the SE of the pier, low cliffs and an extensive wave-cut platform permit examination of the cross-bedding and soft-sediment deformation structures in three dimensions, some deformational trough features being over 3 m wide (Figure 5.28).

If desired the party can also visit the bay to the north between Dwarwick Head and Head of Man. It is a 2 km walk to the bay following the route given above, or a small vehicle can be driven part of the way as described.

Locality 15. Brough, Clett Harbour [ND 221 740]

From Dwarwick Pier return to the B855 and turn left to Brough and Dunnet Head (Figure 5.26). Stop where the road skirts the cliff top with views of Little Clett, a track not suitable for cars descends to the pier. Low tide is required for this locality.

The most obvious feature is the Brough Fault, which forms a wide fractured zone. The stack of Little Clett consists of extensively fractured ORS. On the foreshore the Upper ORS is vertical due to drag against the fault, but the dip flattens out rapidly towards the cliffs.

The Upper ORS has similar structures to those at Dwarwick, and deposition was dominantly fluvial. If tidal conditions permit, scramble 500m north along the shore to the cliff break. The cliff exposure north of the small stream consists of about 4 m of quartz-cemented sandstone in two units separated by a pebble bed. This waterlain sandstone overlies a mixed sequence including less well consolidated, low-angle cross-bedded and laminated sandstone. This sandstone appears to be aeolian in origin, consisting of well-sorted sand, with fine lamination and low-angle internal truncations. Mudstone clasts are generally absent. Elsewhere, McAlpine (1977) recognised aeolian dune and sandy playa facies in the Dunnet Sandstone. He concluded that winds dominantly from the south-west reworked the fluvial sands and formed small dunes with interdune playas on the distal areas of the low-angle alluvial fans.

A volcanic vent is exposed in outcrops some 100 m up the Burn of Sinnigoe near this point. Outcrops are poor, but breccias with volcanic fragments and clasts of ORS and basement lithologies can be seen, often in a sandy matrix. As Peach observed (*in* Crampton and Carruthers, 1914) it appears that the vent pierced the Upper ORS prior to its lithification. Contemporaneous Upper ORS volcanics occur at the base of the Hoy Sandstone in north Hoy. However, the volcanic vent at Duncansby (Locality 7) is considered to be of Permian age.

Locality 16. Dunnet Head [ND 202 768]

It is worth taking the opportunity to visit Dunnet Head for excellent views of inaccessible cliffs of the Dunnet Sandstone, which display the generally good lateral continuity of the bedded units. McAlpine (1977) recognised nine lithostratigraphic units that could be correlated between Dunnet Head and the island of Hoy, which can be seen to the north.

Itinerary 5.4 Old Red Sandstone basin margin deposits at Red Point, Port Skerra, Baligill and Sandside Bay

General purpose

To demonstrate the nature of the sub-Devonian unconformity and basin marginal deposits of the Orcadian Basin.

General access

All localities are close to the A836 between 13 and 18 miles by road to the west of Thurso. For those staying at Helmsdale it is a fine scenic drive along the A897 (mainly single track with passing places) up Strath Helmsdale and down Strath Halladale to this area. This road passes Baile an Or, site of the Helmsdale gold rush, and subject of Excursion 6. Access to individual localities is given with the locality details.

Red Point

Purpose

To demonstrate the unconformity between basement and the ORS, which includes an example of a coincident lake margin deposit with limestone deposited on a dipping basement surface.

Access

About a mile to the west of Reay on the A836 there is a lay-by with an Information Board at [NC 932 646] on the north side of the road (Figure 5.29). The lay-by is big enough to park a coach. From the lay-by there are views to the east of

Dounreay across Sandside Bay. There are no well-defined paths in this area, and the walk is not advised in poor visibility without a compass. Beware of boggy areas in old peat workings. From the lay-by walk west on the road for 150 m, then head north across the moor along the side of the ridge with a valley to the east. Head towards a grassy knoll (Cnoc Glas) on the coast, which will come into view. The stream, sometimes boggy, can be crossed near the edge of the sea cliff. Follow the ill-defined coastal path about 200 m to the east to Point 1 on (Figure 5.29). This walk takes about 30 minutes. A total time of at least 2 hours is required for this excursion.

The cliffs in this area are dangerous and must be treated with caution, particularly when wet.

Locality 17. Red Point [NC 930 659] to [NC 933 659]

Locate yourself with respect to the geology as shown on (Figure 5.29). A lot of time can be spent examining the details of these outcrops. The following notes cover some of the main points; refer to Donovan (1975, 1978) and Janaway and Parnell (1989) for further information and discussion. Donovan demonstrated that a relief of 30 m+ exists on the basement surface in this locality area (Figure 5.30).

Point 1. This striking exposure (Figure 5.31) shows steeply (45°) dipping strata resting on gneissose and granitic basement. Above a thin calcite cemented breccia, grey limestones mantle the surface and display folding due to downslope movement. Massive limestones grade laterally downslope into laminites indicating increasing water depth down the flank of the basement high. This is an example of a lacustrine limestone deposited directly on basement during a period of lake highstand, a coincident lake margin in the terminology of Donovan (1975). The limestone shows irregular silicification in places and Janaway and Parnell (1989) recognised a lower dolomitic unit within the limestone. The limestone is truncated by a coarse breccia of basement and limestone clasts in a sandstone matrix. The limestone clasts are up to 30 cm long and represent reworking of the underlying limestone that was clearly fully lithified at the time of erosion and transport.

Point 2. Here a prominent ridge of red breccia with calcitic cement lies between two areas of basement with faulted margins. The sandstones with breccia tongues (Figure 5.32) beneath the breccia show original dips that rapidly flatten out. Imbrication of clasts can be seen in the breccia. Wave ripples and desiccation cracks are present, indicating periods of exposure, but some breccia beds are draped by thin carbonate-rich laminites deposited in deeper water. The breccias appear to be lake margin deposits, perhaps representing a beach facies.

Point 3. In this area the relief on the basement can be observed, and the sandstones and breccias overlying the unconformity examined in more detail. Sandstones are thin-bedded with wavy and subparallel lamination and contain lenses of breccia resting in shallow hollows with erosive bases. On the east side of this broad gully some large boulders on the unconformity surface are set in a laminated sandstone matrix that was washed into place between the boulders. Some areas overlying the uncomformity are dominated by sandstone and others by breccia. Clamber out of the east side of the gully and follow the cliff to the next valley and descend the grassy slope by the stream at the head of the gully to Point 4 (Fig. 5.33). The steep grassy slopes are very slippery when wet.

Point 4. The junction between a steeply dipping surface of gneiss and flagstone facies is exposed in this valley. The western wall of the valley exposes gneiss with granite veins, and flagstones make up the eastern side. Although minor faulting is present, as would be expected given the competency difference between the gneiss and flagstones, a lateral transition can be seen from gneiss outcrop, though 5 m of breccia containing gneiss and limestone clasts, to flagstones with scattered angular gneiss clasts. The flagstones display typical shallow-water current and wave ripples, laminated sandstones with primary current lineation, and also horizons with polygonal mud cracks. The limestone clasts in the breccia resemble the limestone seen at Point 1 and probably originated from erosion of a limestone that was deposited on the gneiss during a highstand of the lake, and subsequently eroded when it became exposed as water level dropped.

Close examination of the surface of the gneiss outcrop reveals fissures with relics of laminated and massive limestone, and carbonate-cemented patches of breccia still plastered to the gneiss surface. At times of low lake level the gneiss hill was coincident with the playa lake margin. The coarser deposits seen at Point 3 on the other side of the gneiss outcrop appear to represent a lower stratigraphic level. Return along the cliff-top to Cnoc Glas and retrace the route to the lay-by.

Port Skerra

Purpose

To examine the features associated with the unconformity between Moine basement and the Old Red Sandstone.

Access

Turn off the A836 at the Melvich Hotel (Figure 5.34) into Portskerra village. Take the right-hand fork at the road junction and drive to the last row of cottages where a track bears right down to a concreted slipway at [NC 878 663]. A minibus can be parked near the cottages, or down the track at the slipway. There is only room for a couple of vehicles at the slipway, so it is advisable to check that space is available before driving down to the slipway. Large coaches should be left at the Melvich Hotel.

Locality 18. Port Skerra [NC 878 663]

From the slipway the major feature of the geology is clearly seen in the cliffs and reefs protecting the bay (Figure 5.35). An irregular surface of Moine gneisses is overlain unconformably by conglomerates and sandstones of the Old Red Sandstone, here believed to be Middle ORS; but direct evidence is lacking.

In the area of the slipway, and to the south-east, coarse breccias with a green sandy matrix rest on grey- to red-banded gneiss (Figure 5.36). The gneiss is extensively migmatised and more than one melt phase is present, the melt layers being commonly deformed into complex folds. This multiphase high-grade metamorphism and deformation took place in the Ordovician Grampian Orogeny. These gneisses, together with amphibolites representing metamorphosed basic dykes, have been extensively intruded by undeformed late pink granite veins that are probably connected with the Strath Halladale Granite, which is dated at c.425 Ma. Fracturing is locally intense in the basement, but the ORS is less fractured, indicating that some fracture sets predate ORS deposition and were opened by Devonian weathering (Figure 5.37).

In the bay, outcrops on the beach are dominated by hard silica-cemented sandstone with crude parallel lamination in beds up to 1 m thick. Most beds contain scattered angular clasts of basement gneiss and granite which occur in a floating texture in the sandstone matrix. Deposition was rapid with little reworking and the transport distance short. These are probably amalgamated deposits of flash floods.

At the end of the bay the sandstones can be examined (half to low tide) where they abut the tops of knolls of the basement gneiss. The sandstone beds show little modification adjacent to the basement knolls, which have only a thin (20 cm) veneer of locally derived breccia. In the hollows between knolls a greater thickness of breccia is usually present. The first basement knoll contains a sediment-filled fissure over 3 m deep and up to 20 cm wide; part of the fissure fill forms the seaward face of the knoll. A sandstone bed exposed near the low tide mark some 20 m from the basement knoll shows excellent convolute lamination with an amplitude of 60 cm. Current and wave ripples are also present in the sandstones. The sandstones forming the gentle synclinal structure between two basement knolls are mainly parallel laminated, but some cross-bedding and minor channelling is present. The synclinal feature appears to be caused by differential compaction over the irregular basement surface. At low tide it is possible to scramble up the second knoll and examine further details of the unconformity, and also a large mass of diorite cut by sheets of undeformed granite within the Moine basement.

If time permits a visit can be made to the small cove to the west of the headland where the unconformity can also be seen at [NC 8755 6633]. Further details, particularly of the basement, are included by Strachan *et al.* (2009c in press) in Excursion 13 of the revised excursion guide to the Moine.

Baligill

Purpose

Demonstration of marginal features of the Orcadian Basin.

Access

Coaches should drop people at the minor road junction at [NC 853 652] (Figure 5.34). Smaller vehicles can park 400 m down the road near the corner, where a track descends towards the sea past a cottage. Take care not to block farm gates. Binoculars are useful for observing the geology of the cliffs in this area. Walk down the track past the cottage towards localities 19–23.

Locality 19. Balligill Limestone Member [NC 855 659]

Follow the track to the bridge over the stream. Downstream of the bridge (c.20 m) on the west bank a grey carbonate laminite fish bed is exposed, which is directly overlain by a brown medium-grained sandstone with ripple lamination. This is a typical basin margin feature, there being a transition from deep lake to very shallow conditions without the usual transitional facies. This sandstone fines up into thin-bedded flags and a second carbonate laminite is seen in the outcrop with a wall built on top. These laminites are part of the Baligill Limestone Member of the Bighouse Formation (British Geological Survey, 2005). Both these laminite beds contain fish including *Pinnalongus saxoni, Coccosteus cuspidatus, Mesacanthus* and *Cheiracanthus* (record in Newman and Dean, 2005). It is now considered that the characteristic Achanarras fish bed fauna is not seen in the area west of the Forss Fault. The Balligill Limestone Member lies within the Lower Caithness Flagstone Group, about 270 m below the probable equivalent of the Achanarras fauna.

Locality 20. Lime kilns [NC 855 661]

Continue on the track on the east side of the stream through a metal gate to the old lime kilns. At the base of the quarried face opposite the kilns (Figure 5.38) a laminated limestone is exposed in which laminae have stylolitised contacts along organic-rich laminae, and large stylolites cut the bedding at a high angle. Above these lacustrine laminites is a sequence of green shales and dominantly fine-grained sandstones which have excellent loading structures on the bases of beds 5–50 cm thick. A few scattered granite pebbles are also present. Grading is present in some beds and partial Bouma sequences (bcde) deposited by waning currents are seen. This part of the sequence appears to have been deposited in moderately deep water by density currents, but the occasional granite pebbles show that basement was exposed nearby. This sequence is overlain, apparently conformably, by a sandstone with pebbles of quartz and granite at the base. This sandstone is dominantly medium-grained and is cross-bedded with sets up to 1 m in amplitude. At the top of the outcrop the sandstone is thin-bedded and contains current ripples and small-scale cross-bedding. The sandstone is a shallow water deposit of fluvial or lacustrine delta origin and was deposited as a result of coarse sediment prograding over the deeper water deposits during a period of low lake level. Sandstones exposed to the west of the outcrop show cross-bedding that is probably of aeolian origin, suggesting retreat of the lake and establishment of subaerial conditions similar to those seen in the Fresgoe Sandstone Member at Sandside Bay (Locality 24 below).

Locality 21. [NC 857 661]

Continue on the path to the east of the outcrop beside a fence. Basement is seen exposed on a ridge to the left. Cross the ridge to a valley with a small burn. On the west side of the valley there is an exposure of limestone with angular fragments of gneiss, and dipping towards the burn (Figure 5.39). A small pile of quarried limestone blocks of similar lithology lies nearby. Cross-bedded sandstones are exposed on the other side of the valley. It can be seen that the gneiss formed a hill that was mantled by limestone before later burial by sandstones. The scattered limestone outcrops in this area were quarried for lime production for agricultural use. Cross the burn and ascend the path to the promontary of An Dun overlooking the sea 100 m to the north.

Locality 22. An Dun [NC 857 662]

Only a few stones of the dun (fort) remain. The high cliffs have a steep grassy slope on the east side and limestone can be seen dipping steeply off the mound of basement below, although at the top of the cliff strata are nearly flat-lying (Figure 5.40). This locality is dangerous and not suitable for closer examination, particularly in poor conditions. Walk 200 m round the cliff top to the next headland to the east and look back to the cliff below An Dun. A steeply dipping surface of grey limestone mantles the basement gneiss surface. At a prominent ledge on the cliff face the reddish gneiss is exposed and can be viewed from a distance (Figure 5.41). Similar rock-types are more safely seen at Red Point.

Locality 23. [NC 855 662]

Follow the cliff-top path back westwards towards the bay where a fault-bounded ridge of sandstone can be observed with binoculars. Northward-directed cross-bedding in the cliff comprises sets up to 1 m thick. Style varies from low-angle planar cross beds to units in which the cross-bedding is asymptotic to the base of the set. Reactivation features can be seen in several sets. These sandstones appear to be deposits of bars in broad, shallow river channels flowing north into the Orcadian Basin. In hand specimens well-rounded quartz grains can be seen and aeolian reworking is implied. Return up the track to the vehicle.

Note: In the first edition of this guide Baligill Quarry [NC 852 657] was included and the fish fauna taken to indicate the Achanarras faunal level. Some of the fish determinations on which this conclusion was based have been shown to have been incorrect following further collecting in the area by Newman and den Blaauwen (see British Geological Survey, 2005). The quarry is now badly overgrown.

Sandside Bay

Purpose

To examine part of the flagstone sequence to the west of the Bridge of Forss Fault where the Achanarras Limestone member and its characteristic fauna are not present. An interesting unit (Fresgoe Sandstone Member) of aeolian sandstones occurs within the dominantly lacustrine successsion. The stratigraphy of the area is described on BGS special sheet for Dounreay (British Geological Survey, 2005)

Access

Turn off the A836 to Sandside Bay in Reay village (Figure 5.42). The road passes a few houses and after the cattle grid there is parking space on the right, but it is easier to park at the public conveniences a few hundred yards further on. There is also a larger parking area at the end of the public road near Sandside harbour, where a coach could be turned. Warning notices are displayed regarding radioactive particles that have been washed onto the beach from Dounreay. Regular monitoring of the beach for such material takes place.

Locality 24. Sandside Bay, western side [NC 958 655] to [NC 958 662]

The head of the bay is a sandy shore lacking rock exposure, but good exposures occur on both the western and eastern sides of the bay, and display a similar succession with the Fresgoe Sandstone Member forming a prominent feature. The first exposures encountered on the shore are part of the Bighouse Formation. This cyclic sequence contains fish bed laminites in which *Thursius macrolepidotus, Pinnalongus saxoni, Coccosteus cuspidatus, Diplacanthus, Mesacanthus* and *Cheiracanthus* have been recorded (British Geological Survey, 2005). *Pinnalongus* is a dipnoan (lungfish) described by Newman and Den Blaauwen (2007). It is present in the Lower Flagstone Group to the east of the Bridge of Forss Fault, but ranges up into the Upper Flagstone Group west of the fault. The main depositional thickness of the cycles was deposited in shallow water close to the lake margin, and wave and current ripples and polygonal desiccation cracks are common (Figure 5.43). Sandstone beds dominate the sequence and are frequently loaded into the green shale to produce 'ball and pillow' structures.

Continue north to the first low cliff at the top of the beach, where a rapid transition from aeolian sandstone to deep lake laminite can be seen (Figure 5.44). The prominent sandstone at the base of the cliff comprises well-sorted fine sandstone with typical aeolian cross-bedding. The sand dunes must have invaded the dried lake floor during a period of low lake level. The marginal position of Sandside Bay with respect to the edge of the basin is demonstrated by basement outcrops of diorite about 500 m to the SE of the bay; thus the sand dunes probably fringed the basin margin at times of low lake level. The top of the aeolian sandstone was planed off and reworked as the lake waters rose, and some 80 cm of rippled sandstone and shale deposited in shallow water. As the lake deepened further, the shale content increases, the colour turns to grey, and small sand-filled subaqueous cracks dominate the next 50 cm. There follows 50 cm of typical lacustrine laminite with fish remains deposited in the deepest lake phase. Thus the deepening phase of the lake resulted in little sedimentation.

The cyclic sequence continues to the north with a prominent fish bed present in front of the house. At the northern end of the house beneath the wall the base of the Fresgoe Sandstone Member is exposed. This sandstone is exposed on the foreshore and in low cliffs from here to the Harbour wall. This exposure lies adjacent to the parking area at the end of the public road. Seats and an information board can be seen at the cliff edge. The sandstone is about 30 m thick, and displays spectacular aeolian cross-bedding on a large scale with cross-bed sets to more than 2.5 m in thickness, and continuous for tens of metres laterally (Figure 5.45). The sandstone is generally pale yellow, fine-grained and well sorted. Transport direction of the dunes was generally to the north.

Near the harbour wall there is an area of disruption of the dune bedding with folding and steep to vertical dips in the cross-bed lamination. Parts of the sandstone are homogenised, with lamination becoming indistinct. It is probable that a major flood caused disruption and collapse of the dunes to produce these structures.

This sandstone can also be examined on the eastern side of the bay (Locality 25) where the disruption features seem to be absent, but the top and base of the sandstone are better exposed. The top is remarkable for the flat truncation surface (Figure 5.45) with only minor reworking by water, below lacustrine flagstones. It is possible that as the lake and the water table rose, any topography that the dunes retained was removed by wind deflation rather than reworking by water.

Leave the beach and walk around the harbour, ascend the stone steps at the north end of the building, and return to the shore north of Sandside Harbour. From here to the northern limit of the beach the Sandside Bay Formation can be examined. This formation marks a return to cyclic flagstone deposition similar to the Bighouse Formation but with the addition of sandstone beds deposited by relatively high-energy flows (Figure 5.46). The beds occur in several cycles and are best exposed in the cliff opposite a stack at the northerly limit of the beach; a concreted pipe is present in the gully leading north beside the cliff. The sandstone beds range from 5 to 50 cm in thickness and have erosive bases, with a few of the thicker beds displaying flute moulds. Internally the beds are dominated by parallel lamination, which shows primary current lineation on split surfaces; some climbing ripple lamination is also present. The tops of several beds are current rippled. Beds can be traced laterally for tens of metres with little variation. One prominent bed has been disrupted by loading. These beds were clearly deposited by short-lived flash-flood events, and sheet-floods seem a likely mechanism, since channels are not developed. In this location close to the basin margin infrequent storms probably resulted in rapid run-off with the flood spreading as a sheet over the flat exposed playa surface. Current directions are generally northerly, but with a wide range between east and west, inplying that the lake bed was flat and floods arrived at the site from several local sources.

A few metres above these sandstone beds the succession becomes thin-bedded; wave ripples and polygonal desiccation cracks are present. A rapid lake transgression took place resulting in fish-bed laminites. The laminites can be examined 40 m to the north in the wall of the gully. This fish bed contains *Thursius macrolepidotus* (Figure 5.47) and acanthodian fragments.

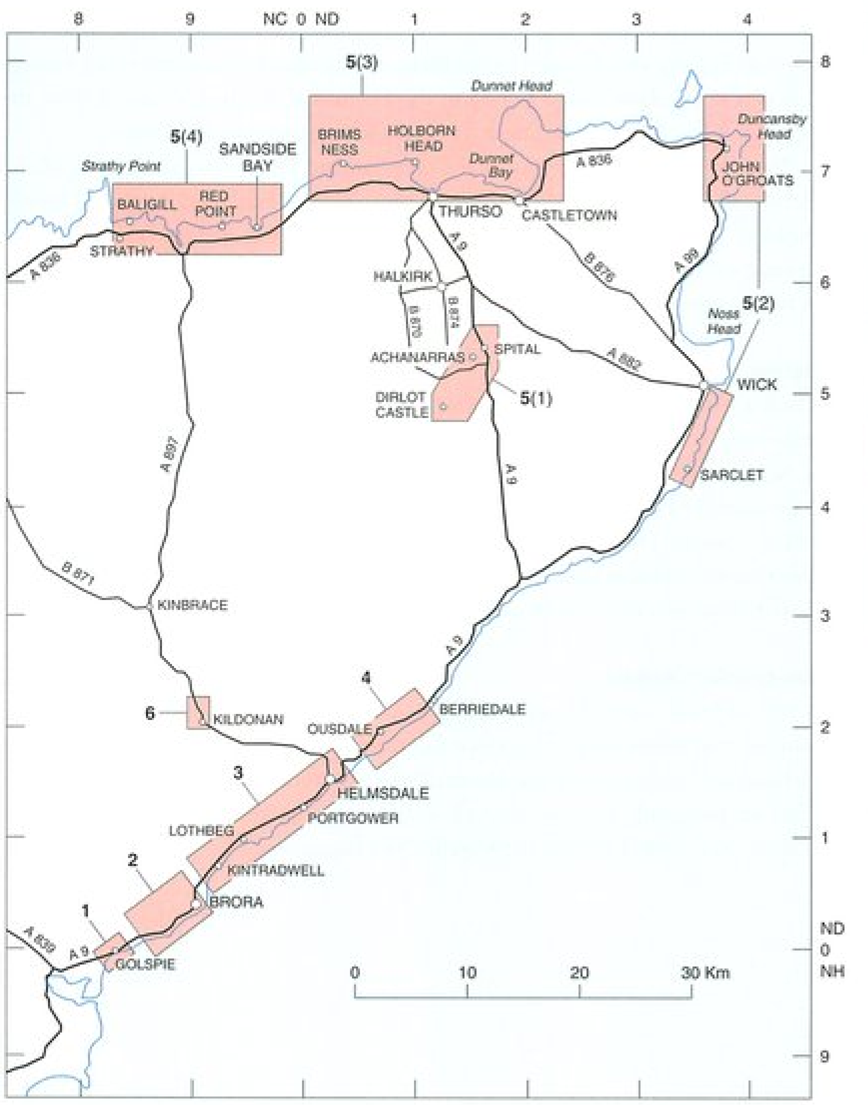
Locality 25. Sandside Bay, eastern side [NC 968 658]

If desired the succession described above can also be examined on the east side of the bay, and compared with that on the west. The aeolian sandstones of the Fresgoe Sandstone Member are well exposed and the top of the member is clearly seen (Figure 5.45). The fish bed laminites of the cycles can also be correlated across the bay (British Geological Survey, 2005). Take care not to enter the area of the Dounreay Nuclear Site; there is extensive security control in this area.

Locality 26. Burn of Isauld [NC 970 657]

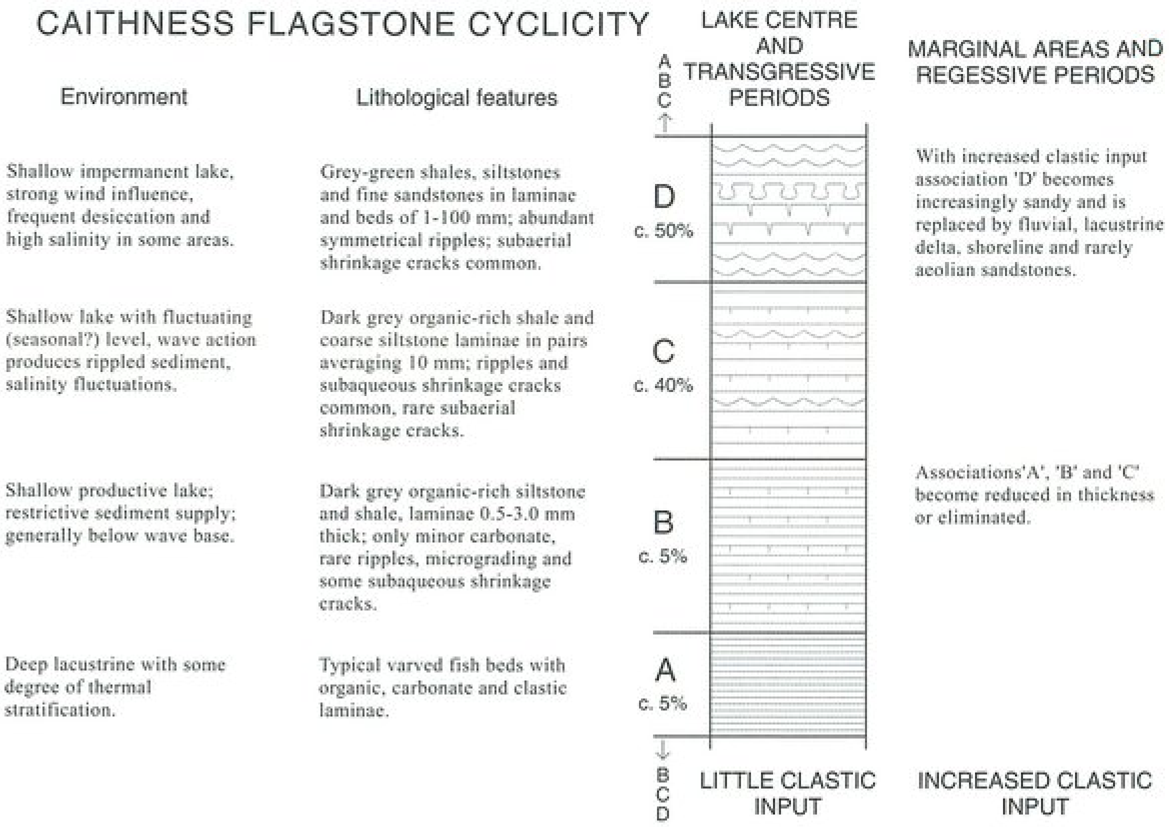
Exposures in the Burn of Isauld can be found by following the burn inland for about 100 m from the eastern corner of Sandside Bay. Small outcrops in and near the stream display breccias, limestone and basement diorite. The limestone, termed the Aryleive Limestone Bed (British Geological Survey, 2005) is up to 10m of massive to laminated limestone that rests unconformably on basement diorite. It is mapped as being locally present at the base of the Portskerra Conglomerate Member, which in part overlies the limestone. The environmental interpretation is comparable to the situation seen at Red Point (Locality 17) and at An Dun (Locality 22). It does not seem possible to prove the relative ages of these limestones, but they might have formed during the same deep lake phase, draping drowned basement highs where there was no source of clastics. They are unlikely to occur in basement lows where sandstones and breccias accumulated. Eventually clastics covered the basement highs as sedimentation increased at the basin margin, and the next deep lake events seen in the area are the fish beds of the Bighouse Formation seen at locality 25, and Baligill (Locality 19).

Figures

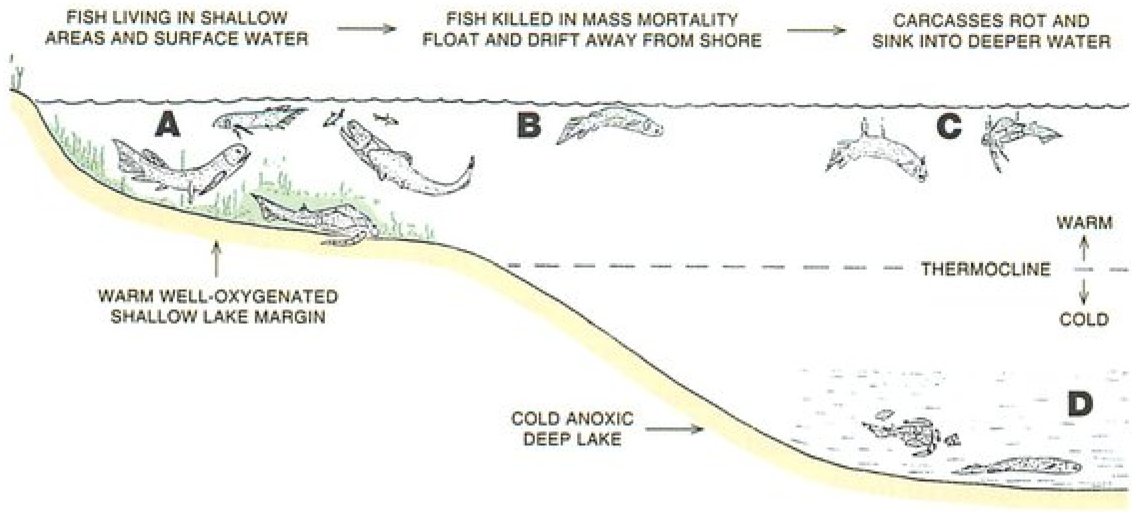


Excursion Localities
1 Golspie; **2** Brora; **3** Kintradwell to Helmsdale; **4** Ousdale; **5** Caithness; **6** Kildonan.

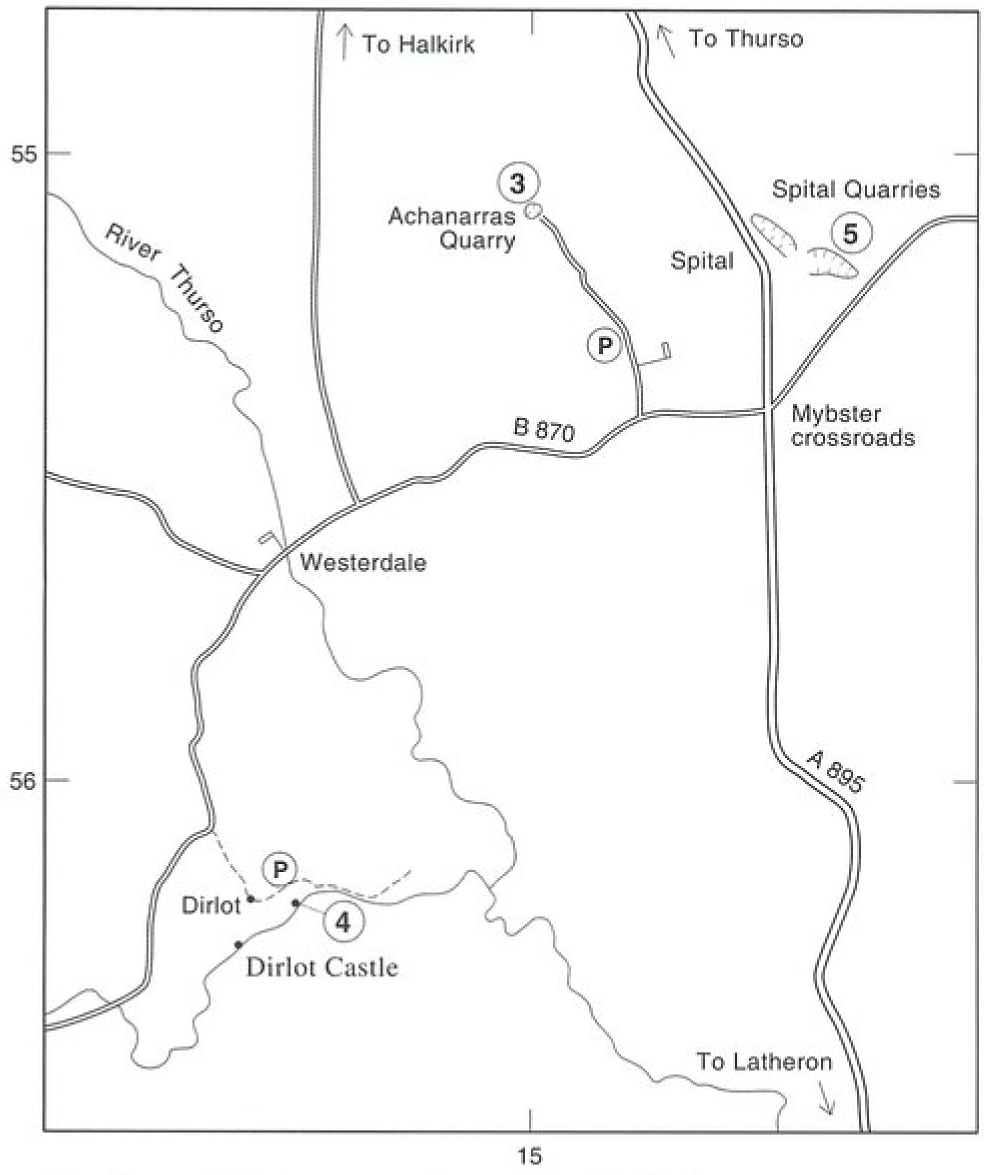
(Figure Unnumbered 1) Excursion localities 1 Golspie; 2 Brora; 3 Kintradwell to Helmsdale; 4 Ousdale; 5 Caithness; 6 Kildonan.



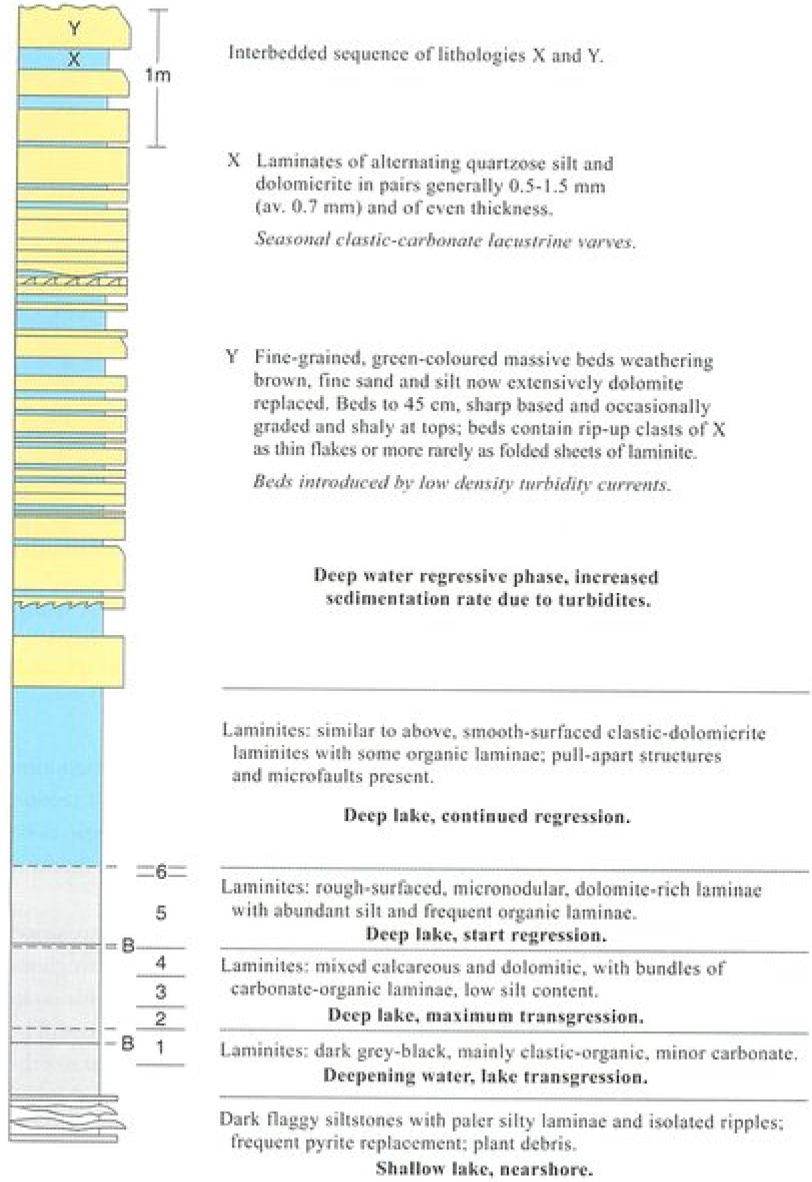
(Figure 5.1) Summary of the characteristics of Lithological Associations A–D of Donovan (1980) which form the cyclic lacustrine facies of the Middle ORS of Caithness.



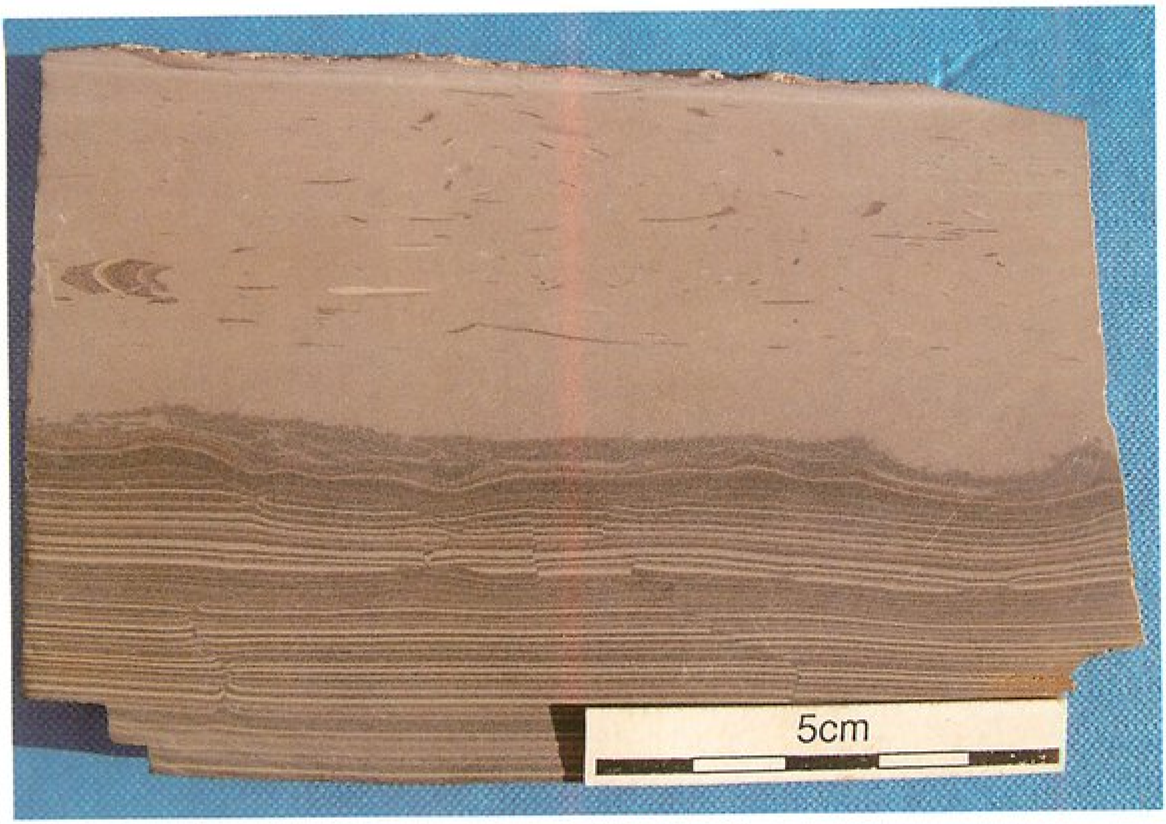
(Figure 5.2) Origin of fossil fish carcasses in deep lake laminite facies. Fish lived in rivers and shallow lake areas (A) where waters were oxygenated. Periodic mortalities due to salinity crisis, or deoxygenation caused by algal blooms, lake overturn or storm mixing, resulted in carcasses (B) drifting 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.

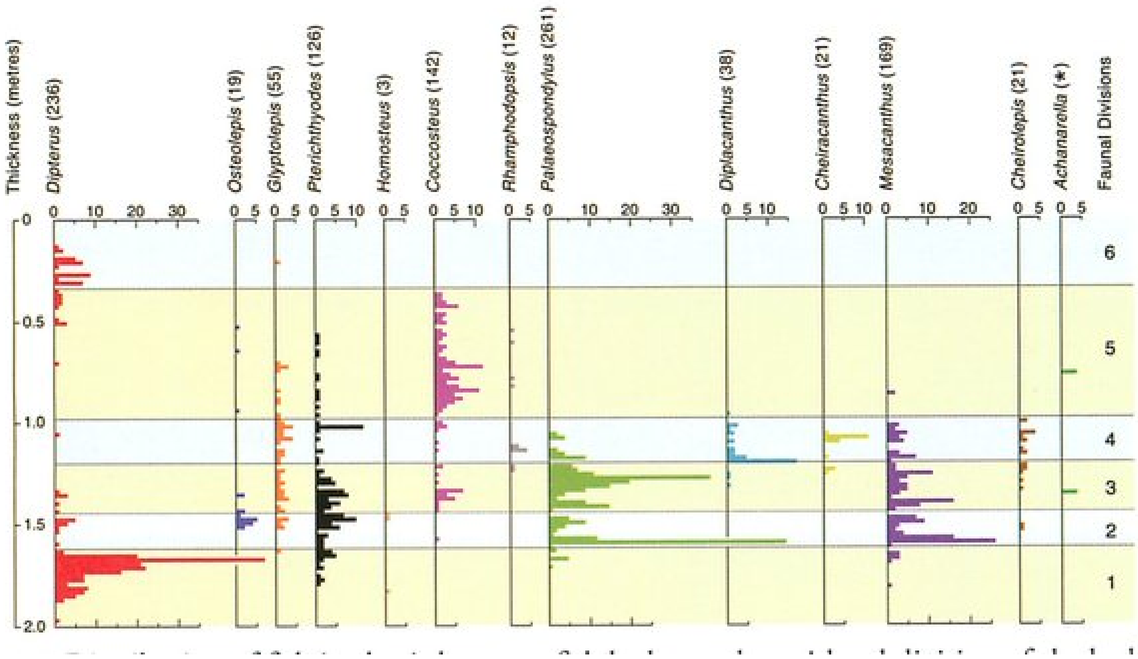


(Figure 5.4) Log of section at Achanarras Quarry. Modified from Trewin (1986).

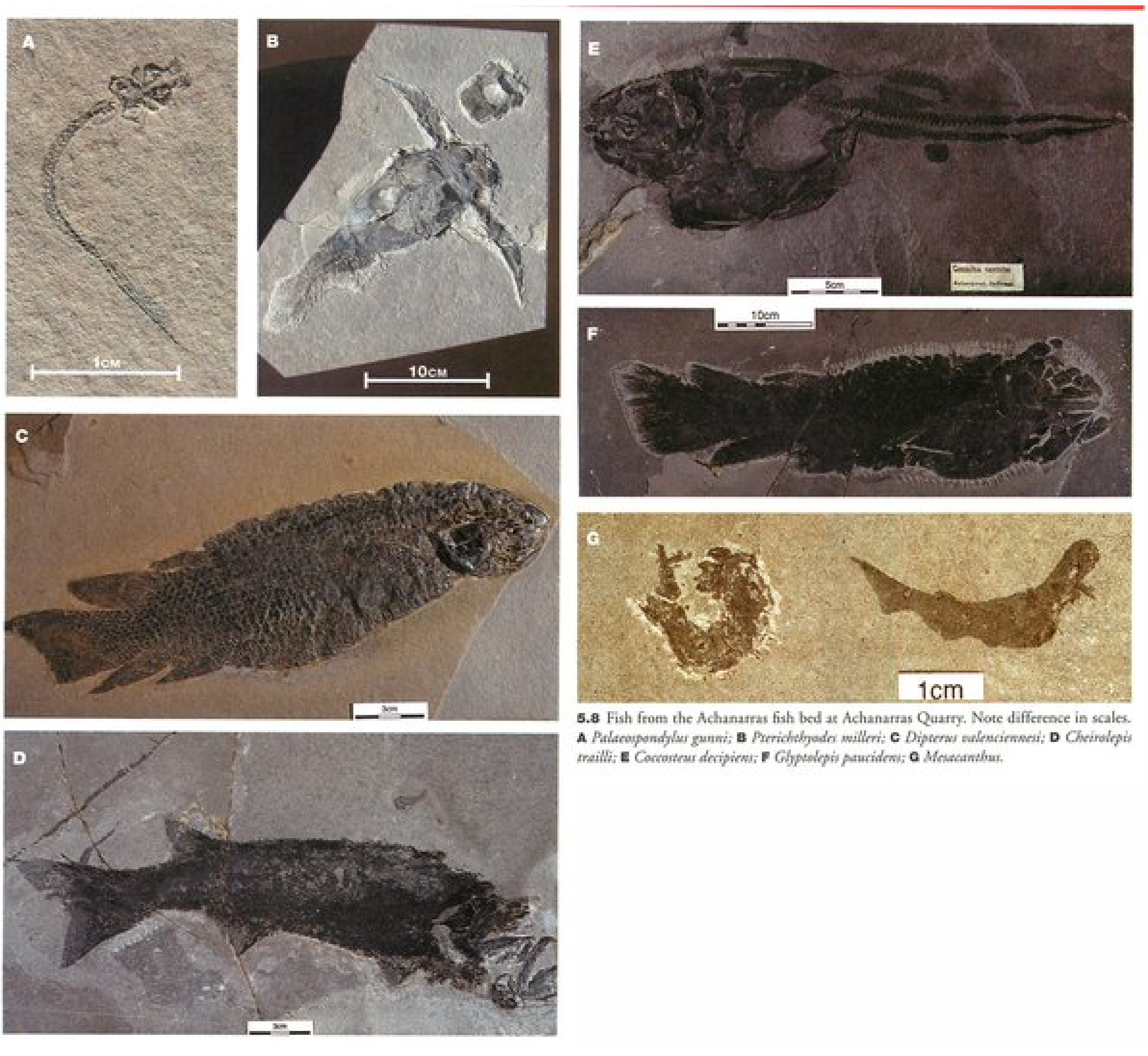


(Figure 5.5) Section of base of siltstone bed resting on laminite. Siltstone bed contains rip-up clasts of laminite and the laminite consists of alternations of silt (dark) and dolomicrite (pale). The siltstone was emplaced by a turbidity current flowing downslope into the deep lake. The laminites deformed 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.

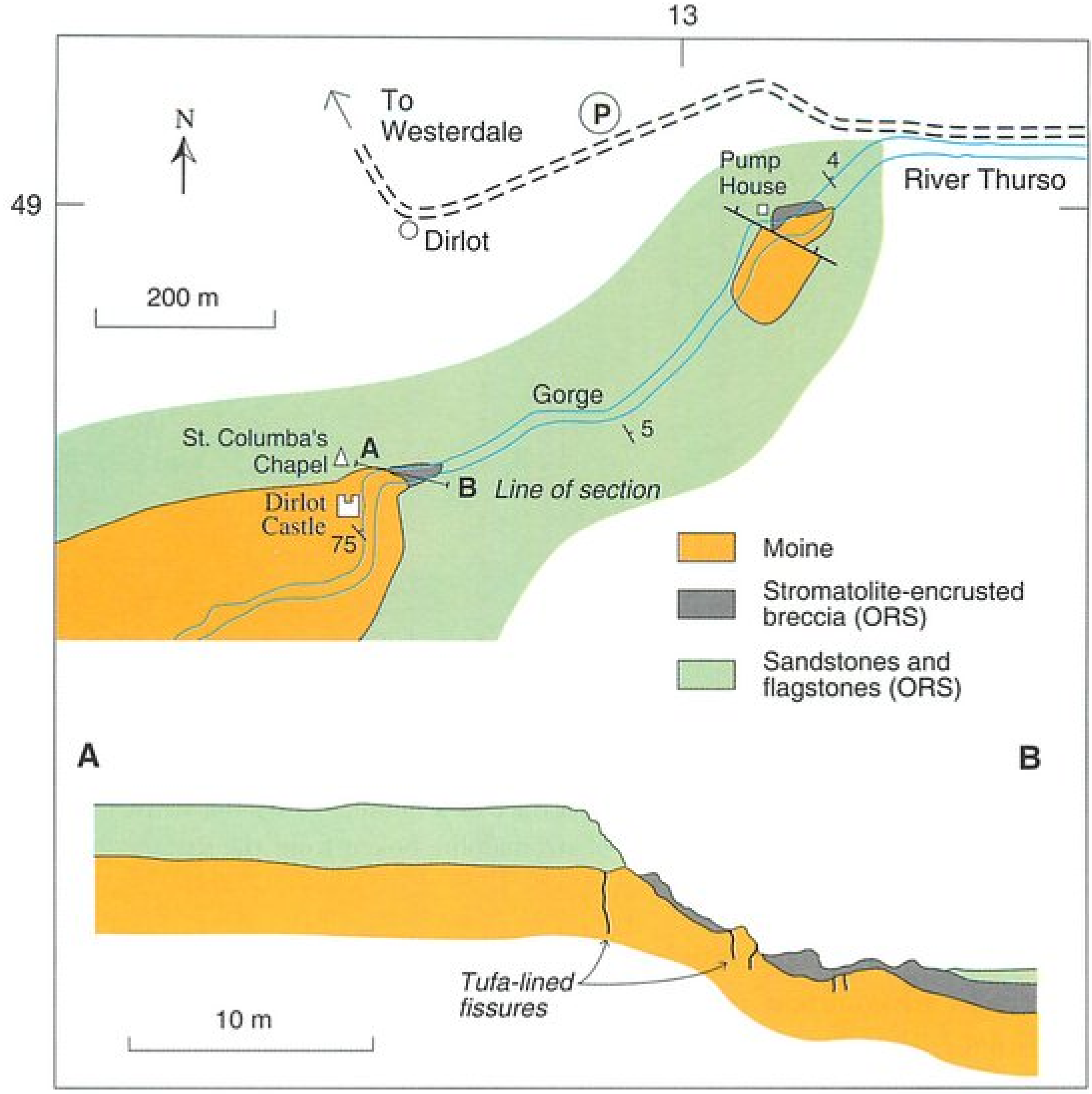
(Figure 5.6) Cut and acid-etched section showing the lamination typical of the central part of the Achanarras fish bed. White laminae are dolomitic. Scale bar 10 mm.



(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.



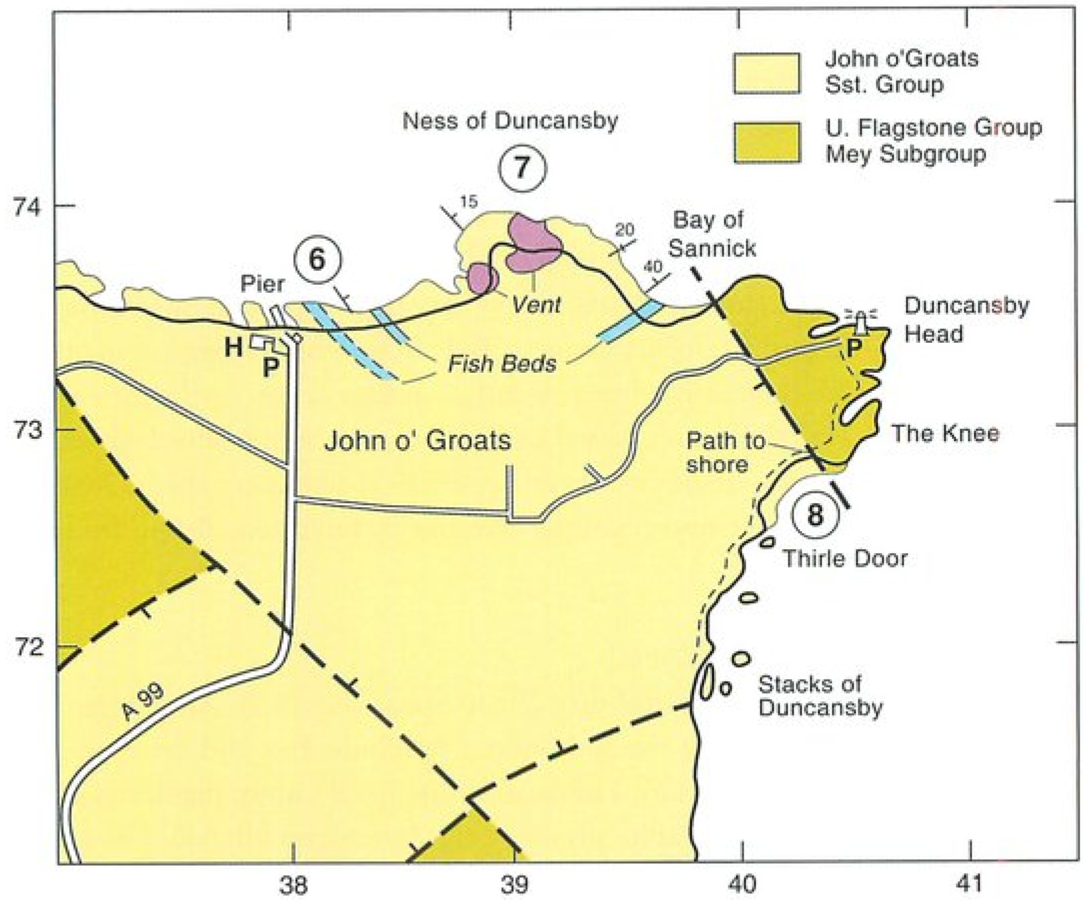
(Figure 5.8) Fish from the Achanarras fish bed at Achanarras Quarry. Note difference in scales. A. Palaeospondylus gunni; B. Pterichthyodes milleri; C. Dipterus valenciennesi; D. Cheirolepis trailli; E. Coccosteus decipiens; F. Glyptolepis paucidens; G. Mesacanthus.



(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.

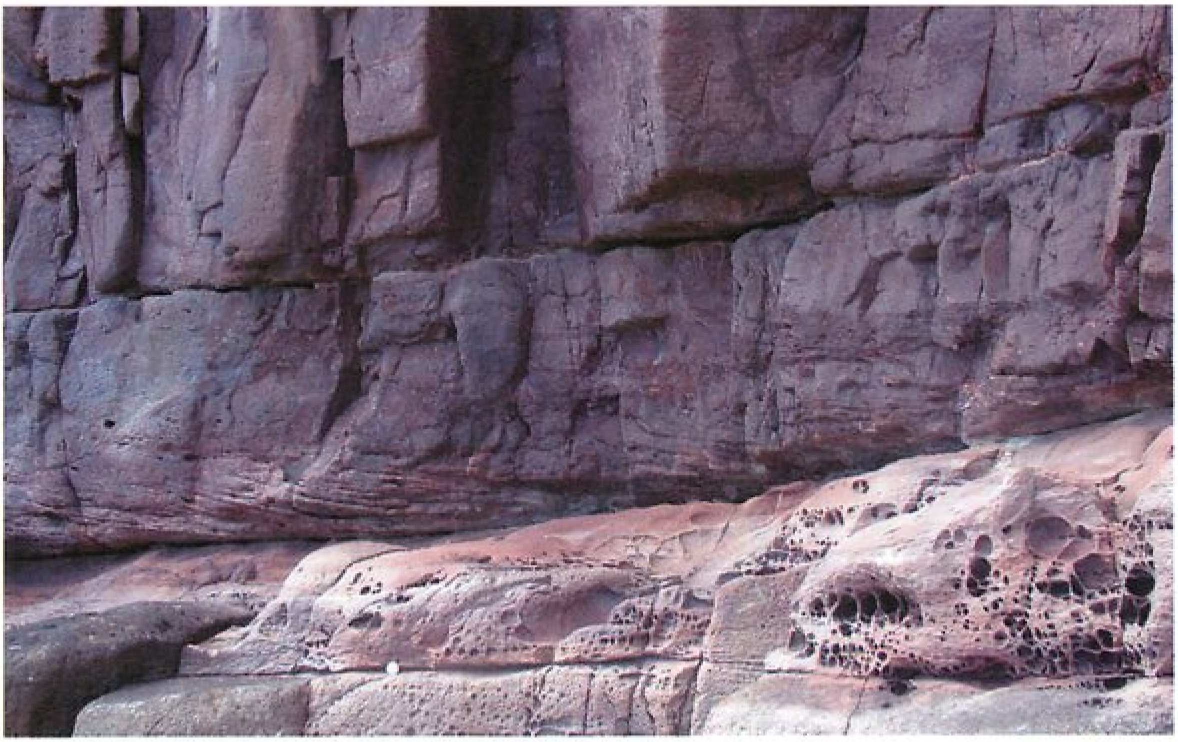


(Figure 5.12) Locality map for Itinerary 5.2, John o' Groats area.

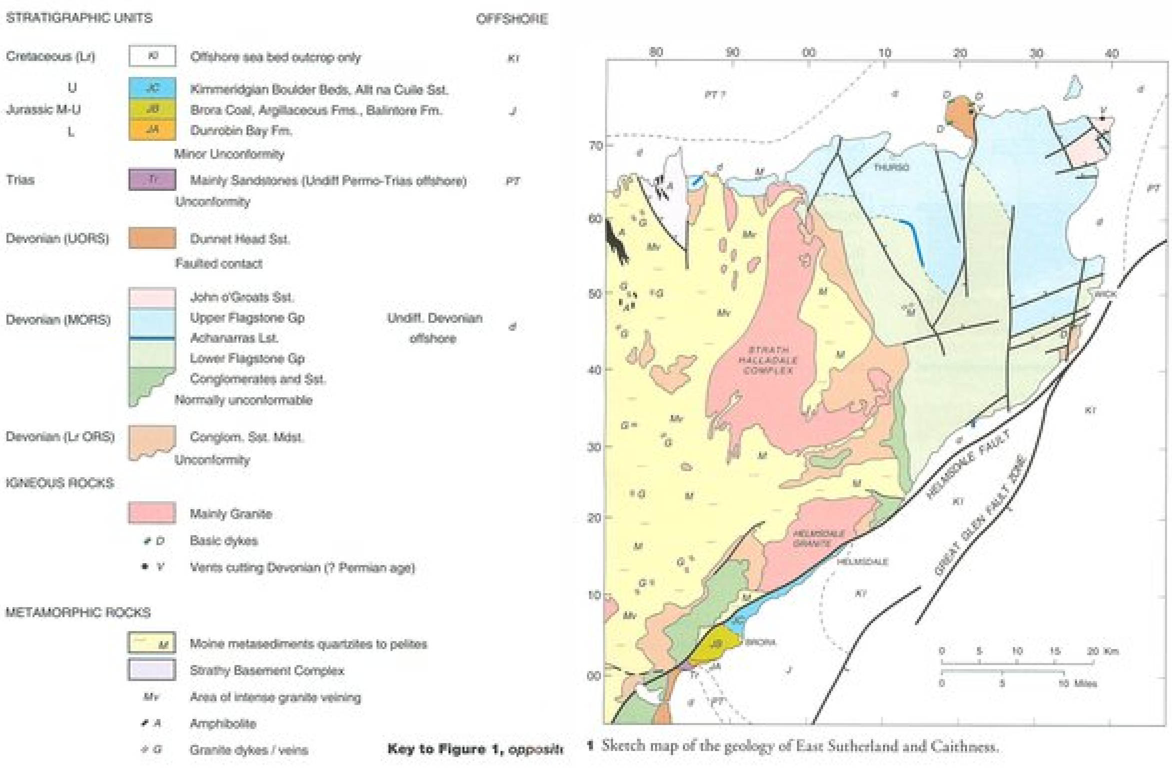
(Figure 5.13) Shore to the east of John o' Groats harbour, Red fluvial sandstones with thin-bedded greenish lacustrine strata that include the John o' Groats fish bed.

(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.

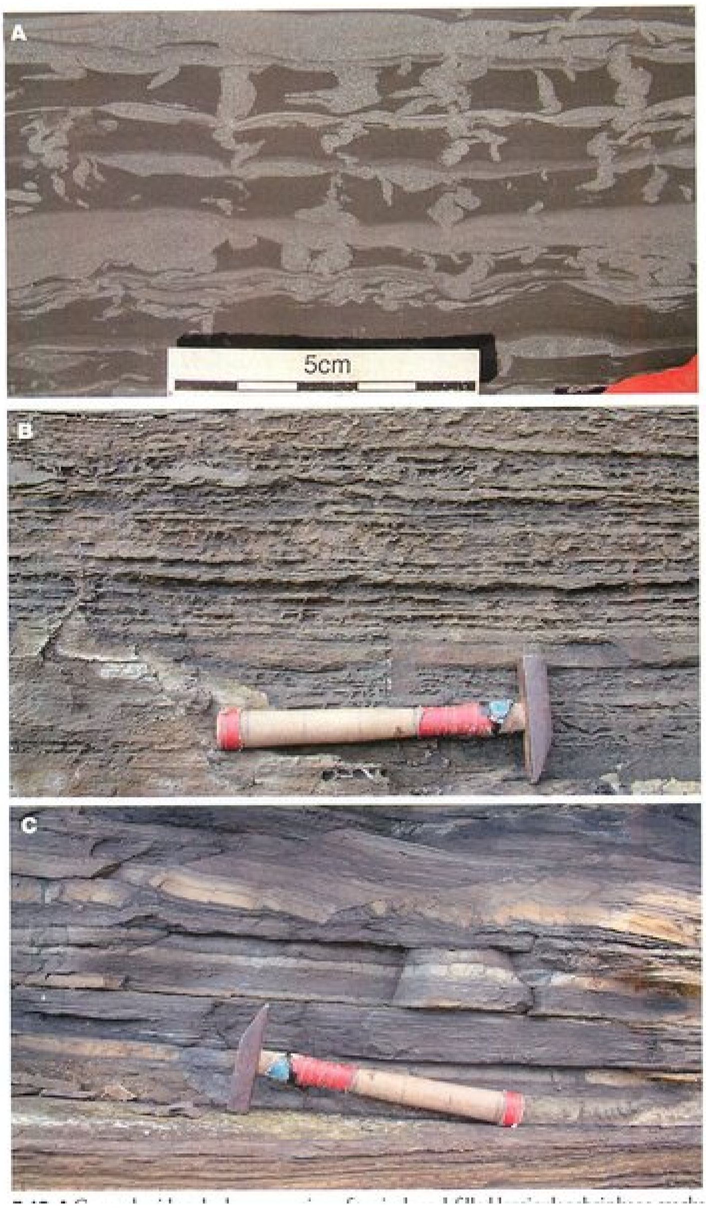


(Figure 5.16) The John o' Groats Sandstone at Locality 8, Duncansby Head.



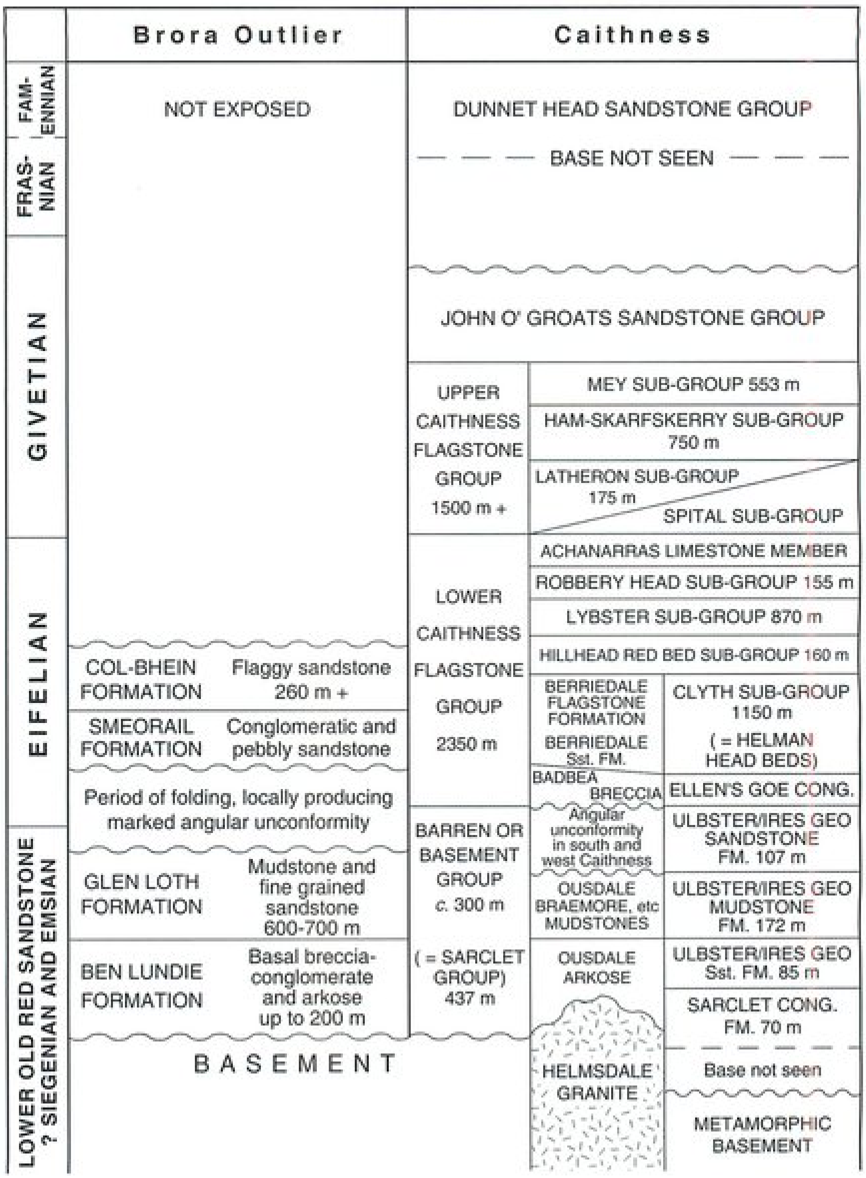
(Figure 1) Sketch map of the geology of East Sutherland and Caithness.

(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).



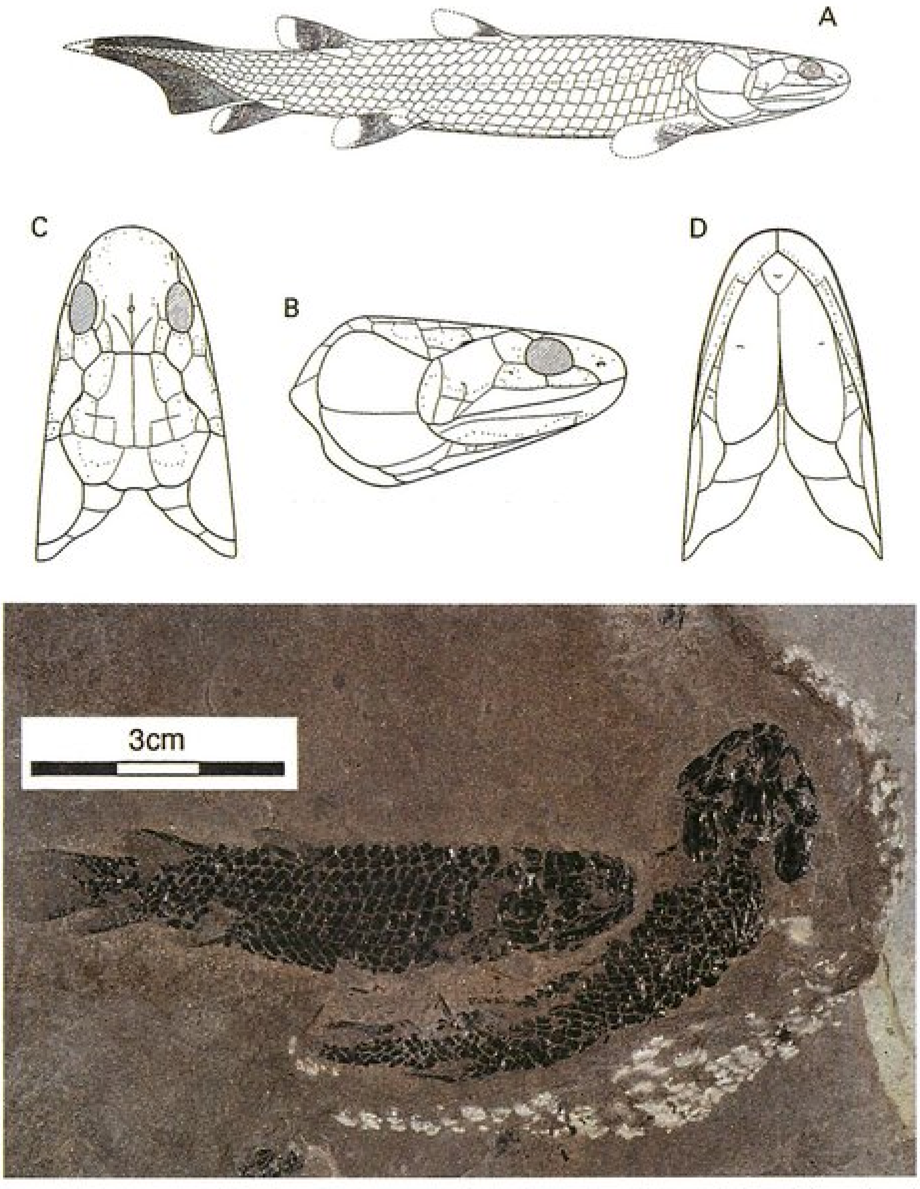
(Figure 5.18) A Cut and acid-etched cross-section of typical sand-filled lenticular shrinkage cracks in Association C. B Sand/ mud couplets with shrinkage cracks enhanced by weathering in quarry face. C Orange weathering dolomitic beds and disruption features near base of quarry section. Lower Flagstone 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 4) Stratigraphic nomenclature for the Devonian in eastern and southern Caithness and the Brora region of Sutherland. Modified from Trewin and Thirlwall (2002).

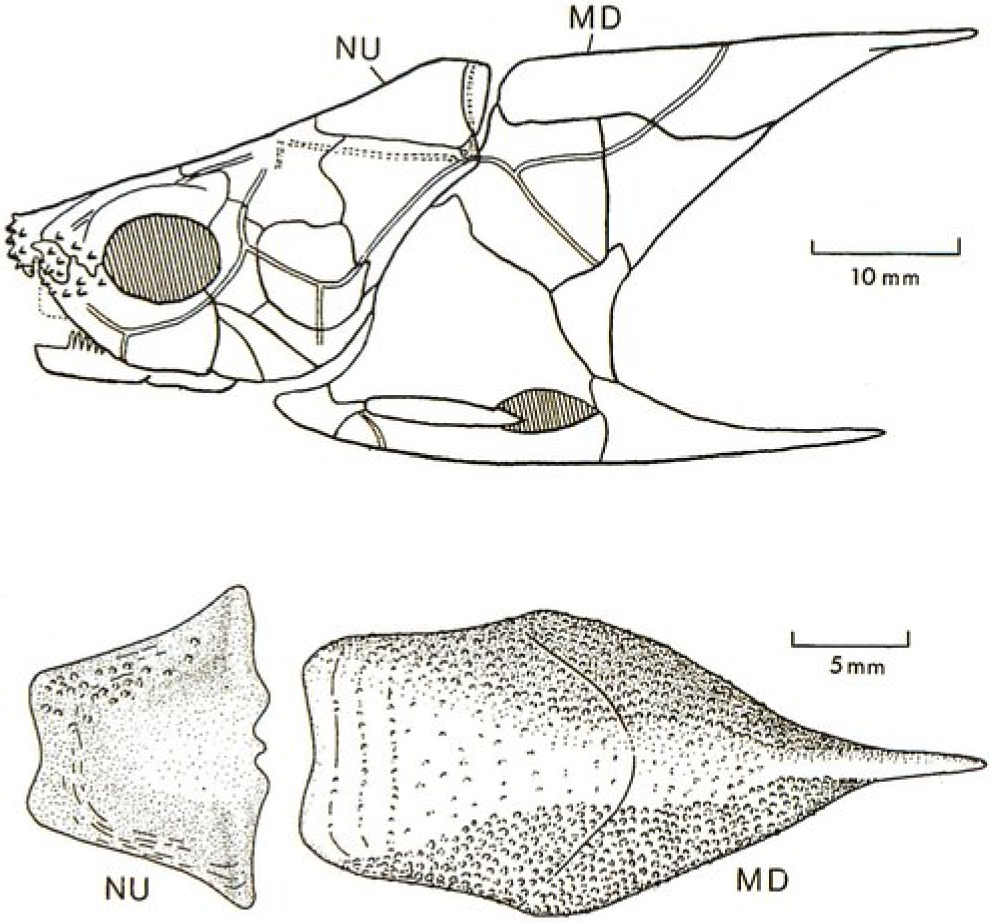
(Figure 5.20) Deformation features in carbonate laminites of a fish bed at Brims Ness. Coin 27mm. from the organic-rich laminites during burial. The cyclic nature of the sequence can be examined on the foreshore at mid to low tide.



(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.

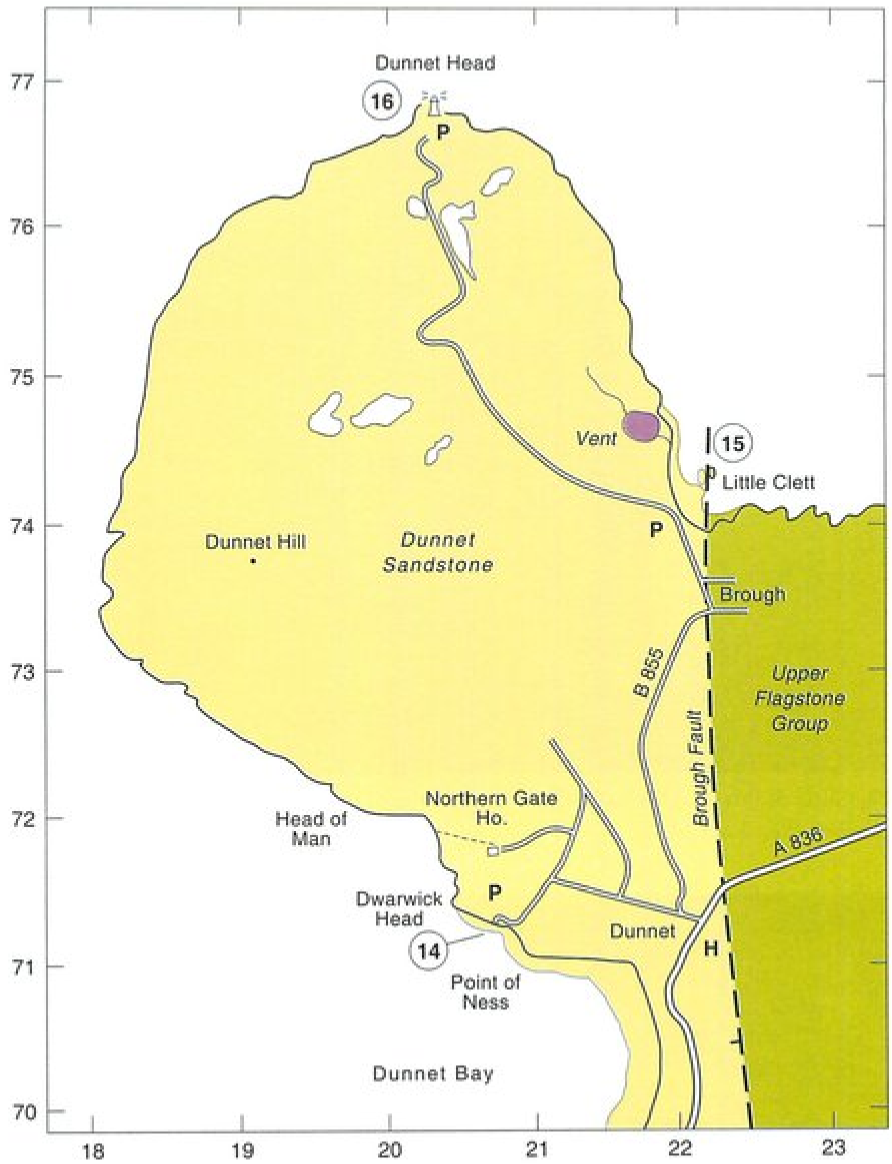
(Figure 5.22) Typical sand-filled lenticular shrinkage cracks from locality 12, Holborn Head Quarry.

(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).

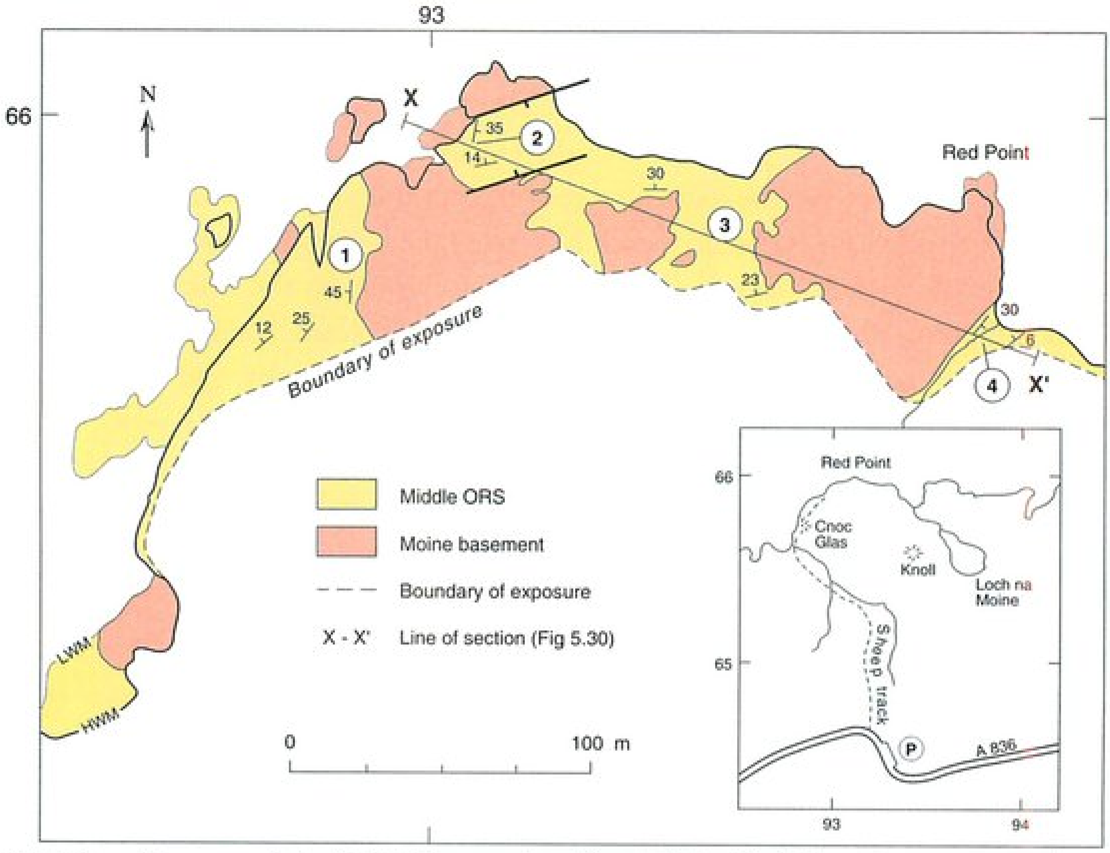
(Figure 5.25) Cross-bedded sandstones of mixed fluvial and aeolian origin. Promontary near isolated stack below building on cliff top, Thurso shore [ND 111 691].



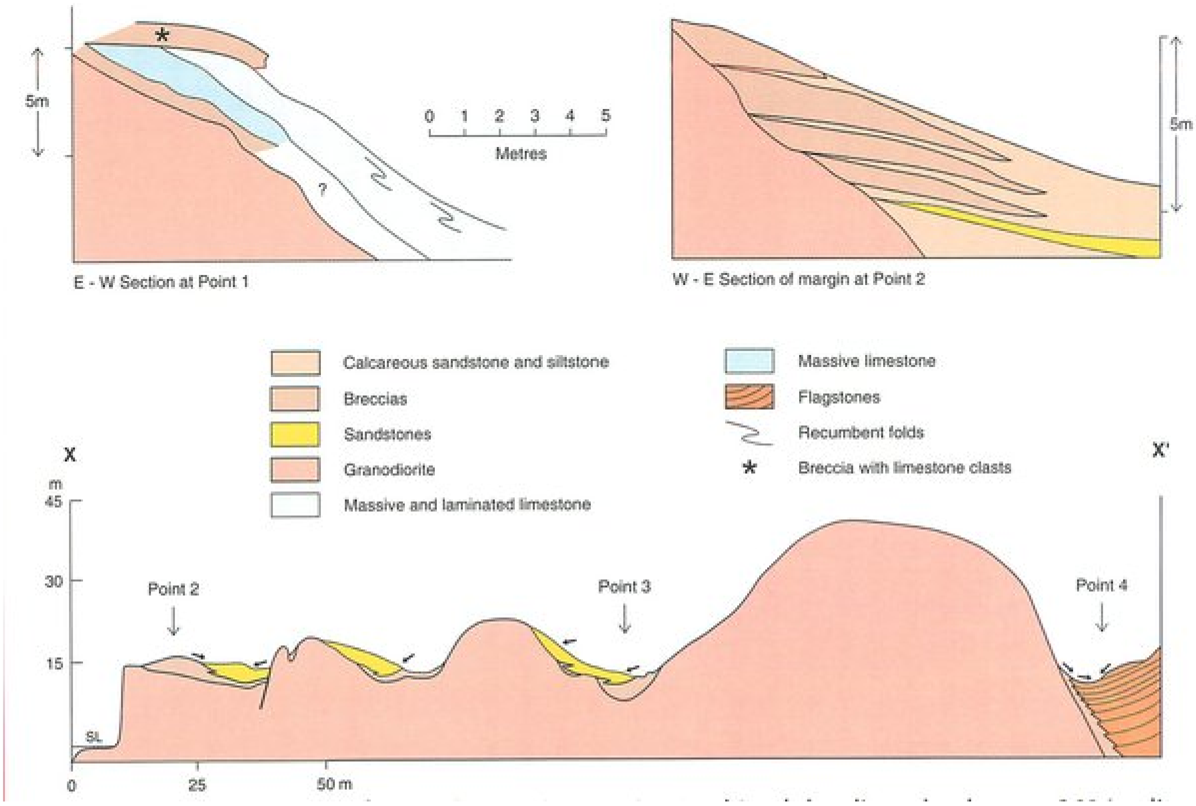
(Figure 5.26) Locality map for Dunnet Head area, itinerary 5.3.

(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.*

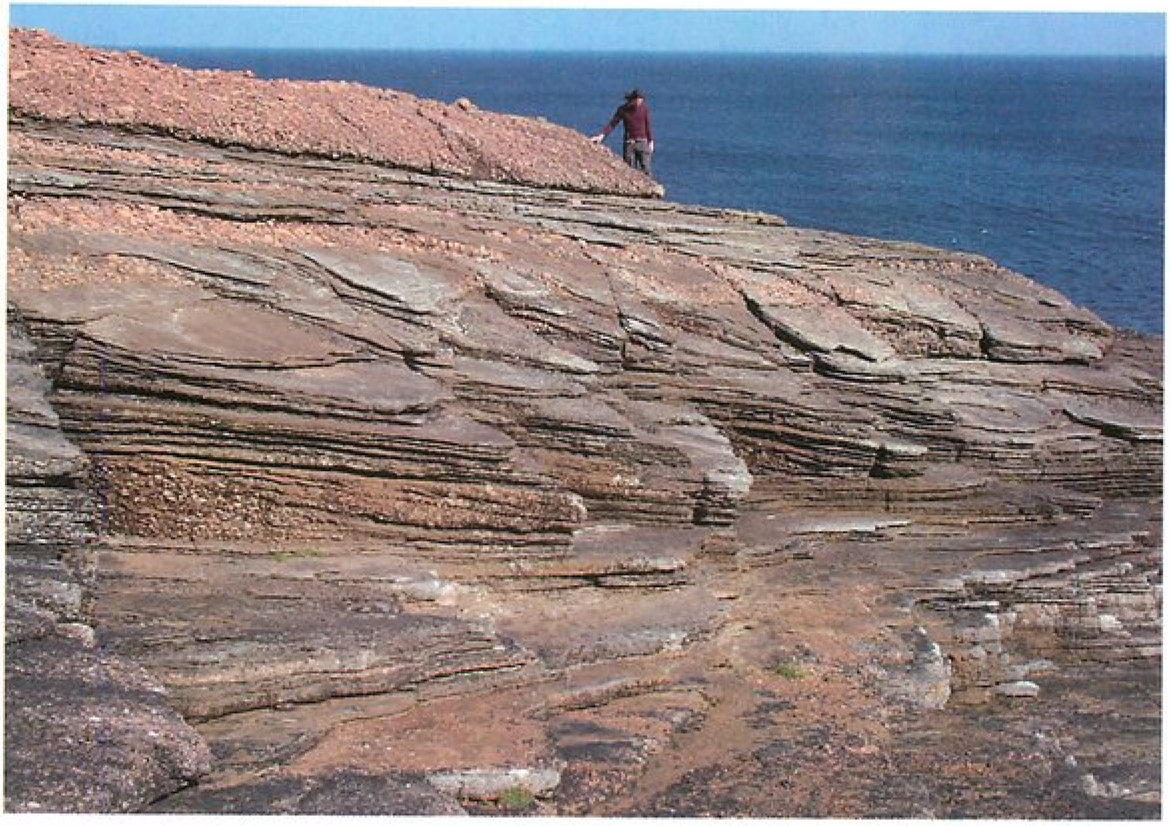


(Figure 5.29) Locality map of the Red Point area, locality 17 (Modified from Donovan 1975).

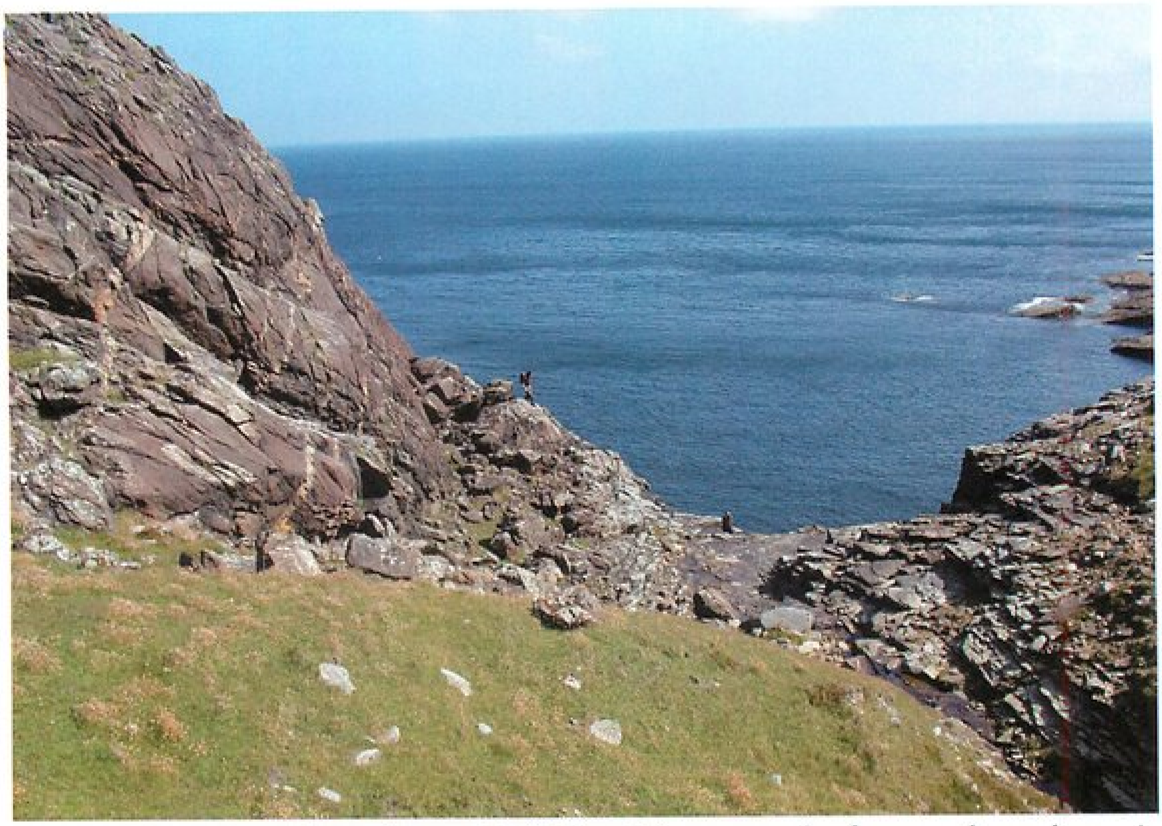


(Figure 5.30) Red Point, basement margin features. Cross sections at points 1 and 2 and along line x–x[1] as shown on (Figure 5.29) (modified from Donovan, 1975).

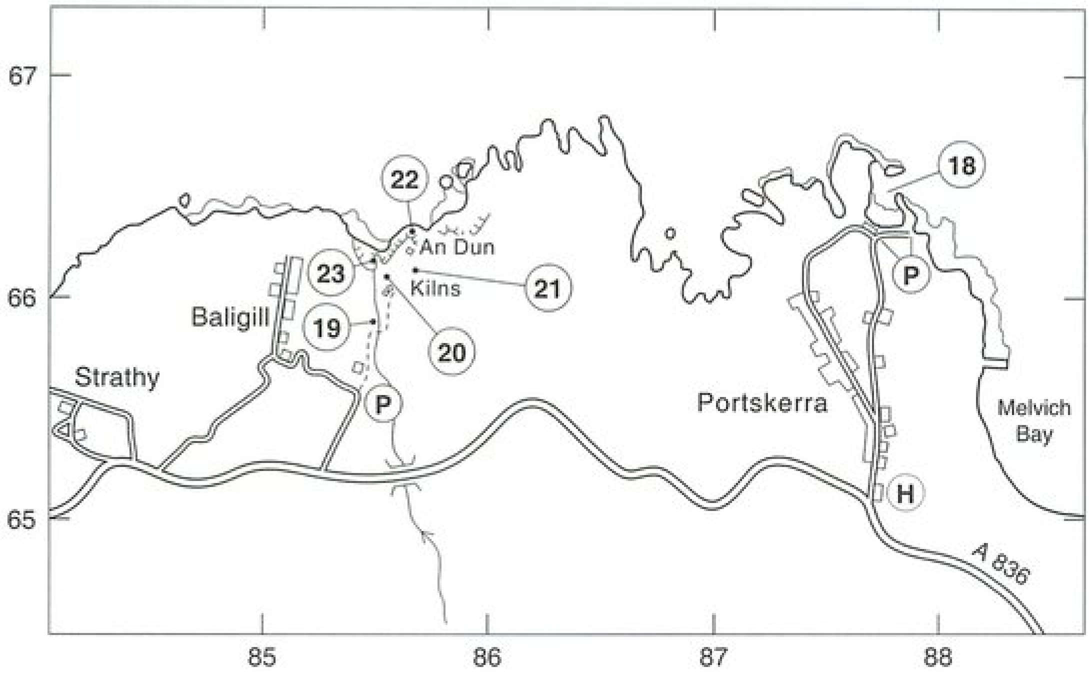
(Figure 5.31) Exposure at Point 1, Locality 17, Red Point. Steeply dipping limestone mantles the basement and is overlain by breccia.



(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.

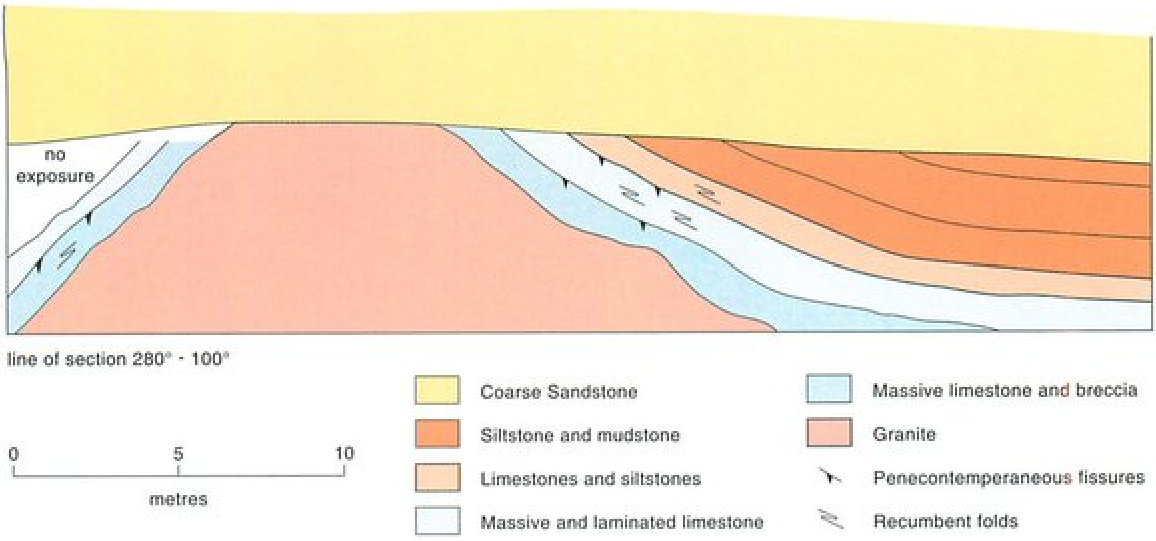
(Figure 5.35) View to the west of Portskerra Bay from the track to the slipway. Knolls of Moine gneiss are draped by Old Red Sandstone.

(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.

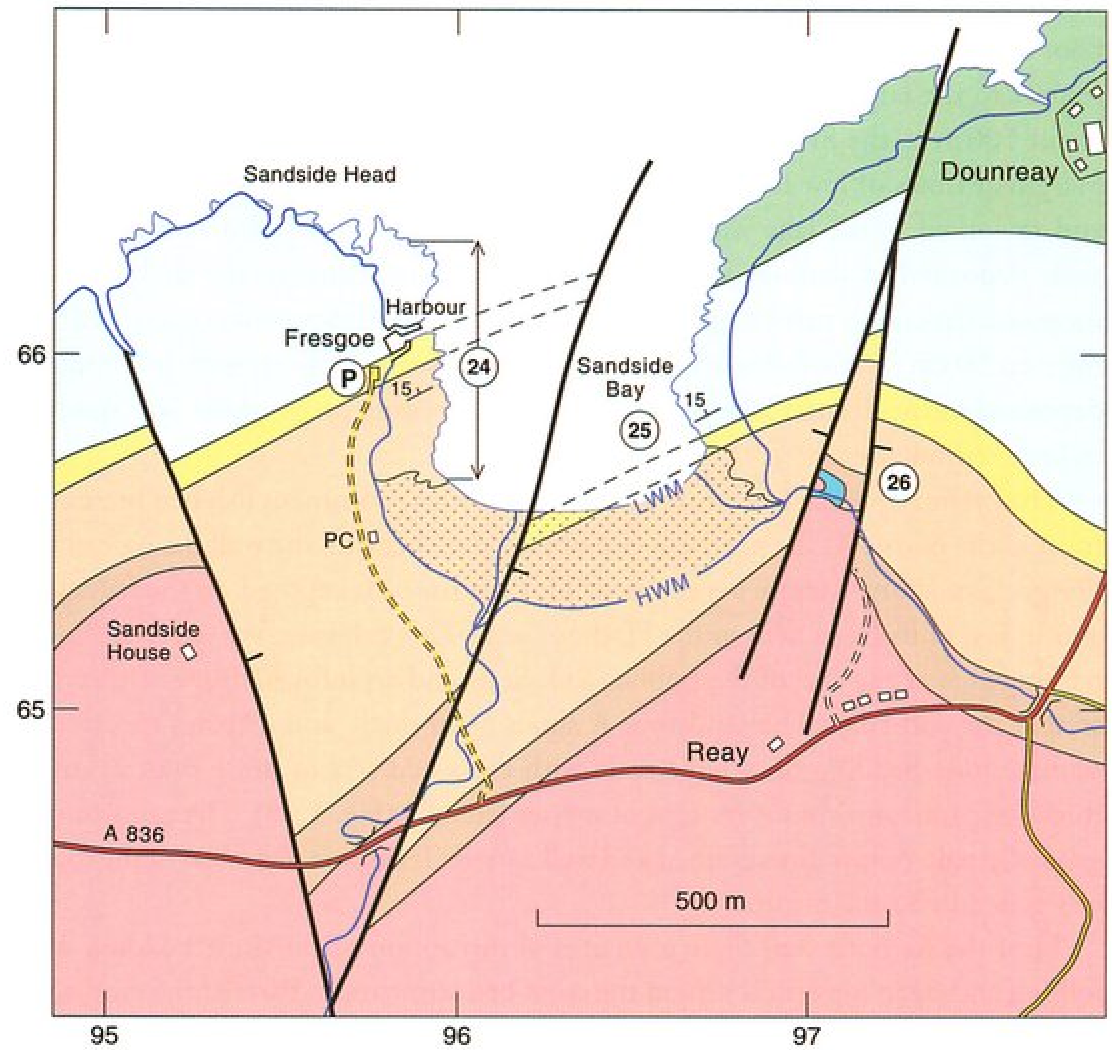
(Figure 5.38) Section at Locality 20, by the lime kilns. Shallowing-up section from lacustrine laminite at base of cliff to fluvial/ aeolian sandstones at top.

(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).

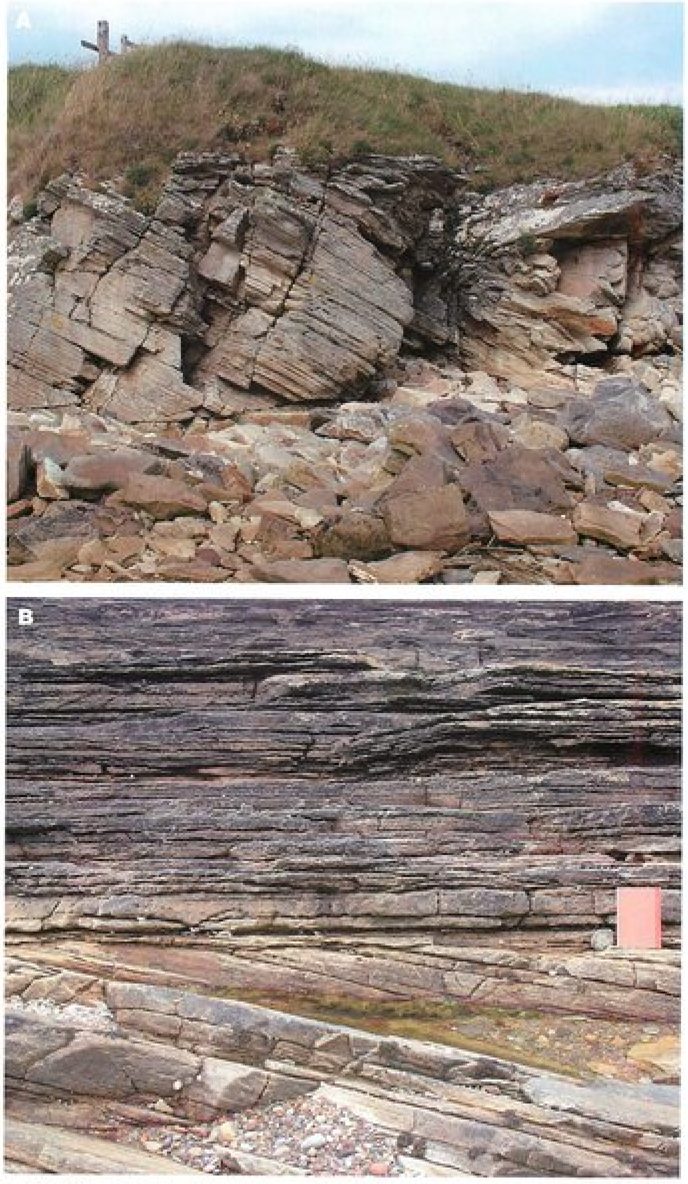
(Figure 5.41) View of the cliff face below An Dun showing outcrop of gneiss beneath grey lacustrine limestone that drapes the steep gneiss surface.



(Figure 5.42) Locality map, Sandside Bay.

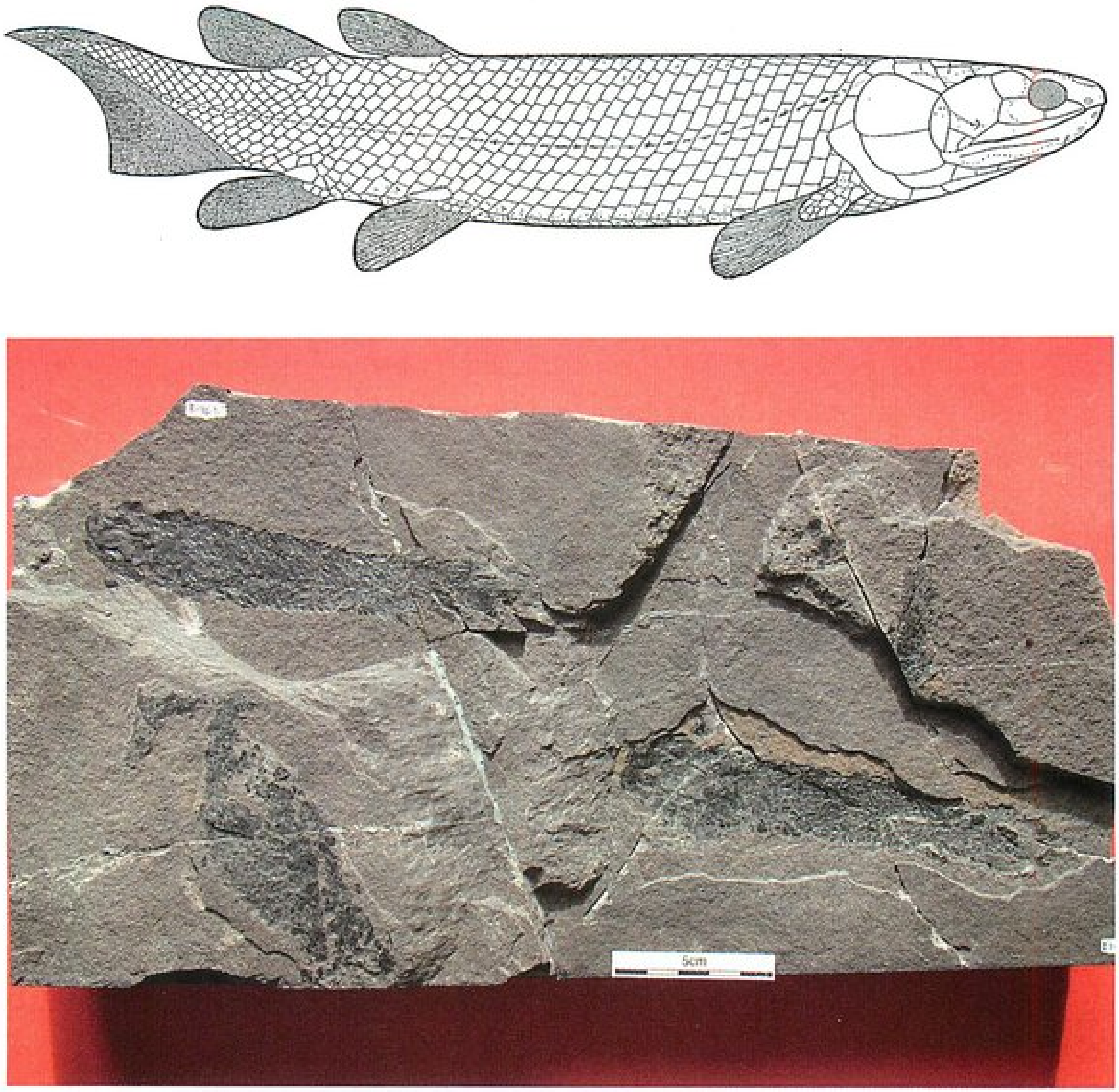
(Figure 5.43) Rippled sandstone overlying polygonal desiccation cracks. Bighouse Formation, Sandside Bay.

(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.