# Chapter 3 Devonian (Old Red Sandstone)

## Introduction

The Devonian rocks of the area are immensely thick. Often 1 red in colour – they were deposited 20°–30° S of the equator (Rayner 1981) — and entirely non-marine, they fall into the facies known in Britain as the Old Red Sandstone and this term, though only broadly equivalent to Devonian in a time sense, is used throughout this account. Unfortunately fossils are rare so that detailed subdivision of the Old Red Sandstone is difficult, but enough fossil fish have been found to show that only rocks belonging to the Upper and Lower divisions occur in the area and that there is a marked unconformity between them. It is, however, now generally agreed that the lowest units of the Old Red Sandstone at Stonehaven are late Silurian in age (House *et al.* 1977, p. 72).

Since Lower Old Red Sandstone rocks occupy approximately two thirds of the surface area included in the guide they are considered in some detail. Within the area they lie within the NE–SW trending Strathmore Syncline and Sidlaw Anticline and are largely cut off to the north-west by the Highland Boundary Fault and to the south-east by an unconformable cover of Upper Old Red Sandstone or by the sea.

## 3a. Lower Old Red Sandstone

Excursion 1 Arbroath

Excursion 2 The Highland Border Complex

Excursion 3 Dundee to Perth

Excursion 5 Wormit Shore

Excursion 7 North Fife Hills

Only in the Stonehaven district is the base of the Lower Old Red Sandstone seen (Excursion 1, Location 13) but its occurrence there enables the thickness of these beds to be determined as about 9 km including volcanic rocks, both lavas and pyrodastics (Armstrong and Paterson 1970). The extreme rarity of fossils in the sediments and consequent absence of dose palaeontological control for correlation has until recently led to difficulties in correlation within the area and much more so in correlation with elsewhere (House *et al.* 1977). These have been well reviewed by Mykura (1991).

Fossil fish and eurypterids are known from the Stonehaven Group at Stonehaven and also occur higher up in the succession in the Arbuthnott Group (Armstrong and Paterson 1970, pp. 10–13). Plant fossils occur in the Arbuthnott and Strathmore Groups (Armstrong and Paterson 1970, pp. 12,16). These too suggest that it is likely that the great thickness of beds in this area is equivalent to the Downtonian to Dittonian of the Welsh Borders, i.e. infra-Gedinnian to Emsian of the Standard Succession (House *et al.* 1977, Table II).

### (1) Kincardineshire (largely after Armstrong and Paterson 1970)

The Stonehaven Group (1550 m), the basal Old Red Sandstone, lies unconformably on the Ordovician Highland Border Complex. In the Cowie Formation (730 m) basal pebble beds and breccias (Excursion 1, Location 13), with one thin lava flow, are succeeded after 90 m by several hundred metres of alternating brown sandstones and reddish mudstones with mud cracks and rare burrows (Excursion 1, Location 11). These are followed by 'volcanic' conglomerates (i.e. with a predominance of volcanic rocks among the pebbles) which are in turn succeeded by grey sandy shales, yielding *Dictyocaris,* and then by tuffs and tuffaceous sandstones. The fish fauna, which includes *Hemiteleaspis, Pterolepis* and *Traquairaspis,* collected near the top of this succession, indicates a Downtonian age, i.e. late Silurian or infra-Gedinnian, for these beds (House *et al.* 1977, p. 72). The Carron Formation (820 m) comprises red-brownish cross-bedded sandstones with abundant volcanic detritus, conglomerates and some agglomerate.

The Dunnottar Group (1600 m) mainly comprises conglomerates with some tuffaceous sandstones, while near the top are some basic andesite and basalt flows. The conglomerates in this group consist predominantly of pebbles and boulders, up to as much as lm across, of mainly metamorphic rocks especially quartzite. In the belief that these clasts were derived directly from the Dalradian rocks on the north-west side of the Highland Boundary Fault such conglomerates were named by Campbell (1913) 'highland' conglomerates and the term has been retained. Such conglomerates have been discussed in detail by Haughton (1988, 1990).

The succeeding Crawton Group (670 m) contains a higher proportion of lavas, but both volcanic and highland conglomerates also occur in addition to sandstones (Excursion 1, Locations 2–5). Near the Highland Boundary Fault andesite is a common lava while near the coast basalt is much more abundant including the well known Crawton Basalts with their very large feldspar phenocrysts. Boulders as much as 1 m in diameter are not uncommon in some of the conglomerates. Haughton (1988, 1990) has demonstrated that whereas the Dunnottar and Crawton conglomerates on the north-western side of the Strathmore Syncline have a northerly source, the Crawton conglomerates on the south-eastern side of the Strathmore Syncline have a now concealed source to the south and east within the Midland Valley. The Lintrathen Porphyry (Excursion 2, Location 4) is an ignimbrite occurring at about the same horizon as the Crawton Basalts and cropping out on both sides of the Highland Boundary Fault between Glenesk and Dunkeld.

The Arbuthnott Group (2100 m) shows differences on either side of the Strathmore Syncline similar to those displayed by the underlying Crawton Group. On the south-east side a great thickness of highland conglomerates, the Johnshaven Formation, passes south into hypersthene-bearing andesites and basalts, the Montrose Volcanic Formation, resting on a highland conglomerate. On the north-west side the group is largely cut out along the Highland Boundary Fault.

The succeeding Garvock Group (1525 m), which has its type area in the Forfar–Brechin area in Angus, comprises highland conglomerates, sandstones and flows of basalt and andesite. The sandstones frequently carry calcareous grains believed to be derived from the erosion of carbonate-rich soils (calcretes). The Pittendreich Limestone of localised but widespread occurrence near the top of the Garvock Group is such a calcrete (Armstrong and Paterson, 1970 p. 14).

The youngest group, the Strathmore Group (1800 m) is free of volcanic rocks and in it conglomerates are restricted to the north-west side of the Strathmore Syncline. Bright red marls and red cross-bedded sandstones predominate, the latter becoming coarser to the north-west. The group is well exposed in the North Esk section at Edzell (Excursion 2, Locations 1–3) and has yielded the plants *Psilophyton* and *Arthrostigma* in the upper part of the group.

When the Kincardineshire succession is traced to the southwest along the Highland Boundary Fault the Stonehaven and Dunnottar Groups are rapidly overlapped and the Crawton Group is much reduced so that the Lintrathen Porphyry at the top of the group rests unconformably on the Dalradian at Alyth and Dunkeld (Armstrong and Paterson 1970).

### (2) Angus (Forfarshire)

The Lower Old Red Sandstone rocks in Angus and south-east Perthshire lie on the Sidlaw Anticline and the succession represents only the Arbuthnott and Garvock Groups of the Kincardineshire succession, a correlation based on palaeontological evidence found in the Arbuthnott Group sediments.

When the Arbuthnott Group is traced south-westwards along the Sidlaw Anticline major facies changes occur. The passage from the Johnshaven highland conglomerates of Kincardineshire into the Montrose Volcanic Formation has been noted above. The olivine-basalts and andesites of this formation give rise to the high ground south of Montrose and at Red Head. These lavas in turn are succeeded by the grey-brown sandstones, flagstones, siltstones and shales of the Dundee Formation (2000 ± m), much quarried in the past and which have yielded fish, *Climatius, Ischnacanthus, Turinea, Cephalaspis,* the eurypterid *Pterygotus* and early land plants including *Parka, Pachytheca, Nematophyton* and *Zosterophyllum.* Examples of both arthropod and fish remains from these rocks can be seen in the Dundee Museum.

The main fossil-bearing horizons in the Dundee Formation are listed by Armstrong and Paterson (1970) and have been used for local correlation. However, one of their findings is that facies variation is so extensive in these rocks that the stratigraphy set up by Hickling (1908) cannot be sustained.

The succeeding Garvock Group equivalents, by their red colour, seen for example in the sandstones at Arbroath (Excursion 1, Location 1) and Red Head, contrast with the grey and brown of the underlying Dundee Formation. The intervening red Auchmithie Conglomerate is a mixed conglomerate which diminishes to the south-west, being gradually replaced by sandstones. The red cross-bedded sandstones are often pebbly or gritty and contain calcareous detritus and occasional calcrete soils. Their last representatives to the south-west are conglomeratic sandstones known only from a borehole near Tayport on the south shore of the Tay (Armstrong *et al.* 1985). There is no detailed correlation from the south-eastern side of the Sidlaw Anticline at this level to the north-western side around Forfar and Brechin.

### (3) The Ochil Hills, Fife, Perth and the Sidlaws

Much of the Ochil Hills falls outwith the area covered by this guide book, but they are mentioned briefly here for completeness and as an aid to correlation. This area differs from those previously considered because volcanic rocks, the Ochil Volcanic Formation, dominate the succession. The volcanic sequence is believed to belong entirely to the Arbuthnott group (Armstrong and Paterson 1970, p. 12) and is 2400 m+ thick. However, the base is nowhere seen. These rocks crop out in a belt striking SW–NE along the Sidlaw Anticline. The thickness apparently decreases north-eastwards. At Bridge of Earn the Ochils lava mass splits into two ranges of hills, a more northerly one which dips north-westwards, passing through Perth to join the Sidlaw Hills where the lavas are some 1500 m thick, and a southerly one dipping south-eastwards and forming the North Fife Hills.

At Bridge of Allan, at the western end of the Ochils, a fauna including *Cephalaspis, Securiaspis* and '*Pteraspis*' occurs in sediments associated with the very highest lavas. The only remaining palaeontological evidence for the age of the lavas is at Wormit in north-east Fife (Excursion 5, Location 3) where the fauna collected near the base of the lavas includes *Brachyacanthus, Ischnacanthus* and *Mesacanthus.* The entire sequence of volcanics is assigned to the Arbuthnott Group by Armstrong and Paterson (1970).

In the western Ochils there is a considerable thickness of pyroclastics and also of sediment directly derived from the erosion of the volcanic rocks. The lavas are mainly pyroxeneandesites and to a lesser extent olivine-basalts. Further eastwards at Glenfarg, the pyroclastics have thinned out leaving a predominantly andesite and basalt succession. Substantial thicknesses of both pyroclastic and volcanic conglomerates occur within the succession in the Auchtermuchty area and the volcanic pile, again predominantly andesites and basalts, is still at least 2400 m thick north-west of Cupar (Armstrong *et al.* 1985, p. 21).

The Arbuthnott Group succession of volcanic rocks in East Fife (1800 m) is well exposed in the Wormit–Tayport area (Excursion 5) and persists, thinning, north-eastwards across the Tay to Broughty Ferry. The fossil horizon at Wormit has been mentioned above. In the lavas both aphyric two-pyroxene types and feldsparphyric types are recognised. Slaggy tops and bottoms of flows are common and flow brecciation not uncommon, e.g. Excursion 7, Location 4. Between the flows volcanic conglomerates, tuffs, sandstones and pyroclastics are all present. There are abundant signs of sediment having been washed into cracks in the flows after extrusion. An upper group of lavas, at least 215 m thick, follows and is exposed in quarries inland and on the shore around Tayport. The flows, which are mainly hyperstherte-andesite (Geikie 1902, Pirie 1933), are 6 to 15 m thick and, like the lower group, contain sandstone veins. Volcanic conglomerates are also present here. Overlying Garvock Group sandstones are known only from a borehole near Tayport (Armstrong *et al.* 1985). The succession dips south-eastwards and like that further west is unconformably overlain by Upper Old Red Sandstone sediments in Stratheden.

The Lower Old Red Sandstone rocks of the Perth area lie between the main Ochil mass to the south-west and the Sidlaws to the north-east. Eleven hundred metres of Arbuthnott Group lavas in the Ochil Volcanic Formation are exposed here, consisting mainly of basalts with a lower porphyritic group and an upper non-porphyritic group. The flows are usually 12–15 m thick (Excursion 3, Location 6). Minor amounts of sediment, ranging from volcanic conglomerates to fine silts, are interbedded with the lavas and have been washed into cracks in the flows. Highland pebbles are remarkably rare. The sediments are well displayed in the roadcuts at the Friarton Interchange on the M90 motorway on the southern outskirts of Perth. They cannot be examined there, but are usually exposed in Friarton Quarry (Excursion 3, Location 6). The lavas pass north-westwards under the younger Garvock Group and Strathmore Group sediments in the Strathmore Syncline. To the south-east, faulting and younger alluvium obscure their relations with older rocks.

The Sidlaw Hills volcanics extend for 40 km north-eastwards from Perth and are at first predominantly composed of olivine-basalts with minor andesites. The lavas are about 900 m thick (Harry 1956, p. 43), while interbedded sediments make up only 60 m. As at Perth they are of Arbuthnott Group age, dip north-west at 10°–15° and pass beneath younger Lower Old Red Sandstone sediments. The lavas thin steadily north-eastwards until in the eastern Sidlaws (Harry 1958) they make up only 60 m of the succession. Basalts still predominate. The top of the volcanics is taken as the top of the Arbuthnott Group though it is known that this is a diachronous boundary (Armstrong and Paterson 1970, p. 11). East of Perth in the Carse of Gowrie the relations between the Sidlaw lavas and the rocks to the south-east are obscured by the North and South Tay Faults, which bring down Upper Old Red Sandstone and Carboniferous sediments into the centre of the Sidlaw Anticline, and also by Quaternary sediments along the River Tay.

### The volcanic centres of the Lower Old Red Sandstone

Despite the almost complete absence of vents of this age the existence of a number of centres of volcanic activity has been deduced, firstly from a study of the thickness of the lavas and pyroclastics, and secondly from a study of the distribution of volcanic conglomerates and the associated sedimentary structures which yield directions of transport.

The Highland Centre was referred to by Campbell (1913, p. 950) as the source of the lavas of Lower Old Red Sandstone age along the Highland Boundary Fault. No great thickness of flows is involved. They comprise some andesites and also the Lintrathen Porphyry which is an ignimbrite (Paterson and Harris 1969). A great thickness of conglomerates including volcanic conglomerates and tuffs ranging from the Stonehaven Group to the Arbuthnott Group in age has been attributed to this source (e.g. Haughton *et al.* 1990, p. 107). The conglomerates contain much rhyolite and acid andesite, implying the former presence of great quantities of acid volcanic rocks nearby. It was originally believed likely, by Campbell (1913), that the volcanoes lay on the other side of the Highland Boundary Fault roughly on the site of some of the Newer Granites exposed there at the present day. Modern work, e.g. Haughton (1990), Thirlwall (1989) and Trench *et al.* (1989), has done little to alter this view.

A Montrose Centre, thought by Campbell (1913, p. 951) to lie beneath the North Sea, was believed by him to be the source of a great thickness of andesites and basalts in the Arbuthnott Group. Local erosion of these lavas has produced volcanic conglomerates in, for example, the Dunnottar Group (Haughton, 1989).

The Ochils Centre: Armstrong and Paterson (1970, p. 12) reported a 2400 m thick volcanic pile which interfingers with sediments including volcanic conglomerates and ashy sandstones. Agglomerates, present on the face of Dumyat, contain 'cottage-sized' blocks (Read 1927, p. 492). It has been suggested that the volcanic centre lies beneath the Carboniferous rocks south of the Ochil Fault.

A thick sequence including pyroclastics between Newburgh and Auchtermuchty together with volcanic conglomerates as well as flows may suggest a volcanic centre, but no vents have been described from the area. Still further eastwards 'several areas of fragmental rocks composed mainly of clasts of various types of lava. are shown, with reservations, as vents on the published map (Sheet 48E)' (Armstrong *et al.* 1985, p. 36), e.g. Myrecairnie Hill (Excursion 7, Location 3).

The absence of volcanic vents has been discussed by Francis (1983, pp. 177–81) who pointed out that in Andean volcanoes only fragments of the circumference are usually preserved, and that on the flanks of a subsiding basin these are normally asymmetrical in any case. Further, from the area of outcrop of the Old Red Sandstone volcanics, they are likely to be the products of more than one volcano. He discusses too the time available for erosion of the volcanic pile after eruption and the probability of the original edifice being completely removed and in addition the root being buried by younger sediments or volcanics. In short the chances of preservation and subsequent re-exposure of the volcanic vents from which the Lower Old Red Sandstone volcanics were erupted are not high. Fissure eruptions have also been suggested (Cameron and Stephenson 1985, p. 38).

As to the age of the Lower Old Red Sandstone volcanics, Thirlwall (1981) has found problems in fitting the calc-alkaline nature of the volcanics to the plate-tectonic models proposed for the period by many workers and which he reviewed. He felt the volcanics to fit best a period of active subduction. This suggested to him that the volcanics, if they are to fit the commonly accepted tectonic model, should be of late Silurian age. Radiometric age dates discussed by him later

(Thirlwall 1983, p. 316) also suggest a Silurian age but they are at variance with the palaeontological evidence.

### Minor intrusions

Almost confined to the Dundee and North Fife area are a considerable number of minor intrusions. They lie largely on the axial part of the Sidlaw Anticline and comprise sill-like sheets, bosses and a small number of thin dykes. Compositionally they resemble the Lower Old Red Sandstone lavas, thus the olivine-dolerites correspond to the basalts, the basic porphyrites correspond to the andesites, the porphyrites to the trachyandesites and the acid porphyrites to felsites or rhyolite.

By far the largest is the Rossie Priory Basic Porphyrite Sheet, more than 150 m thick and cropping out over a distance of 8 km from south-west to north-east (see Excursion 3, Location 4). Dundee Law is composed of augite-porphyrite but exposures are such that the shape of the intrusion is uncertain. Lighter coloured patches in the mass are more akin to acid porphyrite, a rock which is usually fine grained, pale coloured and feldsparphyric. One, pink in colour, an acid porphyrite, is exposed in the Ninewells railway cutting, while the pink rhyolitic felsite of Lucklaw Hill (Excursion 7, Location 1) is one of the most conspicuous landmarks in East Fife.

The chemical similarity between the lavas and the minor intrusions has led to the conclusion that they are of the same general age (Armstrong *et al.* 1985, p. 41), i.e. Lower Old Red Sandstone.

### Conditions of sedimentation during Lower Old Red Sandstone times

The two most conspicuous features of the Lower Old Red Sandstone sediments are firstly their enormous total thickness (9 km) and secondly the often huge thickness of interbedded volcanics.

Haughton (1989), from a study of the Dunnottar and Craw-ton conglomerates in particular, envisaged NE–SW trending basins coincident with Strathmore which were primarily controlled by sinistral NE–SW strike-slip faults. Into these a major northerly 'gravel bed river' (p. 524) carried much coarse material which was augmented by erosion of contemporary volcanics and, particularly during Crawton times, erosion of a metamorphic source area to the south and east, now buried beneath younger sediments within the Midland Valley. The sediments, therefore, are a result of the interplay between faulting, subsidence of the basins, vulcanicity, uplift of the sources, weathering, erosion and deposition from the rivers themselves.

The sediments thin from north-east to south-west, the Stonehaven, Dunnottar and Crawton Groups being overlapped south-westwards until at Dunkeld the Lintrathen Porphyry, an ignimbrite at the top of the Crawton Group, rests directly on Dalradian metamorphic rocks.

The Lower Old Red Sandstone volcanics increase in importance to the south-west, e.g. in the Ochil Hills. Conglomerates from these volcanics advanced to the north-west, locally in alluvial fans. Overall, however, the sandstones at many localities and at a range of horizons in Strathmore show palaeocurrent directions to the south-west. In effect Strathmore was the site of a river system draining to the south-west, bounded to the north-west by a series of alluvial fans fed from the highlands and to the south-east by volcanic uplands and a now buried metamorphic terrane (Haughton 1989).

The substantial vulcanicity during Arbuthnott times is believed by Friend and Williams (1978, p. 15) to have impeded drainage sufficiently to establish lacustrine conditions on a number of occasions and the resulting sediments are the main fossiliferous strata. Overbank river deposits during Garvock times led to calcrete soil profiles, occasionally preserved as limestones, but more usually eroded to provide calcareous detritus. The diminution in conglomerates and increase in fine-grained sediments in Strathmore times reflect a more subdued tectonic regime.

## 3b. Earth movements of Middle Old Red Sandstone age

No rocks of Middle Old Red Sandstone age occur in the whole of the Midland Valley of Scotland. Rather the period was one of earth movement and erosion with little or no deposition. Two main structures in the area date from this period.

These are firstly the Sidlaw Anticline, trending south-west from Montrose to Stirling where it is cut off by the Ochil Fault; on the south-east side of the Anticline the Lower Old Red Sandstone is unconformably covered by Upper Old Red Sandstone and Carboniferous rocks. Secondly, the parallel Strathmore Syncline runs south-westwards from Stonehaven on the coast and lies between the Sidlaw Anticline and the other very large structural feature of the district, the Highland Boundary Fault. The Sidlaw Anticline and the Strathmore Syncline were described early last century in some detail by Lyell (1838, pp. 98–101) in his *Elements of Geology* as illustrations of a typical anticline and syncline (see fig. 2).

The Sidlaw Anticline is a fairly symmetrical structure with dips of 15°–30° on either side, but the Strathmore Syncline is highly asymmetrical. The dips on the south-east limb are those of the Sidlaw Anticline, 15°–30°, but those against the Highland Boundary Fault on the north-west side are high, frequently vertical, or even overturned because of the reverse movement of the Highland Boundary Fault (Ramsay 1962), which forms the north-west flank of the Midland Valley Graben. At the time the rocks of the Highlands overrode those of the Midland Valley, dragging the rocks on the downthrow side up with them to produce a monoclinal structure.

The fold movements can be dated as Middle Old Red Sandstone, since Lower Old Red Sandstone rocks up to and including the Strathmore Group were folded and eroded before some were unconformably overlain by approximately horizontal Upper Old Red Sandstone sediments. It was estimated by Hickling (1908, p. 403) that in the vicinity of Arbroath 2400 m of Lower Old Red Sandstone sediments were eroded away before the Upper Old Red Sandstone sediments were laid down and this figure may well be exceeded along Stratheden in Fife where the Upper Old Red Sandstone rests on Arbuthnott Group volcanics.

## 3c. Upper Old Red Sandstone

Excursion 1

Excursion 3

Excursion 8

Excursion 17

Rocks of this age are quite subordinate in amount to those of the Lower Old Red Sandstone on which they rest unconformably ((Table 3)). In the region now under consideration they occur in three areas, listed below in order from north to south:

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1. A series of small outliers, along the Kincardineshire and Angus coasts, where they are believed to be Upper Old Red Sandstone on the basis of their lithology and their position in relation to the Lower Old Red Sandstone rocks beneath.
2. An area within the Carse of Gowrie, let down by the North and South Tay Faults along the axis of the Sidlaw Anticline. These rocks have been dated by their fauna.
3. The largest area of outcrop extending south-westwards in a belt 2 to 8 km wide from the mouth of the River Eden to Loch Leven and roughly coincident with the Eden Valley. These rocks have also been dated palaeontologically.

The maximum thickness, 600–900 m, occurs in the Carse of Gowrie in area 2, while in area 3 it is over 600 m thick around Loch Leven. In area 1 the known thickness is not more than 60 m.

1. The outliers on the Kincardine and Angus coasts are usually cut off from the Lower Old Red Sandstone by faulting, e.g. at St Cyrus and Boddin Point, respectively north and south of Montrose. In these areas the rocks comprise red, cream and sometimes mottled sandstones often showing cross bedding and channels. They are locally calcareous, sometimes sufficiently so to be identified as calcrete soils, and bear a strong lithological resemblance to the Upper Old Red Sandstone rocks of the Carse of Gowrie. At Arbroath 60 m of channel and bar conglomerates and soft red sandstones crop out and a south-easterly direction of transport is indicated (Ramos and Friend 1982, p. 313). The

pebble content corresponds closely to that of the underlying Lower Old Red Sandstone conglomerates from which they were probably derived (Excursion 1, Location 1). The base is unconformable here, the surface highly irregular and the angular discordance about 15–25°. As mentioned above, Hickling (1908) believed that somewhere in the region of 2400 m of rocks were eroded away before the Upper Old Red Sandstone was laid down. This figure is probably too high for the Arbroath district, but the gap in the succession is certainly considerable.

2. In the Carse of Gowrie Upper Old Red Sandstone rocks, known as the Clashbenny Formation (600–900 m, Browne 1980) have been let down by the North and South Tay Faults along the axis of the Sidlaw Anticline. A series of inliers of these rocks form the Inches or Islands of the Carse of Gowrie (e.g. at Errol and Clashbenny), gently rounded knolls with bright red soil projecting above the flat plain of the Quaternary Carse Clays. At Clashbenny, old quarries, now water filled, are famous as the type locality of *Holoptychius nobilissimus* Agassiz. The sandstones of the Clashbenny Formation are fluviatile, red in colour, and frequently have pale reduction spots. Others are more reddish brown, grey or yellow in colour and rip-up mud clasts are common. Finer grained beds display mud cracks. These rocks are conformably overlain by the Carboniferous. However, the contact with the underlying Lower Old Red Sandstones is not now exposed.
3. Between the mouth of the Eden and Loch Leven outcrops are disappointingly few because of widespread drift deposits, the valley having been occupied by the Stratheden Glacier during the Pleistocene glaciation. There are, however, two main areas of outcrop, the first of which lies around the West Lomond and Bishop Hill (Excursion 17, Locations 1–3). Only here can the contact between the Upper Old Red Sandstone, approximately 600 m thick, and the overlying Carboniferous rocks be seen. The second area lies around Cupar and in it the thickness is approximately 300 m. The best exposures are in the famous Dura Den section 5 km east of Cupar (Excursion 8). Quarry exposures are not important except that at Drumdryan, Cupar, which is of historical interest as the first locality from which *Holoptychius* scales were obtained by Fleming in 1831.

In the Stratheden–Lomond Hills area Chisholm and Dean (1974) subdivided the Upper Old Red Sandstone into a series of formations, now taken together as the Stratheden Group (Paterson and Hall 1986), the two lowest, the Burnside and Glenvale, comprising red to yellow, fine to coarse-grained and pebbly sandstones. Intra-formational clasts are common and trough cross bedding indicates an eastwards flow. The overlying Knox Pulpit Formation is of sandstones, some with millet-seed grains and showing cross bedding and vertical burrows among other features, now interpreted as windblown dune deposits (Hall and Chisholm 1987). The formation does not extend west of Kinross. The rather local Dura Den Formation (30 m) (Excursion 8, Locations 8, 9) is famous for its fossil fish fauna including *Bothriolepis, Phyllolepis, Glyptopomus, Eusthenopteron, Holoptychius* and *Phaneropleuron* of Fammenian age which occurs in cream coloured sandstones alternating with red, cream and green siltstones, some with mudcracks.

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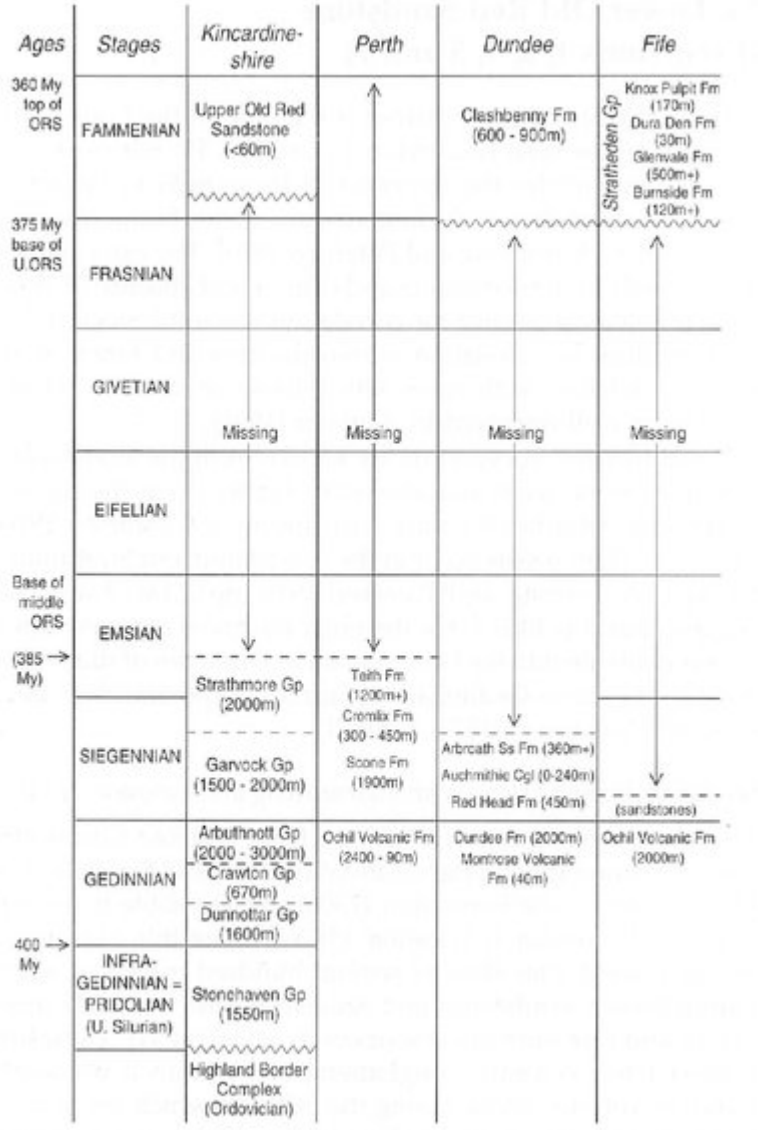
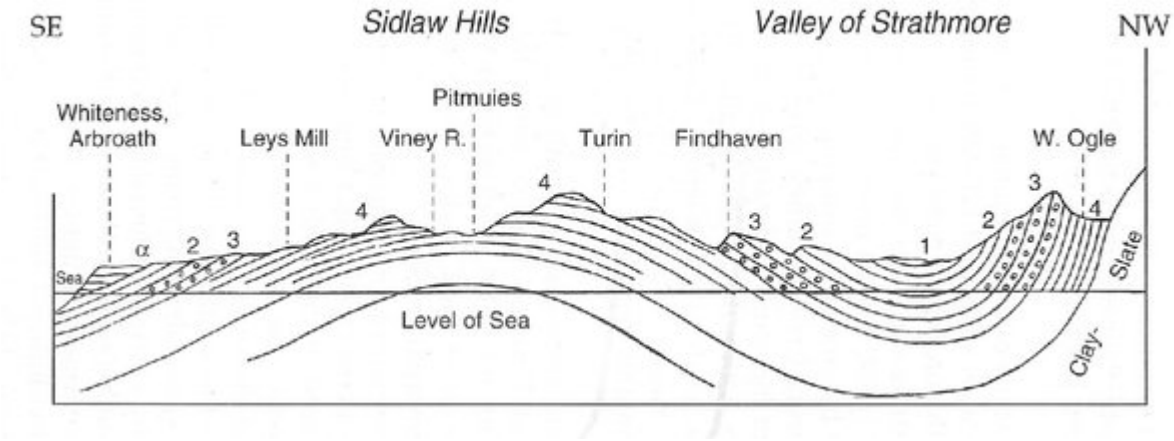
(Figure 2) Section extending from the Highlands south-eastwards to the coast at Arbroath. After Lyell's Elements of Geology (1838, p.99). 1 = red marl or shale, 2 = red sandstone, 3 = conglomerate, 4 = grey paving stone, etc., a = newer deposits in horizontal beds. Most of the section comprises formations of the Lower Old Red Sandstone, but the horizontal beds at Arbroath belong to the unconformable Upper Old Red Sandstone, while the clay-slate at the NW end of the section is part of the Dalradian lying beyond the Highland Boundary Fault, not yet recognised in 1838.




*(Table 3) Correlation table for the Old Red Sandstone of Kincardineshire, Tayside and Fife.*

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