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## Chapter 2 The Orcadian Basin

### Introduction

P. Stone

The Devonian strata preserved in the north-east of mainland Scotland and the Orkney and Shetland islands are the remnants of deposits that accumulated in a major, intramontane lake rift-basin, the Orcadian Basin (Figure 2.1). Offshore well records and seismic data show a north-eastwards continuation of the basin beneath the North Sea, with probably equivalent strata also present to the west, in the West Orkney, Outer Isles and North Minches basins. The succession is over 4 km thick in Caithness and possibly twice that in parts of Shetland, where three distinct basins appear to have been juxtaposed by dextral strike-slip faulting (Mykura and Phemister, 1976). A restoration of the Shetland basins in relation to the main Orcadian depocentre is shown in (Figure 2.2). Overviews of the Orcadian Basin successions and their regional context were provided by Anderton *et al.* (1979), Dineley (1999a), and Woodcock and Strachan (2000). A summary of the Caithness succession was provided by Trewin (1993) and palaeogeographical reconstructions are given by Bluck *et al.* (1992).

Trewin and Thirlwall (2002) give a recent comprehensive account of the basin, and Marshall and Hewett (2003) provide a summary. The following introductory account is based on these sources.

Uplift and erosion dominated the northern Scottish region during Early Devonian times. Uplift was largely driven by the intrusion of an extensive suite of granitic plutons and was accompanied by strike-slip movement on major NE–SW-trending faults. Hence, the accumulation of Lower Devonian strata was localized and of variable lithology, lying unconformably on a surface of Moine, Dalradian and intrusive granitic rocks of the Highlands metamorphic complexes that had considerable local relief variations. A similar pattern continued into Mid-Devonian times, with the localised deposition of lake-margin facies, including carbonates, stromatolites and coarse alluvial breccias on the basement unconformity, but passing distally into and transgressively covered by fluvio-deltaic sandstones and lithologies of the developing deep-lake facies.

Lake transgression and regression occurred repeatedly through Mid-Devonian times and appear to have been relatively rapid events; sub-aerial, desiccation-cracked surfaces and deep-lake laminated mudstone facies occur locally in little more than 1 m of strata (Trewin, 1976). Elsewhere, a complex interplay of lacustrine and lake-shore environments gives intercalations of lake-floor, lake-delta, fluvial and aeolian deposits. During at least one episode, the lake waters extended across the whole basin area, resulting in deposition of the famous Achanarras fossil fish-bearing laminite and its correlatives. At other times, there were smaller and more localized lakes, separated by areas of fluvial or aeolian deposition. The lakes within the Orcadian Basin were fed by streams draining from surrounding high ground in a climate that was hot and varied between humid and semiarid. The lakes were never very deep, perhaps up to about 80 m when the Achanarras Fish Bed was deposited (Hamilton and Trewin, 1988), at which time the lake covered some 50 000 km<sup>2</sup>. However, basinal subsidence was rapid, since up to 5 km of strata accumulated in about only 10 million years. The evidence for decreasing alluvial-fan progradation and more extensive lakes suggests that regional thermal subsidence replaced crustal extension and normal faulting as the main subsidence mechanism in Mid-Devonian times.

The Middle Devonian fish-bearing laminites are a highly unusual lithofacies. Their regular, parallel, planar bedding facilitated their use as flagstones, examples of which can be seen in many British cities, and they are commonly known as 'Caithness Flags'. The GCR sites at Achanarras Quarry and Wick Quarries are disused flagstone quarries. The flagstones were deposited in the large, ephemeral lakes and have a cyclic character. Donovan (1980) recognized a basic sequence of four lithofacies associations ('B', 'C' and 'D'), representing a range of conditions from deep to shallow lake and exposed playa surface ((Figure 2.3); Trewin, 1993; Trewin and Thirlwall, 2002). In practice, a great deal of facies variation arose through local differences in sediment supply, subsidence, carbonate production and water conditions. Donovan's 'A association' — the fish-bearing laminites — were deposited during the deep lake phase as intercalated silt, carbonate and organic laminae. They are interpreted as seasonal varves, controlled by annual climate variations. Clastic

laminae represent input from rivers during the wet season, deposited from suspension. The carbonate laminae formed through increased photosynthesis in the dry season when algal phytoplankton blooms flourished in the lake waters, and the organic laminae formed by the subsequent annual decay of the phytoplankton. Shallower lake facies, the 'B & C associations' of Donovan, are thicker laminated and wave-rippled, with probable subaqueous shrinkage (synaeresis) cracks (although this interpretation is not universally accepted; see Astin and Rogers (1991) and subsequent discussions (Astin and Rogers, 1992, 1993; Trewin, 1992; Barclay *et al.*, 1993); see also Plummer and Gostin (1981) for a discussion on shrinkage cracks). Donovan's 'D association' formed in shallow, ephemeral lake conditions that produced abundant surfaces with polygonal arrays of desiccation cracks and shallow-water rippled surfaces; fluvial and aeolian influences may also have been present.

The Orcadian Basin lake(s) probably drained south-eastwards to the sea, the earliest evidence for possible marine influence within the basin being seen late in the Middle Devonian succession of Orkney (Marshall *et al.*, 1996). A marine connection became more important during Late Devonian times. Over most of the basin, the boundary between Middle and Upper Old Red Sandstone is conformable, but there is some evidence for localized tilting of the Middle Devonian strata, interpreted as a phase of limited basin inversion prior to Late Devonian sedimentation. More commonly, the base of the Upper Devonian Series is marked by a change in depositional environment. The Mid-Devonian lakes were replaced in the basin centre by sabkha plains that were periodically inundated by the sea, whilst meandering- and braided-river deposits accumulated on the basin margins.

Most of the preserved succession and the GCR sites in the Orcadian Basin are of Mid-Devonian age. The stratigraphical positions and ranges of the sites are shown in (Figure 2.4). The lithostratigraphical scheme for the basin is not wholly satisfactory in modern terms and is currently under review. The version used in this account is largely that used by Dineley (1999a) in the *Fossil Fishes of Great Britain* GCR volume (Dineley and Metcalf, 1999), with small modifications to take account of recent developments.

## Shetland

The Devonian strata of Shetland are separated into discrete terranes by a series of major north–south faults (Figure 2.5). There are considerable lithological and structural differences between the sequences in each of the terranes, but all are of Eifelian to Givetian, Mid-Devonian age (Figure 2.4). They have been related to three separate depocentres, juxtaposed by dextral strike-slip fault movements (Mykura and Phemister, 1976). Their possible restoration in relation to the main Orcadian Basin is shown in (Figure 2.2).

The westernmost terrane, to the west of the Melby Fault, is the smallest and may have originated closest to the main Orcadian Basin; its Old Red Sandstone lithofacies, of late Eifelian age, is certainly the most similar of the Shetland varieties to those of Caithness and Orkney. The Melby GCR site shows two wholly lacustrine intervals alternating with thick fluvial sandstones. The lacustrine beds are thinly laminated, silty mudstones with carbonate nodules that contain an important fossil fish fauna, described in the *Fossil Fishes of Great Britain* GCR volume (Dineley and Metcalf; 1999). This fauna is considered to be slightly older than the Achanarras (Caithness) fauna.

East of the Melby Fault, and bounded to the east by the Walls Boundary Fault, lies a terrane that contains the Devonian succession of the Walls Peninsula. This is represented by probable fluvial channel and overbank, littoral and shallow lacustrine lithofacies is perhaps more likely. The Devonian strata of the Walls Peninsula are more severely deformed than any other parts of the Orcadian Basin successions.

The Devonian succession of the eastern terrane, east of the Nesting Fault, is separated from those to the west by a basement terrane devoid of Devonian cover. There are two GCR sites, both with strata of Givetian age, at Easter Rova Head near Lerwick and at The Clefts near Exnaboe. The Easter Rova Head site shows a coarse, conglomeratic lake-margin alluvial fan comprising sheet-flood and mass-flow deposits. It probably rests unconformably on basement rocks, although the contact is not seen. Farther south, at The Clefts, a sequence of interbedded lacustrine mudstones and braided stream, alluvial-fan, deltaic and aeolian sandstones records the transgressive and regressive phases of the Orcadian Basin lake. The lacustrine mudstone contains a fossil fish fauna (described in the GCR fossil fishes volume, Dineley and Metcalf, 1999) of about the same age as that found at Pennyland (Thurso–Scrabster), and slightly younger

than the Achanarras fauna.

## **Orkney**

Givetian strata within the Footabrough to Wick of Watsness GCR site. The thick alternations of sandstone, siltstone and mudstone may have formed by turbidite deposition in a deep lake environment, but some combination of braided The Orkney Islands consist principally of Devonian strata (Figure 2.6). The only significant exceptions are small basement inliers of granitic and schistose lithologies on the southwest coast of the island of Mainland and the adjacent small island of Graemsay. The pre-Devonian relief was of the order of 100 m, and locally steep and craggy. Two of the Orkney Devonian GCR sites, South Stromness Coast Section and Yesnaby and Gaulton Coast Section, show the basal unconformity. At Yesnaby, Lower Devonian sandstone, breccia and conglomerate rest on crystalline basement, whereas at South Stromness the breccias and conglomerate above the unconformity are believed to be of Mid-Devonian, Eifelian age. The likely age difference is emphasized by the tilting of the Lower Devonian strata at Yesnaby so that the basal sedimentary sequence is overlain unconformably by Middle Devonian rocks; at South Stromness the sedimentary relationships above the basal unconformity are all conformable. The Lower Devonian sequence represents alluvial-fan, lacustrine mudflat, aeolian dune and beach deposition.

In their higher parts, both the South Stromness Coast Section and Yesnaby and Gaulton Coast Section provide splendid sections through the Eifelian to Givetian lacustrine succession of the Orcadian Basin. A series of sedimentary cycles records lake transgression and regression, with evidence for sequential deep-lake, shallow-lake margin with alluvial fans, and subaerial, desiccated lake environments, as well as sporadic fluvial sedimentation. Within the deep lacustrine lithofacies of the Stromness site is the well-known Sandwich Fish Bed, the fossil fauna of which is described in the *Fossil Fishes of Great Britain* GCR volume (Dineley and Metcalf, 1999). The Sandwich Fish Bed is the stratigraphical equivalent of the fish-bearing laminite at Achanarras, thus demonstrating the wide extent of this deep lacustrine facies during a phase of maximum lake development.

Sandstones of Givetian age that are probably fluvial also form the lower parts of the successions in the Taracliff Bay to Newark Bay (east Mainland) and the Old Man of Hoy Coast GCR sites. On Hoy, these Middle Devonian sandstones were gently folded before being unconformably overlain by Middle Devonian lavas and Upper Devonian sandstones. In contrast, between Taracliff Bay and Newark Bay, there is an upward, conformable transition into Givetian sandstones and mudstones. These indicate deposition in alternating lake and alluvial-plain environments, with an overall trend towards fluvial sedimentation on an open sabkha plain. The South Fersness Bay (Eday) GCR site provides an alternative viewpoint on the mid-Givetian environment in the Orcadian Basin. There, the sequence of facies records alternations between lake, mudflat, aeolian dune-field and alluvial-plain environments.

The youngest part of the Orkney Givetian succession is seen at the Greenan Nev Coast GCR site (Eday) and the potential site at Bay of Berstane (east Mainland). At Greenan Nev, the lithofacies indicate deposition in alluvial plains and channels and sabkhas. Horizons of carbonate soil nodules (calcrete) and possible fish burrows are preserved. In the Bay of Berstane section, a mudstone contains marine microfossils and pseudomorphs after halite, suggesting that the lakes and sabkha plains of the Orcadian Basin were intermittently inundated by the sea late in Mid-Devonian times.

Volcaniclastic sandstones and basaltic lavas unconformably overlie early Givetian strata in the Old Man of Hoy Coast GCR site. Following the cessation of volcanic activity, the Orcadian Basin became a wide floodplain during Late Devonian times, with fluvial sandstones deposited in braided river channels. Fine-grained sediment accumulated between the channels in small lakes and sabkhas, whilst the fluvial sands were locally reworked into aeolian dune-fields. This sandstone-dominated succession forms the spectacular, 350 m-high cliffs that form the north-west coast of Hoy, as well as the cliffs of Dunnet Head on the Scottish mainland.

## **North-eastern Scottish mainland**

The outcrops of Devonian strata in north-east Scotland, and the location of the GCR sites are shown in (Figure 2.7). The principal outcrops are in eastern Caithness, and in the Moray Firth from east of Elgin westwards to Inverness and north to Golspie. The Turriff Basin is the largest of the smaller outcrops, with smaller outliers at Tomintoul, Cabrach and Rhynie.

Lower Devonian strata are seen in the GCR sites at Rhynie (Aberdeenshire) and Sarclet (Caithness). Middle Devonian strata rest unconformably on Lower Devonian strata in the fault-bounded Turriff Basin, as seen in the impressive sea cliffs at Pennan, New Aberdour and Quarry Haven (see Den of Findon GCR site report, this chapter). The Lower Devonian sequence at the Rhynie site is particularly unusual in that it contains chert beds with exceptionally well-preserved terrestrial plant and arthropod fossils, for which it is world-famous, their preservation being fortuitously due to silicification of lacustrine sediments by a hot spring system. The site is separately selected for the GCR for its fossil plants (Cleal and Thomas, 1995), and is also of great importance in being the surface expression of one of the earliest known examples of a hot spring system. The succession at Rhynie lies close to the western faulted margin of a small, isolated half-graben. Initial local conglomeratic fluvial deposition accompanied by andesitic volcanic activity was followed by ephemeral lacustrine and floodplain environments into which the silica-rich fluids were introduced to produce the cherts, which are fossil sinters. Farther north, within the main outcrop of the Orcadian Basin, the late Emsian sequence at Sarclet (Caithness) shows an upward transition from alluvial-fan conglomerates into mixed, probably fluvial and aeolian facies and then lacustrine facies. This represents one of the earliest lake developments in the Orcadian Basin.

Most of the mainland GCR sites are in Middle Devonian strata, with basal lithofacies unconformably overlying basement seen at Red Point (and nearby Port Skerra and Balygill) in Caithness and at Dun Chia Hill (Loch Duntelchaig) in Inverness-shire. The successions are believed to be Eifelian to Givetian in age and to merge laterally with deeper-water lacustrine deposits farther into the basin. At Red Point, towards the western margin of the Orcadian Basin, limestone and coarse breccia tongues rest unconformably on a high-relief granodiorite basement and merge laterally with fluvial and lacustrine sandstone and mudstone. The Dun Chia Hill site shows the basal relationships at the southern margin of the Orcadian Basin. There, a coarse debris-flow breccia unconformably overlies a steeply undulating basement of Dairadian psammites.

Lower Devonian rocks (the Crovie Group of the Lower Old Red Sandstone) are present in the largely fault-bounded Turriff and Rhynie basins. Middle Devonian (the Findon Group of the Middle Old Red Sandstone) rocks overlie the Crovie Group unconformably. The Turriff Basin extends about 30 km inland from the superb exposures of its fill on the Moray Firth coast at Gamrie Bay and New Aberdour. Coarse, basal conglomerates of the Crovie Group fill an irregular Dalradian basement topography and are succeeded by a 600 m-thick variable succession of alluvial-fan conglomerates and sandstones and floodplain/playa mudstones. The Findon Group also comprises basin-margin alluvial-fan deposits, derived from the south, but fan progradation was halted at the time of maximum Achanarras lake extent, when the Gamrie Fish Bed was deposited, as seen at the Den of Findon GCR site in Banffshire. The description of this site includes a brief account of the magnificent cliff and foreshore sections of the Crovie and Findon groups nearby in Gamrie Bay, New Aberdour and Quarry Haven, which also merit protected status.

The main lacustrine lithofacies of the Orcadian Basin, spanning the Eifelian and Givetian stages, are represented by three GCR sites in Caithness (Wick Quarries, Achanarras Quarry, and Pennyland (Thurso–Scrabster)), in addition to two sites on the southern margin of the basin (Tynet Burn, Moray, and the Den of Findon). The oldest strata, of Eifelian age, are seen in the old flagstone quarries and cliff sections at South Head, Wick. Two sequential lacustrine shallowing and deepening cycles are represented, with a splendid array of shrinkage cracks and soft-sediment deformation features. The disused flagstone quarry at Achanarras contains strata deposited at the acme of lacustrine development around the Eifelian–Givetian boundary. The extensive fossil fish fauna from this site is world-famous and has led to Achanarras Quarry being selected as a GCR site for fossil fishes (Dineley and Metcalf, 1999). Givetian strata at a level above that seen at Achanarras are exposed in the Pennyland cliff and foreshore to the west of Thurso. About 20 lithofacies cycles demonstrate the repeated, abrupt shallowing and deepening of the Orcadian Basin lake. In addition, there is good preservation of a spectacular array of shrinkage crack styles. Fossil fish have been recovered from several levels within the section and the site is separately selected for the GCR as a fossil fishes site (Dineley and Metcalf; 1999).

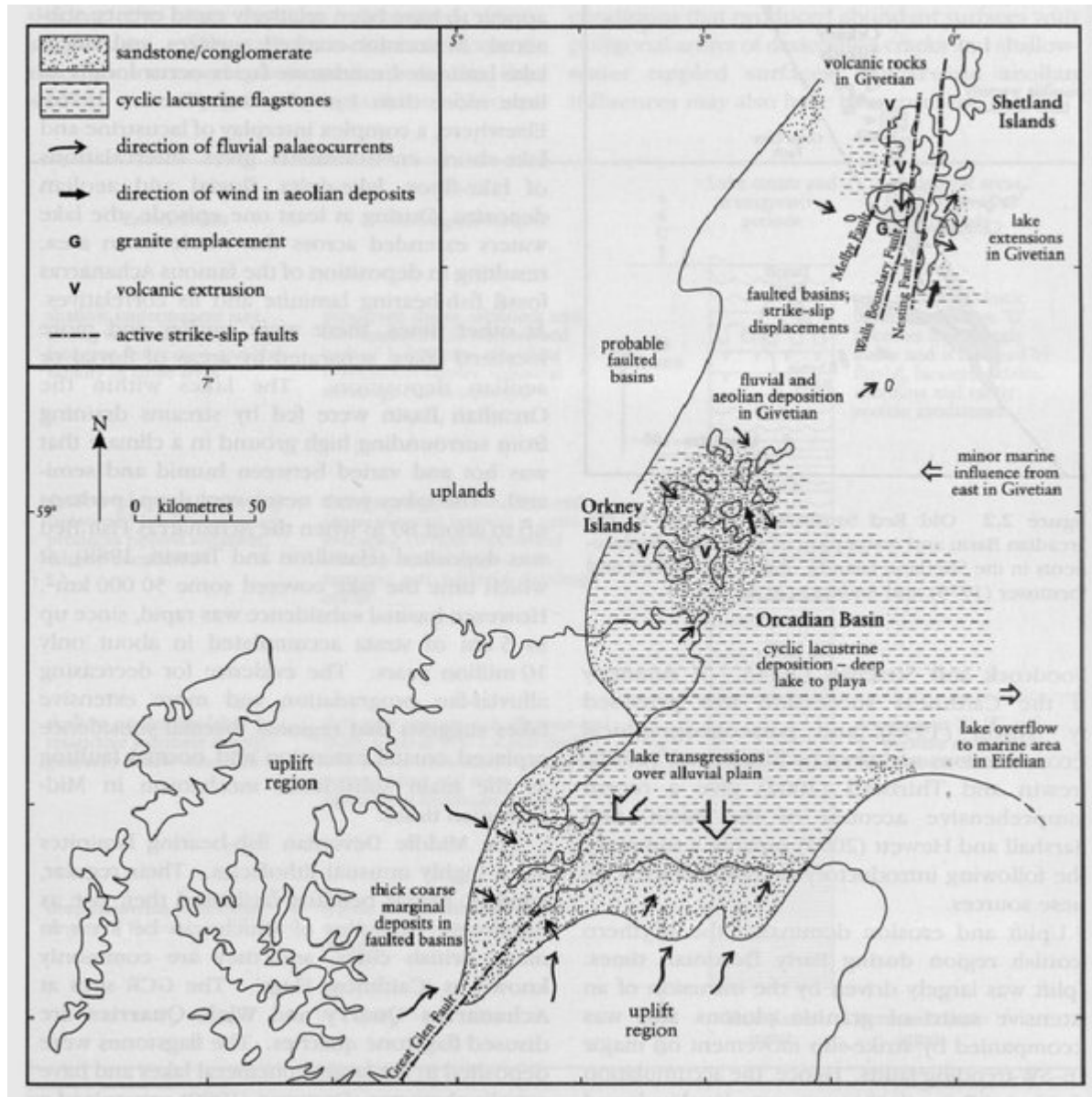
The highest Middle Devonian strata are seen at the John o'Groats GCR site, accorded protected status because of its fish fauna (Dineley, 1999a). A description of this site is extended here to include the fine exposures of the John o'Groats Sandstone Group to the east near Duncansby Head.

Upper Devonian strata are relatively rare within the mainland outcrop of the Orcadian Basin, but are represented in the GCR site at Tarbat Ness (Ross), close to the southern margin of the basin. They are also present at Dunnet Head near

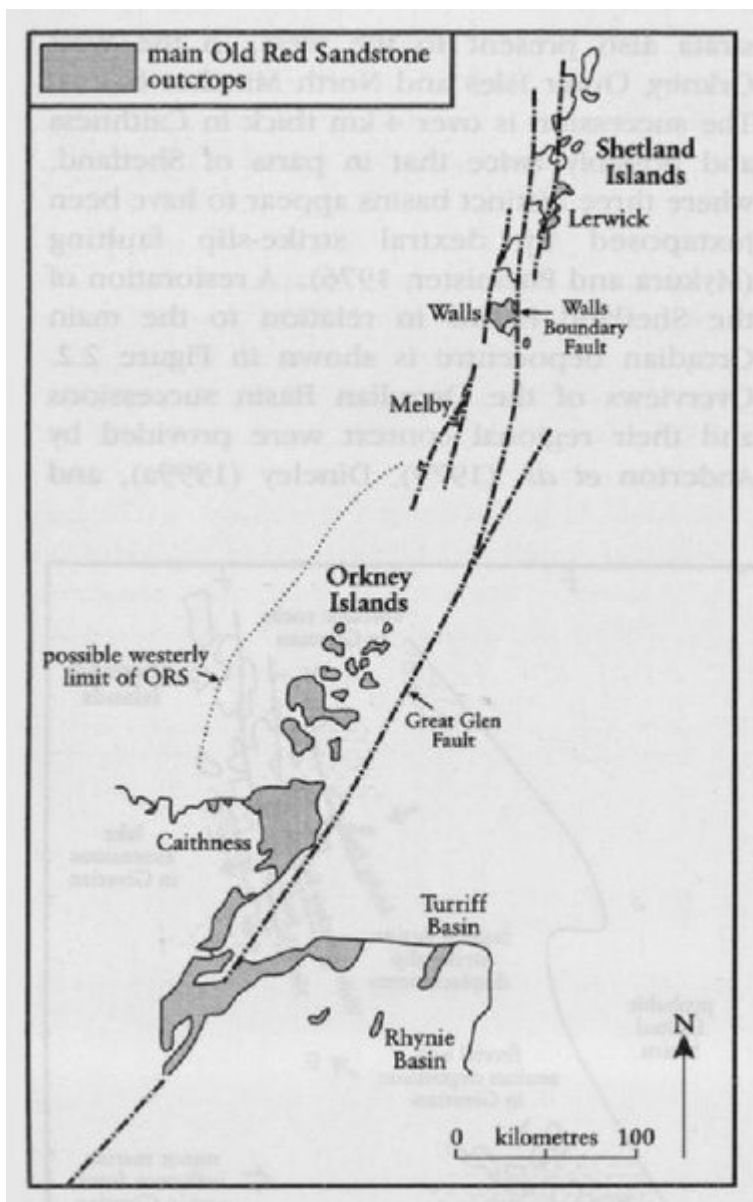
Thurso, where there are spectacular cliffs of the Dunnet Head Sandstone Group, of similar facies to the Hoy Sandstone Formation in Orkney. The cliffs are accessible at the north end of Dunnet Bay, where they provide a superb teaching section of bar and channel facies variations in a low-sinuosity sand-bed river system (B.P.J. Williams, pers. comm.); this section should be considered as a complementary site.

In the lower part of the succession exposed at Tarbat Ness, Givetian fluvial sandstones with sporadic lacustrine mudstones lie at the top of the Middle Devonian succession. They are conformably overlain by fluvial, aeolian and sabkha-like deposits, believed to be Frasnian to Famennian in age. The sabkha deposits contain striking examples of desiccation and evaporitic structures.

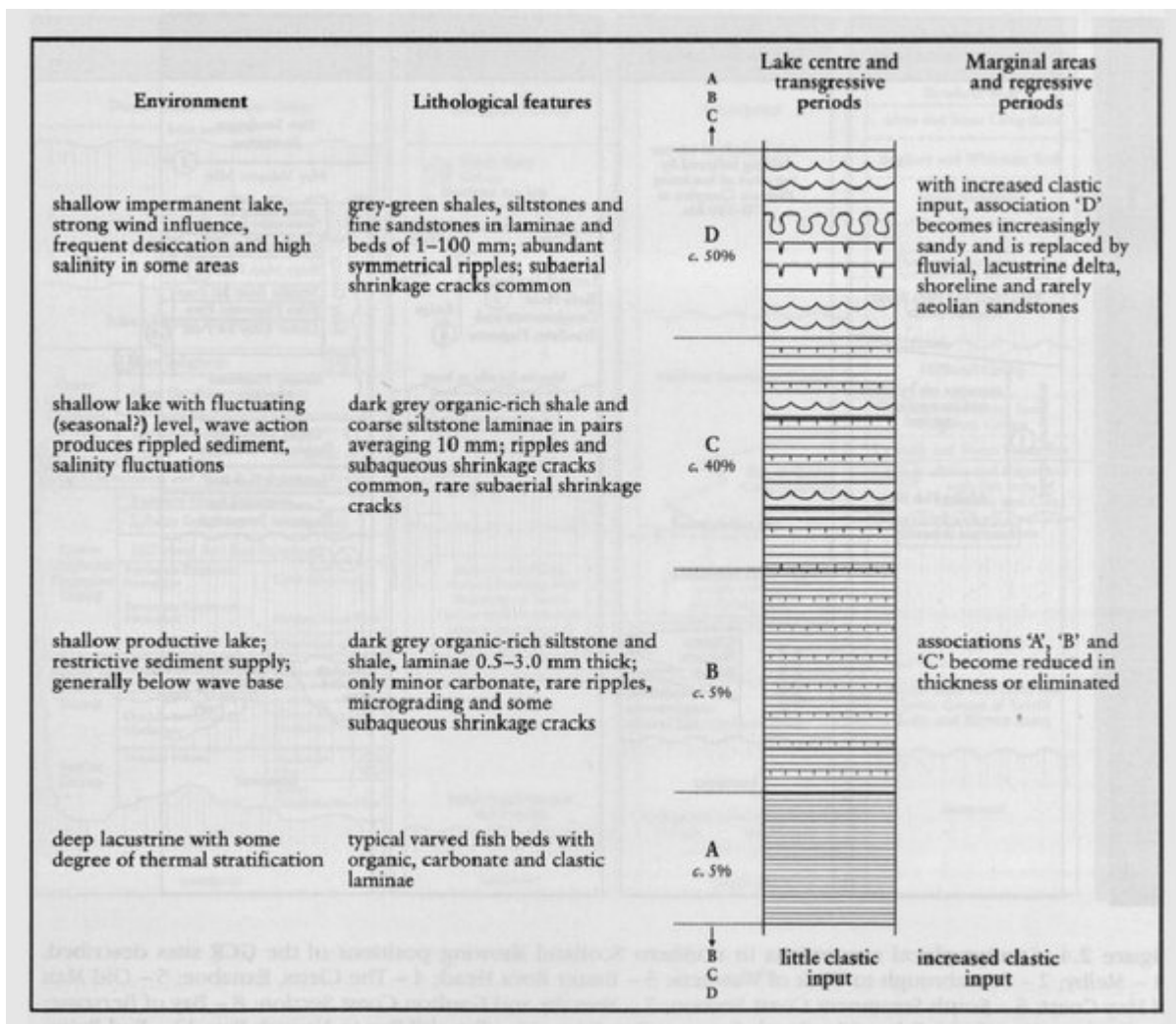
## References



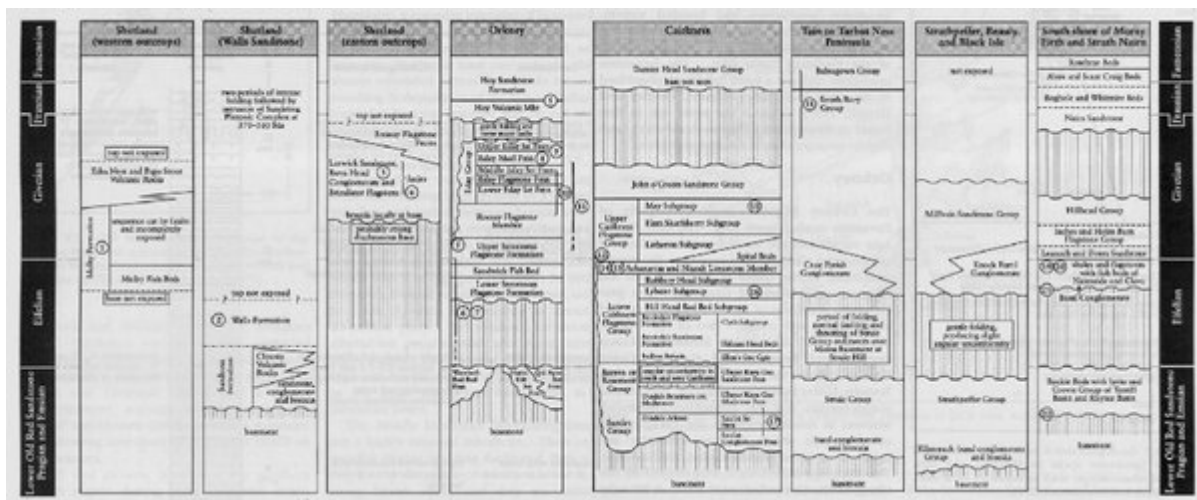
(Figure 2.1) Generalized Mid-Devonian palaeogeography based on present geography of northern Scotland. After Trewin and Thirlwall (2002).



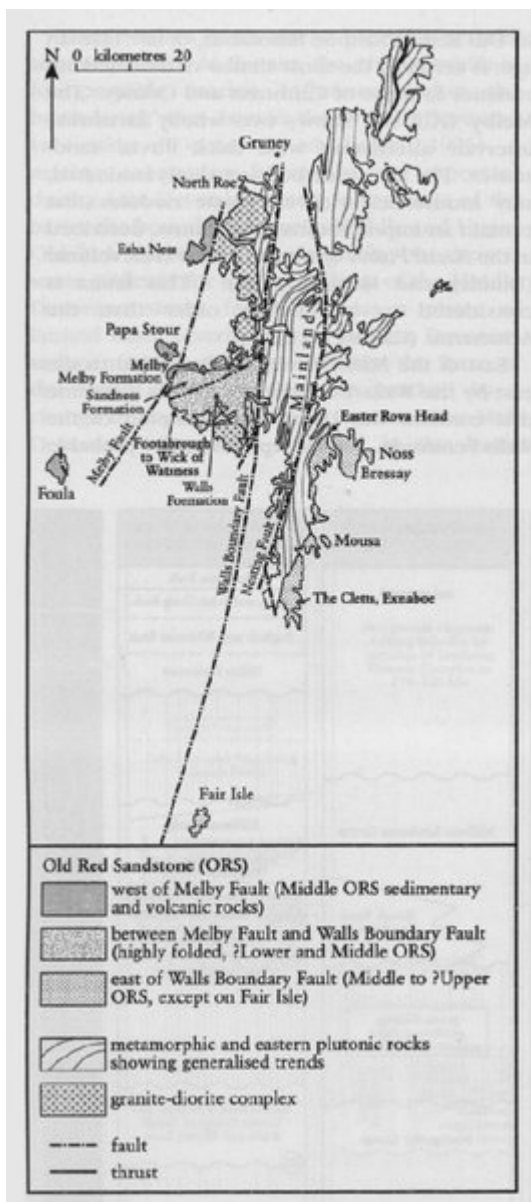
(Figure 2.2) Old Red Sandstone outcrops in the Orcadian Basin and restoration of strike-slip displacements in the Shetland Islands. Based on Mykura and Plemister (1976) and Anderton et al. (1979).



(Figure 2.3) Cyclic lacustrine facies in the Caithness Flagstone Group. After Trewin and Thirlwall (2002), from Donovan (1980).

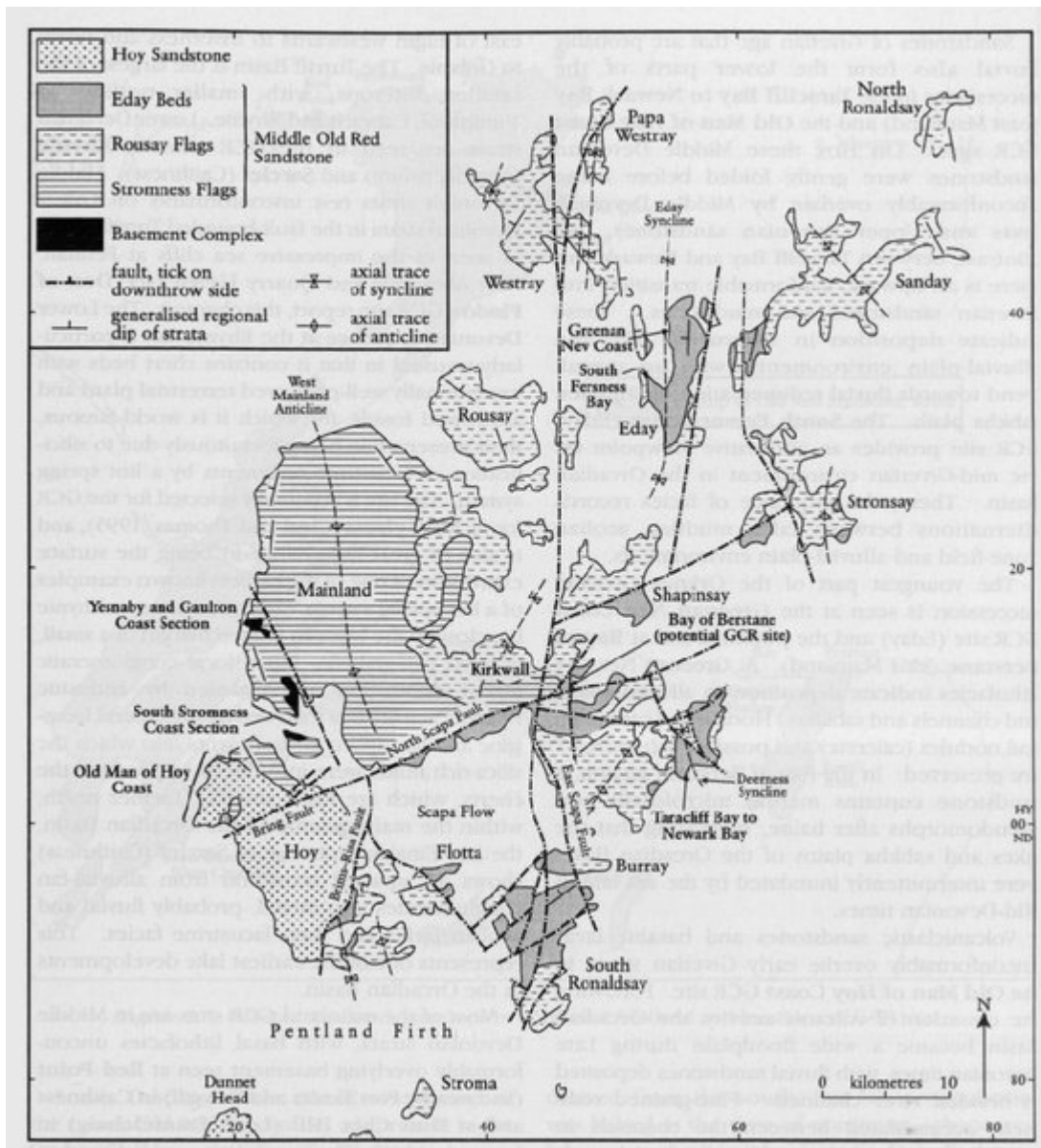


(Figure 2.4) Stratigraphical successions in northern Scotland showing positions of the GCR sites described. (1 — Melby; 2 — Footabrough to Wick of Watsness; 3 — Easter Rova Head; 4 — The Cletts, Exnaboe; 5 — Old Man of Hoy Coast; 6 — South Stromness Coast Section; 7 — Yesnaby and Gaulton Coast Section; 8 — Bay of Berstane; 9 — Greenan Nev Coast, Eday; 10 — South Fersness Bay, Eday; 11 — Taracliff Bay to Newark Bay; 12 — Red Point; 13 — Pennyland (Thurso–Scrabster); 14 — Achanarras Quarry; 15 — John o'Groats; 16 — Wick Quarries; 17 — Sarclat; 18 — Tarbat Ness; 19 — Tynet Burn; 20 — Den of Findon; 21 — Dun Chia Hill (Loch Dunteichaig); 22 — Rhynie.)

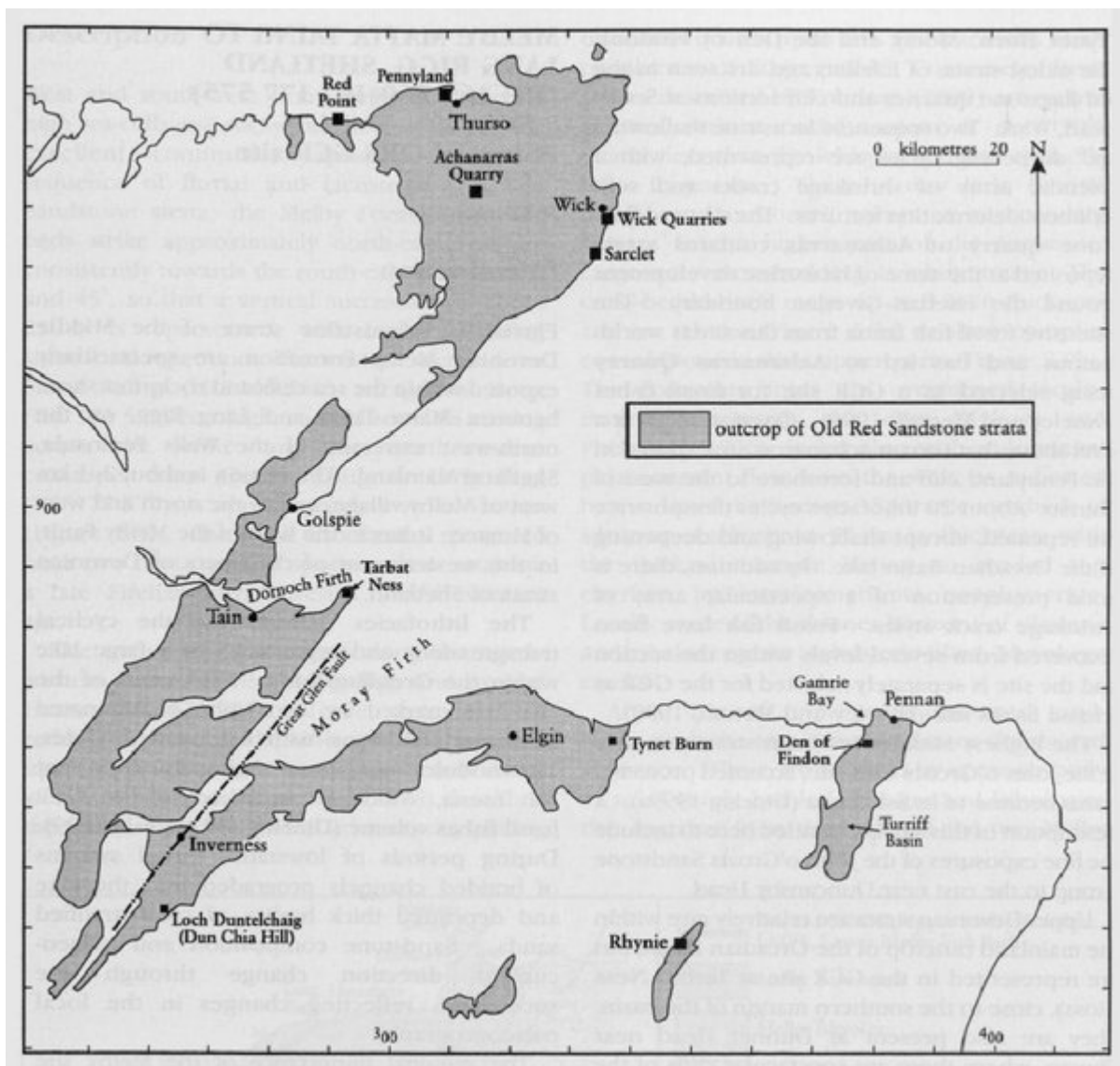


(Figure 2.5) Geological sketch map of the outcrops of Old Red Sandstone rocks in Shetland and their structural relationships; with locations of GCR sites. After Mykura and Phemister (1976).





(Figure 2.6) Geological sketch map of Orkney with locations of GCR sites, indicated in bold typeface. After Mykura and Phemister (1976).



(Figure 2.7) Old Red Sandstone outcrops in north-east Scotland and locations of GCR sites.