British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Stratigraphical framework for the Devonian (Old Red Sandstone) rocks of Scotland south of a line from Fort William to Aberdeen

Research Report RR/01/04

NAVIGATION

HOW TO NAVIGATE THIS DOCUMENT

- The general pagination is designed for hard copy use and does not correspond to PDF thumbnail pagination.

- The main elements of the table of contents are bookmarked enabling direct links to be followed to the principal section headings and sub-headings, figures, plates and tables irrespective of which part of the document the user is viewing.

- In addition, the report contains links:

  - from the principal section and sub-section headings back to the contents page,

  - from each reference to a figure, plate or table directly to the corresponding figure, plate or table,

  - from each figure, plate or table caption to the first place that figure, plate or table is mentioned in the text and

  - from each page number back to the contents page.

Return to contents page

NATURAL ENVIRONMENT RESEARCH COUNCIL

BRITISH GEOLOGICAL SURVEY

Research Report RR/01/04

Stratigraphical framework for the Devonian (Old Red Sandstone) rocks of Scotland south of a line from Fort William to Aberdeen

Michael A E Browne, Richard A Smith and Andrew M Aitken

Contributors: Hugh F Barron, Steve Carroll and Mark T Dean

Cover illustration

Basal contact of the lowest lava flow of the Crawton Volcanic Formation overlying the Whitehouse Conglomerate Formation, Trollochy, Kincardineshire. BGS Photograph D2459.

Bibliographical reference

Browne, M A E, Smith, R A, and Aitken, A M. 2002. Stratigraphical framework for the Devonian (Old Red Sandstone) rocks of Scotland south of a line from Fort William to Aberdeen. *British Geological Survey Research Report*, RR/01/04. 67 pp.

ISBN 0 85272 401 2

Keyworth, Nottingham British Geological Survey 2002

BRITISH GEOLOGICAL SURVEY

The full range of survey publications is available from the BGS Sales Desk at Nottingham and Edinburgh; see contact details below or shop online at www.thebgs.co.uk The London Information Office maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG
☎ 0115-936 3241 Fax: 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.thebgs.co.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA
☎ 0131-667 1000 Fax: 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE
☎ 020-7589 4090 Fax: 020-7584 8270
☎ 020-7942 5344/45 e-mail: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU
Tel: 01392-445271 Fax: 01392-445371

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS
☎ 028-9066 6595 Fax: 028-9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ 01491-838800 Fax: 01491-692345

Parent Body
Natural Environment Research Council Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU
☎ 01793-411500 Fax: 01793-411501
www.nerc.ac.uk

Contents

Figures

Plates

Tables

Summary

The lithostratigraphy of the Old Red Sandstone lithofacies of the Southern Highlands, Midland Valley of Scotland and the Southern Upland Terrane has been reviewed.

The Lower Old Red Sandstone lithofacies contains strata ranging in age from Wenlock (Silurian) to Emsian (Devonian). Prior to this review, there were well over 100 valid formations and members in the late Silurian to early Devonian Lower Old Red Sandstone. The new term Lanark Group includes all late Silurian to Devonian formations in the Lanark Basin which occupied the southern Midland Valley of Scotland. A framework at formation level is proposed for the Lanark Basin; in ascending sequence they are the Greywacke Conglomerate, Swanshaw Sandstone, Pentland Hills Volcanic (and equivalents) and Auchtitench Sandstone formations. Rationalisation of the largely informal lithostratigraphy of the Lower Devonian in the Southern Uplands Terrane is suggested and the terms Great Conglomerate, Auchencrow Burn Sandstone and White Hill Sandstone formations are proposed. The newly defined Reston Group includes these and other Lower Devonian formations in the geographically separated outcrops (other than the Lanark Basin) overlying the Southern Upland Terrane.

The group terminology in the northern Midland Valley of Scotland has been rationalised from six to four, recognising the recent research indicating that the Lower Old Red Sandstone lithofacies was laid down in three sedimentary basins. From oldest to youngest these are the Stonehaven (Group), Crawton (Dunnottar-Crawton Group) and Strathmore (Arbuthnott-Garvock and Strathmore groups) basins, of which the last named is by far the most extensive. The number of formations recognised has been rationalised to 19, with others reduced in status to member level or made redundant.

Middle Devonian strata are not represented as a result of non-deposition or erosion during the Acadian Orogeny.

The Upper Devonian strata all belong to the Stratheden Group. Some initial rationalisation of the formation terminology within the sandstone-dominated Stratheden Group is proposed with the Gargunnock Sandstones and Clashbenny Formation becoming redundant names. In areas where no formal stratigraphy had previously been applied especially in the Southern Upland Terrane, provisional correlations are suggested. The cornstone-bearing Kinnesswood Formation at the top of the Upper Old Red Sandstone lithofacies has been described in the report on the Carboniferous of the Midland Valley of Scotland.

Preface

The Stratigraphy Committee of the British Geological Survey has undertaken to carry out a review of the stratigraphical classification and nomenclature for all parts of Great Britain for which modern information is available. To this end several BGS Stratigraphical Framework Committees (SFCs) have been established, each with the following terms of reference:

i) To carry out a complete review of the lithostratigraphical nomenclature of the designated region, identifying problems in classification, correlation and nomenclature.

ii) To propose a stratigraphical framework and lithostratigraphical nomenclature down to formation level for the whole outcrop.

iii) To organise peer review of the scheme.

iv) To present the results in a document suitable for publication.

v) To see that the Lexicon entries are completed for their area of responsibility.

The Devonian rocks (sensu Old Red Sandstone lithofacies) of the south of Scotland were the subject of a committee under the chairmanship of Mr M A E Browne. The Upper and Lower Devonian south of a line from Fort William to Aberdeen are herein reported.

The purpose of all SFCs is to establish a framework down to formation level that can be used as a central reference by all geologists working in the region. The process of erecting a framework requires decisions to be taken about correlations and equivalencies leading to a simplified nomenclature. Inevitably many names will be rendered obsolete. The frameworks are lithostratigraphical and, though each is set against a chronostratigraphical reference column (Harland et al., 1990; Tucker and McKerrow, 1995), the finer points of the chronostratigraphy of the succession are not our prime concern.

The lithostratigraphical rules applied are those of the North American Commission on Stratigraphic Nomenclature (1983).

It is expected that the frameworks will be refined and improved with time. Indeed, erecting them effectively poses a challenge to stratigraphers which it is hoped will be taken up to contribute to a better understanding of British stratigraphy.

This report has been reviewed by the Stratigraphy Commission of the Geological Society of London.

1 Introduction

The Scottish Old Red Sandstone continental lithofacies (ORS) as described in the synthesis by Mykura (in Craig, 1991) are roughly equivalent in age to Devonian marine deposits in south-west England. It has long been recognised that the ORS spans Silurian to Carboniferous) serving to emphasise this point. The topmost beds of the lithofacies, the cornstone-bearing sandstones of the Kinnesswood Formation are now considered to be almost entirely Carboniferous in age. They were included in the framework report for the Carboniferous of the Midland Valley of Scotland (Browne et al., 1999). They are the basal unit of the Inverclyde Group (Paterson and Hall, 1986).

The subdivision of the sandstone dominated Scottish Old Red Sandstone lithofacies into the Lower, Middle and Upper Old Red Sandstone was by Murchison (1859). He thought (erroneously in retrospect) the fluvial and volcanic Lower Old Red Sandstone (latest Silurian to early Devonian) only occurred south of the Grampians. He correctly believed the lacustrine influenced Middle Old Red Sandstone (mainly mid Devonian) is confined to the area of what is now known as the Orcadian Basin north of the central Highlands. The fluvial Upper Old Red Sandstone (mainly late Devonian to earliest Carboniferous) was by contrast recognised throughout Scotland but resting unconformably on older strata. From both onshore and offshore North Sea data, the latter characteristic is now seen to be flawed in the Orcadian Basin where Marshall et al. (1996) recognised an onlapping conformable Middle to Upper Old Red Sandstone succession with marine incursions. The ‘Old Red Sandstone’ remains as an informal term.

This report reviews the Lower Devonian (sensu Lower Old Red Sandstone) Lanark and Reston groups in the southern part of the Midland Valley of Scotland (MVS) and the Scottish Borders (Southern Upland Terrane, SUT) and presents lithostratigraphical detail for the Upper Devonian (Stratheden Group) of the whole area (see Figure 1). It also presents a new framework at group level for the Lower Devonian of the northern MVS (Table 1) together with an account of the now-valid formations used by the BGS in this area. A list of valid lithostratigraphical units for the Scottish Devonian (Old Red Sandstone lithofacies) south of a line from Fort William to Aberdeen is listed in Appendix I. Appendix II tabulates a list of obsolete terms and those of reduced status. This review is timely given that the Devonian (Caledonian) igneous rocks (Stephenson et al., 1999), fossil fishes (Dineley and Metcalf, 1999) and Palaeozoic botany (Cleal and Thomas, 1995) of Great Britain have been reviewed in three volumes of the Geological Conservation Review Series. Work is ongoing on the Devonian Sedimentary Rocks volume.

1.1 PALAEOGEOGRAPHY

The palaeogeography of the Devonian in the southern part of Scotland can be described in two parts; firstly the Upper Silurian to Lower Devonian rocks (late Wenlock to Emsian age) and secondly the Upper Devonian strata (Frasnian to Famennian age) which were deposited unconformably on the former after the Acadian Orogeny. The Devonian palaeogeography of the area has been illustrated in terms of the whole of the British Isles (Cope et al., 1992, Maps D1–4). The basins and the enigmatic sediment sources of these rocks are discussed by Bluck (2000).

1.1.1 Late Silurian to Early Devonian

The Late Silurian to Early Devonian palaeogeography of the southern part of Scotland is one of graben development in a sinistral strike-slip regime (Phillips et al., 1998). The clastic infill to the grabens was punctuated by calc-alkaline volcanic eruptions. The earlier interpretation that the LORS deposits were molasse derived from the Caledonian mountain chain has been challenged by Haughton and Bluck (1988) and Bluck (2000) on the basis that these mountains must have been substantially eroded prior to the early Devonian and that there is too little first cycle detritus. During the Devonian the LORS continent was situated in the equatorial zone, about 25° S at the beginning (Trench and Haughton, 1990) and about 10° S at the end. The active clastic terrestrial deposition did not allow the preservation of many fossils so biostratigraphical correlation is difficult. Minor regional variations in the palynology (Wellman, 1993b) are possibly due to variations in the composition of the terrestrial vegetation. The MVS appears to have been divided, possibly by a volcanic ridge located above an Ordovician arc, into sets of northern and southern basins; the Stonehaven, Crawton and Strathmore basins in the north and the Lanark Basin in the south (Figure 1). Farther west, it is possible that the Strathmore and Lanark basins merged and continued south-westwards into Ireland. The calc-alkaline lavas and associated intrusions have been dated at about 410 Ma in both the northern and southern parts of the MVS (Thirlwall, 1988) but volcanism may have started earlier in the north as minor amounts of acid/intermediate lava occur in the late Wenlockian to early Ludlovian Stonehaven Group and continue into the Dunnottar-Crawton Group. Within the Dunnottar-Crawton Group and the succeeding Arbuthnott-Garvock Group, thick piles of lavas accumulated locally in composite or strato-volcanoes. Thinner, but still more widespread ignimbrites and pyroclastic deposits were also erupted.

The main graben development is within the MVS and started in late Silurian (Wenlockian–Ludlovian) times in the north-east, with the Stonehaven Basin. This small wholly continental basin developed as a result of sinistral shear in the Highland Boundary Fault Zone. The Stonehaven Group deposits were transported to the north-west and include clasts indicating a medium-grade metamorphic source lay to the south of the Highland Boundary Fault (Robinson et al., 1998). Subsequently the Crawton Basin (Marshall et al., 1994; Haughton, 1988; Haughton and Bluck, 1988) extended south-westwards in the northern part of the MVS and was filled with large volumes of recycled conglomerates and sandstones mostly derived from the north (including Ordovician muscovite-

		Area just north of the Highland Boundary Fault	Northern Midland Valley	Arran, Kintyre and Farland Head	Southern Midland Valley	Southern Upland Terrane	
Late Devonian	Famennian	STRATHEDEN GROUP					Upper Old Red Sandstone
	Frasnian						
Mid Devonian	Givetian-Eifelian	*Unconformity*					
Early Devonian	Emsian		STRATHMORE GROUP	STRATHMORE GROUP	LANARK GROUP	RESTON GROUP	Lower Old Red Sandstone
	Pragian	ARBUTHNOTT-GARVOCK GROUP	ARBUTHNOTT-GARVOCK GROUP	ARBUTHNOTT-GARVOCK GROUP			
	Lochkovian	DUNNOTTAR-CRAWTON GP	DUNNOTTAR-CRAWTON GROUP				
Silurian	Pridolian-Wenlockian		STONEHAVEN GROUP				

Table 1 Summary of the late Silurian to Devonian groups in the areas covered by the report.

biotite granite, late Silurian granitoids and metamorphic clasts up to staurolite grade, Haughton et al., 1990). Some of the conglomerates were southerly derived, from a cryptic flysch and high-level granite source within the MVS. The Crawton Basin succession appears to be linked to that in the Stonehaven Basin (Phillips et al., 1998), but its development was accompanied by large-scale synsedimentary faulting. In the Callander to Loch Lomond area there are south-easterly-derived conglomerates which include recycled quartzite clasts (Bluck, 1984). The MVS and Grampian terranes appear to have docked by late Silurian time since when strike slip movements between them can only be of the order of tens of kilometres (Trench and Haughton, 1990). The large scale of the coarse conglomeratic channels, the complex pattern of palaeoflow and evidence of high sediment flux and water discharge suggests deposition from antecedent rivers (Haughton, 1989). This regime produced the large 'wet-type' fans with

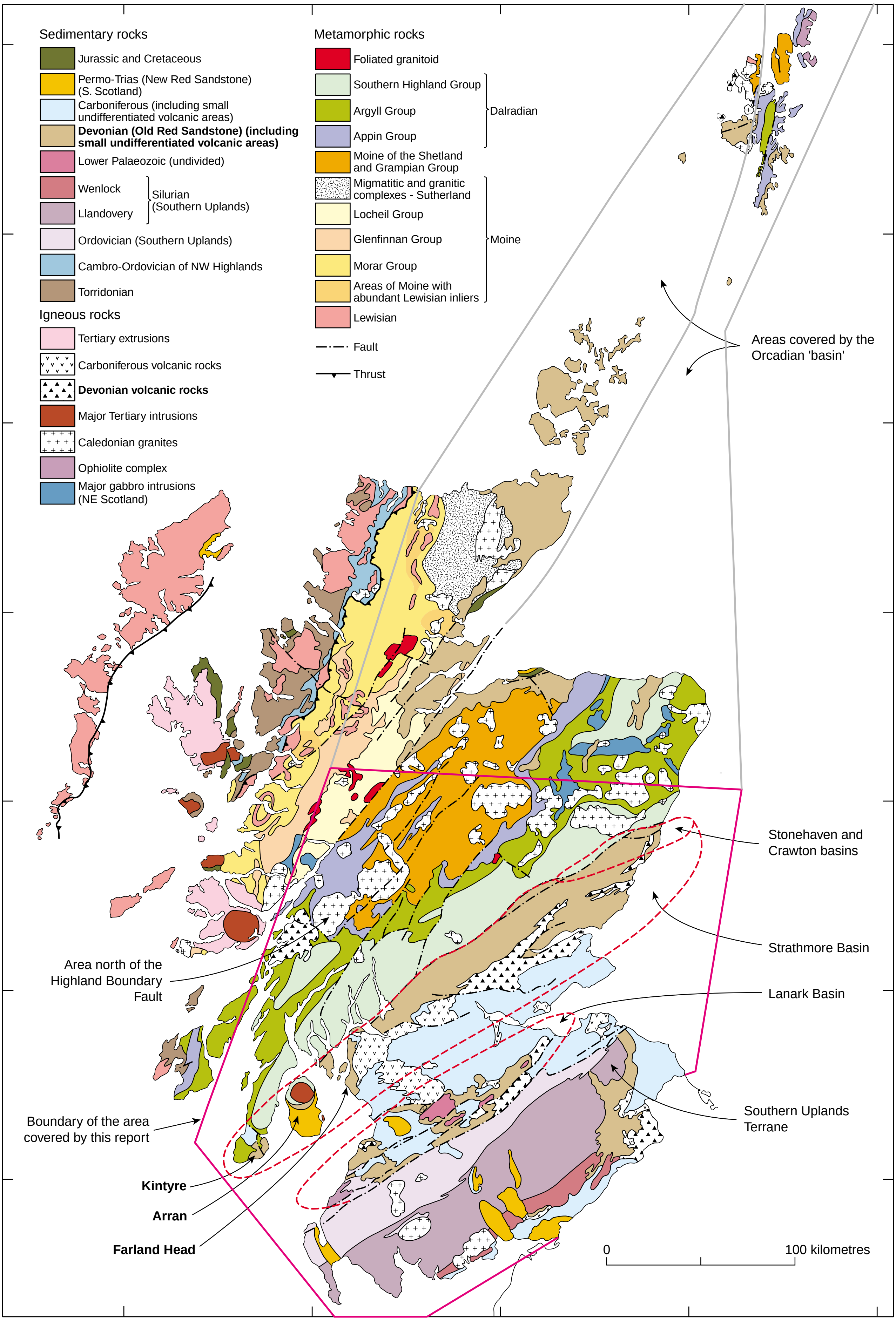

Figure 1 Geological map of Scotland showing the late Silurian to Devonian (Old Red Sandstone) outcrops.

no evidence of an axial lake. The later, more extensive Strathmore Basin was filled with clastic sediment deposited by a major river system extending along the whole of the north of the MVS. These continental fluviatile deposits are interstratified with subaerial calc-alkaline lavas and volcaniclastic rocks. The northern basins appear to have been filled axially and laterally by rivers generally flowing south-westwards and the fill thins in that direction. As a result, from Callander to Arran and south to Farland Head, the earliest Lower Devonian deposits are correlated with the Arbuthnott-Garvock Group on lithostratigraphic and biostratigraphic grounds (Wellman, 1993b).

The river systems were substantial and may have been sourced in the mountain ranges of Norway or Greenland, where there is evidence of considerable Scandian uplift from 410–380 Ma. In the Arbuthnott-Garvock Group the sandstones are characterised by palaeocurrents directed to the south-west in a mainly braided river system. The drainage pattern strongly suggests that a basin margin or positive area lay to the east of the present Angus/Kincardine coastline (Armstrong et al., 1985). Restricted argillaceous lacustrine deposits, such as those of Lake Forfar (Trewin and Davidson, 1996), occur within the fluvial arenites of the Arbuthnott-Garvock Group which are thought to be the result of impeded drainage caused by the local volcanic piles or synsedimentary faulting. Lower Devonian fish and eurypterid fossils found in the lacustro-deltaic deposits indicate flourishing free-swimming and bottom-living faunas. Plants, millipedes and other arthropods were washed in from the shores. In the deepest water lacustrine deposits the presence of carbonaceous laminae suggests that water conditions were seasonally anaerobic. It has been estimated that 2000 years of laminite deposition occurred before Lake Forfar silted up. In the upper part of the Arbuthnott-Garvock Group, nodules of pedogenic carbonate developed in the overbank deposits which were reworked by meandering streams in a hot, seasonally wet and dry, climate.

The younger (Emsian) thick siltstones and mudstones of the Strathmore Group may be distal parts of alluvial fans, sourced from the Highlands or farther afield, which were not reworked fluvially (Armstrong et al., 1985). An alternative interpretation is that the argillites are aeolian clay pellet deposits (Dare-Edwards, 1984; Yang, 1997). This sequence contains cross-bedded and rippled sandstones up to 2 m thick and these are thought to be overbank deposits of large river systems (Haughton and Bluck, 1988). Local thick fanglomerates were still being deposited close to the Highland Boundary Fault at this time. On Arran, the Strathmore Group comprises argillaceous floodplain deposits interdigitated with thin sheeted fanglomerates.

In the Lanark Basin, along the southern margin of the MVS, rudaceous alluvial fans fine up generally into fluvial sandstones. The source of this detritus is thought to be from horsts of flysch to the east (Syba, 1989) created by strike-slip within the MVS. A period of calc-alkaline volcanic eruptions from at least four centres produced substantial piles of subaerial volcanic rocks. These were locally eroded and the detritus reworked by rivers which were carrying a load of more distal quartzose/metamorphic origin from the north-east. A comparison of the Lower Devonian successions in the north and south of the MVS shows lithological similarities between the upper part of the Arbuthnott-Garvock Group and the Auchtitench Sandstone Formation in the Lanark Group (Phillips et al., 1998). Thus by Pragian/Emsian times, there may have been a link between the Strathmore and Lanark basins at least in the east.

Within the Grampian Terrane, in the Lorn-Oban area, calc-alkaline volcanism had already started before fossiliferous sedimentary rocks (Přídolí–Lochkovian) were deposited on planated Dalradian basement (Marshall, 1991; Bluck, 2000). The preserved overlying subhorizontal lavas and ignimbrites may represent only a small part of their original extent. The sedimentary rocks accumulated in small fault-bound basins, as scree breccias and fanglomerates passing basinward into fluvial sands and then lacustrine muds with thin carbonate beds (Stephenson and Gould, 1995).

Early Devonian sinistral strike-slip on the Southern Upland Fault (SUF) appears to have affected the sedimentary connection between the MVS and the Lower Devonian strata deposited on the SUT. Separation of the basins south of the SUF from basins in the MVS is indicated by the different provenance shown by the basal conglomerates and sandstones. The calc-alkaline volcanic rocks in the SUT also have slightly different geochemistries to the MVS volcanic rocks and therefore their original position with respect to the MVS rocks is suspect. The Lower Devonian sandstones and conglomerates rest on an eroded surface of Lower Palaeozoic turbidites, suggesting that the north-eastern part of the SUT was in a near peneplained condition (Bluck, 2000; Bluck et al., 1992). Lower Devonian lava fields may have had a limited extent in the SUT, as around Eyemouth, the overlying fluviatile deposits overlap onto the Lower Palaeozoic rocks. The Cheviot volcanic field, intruded by the associated granite (about 395.9 Ma, Thirlwall, 1989), was extensively eroded and appears to be younger than the volcanic formations in the MVS.

1.1.2 Late Devonian

Continental Upper Devonian strata of southern Scotland were deposited unconformably on Lower Devonian rocks after uplift and erosion following the Acadian orogenic episode. Clastic deposits of fluviatile and aeolian origin predominate but tend overall to be finer grained than the Lower Devonian beds. A single major basin trending east-north-east has been modelled (Hall et al., 1998 and references therein) towards the north of the MVS. The deposits in the western and northern parts of this Late Devonian basin are thicker and more rudaceous than in the southern parts due to major braided rivers which built up fans of relatively mature detritus from the west and north. The vein quartz and schist clasts are considered to be derived from the Dalradian whereas the rounded boulders of quartzite, lava and granite may be reworked from Lower Devonian rocks. Penecontemporaneous strike-slip faulting has been postulated (Bluck, 1980; 2000) and movements on the Largs Fault zone occurred before the succeeding Carboniferous Inverclyde Group was deposited (Paterson et al., 1990).

In the northern part of the MVS, the predominant palaeocurrent directions were towards the east and south-east indicating an axially-draining braided river system. Bluck et al. (1992) have postulated substantial rivers of over 10 m depth in the west of the MVS, possibly sourced from the north then flowing east along the MVS. Rainfall at this time is considered to have been moderate, if somewhat seasonal. Aeolian deposits within the younger formations tend to occur in the axial part of the basin and indicate that the rainfall and relief may have diminished during this period. They may also reflect global eustatic sea level change. Prevailing easterly and north-easterly winds caused the migration of dune sands to the west and south-west (Hall and Chisholm, 1987). In places to the west, dune sands were blown on to the floodplains or locally reworked by the rivers. Famennian fish beds occur in shallow water, fine-grained facies associated with ripples, burrows and desiccation cracks. This setting is transitional from fluviatile to aeolian facies; possibly an ephemeral abandoned channel or even an estuary. South of this basin, exposure of the Stratheden Group is limited to the Ayrshire coast where rudaceous to arenaceous fluviatile deposits may have formed part of a separate fan in the west as a result of the remnant high between the Lower Devonian Lanark and Strathmore basins. To the east, in the present North Sea, a gulf of the mid- and late-Devonian sea reached the Orcadian Basin from the south-east (Marshall et al., 1996) where Middle and Upper Devonian sequences are seen as a single westward on-lapping succession with marine intercalations from Mid to Late Devonian times.

The variable, commonly thin, development of Upper Devonian continental fluviatile/lacustrine red beds with local fish beds over the eastern part of the SUT (which includes the Cockburnpath–Pease Bay outcrops) may be separate from the MVS basin to the north. However, in both the MVS and SUT, alluvial gravels and fluviatile/lacustrine beds pass up into fluviatile sandstones bearing pedogenic carbonate which are referred to the Carboniferous Kinnesswood Formation. Leeder (1973) postulated internal drainage in a Scottish Border basin in the Jedburgh area, but the overall pattern can be explained by an easterly flowing river system (Paterson et al., 1976) and the basin may have joined the Northumberland basin farther east. In the central North Sea, relatively mature fluvial systems with upward fining and coarsening cycles are dated as Frasnian but the top of these red beds may be Early Carboniferous in age (Gatcliff et al., 1994).

2 The Upper Silurian to Lower Devonian rocks in the Lanark Basin in the southern Midland Valley of Scotland

The Old Red Sandstone in the southern MVS comprises the former Upper and Lower Old Red Sandstone successions separated by an unconformity which represents a period of tectonic activity, uplift and erosion during Mid Devonian times.

The Lower Old Red Sandstone (LORS) succession in the southern part of the MVS has not received as much study as that in the north; partly because the outcrops are less extensive and more faulted (Cameron and Stephenson, 1985). Bluck (1978) described the LORS sequence in the southern MVS as being deposited in the Lanark Basin.

2.1 LANARK GROUP (LNK)

Lithology:
The Lanark Group (LNK) includes all the sedimentary and volcanic formations of latest Silurian to earliest Devonian age (the former LORS) in the south of the MVS (Figure 2). It comprises the clastic Greywacke Conglomerate, Swanshaw Sandstone, Auchtitench Sandstone formations as well as the intercalated volcanic formations. The sequence is predominantly fluviatile with associated calc-alkaline lava flows and volcanic detritus.

Name derivation:
The group term was introduced by Smith for the New Cumnock Sheet 15W (British Geological Survey, 1999a) and named after the most complete local exposures of the LORS sequence which occur in Lanarkshire.

Type area:
The type area [NS 75 25] lies south-west of Douglas in Lanarkshire, up to the Southern Upland Fault.

Upper and lower boundaries:
The base of the group is taken at the unconformity or disconformity of the Greywacke Conglomerate Formation upon the Wenlock–?Ludlow clastic sandstones and siltstones which form Silurian inliers within the southern MVS. The fact that the base is locally difficult to recognise has made correlation difficult from the earliest geological surveys of the area. The top of the group is defined by the unconformity with the Stratheden and Inverclyde groups. Lateral variations are shown in Figure 2.

Thickness:
The thickness of the group is in the order of 3000 m.

Age:
The precise age of the Lanark Group is difficult to determine because of the lack of good fossil evidence. However, the Pentland Hills Volcanic Formation has been dated at 412.6 $\pm$ 5.7 Ma (Rb/Sr) and to the south-west, the Tinto Felsite intrusion has been dated at c. 411.9 $\pm$ 1.9 Ma using Sm-Nd garnet whole rock isochrons and biotite ratios 39Ar-40Ar (Thirlwall, 1988). These dates approximate to the early Devonian (base of the Devonian at 417 Ma, Tucker and McKerrow, 1995; 418 Ma, Tucker et al, 1998).

2.1.1 Greywacke Conglomerate Formation (GRWC)

Lithology:
The Greywacke Conglomerate Formation comprises mottled purple and brownish red, massive to crudely bedded conglomerate with a few sandstone interbeds. The clasts are predominantly of ‘greywacke’ sandstone with subordinate chert. Other rock types are generally a very minor component; except in the Tinto–Carmichael area, where up to 46% of the clasts are of fine-grained igneous rock including microgranites (McGiven, 1968). Some quartzite, quartz and coarse-grained igneous clasts are also recorded. The conglomerate contains mainly pebbles but also cobbles and boulders particularly towards the base. The pebbles are commonly rounded to subrounded in the type area around the Hagshaw Hills. The conglomerates are bimodal in grain-size distribution with a grey-brown poorly-sorted sandstone matrix. The conglomerates are generally clast-supported and in places where the sandstone matrix is absent, interstices are filled with calcite. Subordinate sandstone interbeds and lenses are more common in the upper part of the formation.

Details of the palaeoflows and sedimentology are given by McGiven (1968) who concluded that the formation was deposited in a terrestrial environment from alluvial fans sourced from a south-easterly direction. Sheet floods were the dominant agents involved in the construction of the fans. Syba (1989) also studied the formation and noted that it formed by the vertical stacking of small proximal fans. These fans were dispersed mainly from the east and to a lesser extent to the south (Syba, 1989) with the geochemistry of the clasts suggesting that they probably came from a cryptic greywacke source within the MVS.

Name derivation:
This conglomerate was recognised as distinctive, containing greywacke pebbles, by Geikie et al. (1871). The term Greywacke-conglomerate was used informally by Peach and Horne (1899) and Read (1927). Subsequently the term Greywacke Conglomerate was used by Rolfe (1960, 1961), Bluck (1978) and Cameron and Stephenson (1985).

Type section:
The type section is along the Monk’s Water/Douglas Water section near Monksfoot Farm [NS 784 287 to 787 283].

Upper and lower boundaries:
The formation was taken as the basal conglomerate of the LORS succession in the southern MVS. Its base is unconformable or disconformable with the underlying paralic sequences of Wenlock to Ludlow age (or older) found in inliers on the south side of the MVS. In the type area, south of the Hagshaw Hills, it rests on the Silurian Quarry Arenite Formation. The top of the formation is taken at the base of the predominantly sandstone sequence which forms the Swanshaw Sandstone Formation but locally the Greywacke Conglomerate Formation is succeeded by volcanic rock.

Thickness:
The greatest thickness of the formation occurs in the

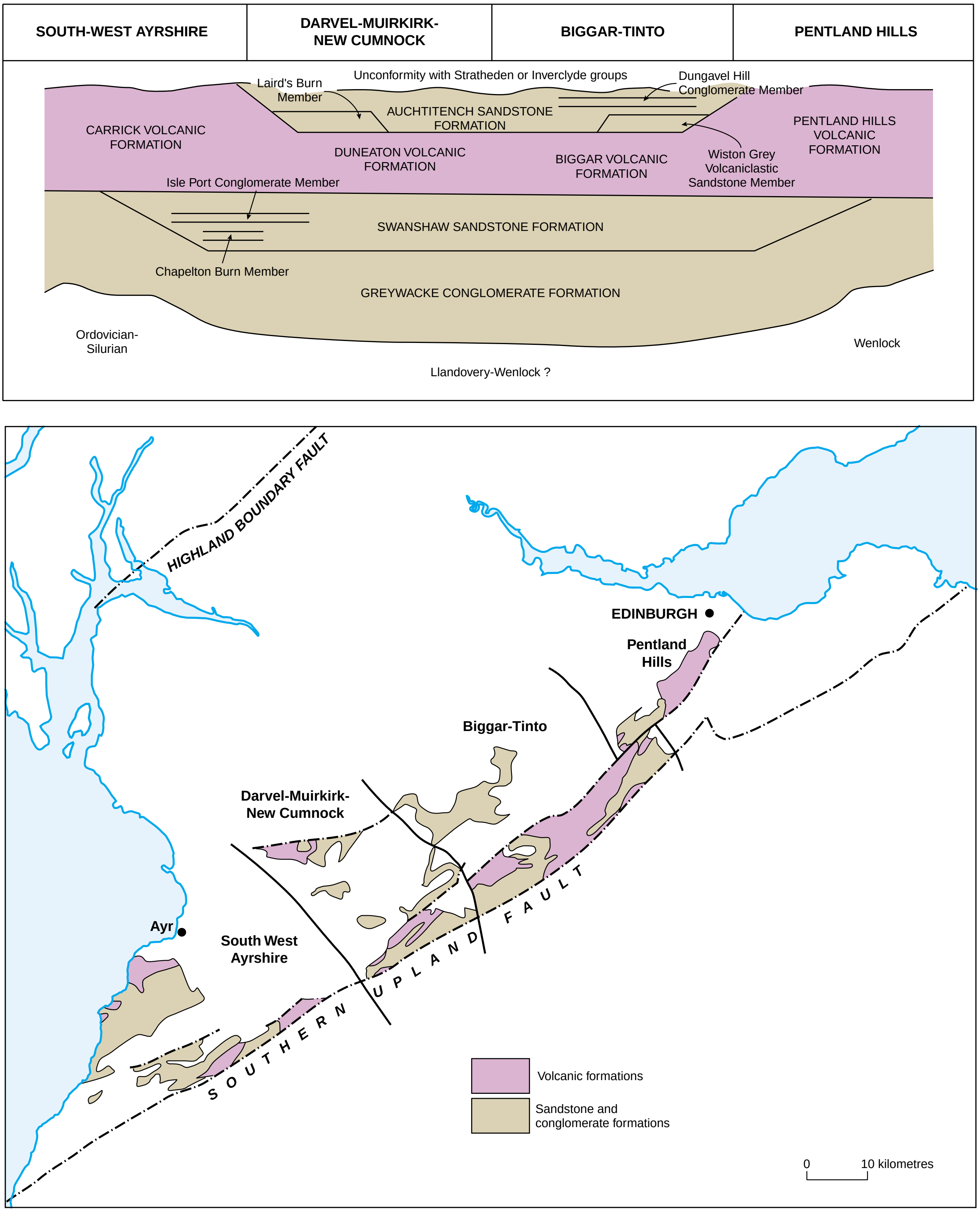

Figure 2 Lanark Group in the southern Midland Valley of Scotland.

Podowrin Burn [NS 790 285], south of the Hagshaw Hills, where an estimated 560 m is exposed. From this area, the formation thins westwards, to around 25 m, north-east of Cairn Table [NS 732 245]. This variation in thickness is probably due to the deposition of the formation in alluvial fans.

Extent:
Greywacke Conglomerate Formation deposition extended along the southern MVS from the Pentland Hills south-west into Ayrshire between Straiton and the Southern Upland Fault. In the latter area the greywacke-conglomerates occur either directly above or close to the unconformity with the Ordovician. However, in places in Ayrshire, sandstone lies just above the unconformity. Sandstone also occurs, together with conglomerate containing 'greywacke' clasts, interbedded with basaltic lavas (e.g. east of Craig of Dalwine [NX 355 965, Sheet 8W]). The latter observation

can be interpreted as either an early eruption of lavas or a later intercalation of coarse clastic material sourced from a wacke sandstone provenance.

In the Pentland Hills area, Mitchell and Mykura (1962) believed that the clasts ('greywacke' etc.) towards the base of the basal conglomerate were locally derived from the Llandovery–Wenlock inlier. In this area they also noted that pebbles of the volcanic rocks do not normally occur in the lower part of the sedimentary sequence, except in the vicinity of Loganlee. Towards the top of the sequence (probably equivalent to the Swanshaw Sandstone Formation) pebbles from a number of volcanic members of the Pentland Hills Volcanic Formation are found.

Age:
Cameron and Stephenson (1985) considered this formation to be of Early Devonian age. Since the age of the overlying Duneaton Volcanic Formation is c. 411 Ma (Thirlwall, 1988) and the base of the Devonian c. 418 Ma (Tucker et al., 1998), this is probably correct (cf. Smith, 1995).

2.1.2 Swanshaw Sandstone Formation (SWAS)

Lithology:
The Swanshaw Sandstone Formation is predominantly a red-brown to pinkish brown lithic arenite succession with subordinate pebbly sandstones and conglomerates. The sandstones are typically medium grained and moderately well sorted. Sandstone beds are planar to cross-bedded, and fluviatile in origin. Minor red-brown or green siltstones and silty mudstones are intercalated; although much of this facies has been penecontemporaneously eroded or incorporated into the sandstones as rip-up clasts. The sandstones are immature including similar rock fragments and minerals to those in the Greywacke Conglomerate Formation and they are derived probably from the same source rocks. The formation generally fines upwards from pebbly sandstones into fine- and medium-grained sandstones. However, towards the top of the formation in the type area, there is an intercalated conglomerate, (Smith, 1994), containing mainly greywacke pebbles but also some quartz and volcanic pebbles. A comparable conglomerate, the Isle Port Member, has been defined in Culzean Bay, south of Ayr [NS 245 130] (Smith, 2000). This conglomerate includes sparse limestone clasts derived from a cryptic source to the south of the present MVS and containing mid-Ordovician conodont faunas (Armstrong and Owen, 2000).

Name derivation:
The Swanshaw Sandstone Formation was previously included in the LORS succession. The formation was defined by Smith (1993; 1994; 1995) in the type area near Swanshaw Burn, east of Cairn Table [NS 735 240]. The Lanark Sandstone Formation (LKSF in the BGS lexicon) has been superseded by the synonymous Swanshaw Sandstone Formation and is redundant.

Type section:
The type sections occur in Swanshaw Burn [base at NS 7308 2461] and Duneaton Water [top at NS 7479 2341].

Upper and lower boundaries:
The base of the formation is transitional with the underlying Greywacke Conglomerate Formation and the top transitional with the incoming of the andesitic/basaltic lava flows of the Duneaton Volcanic Formation.

Thickness:
The formation is estimated to be 700–900 m thick (Richey et al., 1930).

Extent:
The Swanshaw Sandstone Formation can be traced around the Lesmahagow inlier, north-eastwards into the Pentland Hills area (British Geological Survey, 1996b) and south-westwards into Ayrshire (Eyles et al., 1949; Richey et al., 1930). It has also been mapped south of Darvel in north Ayrshire. The upper conglomerate in the type area may correlate with the conglomerate found at a similar stratigraphic level within the formation in Ayrshire [NS 370 032] (Eyles et al., 1949). In Ayrshire, the Swanshaw Sandstone Formation includes thin interbeds and rip-up clasts of red, green or grey mudstone and very occasional nodules of ferruginous limestone. The sandstones just below the Carrick Volcanic Formation in Ayrshire tend to be rather fine grained, micaceous, thin bedded and calcareous. Some of the beds are tuffaceous and appear to be associated with Mochrum Hill [NS 265 100], a large volcanic vent of early Devonian age west of Maybole. As the tuffaceous beds lie at a stratigraphical level slightly higher than the sedimentary rocks pierced by the vent (Eyles et al., 1949), it is possible that the reported tuffs represent volcanic ash reworked from the Mochrum Hill vent and interbedded with sands on the surrounding floodplains.

In north Ayrshire, Geikie et al. (1872) recorded *Cephalaspis lyelli*, a fossil fish typical of LORS assemblages, from sandstone quarries on Penning Hill, north-west of Tulloch Hill [NS 583 355]. Subsequently further poor specimens were determined (Richey et al., 1930) as *Cephalaspis* sp. indet., possibly *C. powriei* (Lank). In addition, Westoll (in House et al., 1977) listed *C. traquairi*, and *C. lyelli* from near Distinkhorn. These sandstones all underlie the LORS lavas and are thought to belong to the Swanshaw Sandstone Formation.

Age:
Westoll (in House et al., 1977) inferred that the age of the above fish faunas is Lochkovian (Gedinnian), but the radiometric ages of the overlying lavas in the southern MVS (Thirlwall, 1988) indicate that the lavas are about 415–410 Ma, i.e. Lochkovian–Pragian (Tucker et al., 1998). The validity of the radiometric ages of these volcanic rocks compared to the biostratigraphical ages of the associated sedimentary rocks has been debated (Thirlwall 1981, 1988; Astin 1983).

2.1.3 Volcanic formations

The widespread eruption of calc-alkaline LORS lavas along the southern margin of the MVS appears to have focussed around four centres as presently exposed. These centres, named by Geikie (1897) from north-east to south-west, are the Pentland Volcano, the Biggar Centre, the Duneaton Centre and the Ayrshire Volcanoes. Andesitic to basaltic lavas comprise the bulk of the volcanic piles, however, in the Pentland Volcano and the Biggar Centre there are also rhyolites, trachytes or dacites. The geochemistry of the suite has been examined (Thirlwall, 1981) and is considered to be calc-alkaline in character, related to a subducting slab of oceanic plate descending to the west-north-west.

Because of the differences in the components and possibly age range of the eruptive activity from the four centres, they have each been given formation status. They are the Duneaton Volcanic Formation (Smith, 1994; 1995), the Pentland Hills Volcanic Formation (British Geological Survey, 1996b), the Biggar Volcanic Formation (Phillips and Barron, 2000) and the Carrick Volcanic Formation (Smith, 2000).

2.1.4 Duneaton Volcanic Formation (DNV)

Lithology:
The Duneaton Volcanic Formation comprises mainly basaltic andesite lavas with some intercalated andesitic flows and volcaniclastic sandstones and breccias. The formation lies conformably above the Swanshaw Sandstone Formation in the type area and although there are thin tuff beds intercalated with the sedimentary rocks near the base, there are no exposed underlying vents or feeders. The lavas in the Duneaton Volcanic Formation range from olivine-bearing basalts to hornblende-bearing andesites. The lavas are generally somewhat weathered, purplish to greenish grey with extensive amygdaloidal and autobrecciated zones. They vary from aphyric lavas to those with conspicuous plagioclase and pyroxene phenocrysts, but no systematic differentiation was found. Local haematisation probably developed subaerially. Some lava flows contain irregular blocks of fine-grained sandstone and siltstone. The intercalated volcaniclastic sandstones and breccias are variable in thickness and composition. These rocks are poorly sorted with rounded clasts, and are probably locally derived.

A geochemical study (Phillips, 1994) of the Duneaton lavas showed that the majority were basaltic andesites typical of calc-alkaline suites and consistent with the LORS suite elsewhere in the MVS (Thirlwall, 1981).

Name derivation:
The distinct volcanic area near the Duneaton Water was identified by Geikie (1897) in which lavas and tuffs alternated with sandstones and conglomerates. The Duneaton Volcanic Formation was erected in the Lanarkshire area [NS 75 23], along the Duneaton Water (Smith, 1994; 1995).

Type section:
The type sections lie along Duneaton Water [NS 7479 2341–7770 2256] and its tributaries.

Upper and lower boundaries:
The base of the formation is the base of the volcanic pile, as exposed in Duneaton Water [NS 7479 2341], above the Swanshaw Sandstone Formation. The top of the formation is taken where the overlying volcaniclastic arenite and/or rudite succession predominates along Duneaton Water [NS 7770 2256] although there are, locally, minor intercalations of olivine-basalt in the overlying Auchtitench Sandstone Formation.

Thickness:
The thickness of the formation varies considerably, from 300 m to around 1200 m in the type area.

Extent:
The volcanic pile extends from Lanarkshire into Ayrshire between the Douglas and Ayrshire Carboniferous basins. It has also been traced in the Lanark Group outcrop south of Galston and Darvel.

Age:
There is no biostratigraphical evidence for the age of the formation but radiometric dating of the Lanark Group lavas elsewhere in the southern MVS (Thirlwall, 1988) indicates a range of 410 to 415 Ma i.e. early Devonian.

2.1.5 Pentland Hills Volcanic Formation (PDH)

Lithology:
The Pentland Hills Volcanic Formation comprises basalts, andesites, trachytes and rhyolites. It disconformably overlies the Greywacke Conglomerate and Swanshaw Sandstone formations and contains several distinct lava members together with interbedded pyroclastic rocks and some sedimentary beds. The lithologies of the individual members are listed below:

Blackford Hill Volcanic Member (BLCK): Thick andesite flow with overlying olivine basalt.
Braid Hills Volcanic Member (BRAI): Trachyte and trachyandesite with thin tuff at base.
Fairmilehead Volcanic Member (FAI): Pyroxene andesite and biotite trachyte with thin flows of olivine basalt.
Carnethy Volcanic Member (CAHI): olivine-basalts and basic andesites.
Woodhouselee Volcanic Member (WDH): trachytes, andesites and other silicified acid rocks.
Caerketton Volcanic Member (CAE): acid tuffs; local trachyte and andesite.
Allermuir Volcanic Member (ALMR): basic andesites and olivine basalts with intercalations of sandstone, basic tuffs and breccias; local rhyolite and rhyolitic tuff.
Capelaw Volcanic Member (CPW): dacite or feldsparphyric rhyolite and olivine basalts and basic andesites.
Bell's Hill Volcanic Member (BHHB): rhyolites with lenses of conglomerate.
Bonaly Volcanic Member (BNY): feldsparphyric andesites and olivine basalts; local rhyolites.
Warklaw Hill Volcanic Member (WKH): olivine basalts.
Torduff Hill Volcanic Member (TDH): trachyte.

Name derivation:
The formational name was introduced by Barron (British Geological Survey, 1996b; Barron, 1998) and the rocks described in detail in Mykura (1960).

Type area:
The type area is exposed in the Pentland Hills of the Lothians.

Upper and lower boundaries:
The base of the formation is seen west of Braid Law [NT 180 590] where the Bell's Hill Volcanic Member overlies the Swanshaw Sandstone Formation. About one kilometre north, the base of the formation oversteps on to the Greywacke Conglomerate Formation suggesting that there is a disconformity at the base. The top of the formation is the unconformity with the Inverclyde Group exposed west of West Kip [NT 175 607], extending north-eastward as far as the north-east slopes of Blackford Hill, Edinburgh [NT 267 712].

The three uppermost members of the formation are in faulted contact with the remainder of the formation. Despite resemblances between the Braid Hills and Woodhouselee members, Mykura (1960) considered that they were not equivalent, and that the Fairmilehead

Volcanic Member probably overlay the Carnethy Volcanic Member at depth.

Thickness
The formation reaches a maximum thickness of around 2000 m at the northern end of the outcrop, thinning considerably to the south-west.

Age:
Thirlwall (1988) obtained a radiometric age of 412.6 ± 5.7 Ma (Early Devonian) from the Capelaw Volcanic Member at Swanston on the northern side of the Pentland Hills.

2.1.6 Biggar Volcanic Formation (BGRV)

Lithology:
The Biggar Volcanic Formation not only contains basalts and basaltic andesites but also hornblende andesites, trachytes, rhyolites, felsites and rhyolitic tuffs and breccias. The volcanic rocks are commonly vesicular or amydaloidal and altered to a purplish brown colour. The Biggar volcanic centre was separated by Geikie (1897) from the other LORS volcanic centres in the southern Midland Valley. He noted that the volcanic rocks around West Linton intercalated with the sandstone, whereas towards Biggar, the lavas accumulated without sedimentary intercalations.

Name derivation:
The formational name was introduced by Phillips and Barron (2000) for the volcanic rocks south-west of Biggar.

Type area:
The type area is around Biggar [NT 040 380] and extends west of Tinto where a type section comprising micro- and macroporphyritic basaltic and andesitic lavas occurs in Parkhall Burn [NS 866 296 to 863 319].

Upper and lower boundaries:
The formation is underlain by the Swanshaw Sandstone Formation and overlain by the Auchtitench Sandstone Formation.

Thickness:
The total thickness of the formation is difficult to estimate because of faulting, but probably at least 1000 m.

Age:
The formation has not been dated but likely to be slightly older than the 411.9 ± 1.9 Ma Sm-Nd date given by Thirlwall (1988) for the associated Tinto Felsite.

2.1.7 Carrick Volcanic Formation (CRKV)

Lithology:
The Carrick Volcanic Formation in central Ayrshire comprises mainly basalt and basaltic andesite lavas which are well exposed on the coast near Dunure, Culzean Castle and Maidens and in the Carrick Hills. The lavas in central Ayrshire are commonly subject to alteration, being partly haematised. The flows having slaggy tops that range from 3 to 15 m thick. Thin sandstone and conglomerate intercalations and sandstone-filled fissures in the lavas have been described by Geikie (1897). In contrast, fluidisation of wet sediments during the emplacement of associated hypabyssal intrusions has been described from the Ayrshire coast (Kokelaar, 1982) which explains some of the complex relationships between the igneous and sedimentary rocks. These are also described from the geological conservation sites, Port Schuchan to Dunure Castle; Culzean Harbour and Turnberry Lighthouse to Port Murray (Durant, 1999a). Olivine-rich basalt is widespread at the base, but there is evidence of earlier lava eruptions from the lava pebbles present within the Swanshaw Sandstone Formation below.

No lavas more acid than andesite are known from central Ayrshire (cf. the Pentland Hills Volcanic Formation.), although flow-banded rhyolites south of Dalrymple may be extrusive. In north Ayrshire the lavas are mainly altered andesite and olivine-basalts (Richey et al., 1930).

The intercalated volcanic conglomerates and sandstones are mainly derived locally from the volcanic rocks. It is uncertain whether there are any true airfall tuffs in this area. In the Carrick Hills and Dunure areas, there are thin interbeds of fine-grained sandstone and sandy mudstone in which several trace fossils have been found (Eyles et al., 1949; Walker, 1985) and these have been used to interpret the prevailing environment as an ephemeral shallow lake. The intercalated tuffaceous pebbly sandstone east of Knockoner [NX 366 998] (Eyles et al., 1949) contains a thin bed of pedogenic carbonate.

Name derivation:
The formational name is derived from Brown Carrick Hill, south of Ayr and was introduced by Smith (2000). It was formerly the LORS volcanic group of Eyles et al. (1949).

Type section:
The type section for the Carrick Volcanic Formation is along the foreshore from west of Drumshang [NS 2449 1382] to Bracken Bay, south of Ayr [NS 273 182].

Upper and lower boundaries:
At the base of the formation, west of Drumshang, a basaltic andesite has a sharp, irregular junction above a brick-red sandstone (Swanshaw Sandstone Formation) containing volcanic clasts and scattered pebbles of sandstone (Smith, 2000). The top of the volcanic pile is not seen because it is unconformably overlain by rocks belonging to the Stratheden and Inverclyde groups (i.e. there is no representative of the Auchtitench Sandstone Formation in this area).

Thickness:
In the Carrick Hills, east of Dunure, the volcanic sequence is 300–450 m thick and can be divided into the following lithologies (Eyles et al., 1949):
Hypersthene-andesite and olivine basalts, both with porphyritic feldspar
Augite-andesite with few/no phenocrysts
Olivine basalts with porphyritic feldspars
Olivine-rich basalts (non-porphyritic) with a basal augite-andesite flow

In the Dalmellington area, a sequence 600 m thick contains comparable lithologies:
Mainly olivine basalts with porphyritic feldspars
Olivine-rich basalt, thin and locally absent
Tuffaceous conglomerate
Olivine-rich basalt (non-porphyritic) with conglomerate beds (oldest)

Extent:
Several centres of volcanic eruption have been postulated for the lavas in Ayrshire (Geikie, 1897) but there are few known vents in the area except for one at Mochrum Hill [NS 265 100] and a smaller, faulted one near Bracken Bay [NS 276 181]. One small vent north-east of Little Shalloch [NS 456 033] lies within the Carrick Volcanic Formation around Dalmellington, which is poorly exposed and faulted. Because of the predominance of olivine basalts and pyroxene andesites throughout the LORS volcanic rocks of Ayrshire, it is not thought necessary to create separate formations for each outcrop area.

Age:
Radiometric dating of the Lanark Group lavas elsewhere in the southern MVS (Thirlwall, 1988) indicates a range of 410 to 415 Ma i.e. early Devonian in age.

2.1.8 Auchtitench Sandstone Formation (AUC)

Lithology:
The Auchtitench Sandstone Formation comprises mainly red- or purplish-brown and grey-green and buff sandstones and conglomerates. The succession is made up predominantly of volcaniclastic debris derived from the subjacent Lower Devonian volcanic suites. The beds were deposited in a high-energy fluviatile environment. The subordinate interbeds of reddish brown or green siltstone and silty mudstone were probably preserved on the interfluves together with local, impersistent flows of olivine basalt.

The basal beds are exposed along the Duneaton Water [NS 777 226] where fine- and medium-grained volcaniclastic sandstones are intercalated with conglomerates containing pebbles of andesitic lava (Plate 1). To the south-west in the Laird's Burn to Penbreck Burn area [NS 73 21], the basal beds are distinguished as the Laird’s Burn Member (Smith, 1994). This local member, up to 350 m thick, comprises yellow-brown to pale buff, fine- and medium-grained tuffaceous and volcanic sandstones that are locally cemented by carbonate. In places, there are also interbeds containing angular and rounded volcanic pebbles.

The typical sandstone beds in the rest of the formation are medium- or coarse-grained, between 0.1 and 0.5 m thick and moderately to poorly-sorted. Some of the beds are fairly massive with scattered lava pebbles and silty mudstone rip-up clasts; others are low-angle planar or trough cross-bedded. Some of the sandstone beds fine up into reddish silty mudstone with sporadic calcareous nodules. Pebble and cobble conglomerates containing mainly rounded andesitic and basaltic lava clasts set in a granular- to medium-grained sandstone matrix are commonly intercalated and were probably deposited in extensive sheets or channels by powerful braided rivers. To the south-east, near the Southern Upland Fault, the conglomerates contain lava boulders up to 1.2 m in length. Some of the conglomerates are matrix-supported but most are clast-supported, coarsening up in units 4 to 5 m thick with locally, clast imbrication indicating palaeocurrents flowed to the north.

Although the sandstones contain 75–90% volcanic rock fragments, the upper beds also contain polycrystalline quartz, perthitic feldspar and microcline, microdiorite, myrmekite, tourmaline and garnet as well as some mica schist and psammite clasts. This suggests that a source other than just the LORS suite was providing the detritus; one in which hypabyssal or granitic intrusions were being eroded either within the MVS or SUT.

Name derivation:
The formation is named after the type area around Auchtitench Hill [NS 710 180] (Smith, 1993; 1994; 1995). Formerly, publications of the Geological Survey included the strata within the LORS lithofacies (Geikie et al., 1871). The term Lava Conglomerate was used as an informal term

Plate 1 Coarsening-upward conglomerate bed containing andesitic lava clasts within the Auchtitench Sandstone Formation. North-east of Corsencon Hill, east of New Cumnock (D5377).

(Bluck, 1978) referring to the conglomerates containing predominantly lava clasts, which in the Dalmellington area, lie within the lava pile. The constituent Dungavel Hill Conglomerate (named after Dungavel Hill [NS 940 300], see Cameron and Stephenson, 1985) is a local member. The uncertain persistence or correlation of the several lava pebble/cobble/boulder conglomerates within the Auchtitench Sandstone Formation makes the formal naming of rudaceous members of limited value. Informal members have been named to aid local description, e.g. the Cairn Kinney member (Smith, 1993), south of Duneaton Water [NS 785 215].

Type section:
The type section is exposed along the Duneaton Water [NS 7770 2256 (base) to 8060 2194].

Upper and lower boundaries:
The base is the conformable junction overlying the Duneaton Volcanic Formation and the youngest beds exposed lie in the syncline to the north-west of the Southern Upland Fault. West of Auchtitench Hill [NS 669 178], the formation is unconformably overlain by the basal Carboniferous Kinnesswood Formation (Inverclyde Group).

Thickness:
In the type area around Auchtitench Hill the formation is at least 1000 m thick.

Extent:
The Auchtitench Sandstone Formation extends north-east towards Biggar where greenish grey ashy sandstones (Wiston Grey Volcaniclastic Sandstone Member) are exposed near the base of the formation above the Biggar Volcanic Formation. It also occurs above the Duneaton Volcanic Formation in the Lanark Group outcrop south of Darvel.

Age:
There is no palaeontological evidence for the age of these beds since they only contain traces of burrows. However, they are thought to be early Devonian (Pragian?) as the radiometric age of the underlying lavas is 410 to 415 Ma (Thirlwall 1988).

3 The Upper Silurian to Lower Devonian rocks in the Southern Upland Terrane

There is little work on the formal lithostratigraphy of the Siluro-Devonian rocks within the SUT (House et al., 1977; Greig, 1971; Mykura in Craig, 1991). Because the terrane has generally been one of positive relief since Palaeozoic times, the Siluro-Devonian successions are commonly isolated and incomplete. In the Eyemouth and Jedburgh areas, Upper Devonian sequences are unconformable on Siluro-Devonian strata and no Middle Devonian rocks are recorded. Geological studies of the ORS lithofacies suggest, but do not prove, that the Siluro-Devonian rocks in this terrane were deposited in separate basins from those postulated for the MVS and therefore separate group and formation names are given for the SUT and MVS. One example of the difference between successions is that between the Lamancha Conglomerate Formation, which contains Haggis Rock clasts derived locally from Ordovician rocks, and the Greywacke Conglomerate Formation which does not contain clasts comparable with the strata in the SUT. Thirlwall (1981) showed that the early Devonian volcanic rocks on either side of the Southern Upland Fault were somewhat chemically different even though the magmatism occurred at about 410 Ma in both terranes (Thirlwall, 1989). This supports the argument that there is a significant break, either transcurrent or across strike, at the Southern Upland Fault. Therefore, within the SUT, the Reston Group is chosen here as an appropriate term, named after the village [NT 883 622] near Eyemouth where the Siluro-Devonian succession is most complete.

3.1 RESTON GROUP (REST)

Lithology:
The Reston Group comprises all the Siluro-Devonian clastic and volcanic lithologies lying within the SUT. It includes the Lamancha Conglomerate and Great Conglomerate formations; the succeeding Eyemouth Volcanic and Auchencrow Sandstone formations defined in the St Abb's to Eyemouth area, and the Cheviot Volcanic and White Hill Sandstone formations in the Cheviot Hills (Figure 3).

Name derivation:
The group name derives from the village of Reston [NT 885 622] in the type area.

Type area:
The type area is around Eyemouth in the Scottish Borders where the succession is most complete.

Upper and lower boundaries:
The base of the group is the unconformity above the Ordovician and Silurian rocks of the SUT and its top is the unconformity with the Upper Devonian Stratheden Group.

Thickness:
The group has a maximum thickness of 2350 m.

Biggar and Peebles area

3.1.1 Lamancha Conglomerate Formation (LCHA)

Lithology:
The Lamancha Conglomerate Formation consists of reddish brown conglomerates and breccias containing clasts of local derivation within a sandstone matrix. Dr J Floyd (pers. comm., 1999) states that the formation contains clasts of Haggis Rock derived from the underlying Ordovician rocks and probably lay in a separate basin to that in which the Great Conglomerate Formation accumulated.

Another small outlier of conglomerate south-west of Biggar and cut by the Southern Upland Fault [NS 995 315], was formerly considered to be Devonian, but contains a different clast content (Barron, pers comm. 1999) and is now thought to be Ordovician in age.

Name derivation:
The formation is named after Lamancha, a farm about 4 km south-west of Leadburn.

Type area:
The type area lies near Lamancha [NT 200 515].

Upper and lower boundaries:
The base rests unconformably on folded Ordovician rocks in the SUT (British Geological Survey, 1996c). The top of the formation is not seen as it is cut out by the Southern Upland Fault.

Thickness:
The formation is at least 50 m thick.

Dunbar, Lauder and Haddington area

3.1.2 Great Conglomerate Formation (GCGL)

Lithology:
The Great Conglomerate Formation, adjoining the Lammermuir Fault south of Dunbar, is predominantly composed of greywacke clasts ranging up to boulders in size, loosely cemented with a sparse reddish brown sandstone matrix (Plate 2). Some of the pebbles are of quartzite and weathered dioritic rock. The conglomerate is interbedded with thin sandstones and silty sandstones with scattered pebbles.

Outliers of conglomerate occur on Carfrae Common and a smaller one north of Kelphope Hill. Lenticles of red-brown pebbly sandstone and thin beds of red-brown siltstone and mudstone are present in these outliers. Besides greywacke sandstone, their clast content includes chert, quartzite and igneous rocks such as quartz-porphyry and felsite. These small outliers of conglomerate are correlated with the Great Conglomerate Formation on lithostratigraphical grounds (cf. McAdam and Tulloch, 1985).

The Great Conglomerate Formation has been correlated (cf. Rock and Rundle, 1986) with the prevolcanic sedimentary rocks at Bell Hill [NT 916 680] in the St Abb's to Eyemouth area (Figure 3). Conglomerates and sandstones

Peebles	*Dunbar-Lauder*	*St Abb's-Eyemouth*	*Cheviots*
		Unconformity	Unconformity
		Auchencrow Burn Sandstone Formation	
		Eyemouth Volcanic Formation	Cheviot Volcanic Formation
Lamancha Conglomerate Formation	Great Conglomerate Formation	Great Conglomerate Formation	White Hill Sandstone Formation
Unconformity	Unconformity	Unconformity	Unconformity
Ordovician or Llandovery/Wenlock rocks			

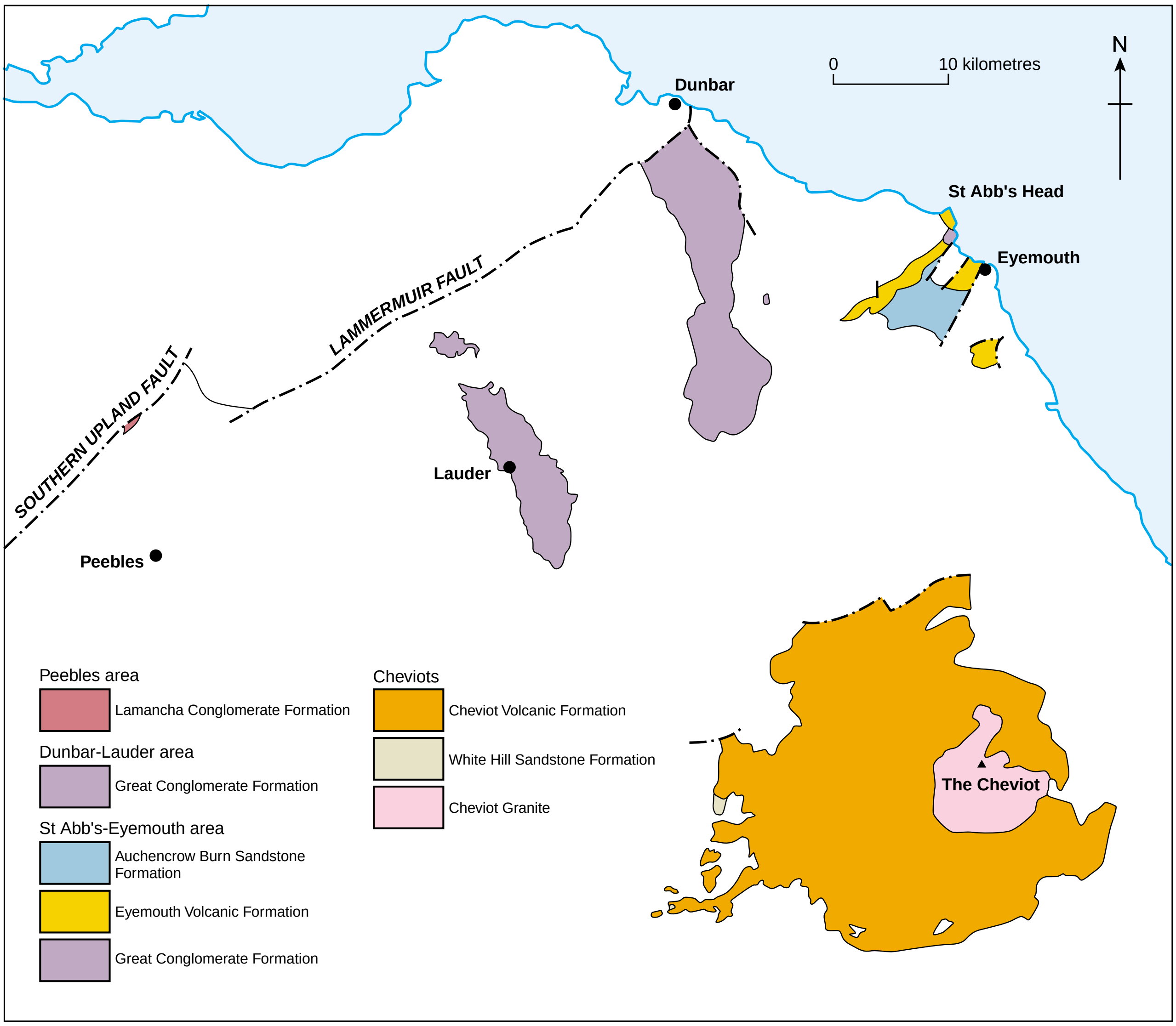

Figure 3 Lithostratigraphy of the Reston Group.

(devoid of lava clasts) crop out around Bell Hill, south of St Abb's Head, and the succession includes fine and coarse breccias, pebbly sandstones and thinly bedded siltstones (Greig, 1988). Clasts include angular to subrounded pebbles of greywacke up to 0.3 m in length.

Name derivation:
The Great Conglomerate (the informal term used in Davies et al., 1986) was formerly assigned to the Devono-Carboniferous and referred to as the Lower or Great Conglomerates (Howell et al., 1866, p.20) and as the great conglomerates (Clough et al., 1910, p.28). The redundant informal term Lauder Conglomerate (Rock and Rundle, 1986) was used for the equivalent strata in the Lauder area. Near Galashiels equivalent beds were mapped as ?LORS.

Type area:
The type area is around Back Water [NT 6994 6997].

Upper and lower boundaries:
The Great Conglomerate Formation rests unconformably on the folded Lower Palaeozoic rocks of the SUT and its base is exposed in Dean Burn [NT 6572 7184]. The top of the conglomerate is not seen as it has a faulted relationship with the upper Devonian–lower Carboniferous strata in the Dunbar area. Near St Abb's the formation lies unconformably on Silurian rocks and is overlain by the Eyemouth Volcanic Formation at White Heugh [NT 918 680].

Thickness:
South of Dunbar, from the Lammermuir Fault to south of Dirrington Great Law, the tract of Great Conglomerate Formation has a maximum estimated thickness of 350 m. North of St Abb's, the succession is at least 120 m thick (Greig, 1988).

Age:
There is no biostratigraphical evidence for the age of these strata (Davies et al., 1986), but they are cut by a lamprophyre dyke (Rock and Rundle, 1986) which has been dated at 400 ± 9 Ma (K-Ar biotite). This age is early Devonian.
Rock and Rundle (1986) considered that the deposit may be Upper Silurian rather than Lower Devonian in age (cf. the Lanark Group). However, Thirlwall (1988) tentatively suggested that these dates might be affected by excess Ar and therefore be too old.

St Abb's Head to Eyemouth area

The Bell Hill pre-volcanic sedimentary rocks of Greig (1988), underlying the Eyemouth Volcanic Formation, are part of the Great Conglomerate Formation (see above).

3.1.3 Eyemouth Volcanic Formation (EYVO)

Lithology:
The Eyemouth Volcanic Formation includes the olivine-phyric basalts, basaltic andesites and andesite lavas which crop out between Eyemouth and St Abb's Head (Greig, 1988). Some of the andesites are feldspar-phyric and some have a variety of ferromagnesian minerals. Tuffs containing lava fragments are reported as interbeds within the lavas. The rocks are generally altered and difficult to classify but biotite-bearing dacite or rhyodacite and biotite-feldspar-phyric rocks are present. The Pettico Wick to St Abb's Harbour section is described by Stephenson (1999) as part of the Caledonian Igneous Conservation Review.

Plate 2 Great Conglomerate Formation showing range of grades and fracturing of boulders and slight imbrication. Burn Hope, 4 km upstream from Oldhamstocks (D2745).

Name derivation:
The name derives from the coastal town of Eyemouth [NT 945 640]. At St Abb's Head these volcanic rocks were informally referred to as St Abb's Lavas (House et al., 1977; Rock and Rundle, 1986).

Type section:
The type section is on the coast from Pettico Wick [NT 907 692] to north of St Abb's [NT 918 680] (see Stephenson, 1999).

Upper and lower boundaries:
North of St Abb's, at Bell Hill [NT 916 680], the lavas rest on the Great Conglomerate Formation, but north-west of Coldingham, they rest on Silurian strata. South-west of Eyemouth the volcanic formation is overlain by the Auchencrow Burn Formation.

Thickness:
The succession is estimated to be 500–600 m thick (Greig, 1988, p.23).

Age:
No age dating has been done on these lavas as no fresh high Rb/Sr mineral has been found (Thirlwall, 1988) but they are assumed to be early Devonian.

3.1.4 Auchencrow Burn Sandstone Formation (AUCR)

Lithology:
The newly established Auchencrow Burn Sandstone Formation occurs in the Eye valley from Reston to Ayton where sandstones crop out which are derived from the

erosion of lavas similar to those in the Eyemouth Volcanic Formation. The formation typically contains reddish brown coarse-grained to pebbly sandstones with intercalated subordinate tuffs, siltstones and mudstones (Greig, 1988). Locally there are coarse conglomerates and one exposure of a thin pedogenic carbonate bed.

Name derivation:
The name derives from the burn near Auchencrow, which cuts through the top of the formation.

Type section:
A partial type section through the lower part of the formation is exposed in Eye Water, east of Coveyheugh [NT 870 625 to 886 622]. A section towards the top of the formation is seen in Auchencrow Burn [NT 86 59].

Upper and lower boundaries:
These sedimentary rocks overlie the Eyemouth Volcanic Formation but also locally overstep onto Silurian and ?Ordovician rocks which suggests that either the lava pile was patchy or there was a phase of penecontemporaneous faulting and erosion during the Early Devonian. The uppermost beds are cut out by faulting or overlain by upper Devonian–lower Carboniferous conglomerates.

Thickness:
The succession is at least 430 m thick (Greig, 1988) and probably up to 1400 m thick (British Geological Survey, 1982).

Age:
Fragments of *Pterygotus* sp. from Auchencrow Burn [NT 86 59] indicate an Early Devonian age for the strata.

Cheviot area

3.1.5 White Hill Sandstone Formation (WHIL)

Lithology:
The newly established White Hill Sandstone Formation comprises an impersistent sequence of red sandstone and mudstone with local beds of conglomerate.

Type area and name derivation:
The formation crops out south of White Hill (near Jedburgh, [NT 667 097] and in a presumed correlative outlier farther west near Oxnam.

Upper and lower boundaries:
These beds lie unconformably on folded Wenlockian strata in the SUT. In Shaw Burn [NT 665 094], near White Hill, a conglomerate containing rounded pebbles of red sandstone and volcanic rock is overlain by, and may be intercalated with, the overlying Cheviot Volcanic Formation.

Thickness:
The formation is up to 30 m thick.

Age:
There is no direct evidence of its age, but it is likely to be early Devonian as the closely associated Cheviot Volcanic Formation has been dated at around 380 to 396 Ma (Thirlwall, 1988).

3.1.6 Cheviot Volcanic Formation (CHEV)

Lithology:
The newly established Cheviot Volcanic Formation forms a thick pile of oligoclase andesite and augite-hypersthene andesitic lavas with subordinate biotite-phyric rhyolitic and pyroclastic rocks. The reported pyroclastic rocks (tuffs of Mykura, 1991) are local and occur mainly at the base of the succession and there are rare thin sandstone intercalations. The volcanic rocks are considered comagmatic with the Cheviot Granite.

Name derivation:
The name derives from the Cheviot Hills. It has previously been informally termed the Cheviot Volcanic Series (Greig, 1971; Mykura, 1983; 1991). Waterston (1965) and House et al. (1977) referred to the volcanics as the Cheviot Volcanic 'Group' with an informal Basal Agglomerate unit cropping out in England.

Type area:
The type area lies within the Cheviot Hills [NT 80 20]. The formation extends across the border into Roxburghshire from the volcanic centre in England where the volcanic pile is intruded by the Cheviot Granite (Figure 3).

Upper and lower boundaries:
The base of the volcanic rocks rests mainly on folded Wenlockian strata but locally it rests on the White Hill Sandstone Formation (see above) which may be penecontemporaneous in age. The top of the volcanic pile is unconformably overlain by upper Devonian to lower Carboniferous strata.

Thickness:
The formation is at least 1000 m thick.

Age:
The Cheviot Volcanic Formation has relatively high Rb/Sr ratios when fresh and three Rb/Sr whole rock and mineral ages have been determined (Thirlwall, 1988); 391 $\pm$ 8 Ma, 380 $\pm$ 11 Ma and 395.9 $\pm$ 3.8 Ma. These Early to Middle Devonian ages are considered to be within the error of the radiometric ages for the Cheviot Granite. No biostratigraphical evidence for the age of the formation has been found.

4 The Upper Silurian to Lower Devonian rocks in the Northern Midland Valley

Campbell (1913) was the first to describe the lithostratigraphy at group level of the ‘Old Red Sandstone and Downtonian rocks’ of south-east Kincardineshire. He recognised the 'Stonehaven Beds' in the latter rocks and five groups in the ORS. In ascending succession these were the Dunnottar, Crawton, Arbuthnott, Garvock and Strathmore groups. Armstrong and Paterson (1970) only changed Campbell's group scheme by changing the status of the Stonehaven Beds to that of group level. They applied their revised six-group scheme to the whole of the main outcrop of the LORS in the northern MVS. The only major difference between Campbell's and Armstrong and Paterson's (1970) scheme is that the latter assigned their Carron Formation to the Stonehaven rather than the Dunnottar Group. Palynological work by Marshall (1991) indicates a late Wenlock to early Ludlow age for strata near the top of the Cowie Sandstone Formation, the lower of the two formations recognised in the Stonehaven Group.

Marshall et al. (1994) studied vitrinite reflectivities of the organic matter in the LORS sedimentary rocks to try to elucidate the structural and burial history of the ORS of the MVS. They concluded that the Cowie Sandstone Formation was part of a separate depositional succession in what is here called the Stonehaven Basin. They considered that the Cowie Sandstone Formation was structurally juxtaposed by strike-slip faulting into its present position in apparently contiguous succession with the Carron Sandstone Formation. They believed that the Cowie Sandstone Formation has only ever been overlain by the higher stratigraphical groups (i.e. Arbuthnott to Strathmore). Marshall et al. (1994) effectively assigned the Carron Sandstone Formation to the Dunnottar Group based on similarities of process and sediment composition between the sandstones in the two units. However, it should be noted that Carroll (1995a) states that the contact between the Cowie and Carron formations is conformable; exposed at extreme low tide on the foreshore at Cowie Harbour [NO 884 868]. On this evidence, for now, the Carron Sandstone Formation is described with the Stonehaven Group

Marshall et al. (1994) also reflect the sedimentological work of Haughton (1988) and Haughton and Bluck (1988) in recognising a small Crawton Basin beneath the eastern extremity of the more extensive Strathmore Basin. The Crawton Basin is recognised as a narrow conglomerate-filled basin probably developed along a major terrane boundary in which the Dunnottar (including the Carron Formation) and Crawton groups were laid down. It is an anomaly in the context of the sedimentary basins that volcanic rocks have been assigned to the Crawton Group as far west as Blairgowrie. These include the radiometrically dated Lintrathen Tuff Member (ignimbrite), but such rocks can be accommodated in the existing lithostratigraphical framework because they are not bounded by the watersheds of drainage basins. No palynological or other palaeontological data are available to provide chronostratigraphical control but Thirlwall (1988, recalculated) provides a date for the Lintrathen Tuff Member (ignimbrite) of 415.5+/- 5.8 Ma. This result may be regarded as Early Devonian.

The Strathmore Basin is recognised as an elongate, largely axially filled trough that extended across the northern MVS. This basin oversteps the two earlier basins and in it are preserved the Arbuthnott, Garvock and Strathmore groups. The most reliable chronostratigraphical control for the age of the sedimentary rocks is provided by the palynological work of Richardson (1967) and Richardson et al. (1984). The Arbuthnott Group is seen as early Lochkovian (Gedinnian) belonging to the *micrornatus-newportensis* Zone (lower and middle sub-zones). This zone is of early but not earliest Devonian age, there being one partly Devonian zone *(tripapillatus-spicula)* below elsewhere. The palynological data are tied closely to radiometric dating at Wormit in Fife (407+/-6 Ma in Thirlwall, 1983). The Strathmore Group is seen as Emsian belonging to the *annulatus sextantii* Zone (Richardson et al., 1984, fig. 2).

From the review of recent work on the northern MVS and Southern Highlands, simplification of the classification at group level has been made (Table 2, Figures 4 and 5). Classification at formation level is given in Table 3. The proposal retains the Stonehaven Group (in the Stonehaven Basin). It combines the Dunnottar and the Crawton groups as the Dunnottar-Crawton Group that is found in a small geographical area mainly in the Crawton Basin. In the Strathmore Basin the proposal separates the Arbuthnott-Garvock Group from the Strathmore Group on key lithological criteria.

The Stonehaven Group consists mainly of sandstones that rest unconformably on the Highland Border Complex at Ruthery Head [NO 887 873]. The presence of numerous beds of grey and red mudstone, including the fossiliferous Cowie Harbour Fish Bed is a feature (Cowie Sandstone Formation) of the group as are some conglomerate beds (Carron Sandstone Formation). Lava flows are scarce.

The Dunnottar-Crawton Group consists mainly of conglomerates that rest with at least disconformity on the Stonehaven Group at Downie Point. The conglomerates are coarse and massive. Sandstones also occur along with intercalations of lava flows. Volcanic detrital sedimentary rocks are developed. The Dunnottar-Crawton Group combines the two former groups within the relatively small Crawton Basin and can be used to map inland areas where the former groups cannot be separated.

Table 2 LORS Group lithostratigraphy in the northern Midland Valley of Scotland and Southern Highlands.

Groups, 1970	New terminology	Age
Strathmore	Strathmore	Emsian
Garvock	Arbuthnott-Garvock	
Arbuthnott		Lochkovian
Crawton	Dunnottar-Crawton	
Dunnottar		
Stonehaven	Stonehaven	Wenlock-Ludlow

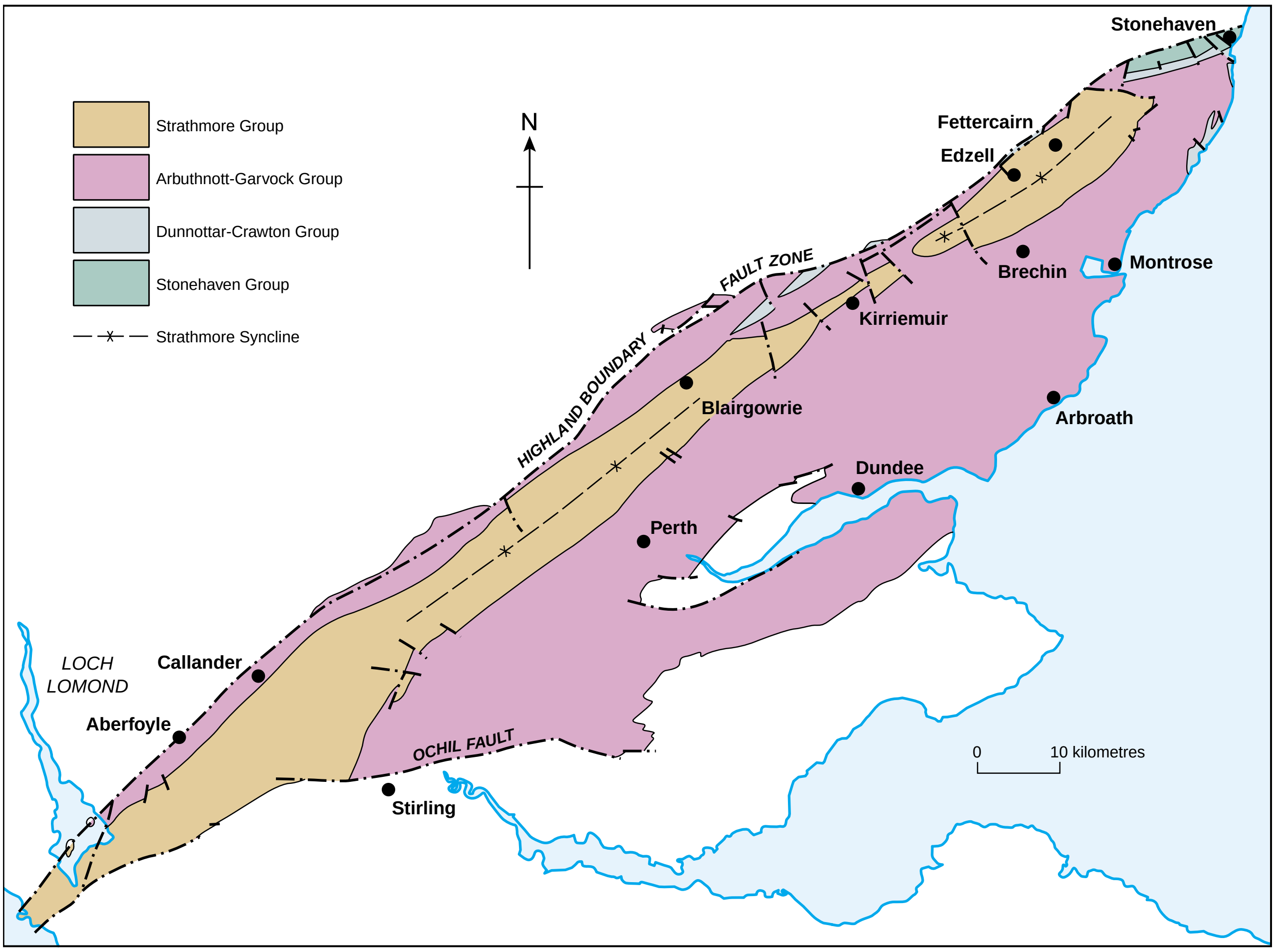

Figure 4 Distribution of Upper Silurian and Lower Devonian groups in the northern Midland Valley of Scotland.

The Arbuthnott-Garvock Group consists mainly of sandstones with significant, thick intercalations of lava flows, some conglomerates and volcanic detrital sedimentary rocks. Many intercalations of upward-coarsening lacustrine cycles (commonly more than 30 m thick) consisting of mudstone, siltstone and flaggy sandstone are a feature (Dundee Flagstone Formation) of the group. Another feature of the group (Scone Sandstone Formation) is the common occurrence of pebbles of limestone and calcareous mudstone, which were produced as the result of the penecontemporaneous erosion of beds with pedogenic calcareous nodules. The Arbuthnott-Garvock Group combines the two former groups developed in the lower to middle part of the Strathmore Basin and can be used to map areas where the former groups cannot be easily distinguished. The new hyphenated name avoids introducing a new term and the confusion of downgrading or deleting the old ones. The Strathmore Group consists largely of red, brown and green sandstones with conglomerates (especially near the Highland Border) and characteristic thick developments of red siltstone and silty mudstone in the lower part of the succession (Cromlix Mudstone Formation). Upward coarsening cycles and pebbles of pedogenic limestone are not features of this group.

Stonehaven–Fettercairn area

4.1 STONEHAVEN GROUP (SHG)

Lithology:
The Stonehaven Group comprises the Cowie Sandstone and Carron Sandstone formations (Figure 5). These consist mainly of cross-bedded and horizontally laminated, quartzo-feldspathic sandstones. There are numerous intercalations of silty mudstone and siltstone in the lower division, the Cowie Sandstone Formation, and abundant fragments of volcanic rock in the upper division, the Carron Sandstone Formation. Robinson et al. (1998) reported that the sandstones in the two formations show a dominant palaeocurrent direction to the north-west and contain detrital garnets indicating a metamorphic source terrane to the south-east. In contrast Gillen and Trewin (1987) measured palaeocurrent indicators for the Cowie Sandstone Formation showing transport to the east-south-east near the base and to the south-west in the rest of the formation.

The group crops out on the northern limb of the Strathmore Syncline in a zone up to 2.5 km wide adjacent and parallel to the Highland Boundary Fault. It is exposed around Stonehaven Bay and in the Carron Water.

Name derivation:
The name was introduced by Armstrong and Paterson (1970) replacing the older term, Stonehaven Beds previously set up by Hickling (1908) and accepted by Campbell (1913).

Type section:
The type section is in Stonehaven Bay from Ruthery Head [NO 8872 8727] to just north of Downie Point [NO 8805 8525].

Table 3 Late Silurian to Early Devonian formations in the northern Midland Valley of Scotland.

Callander–Aberfoyle	Stirling–Perth–Dundee	Blairgowrie–Edzell	Stonehaven–Fettercairn	
Teith Sandstone	Teith Sandstone	Teith Sandstone	Teith Sandstone	Strathmore Group
		Gannochy Conglomerate		
Cromlix Mudstone	Cromlix Mudstone	Cromlix Mudstone	Cromlix Mudstone	
Ruchill Flagstone	Scone Sandstone	Scone Sandstone	Deep Conglomerate	Arbuthnott-Garvock Group
Craig of Monievreckie Conglomerate	Dundee Flagstone	Craighall Conglomerate	Montrose Volcanic	
	Ochil Volcanic		Catterline Conglomerate	
		Lintrathen Tuff Member	Crawton Volcanic	Dunnottar-Crawton Group
			Whitehouse Conglomerate	
			Gourdon Sandstone	
			Tremuda Bay Volcanic	
			Dunnottar Castle Conglomerate	
			Carron Sandstone	Stonehaven Group
			Cowie Sandstone	

Upper and lower boundaries:
The base of the group is taken at a marked unconformity at the base of the Cowie Sandstone Formation on Ordovician Highland Border Complex rocks at Ruthery Head [NO 887 873] (Armstrong and Paterson, 1970). Elsewhere the base is faulted. The top of the group is marked by the disconformity below the thick, clast-supported Downie Point Conglomerate Member of the overlying Dunnottar-Crawton Group.

Thickness:
It has a minimum thickness of 1800 m (Carroll, 1995a).

Age:
The lower part of the group is late Wenlock to early Ludlow in age (Marshall, 1991; Wellman, 1993a). However, the upper part i.e. the Carron Sandstone Formation could be significantly younger (Marshall et al., 1994) as they argued that there is a break in sediment composition and process between the Cowie Sandstone and Carron Sandstone formations.

4.1.1 Cowie Sandstone Formation (CWE)

Lithology:
The Cowie Sandstone Formation consists of dull red, purple, grey, buff and yellow, cross-bedded and flat-bedded, medium-grained, quartzo-feldspathic sandstones with intercalations of red, purple and grey siltstone and mudstone. Intraclasts of these argillaceous rocks are found in some sandstones indicating reworking of overbank floodplain deposits. There is a thin, pebbly conglomeratic facies developed in the basal 50 m of the formation associated with a single thin (2 m) altered intermediate to acid lava flow. However, in the upper part of the formation conglomerate beds composed of rounded pebbles of acid volcanic rocks are present. The Cowie Harbour Fish Bed occurs in grey strata near the top of the formation. The conservation site for the late Silurian fossil fish at the Touttie s [NO 881 866] (Dineley and Metcalf, 1999) includes the fish bed, which also contains the arthropod *Dictyocaris.*

Name derivation:
The name was introduced as the Cowie Formation by Armstrong and Paterson (1970).

Type section:
The type section is in Stonehaven Bay between Ruthery Head [NO 8872 8727] and Cowie Harbour [NO 8815 8665].

Upper and lower boundaries:
The base of the formation is unconformable as described for the Stonehaven Group. The top of the formation is transitional according to Carroll (1995a) and is taken at the top of the highest grey sandy siltstone bed of the Cowie Harbour Siltstone Member.

Thickness:
According to Armstrong and Paterson (1970) the formation is 730 m thick but Carroll (1995a) gives the thickness as 490 m at Cowie Harbour where it may be attenuated by faulting.

Members:
Carroll recognised six members (in ascending order : Purple Sandstone, **Castle of Cowie,** Brown and Grey Sandstone, **Cowie Harbour Conglomerate,** Red Sandstone and **Cowie Harbour Siltstone** members) with the higher ones thickening to the west indicating increased rates of subsidence in the western part of the Stonehaven Basin. The three emboldened units are considered validly named members in this review.

4.1.2 Carron Sandstone Formation (CRN)

Lithology:
The Carron Sandstone Formation consists predominantly

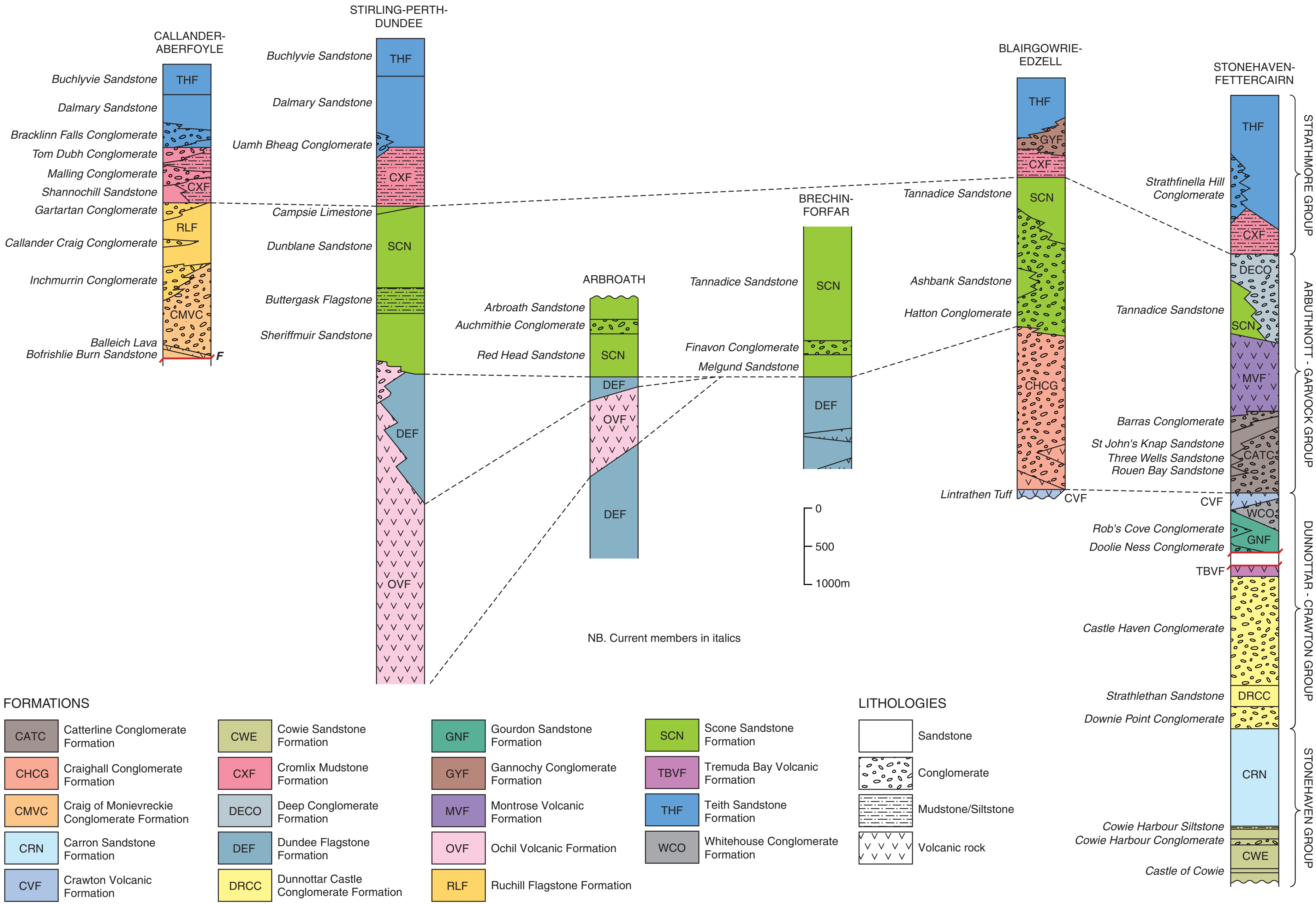

Figure 5 Generalised vertical sections of the Upper Silurian and Lower Devonian groups in the northern Midland Valley of Scotland.

of brown, dull reddish-brown and grey, locally pebbly, medium-grained lithic sandstones, with a locally substantial volcanic content. More quartz-rich sandstones are also present than in the Cowie Sandstone Formation. The sandstones are thinly bedded and weakly planar laminated in the lower part of the unit and trough cross-bedded in the upper. A thick development of breccia, composed of angular fragments of hypersthene-andesite and biotite-andesite in a matrix of devitrified and altered volcanic glass occurs in the sequence at Stonehaven.

Name derivation:
The name was introduced as the Carron Formation by Armstrong and Paterson (1970).

Type section:
The type section is on the coast in Stonehaven Bay between Cowie Harbour [NO 8815 8665] and just north of Downie Point [NO 8805 8525].

Upper and lower boundaries:
The sandstone base of the formation is at the top of the highest grey sandy siltstone bed at the top of the Cowie Sandstone Formation, the contact being exposed at low tide on the foreshore at Cowie Harbour. The top of the formation is taken at the disconformity or abrupt contact (Robinson et al, 1998) marking the incoming of coarse, massive conglomerates belonging to the Dunnottar-Crawton Group.

Thickness:
According to Carroll (1995a) the formation is between 1220 m thick at Stonehaven and 1260 m in the Carmont Hill area indicating comparative constancy of subsidence rates across the Stonehaven Basin. The thickness given by Armstrong and Paterson (1970) was only 820 m.

4.2 DUNNOTTAR-CRAWTON GROUP (DRCR)

Lithology:
The Dunnottar-Crawton Group is a new name combining the previous Dunnottar Group and Crawton Group (both named by Campbell, 1913, and redefined by Armstrong and Paterson, 1970). The group comprises the Dunnottar Castle Conglomerate (including the Downie Point Conglomerate, and Strathlethan Sandstone members), Tremuda Bay Volcanic, Gourdon Sandstone (Rob's Cove Conglomerate and Doolie Ness Conglomerate members), Whitehouse Conglomerate and Crawton Volcanic formations. Although these formations can be recognised in the coast sections, inland they are difficult to distinguish, hence the combined group name.

The group is composed mainly of coarse, massive and very thickly bedded conglomerates with generally minor intercalations of lithic and volcaniclastic sandstones. The conglomerate clasts are from Highland, cryptic MVS basement and volcaniclastic sources.

The conglomerates are clast-supported, with angular to well-rounded boulders, cobbles and pebbles. In the Downie Point Conglomerate Member these consist predominantly of lava, psammite and quartzite, but above the Strathlethan Sandstone Member, the conglomerates are of markedly different provenance and were deposited from streams flowing in opposing north-westerly and south-easterly directions (Haughton, 1989). Poorly-sorted volcaniclastic sandstone and conglomerate are interbedded with non-volcaniclastic conglomerate. Non-volcaniclastic deposits consist of poorly sorted conglomerate, with angular clasts, and bimodally-sorted conglomerate with rounded clasts. Flows of trachybasalt, trachyandesite and andesitic lava occur in the lower and middle parts of the group. The top of the Dunnottar-Crawton Group (see Crawton Volcanic Formation) is characterised by the sparse occurrence of volcanic rocks including trachybasaltic lavas and welded dacitic tuff or ignimbrite (Lintrathen Tuff Member). Siltstone, mudstone and calcrete are rare to trace components.

Name derivation:
The original separate group names were introduced by Campbell (1913) and accepted by Armstrong and Paterson (1970). The new hyphenated name avoids introducing a new term and the confusion of downgrading or deleting an old cherished one.

Type section:
The type section for the group is in sea cliffs and on the foreshore from Downie Point [NO 8805 8525] to Mons Craig [NO 8810 8255] just north of Thornyhive Bay. [See also stratotypes of component formations (Dunnottar Castle Conglomerate; Tremuda Bay Volcanic; Gourdon Sandstone; Whitehouse Conglomerate and Crawton Volcanic)]. A partial type section is in sea cliffs and on the foreshore from Doolie Ness to Knox Hill and at Little John's Haven to Inverbervie [NO 833 707 to NO 854 743] with a reference section in sea cliffs and on the foreshore at Crawton Bay [NO 878 797 to 881 825].

Upper and lower boundaries:
The group lies apparently disconformably on the Stonehaven Group and is conformably overlain by the Arbuthnott-Garvock Group. The base of the group is taken at the base of the Downie Point Conglomerate Member, where thickly-bedded or massive conglomerate overlies pebbly sandstone of the Carron Sandstone Formation. In the type area, the top of the group is taken at the top of the highest lava of Crawton Volcanic Formation, where this is overlain by clast-supported conglomerate at the base of the Arbuthnott-Garvock Group. Elsewhere it is taken at the top of the Lintrathen Tuff Member or at the base of the lowest of a series of andesitic lavas belonging to the Arbuthnott-Garvock Group. The group is believed to be progressively overstepped towards the south-west by the Arbuthnott-Garvock Group.

Thickness:
The group has a thickness of as much as 3200 m east of Mons Craig Fault in the Stonehaven area based on Carroll (1995a) or 2330 m (Armstrong and Paterson, 1970). However, to the south-west of that fault it ranges in thickness from 1350 to 1500 m. This variation in thickness is suggested to indicate that the fault may have been active during sedimentation. The group is presumed to be overlapped by younger groups to the south-west.

Extent:
The Dunnottar-Crawton Group distribution is similar to that of the Stonehaven Group being mainly restricted to the Stonehaven area cropping out in a strip subparallel to the Highland Boundary Fault on the north-western and south-eastern limb of the Strathmore Syncline. However, scattered outliers of the youngest strata south-west to

Kirriemuir have been mapped in association with the geochronologically important Lintrathen Tuff Member.

On the north limb of the Strathmore Syncline, west of the Mons Craig Fault, the interval between the top of the Stonehaven Group and the top of the Dunnottar-Crawton Group consists entirely of clast-supported conglomerate interbedded with trachyandesitic and trachybasaltic lavas. No correlation can be made between these lavas and those of the Tremuda Bay Volcanic Formation or Crawton Volcanic Formation on the southern limb of the Strathmore Syncline.

4.2.1 Dunnottar Castle Conglomerate Formation (DRCC)

Lithology:
The Dunnottar Castle Conglomerate Formation consists primarily of massive and weakly-bedded, clast-supported conglomerate with lenses of horizontally-bedded, medium-grained sandstone (Plate 3). The conglomerate is of essentially 'Highland' type in that its coarse fraction is dominated by andesitic lavas, quartzite and psammite. Clasts of 'granite' and porphyritic microgranite are present in greater proportions in this formation than in the conglomerates of the underlying formations, as are clasts of a diverse assemblage including vein-quartz, chert, metabasalt, gabbro, migmatitic 'gneiss' and flow-banded rhyolite, (Haughton, 1989). In the lower part of the formation, the Strathlethan Sandstone Member consists mainly of grey and grey-green, medium-grained, locally pebbly, cross-bedded lithic sandstones. However, the basal beds are of red, massive, medium- to coarse-grained volcaniclastic sandstone, containing angular clasts of felsite and andesitic lava with rarer, rounded clasts of quartzite. Sequences of red, coarse-grained, medium bedded, volcaniclastic sandstone up to 30 m thick are present in the upper part of the formation which are composed largely of coarse-grained, angular clasts of fine-grained 'felsitic' material. One bed of matrix-supported conglomerate is notable in that its coarse fraction consists almost exclusively of (broadly andesitic) volcanic clasts and also that its matrix is composed of muddy siltstone or very fine-grained sandstone with convolute laminations. This bed may be the product of a debris-flow. The formation marks the first appearance of the conglomerate that typifies much of the LORS lithofacies of the north-east MVS. Robinson et al. (1998) reported imbrication fabrics from this formation. These change from indicating northward-directed palaeocurrents in the lower part (in conglomerates above the Strathlethan Sandstone Member) north of Jobs Craig [NO 884 845], 600 m north of Dunnottar Castle, to south-easterly-directed in the remainder, without significant changes in clast composition. Gillen and Trewin (1987) reported low-grade metamorphic clasts, similar to Dalradian Southern Highland Group lithologies, in the conglomerates above the Strathlethan Sandstone Formation.

Name derivation:
The name, Dunnottar Castle Conglomerate Formation, was introduced by Armstrong and Paterson (1970).

Type section:
The type section, as now defined, is on the coast south from Downie Point [NO 8805 8525] to the base of the lava flows at Tremuda Tongue [NO 8810 8315].

Upper and lower boundaries:
The formation base is taken at the base of the lowest massive conglomerate unit of the Downie Point Conglomerate Member, which rests with disconformity on the Carron Sandstone Formation. The top is taken below the lowest lava flow of the Tremuda Bay Volcanic Formation (Figure 5).

Thickness:
The redefined formation is 2385–2482 m thick according to Carroll (1995a) but 1555 m in Armstrong and Paterson (1970).

Members:
Three members, formerly of formation status, are now recognised (Figure 5). They are the basal Downie Point Conglomerate Member (180–225 m thick; Carroll, 1995a), the overlying Strathlethan Sandstone Member (225–277 m thick; Carroll, 1995a) and the newly named Castle Haven Conglomerate Member (1980 m thick, Carroll, 1995a).

4.2.2 Tremuda Bay Volcanic Formation (TBVF)

Lithology:
The Tremuda Bay Volcanic Formation consists of a number of lava flows of microporphyritic, olivine-bearing hawaiite (classification of Le Maitre, 1989 and using major element analyses of Thirlwall, 1979).

Name derivation:
The name was introduced by Armstrong and Paterson (1970).

Type section:
The partial type section is in Tremuda Bay from the base of the unit [NO 8810 8315] to the fault at Mons Craig [NO

Plate 3 Dunnottar Castle Conglomerate Formation with sandstone lenses, Catterline, Kincardineshire (D2457).

8800 8255].

Upper and lower boundaries:
The base of the formation rests on conglomerates of the Dunnottar Castle Conglomerate Formation. The top of the formation is faulted in the type section. The andesitic lava-flow at Todhead Point [NO 8708 7694] is no longer correlated with the Tremuda Bay flows (Armstrong and Paterson, 1970) but lies within the Arbuthnott-Garvock Group.

Thickness:
The formation is estimated to be at least 170 m thick (Carroll, 1995a).

4.2.3 Gourdon Sandstone Formation (GNF)

Lithology:
The Gourdon Sandstone Formation consists characteristically of dull red, brown or purple, medium to thickly planar to cross-bedded, pebbly, medium to coarse-grained, commonly volcaniclastic sandstones, largely composed of angular fragments of acid lava at Gourdon but of much wider variety elsewhere. Red, brown, grey or green conglomerate beds and members contain a considerable proportion of metamorphic clasts. The coarse fraction of clasts is dominated by well-rounded cobbles and pebbles of psammite, quartzite and granite. One conglomerate bed between Crooked Haven [NO 8575 7460] and Open Cadden [NO 8585 7479] is seen to occupy a valley trending north-north-west incised in the sandstones. Locally, a thin lava flow is present.

Name derivation:
The name was introduced by Armstrong and Paterson (1970). The strata assigned to it were re-assessed by Carroll (1995b) and he re-assigned volcaniclastic sandstones and conglomerates in Rouen Bay to a higher stratigraphical level.

Type section:
The partial type section is south of Inverbervie on the shore at Gourdon Harbour [NO 8257 7064] to Doolie Ness [NO 8328 7092].

Upper and lower boundaries:
The base of the formation is unexposed. The top is taken at the base of the Crawton Volcanic Formation or the base of the Whitehouse Conglomerate Formation where present (Figure 5).

Thickness:
It is between 300 m and 450 m thick.

Members:
It contains two named members: the Doolie Ness Conglomerate [NO 8328 7092 to NO 8307 7084] and Rob's Cove Conglomerate [NO 8496 7385 to NO 8447 7300] members. The Rob's Cove Conglomerate Member contrasts with other conglomerates in being very poorly sorted and containing angular to subrounded clasts of a diverse range of lithologies. Haughton (1988) lists metagreywacke, lithic sandstone, gravel conglomerate, hornblende andesite, foliated and unfoliated granodiorite, and tonalite. Subsidiary rock types include metabasalt, basalt, felsite, hornfels, jasper, quartzite, vein quartz and limestone. The diversity of the assemblage and extreme textural immaturity are unique (Carroll, 1995b) and derivation from a hidden MVS flysch terrane lying to the south and south-east of Inverbervie was suggested by Haughton (1988) based on this evidence and the general palaeocurrent trends towards the north-west.

4.2.4 Whitehouse Conglomerate Formation (WCO)

Lithology:
The Whitehouse Conglomerate Formation consists characteristically of very coarse conglomerate, containing blocks chiefly of 'Highland' origin, up to 1m in diameter. It is predominantly a thick-bedded, massive or weakly cross-stratified, red-brown, clast-supported conglomerate. These lithofacies pass upwards and laterally into thick lenses of horizontally-bedded and cross-stratified, pebbly sandstones. Clast lithology in the coarse fraction is dominated by igneous rocks (mainly granite and porphyry) with lesser amounts of andesite and basalt, although metamorphic lithologies (chiefly psammite and quartzite) are locally abundant. Distinctive metamorphic and sedimentary lithologies such as metabasalt, gravel conglomerate and greywacke are locally abundant and indicate that there may be some input from a southerly direction or reworking of the underlying Rob's Cove Conglomerate Member. The coarse fraction is composed entirely of igneous lithologies at the top of the formation immediately below the overlying Crawton Volcanic Formation. The matrix of the conglomerate is typically a medium- to coarse-grained lithic sandstone reflecting the composition of the clasts.

Name derivation:
The name was introduced by Armstrong and Paterson (1970).

Type section:
A partial type section is exposed in the cliffs between Fowls Heugh [NO 881 800] and Thornyhive Bay [NO 880 824]. A further incomplete section extends westwards from near the base of the unit west of the mouth of Gourdon Harbour [NO 8257 7064].

Upper and lower boundaries:
The base of the formation is not seen but is taken to lie at the mouth of Gourdon Harbour [NO 8257 7064]. The Crawton Volcanic Formation oversteps the top e.g. north of Inverbervie at [NO 843 731]) and there is evidence of lateral passage upwards from the Gourdon Sandstone Formation into the volcanic formation in this area.

Thickness:
Its thickness is estimated at Gourdon to be 300 m and between Crawton Bay and Thornyhive Bay it is at least 245 m. It is reduced to only 60 m from Bervie Brow to Whistleberry as the lower part of the formation is replaced by the volcaniclastic Gourdon Sandstone Formation.

4.2.5 Crawton Volcanic Formation (CVF)

Lithology:
The Crawton Volcanic Formation consists of macroporphyritic lava flows of basaltic andesite. At Thornyhive Bay, it consists of two lava flows of which only the lower is prominently macroporphyritic (the 'Crawton-type' lava of Campbell, 1913). Major element analyses of the macroporphyritic lavas exposed at Crawton, a short distance to the south of Fowls Heugh, indicate these to be high K

Plate 4 Basal contact of lowest lava flow of the Crawton Volcanic Formation overlying the Whitehouse Conglomerate Formation, Trollochy, Kincardineshire (D2459).

shoshonitic (analyses by Thirlwall, 1979, classification of Le Maitre, 1989). The flows are separated by beds of clast-supported pebble and cobble conglomerate of broadly 'Highland' provenance but with significant quantities of macroporphyritic lava clasts.

Name derivation:
The name was introduced by Armstrong and Paterson (1970).

Type section:
The type section is at Crawton Bay [NO 8805 7975 to NO 8775 7962] which is described by Smith (1999a) in the Caledonian Igneous Rocks Review.

Upper and lower boundaries:
The base of the formation is at the base of the lowest lava flow (Plate 4) on the Whitehouse Conglomerate Formation or locally the Gourdon Sandstone Formation (Figure 5). It is overlain by the Catterline Conglomerate Formation (Arbuthnott-Garvock Group).

Thickness:
The Crawton Volcanic Formation is about 70 m thick at Crawton Bay, 60 m where it crops out west of Fowls Heugh, but a full sequence is exposed in Thornyhive Bay [NO 8790 8246 to NO 8790 8253] between the Mons Craig and Gallaton faults where it is only 20 m thick. On the northern limb of the Strathmore Syncline, in the Cloch-na Hill area [NO 820 830], the formation is up to 270 m thick, but apparently fades out completely a short distance to the west of Fallside. It is clear that the thickness of this formation varies considerably.

Members:
This formation includes the geochronologically and lithostratigraphically significant Lintrathen Tuff Member ('Lintrathen Ignimbrite', quartz porphyry of Lintrathen, or Glenbervie Porphyry) which straddles the MVS and the Grampian Terrane. Paterson and Harris (1969) briefly commented on its petrographical similarity to ash-flow tuff deposits. Henderson and Robertson (1982, fig. 3a) showed that the member rests unconformably on the Margie Formation (Highland Border Complex) in the River North Esk. Angular fragments of basement lithologies have been recorded in the Lintrathen Tuff Member near Dunkeld (Paterson and Harris, 1969). At Glenbervie this member ranges in thickness from an estimated 160 m at Kinmonth Den [NO 7754 8109] to about 50 m near North Blairs [NO 747 811] (Carroll, 1995c).

Trench and Haughton (1990, p.252–253) analysed Mg, Fe and Ti abundances in biotite phenocrysts from the Glenbervie and Lintrathen porphyries and found them to lie within a narrow and similar range. They took this to support the correlation of these horizons suggested by earlier authors.

Age:
Significantly, if the correlation of the Lintrathen Tuff Member is accepted, the date of 415.5 ± 5.8 Ma (Thirlwall, 1988) can be adopted as a date for the onset of Arbuthnott-Garvock Group deposition.

4.3 ARBUTHNOTT-GARVOCK GROUP (ATGK)

Lithology:
The Arbuthnott-Garvock Group crops out extensively on both limbs of the Strathmore Syncline (Figures 4 and 5) and to a lesser extent in south-west Scotland (Figure 6). Sandstone predominates, interbedded with clast-supported conglomerate with well-rounded boulders, cobbles and pebbles predominantly of lava, psammite and quartzite in the north-east and adjacent to the Highland Boundary Fault. Siltstone and mudstone are interbedded with the sandstone, e.g. in the Dundee area and Strathallan. Piles of andesitic, basaltic and some rhyolitic lavas, locally very thick, are interbedded with conglomerate and sandstone in many areas. Lenses and thicker formations of volcaniclastic sandstone are interbedded with conglomerate in the Stonehaven area and are associated with lavas elsewhere. A calcrete occurs near the top of the group in many areas. Constituent formations are the Catterline Conglomerate, Montrose Volcanic, Deep Conglomerate, Scone Sandstone, Craighall Conglomerate, Dundee Flagstone, Ochil Volcanic, Craig of Monievreckie Conglomerate and Ruchill Flagstone.

On the northern limb of the Strathmore Syncline around Stonehaven notably, but also along the Highland Border the group is dominated by clast-supported, rounded, pebble and cobble conglomerates normally of ‘Highland’ type (quartzite and psammite) with thick to very thick lenses of planar-bedded, medium-grained sandstone.

On the south-eastern limb, the group consists of; a lower part composed predominantly of conglomerate with lesser amounts of sandstone; a middle part composed predominantly of andesitic lavas; and, more generally in the northern MVS, an upper part dominated by sandstones, in part with shale-flagstone type lake delta sequences. Armstrong and Paterson (1970) referred the lower, clastic, division to the now redundant Johnshaven Formation and the middle division to the Montrose Volcanic Formation. The sandstones are normally bright red or grey, fine- to medium-grained, trough cross-bedded and locally pebbly. Thin beds of sandy mudstone, in places containing irregular pedogenic carbonate nodules, also occur. A thin but persistent zone containing lenticular bodies of concretionary limestone is developed in the sandstones near the top of the group. The carbonate originated as a result of pedogenic processes in semi-arid, seasonally wet conditions. A particular feature in the Scone Sandstone Formation, in the upper part of the group, is the presence in its sandstones of many pebbles (even boulders) of concretionary limestone or calcareous mudstone which represent rip-up clasts formed by intraformational erosion of the channel and overbank deposits. In general the upper part of the group lacks the lacustrine shale and flagstone lithologies typical of the underlying Dundee Flagstone Formation.

Name derivation:
The Arbuthnott-Garvock Group is a new name combining the previous Arbuthnott Group and the Garvock Group (both named by Campbell, 1913, and redefined by Armstrong and Paterson, 1970). The terms Arbuthnott and Garvock groups were first applied by Campbell (1913) to a conglomeratic sequence in Kincardineshire but over the greater part of the Strathmore region the strata are dominated by sandstones (Armstrong and Paterson 1970).

Type section:
A partial type section is in sea cliffs and on the foreshore at Crawton Bay [NO 8775 7962] to Whistleberry [NO 878 797 to NO 862 752]. Two reference sections are in the banks of the Allan Water between Bridge of Allan and Kinbuck [NS 789 977 to NN 792 054] and in the valley of the Bervie Water and an unnamed tributary [NO 831 729 to NO 795 750].

Upper and lower boundaries:
The base of the group is diachronous, rising to higher levels towards the south-west. In the type area it lies above the highest lava of the Crawton Volcanic Formation, where this is overlain by clast-supported conglomerate. Elsewhere its base is taken to lie at the eroded top of the Lintrathen Tuff Member (cf. Paterson and Harris, 1969). Where these horizons are absent, in the Stonehaven–Fettercairn area, the base has been taken at the base of the lowest of the series of andesitic lavas that characterise the lower part of the group in this area.

The top of the group is taken at the base of bright red, massive, poorly sorted siltstone and sandy siltstone of the Cromlix Mudstone Formation, (Strathmore Group) overlying coarser-grained sandstone or conglomerate of the Arbuthnott-Garvock Group. Locally, the top is diachronous in areas adjacent to the Highland Boundary Fault where conglomerate interfingers with the Cromlix Mudstone Formation.

Thickness:
The Arbuthnott-Garvock Group is between 2400 and 4000 m thick. This figure is based on the following information. Armstrong and Paterson (1970) considered the (former) Arbuthnott Group to be of effectively constant thickness, (about 2100 m), suggesting that the variations in outcrop width were caused by normal faults trending near-parallel to the strike of bedding. Detailed field mapping by Carroll (1995a) around Stonehaven has suggested that faulting of this type is not the major cause of the mappable variations in outcrop width and that these reflect original variations in stratigraphical thickness. He suggested that the Johnshaven Formation (now Catterline Conglomerate Formation) of Armstrong and Paterson consisted of three formations (the last two now reduced to member status): the Catterline Conglomerate, St. John’s Knap Sandstone and Barras Conglomerate formations. The mapped boundaries of the St. John’s Knap Sandstone Formation trend obliquely to strike in the area to the south of the Catterline Burn and were interpreted as diachronous sedimentary facies boundaries. The (former) Garvock Group was considered to have a thickness of 1200–2000 m (Armstrong and Paterson, 1970). The sedimentary rocks thin south-westwards into the main MVS outcrops but in the Stirling area the Ochil Volcanic Formation alone reaches 2400 m thick.

4.3.1 Catterline Conglomerate Formation (CATC)

Lithology:
The Catterline Conglomerate Formation is predominantly a thickly-bedded, red brown or grey, clast-supported, cobble to pebble conglomerate with rare thick to very thick lenses of planar-bedded and cross-bedded pebbly sandstone interbedded with a few thin lava flows and mudstone beds. Conglomerate of this formation tends to be dominated by igneous rocks, predominantly granite and porphyritic microgranite with lesser amounts of andesitic and basaltic lava, although metamorphic lithologies including psammite, quartzite and ‘gneiss’ are locally abundant. Locally the coarse fraction is completely composed of igneous lithologies (extrusive and intrusive). The matrix of the conglomerate is typically a medium- to coarse-grained lithic sandstone, the composition of which tends to reflect the lithologies of associated coarse clasts, ranging from quartzo-feldspathic to volcaniclastic. Locally the matrix is entirely composed of coarse-grained volcaniclastic sandstone (e.g. Barras Conglomerate Member). Lava flows occur locally as near the base at Todhead Point [NO 870 770] and near the top by Three Wells Quarry [NO 805 722].

Name derivation:
The name was introduced by Carroll (1995a).

Type section:
A partial type section (below the St John’s Knap Sandstone Member) is exposed on the coast from its base in Crawton Bay [NO 8775 7962] to Catterline and in Catterline Den [NO 8670 7970].

Upper and lower boundaries:
The base of the formation is conformable on the top of the Crawton Volcanic Formation at Crawton. The formation

passes laterally by interdigitation into the Dundee Flagstone Formation and the top is also diachronous being taken at the local base of the Montrose Volcanic Formation.

Thickness:
It ranges in thickness from less than 870 m to 1080 m, thickening from north to south according to Carroll (1995a).

Members:
The formation includes four named members (Figure 5). In the lowest, the Rouen Bay Sandstone Member (about 100 m thick), 'Highland' conglomerate is replaced by poorly sorted, volcaniclastic sandstone and conglomerate with angular clasts. The St. John's Knap Sandstone Member ranges from 255 to 345 m, becoming thicker from north to south. It consists of massive or very thickly-bedded, medium- to coarse-grained lithic or less commonly volcaniclastic, locally pebbly sandstone with lenses of clast-supported conglomerate. Pebbles within the conglomerates are dominated by lithologies indicative of generally acidic volcanism including flow-banded rhyolite, pitchstone and welded tuff. The Three Wells Sandstone Member is a mainly yellow to grey lithic sandstone. The highest, the Barras Conglomerate Member, ranges from 225 to 250 m in thickness.

4.3.2 Montrose Volcanic Formation (MVF)

Lithology:
The Montrose Volcanic Formation consists of olivine-bearing basaltic andesite lava flows with intercalated sedimentary rocks. The flows are often vesicular, aphyric and feldspar-phyric, and beds of autobrecciated lava up to 4 m thick may be seen. Volcaniclastic conglomerate and coarse-grained sandstone are intercalated. A thick bed of 'ignimbrite' was recorded in an excavation at Temple of Fiddes [NO 817 819] at a stratigraphical level about 120 m above the top of the Crawton Volcanic Formation. This tuff had been correlated with the tuffs of Glenbervie and Lintrathen by Paterson and Harris (1969) but is now assigned to the Montrose Volcanic Formation.

Name derivation:
The name was first used by Armstrong and Paterson (1970) to collectively refer to the 'lenticular masses of lava intercalated in the sedimentary strata of the 'Johnshaven' and Dundee formations in the Montrose district'. They recognised several informal members: Ferryden, Dunnichen, Ethie, Tealing, St Cyrus and Morphie-Bruxie Hill members.

Type section:
A partial type area is south of Montrose at Bruxie Hill [NO 822 802] and around Castle of Fiddes [NO 824 812].

The coastal sections between Scurdie Ness to Usan Harbour and Black Rock to East Comb are described by Smith (1999b) in the Caledonian Igneous Rocks Review.

Upper and lower boundaries:
The base of the formation where represented by the St Cyrus member appears conformable. The local base of the Morphie-Bruxie Hill member appears conformable on the Barras Conglomerate Member in the Stonehaven and Inverbervie areas. Elsewhere the base is markedly diachronous (Carroll, 1995c) as in the Glenbervie area where the formation appears to die out westwards near Herscha Hill [NO 741 803].

Thickness:
The Montrose Volcanic Formation reaches a maximum thickness of between 450 m in the area of Bruxie Hill and 560 m at Murraystone Hill [NO 820 778] north-east of Arbuthnott.

4.3.3 Deep Conglomerate Formation (DECO)

Lithology:
The Deep Conglomerate Formation consists predominantly of typically red, brown or yellow, massive, clast-supported 'Highland' conglomerate with well-rounded, pebble to boulder-sized clasts. In the lower part, these consist mainly of volcanic lithologies in a matrix of lithic sandstone. The matrix is largely of detrital quartz with microporphyritic and non-porphyritic devitrified volcanic glass. The upper part contains predominantly quartzite and psammite clasts with lesser amounts of lava (about 30%) and rare pedogenic carbonate horizons. Local evidence shows the conglomerate bodies to range in thickness from 3 to 30 m. Pebbly and clay-flake sandstones are also present and in places form parts of upward-fining cycles. Trough cross-bedding is developed in these lenticular sandstones which form units up to 10–15 m thick. Laminations of sandy siltstone and mudstone are minor components. A non-porphyritic andesitic lava flow is present on the Hill of Garvock [NO 7363 7032].

Name derivation:
The formation was introduced by Carroll (1995c; 1995d) in the Auchenblae and Laurencekirk areas and named from the farm of Deep [NO 780 780].

Type section:
Partial type sections are in the Bervie Water between [NO 7898 7462] and [NO 7737 7467] and on and around Hill of Garvock especially in the Corbies Den [NO 7392 7155 to NO 7362 7205].

Upper and l*ower boundaries:*
The base of the formation is apparently conformable on the top of the Montrose Volcanic Formation, where present. Its top has been placed at the lowest appearance of the distinctive bright red siltstone of the Cromlix Mudstone Formation, (Strathmore Group) although this boundary is somewhat diachronous. The Deep Conglomerate and the Scone Sandstone Formation are laterally equivalent interfingering units.

Thickness:
The formation ranges in thickness from less than 650 m to more than 880 m in its type area.

Blairgowrie–Edzell area

4.3.4 Craighall Conglomerate Formation (CHCG)

Lithology:
The Craighall Conglomerate Formation consists mainly of generally massive, grey or purplish-grey, very coarse-grained (up to 0.7 m) conglomerate, characteristically with subangular to well-rounded clasts of lava but with minor amounts of 'Highland' psammite and quartzite, and granite locally. It has a clast-supported framework. Thin beds of coarse-grained volcaniclastic sandstone and maroon coloured mudstone and siltstone are also present. Abundant volcanic units are interbedded consisting mainly of fine-

grained, microporphyritic basaltic andesite lavas distinguishing it from other units such as the Craig of Monievreckie and Catterline Conglomerate formations.

Name derivation:
The name was introduced in the Blairgowrie area (British Geological Survey, 1999b) on the north-west limb of the Strathmore Syncline, and the rocks occur on both sides of the Highland Boundary Fault.

Type section:
The type section is upstream of Samuel's Pool [NO 1750 4765] in the mainly inaccessible walls of gorges cut by the River Ericht.

Upper and lower boundaries:
The base of the formation, commonly a breccia with 'Highland' clasts, rests unconformably upon Dalradian rocks, or locally on the Lintrathen Tuff Member at the top of the Dunnottar-Crawton Group. It passes up by interdigitation into other Arbuthnott-Garvock Group rocks including the Hatton Conglomerate Member (Scone Sandstone Formation; see Section 4.3.7) in which the clasts are predominantly of 'Highland' derived rocks.

Thickness:
The thickness is estimated to be 2000 m but the outcrops are much affected by faulting within the Highland Boundary Fault complex.

Stirling–Perth–Dundee area

4.3.5 Ochil Volcanic Formation (OVF)

Lithology:
The Ochil Volcanic Formation consists of lava flows and volcaniclastic sedimentary rocks, mainly conglomerates and some non-volcanic beds. The flows range in composition from the predominant pyroxene- and olivine- basaltic andesite through trachyandesite and hornblende-andesite to rhyodacite (Plate 5). The acidic rocks are both limited in distribution (to the Ochil Hills) and stratigraphical position (in the upper part of the unit).

Name derivation:
The name was introduced by Armstrong and Paterson (1970).

Type area:
The type area is in the Ochil Hills around Stirling to Tillicoultry [NS 800 970 to NS 950 990]. Localities at Balmerino to Wormit, Sheriffmuir Road to Menstrie Burn, Craig Rossie and Tillicoultry were described by Browne (1999), as part of the Caledonian Igneous Rocks Review.

Upper and lower boundaries:
The base of the formation is not seen in the type area or in the North Fife Hills but may rest on pre-Devonian rocks. Elsewhere the base of the formation is diachronous as in the Sidlaw Hills. The formation passes both laterally and upwards into contemporary nonvolcanic sedimentary rocks of the Dundee Flagstone Formation or upwards into the Scone Sandstone Formation.

Thickness:
The thickness of the formation is as much as 2400 m, based on Francis et al. (1970).

Plate 5 Autobrecciated lava Ochil Volcanic Formation Shore east of Stannergate, Dundee (D2735).

4.3.6 Dundee Flagstone Formation (DEF)

Lithology:
The Dundee Flagstone Formation consists mainly of medium- to coarse-grained, cross-bedded sandstones of fluvial origin with many intercalations up to 30 m thick of thinly bedded (flaggy) sandstone interbedded with siltstone and mudstone of deltaic and lacustrine type. These intercalations are of distinctive lithology and particularly characteristic of the formation. They include a number of fish beds that have also yielded arthropods and plant remains (Westoll, 1951; Lang, 1927).

Name derivation:
The formation was first introduced by Armstrong and Paterson (1970) as the Dundee Formation.

Type area:
The type area is around Dundee including the north-east end of the Sidlaw Hills [NO 300 330 to NO 540 400] with Tillywhandland Quarry [NO 528 537] near Forfar (Trewin and Davidson, 1996) as a reference section. Tillywhandland and Aberlemno [NO 526 551] quarries and Whitehouse Den [NO 426 397] were included in the Fossil Fishes of Great Britain Conservation Review (Dineley and Metcalf, 1999). Aberlemno Quarry, as Turin Hill, also features in the Palaeobotany of Great Britain Conservation Review by Cleal and Thomas (1995).

Upper and lower boundaries:
The base of the formation is only known where it rests on the Ochil Volcanic Formation. It interdigitates laterally with the Catterline Conglomerate Formation and the lava flows and volcanic detrital rocks of the Ochil Volcanic Formation. The top is also diachronous with the Scone Sandstone Formation but is usually taken at the roof of the locally highest fish bed.

Thickness:
The thickness of the formation was not stated by Armstrong and Paterson (1970, Figure 5) but may approach 1800 m.

4.3.7 Scone Sandstone Formation (SCN)

Lithology:
The Scone Sandstone Formation consists largely of grey, yellow, brown, red and purplish or reddish brown, generally medium- to coarse-grained, cross-bedded, arkosic to lithic sandstones characteristically containing calcareous mudstone and limestone clasts of intraformational origin. Pebbles of metasedimentary and volcanic rocks are also present. Impersistent beds, some more than 50 cm thick, of reddish-brown or greenish-grey silty mudstone and siltstone form a small percentage of the unit. Limestone occurs in thin, lenticular beds typically pale grey in colour and fine-grained. It is concretionary and of pedogenic origin. It occurs more abundantly as reworked clasts throughout the unit. Lava flows are locally present as around Laurencekirk and west of Perth.

Name derivation:
The formation was introduced by Armstrong et al. (1985) but now includes the strata assigned by them to the overlying Campsie Formation (now a member), as well as the Blairgowrie Sandstone Formation (redundant) and the Tannadice Formation (now a member) in the Forfar area.

Type area:
The type area is north of Perth in the banks of the River Tay between Scone and Stanley [NO 120 230 to NO 100 300]. Wolf's Hole Quarry [NS 790 981] was included in the Fossil Fishes of Great Britain Conservation Review (Dineley and Metcalf, 1999). This locality is at or near the base of this formation (Sheriffmuir Sandstone Member).

Upper and lower boundaries:
The base of the formation is transitional with the underlying Dundee Flagstone and Ochil Volcanic formations. Conglomerates and pebbly sandstones with volcanic clasts commonly occur where volcanic strata underlie the unit. The top of the formation is transitional by interbedding to the Cromlix Mudstone Formation. The transitional strata (Campsie Limestone Member) are characterised by the occurrence of concretionary pedogenic limestone (e.g. Pittendriech and Stanley limestones) that in the past has been quarried for lime. They also include conglomerates with mixed clasts. The formation is intercalated with the Deep Conglomerate in the Glenbervie area.

Plate 6 Cross-bedded sandstones showing hardened calcareous zones on upper parts of co-sets. Arbroath Sandstone Member, Whiting Ness, Arbroath (D1036).

Thickness:
The formation is about 2000 m thick.

Members:
The component members in different areas (Figures 4 and 5) are: Tannadice Sandstone, Ashbank Sandstone and Hatton Conglomerate around Blairgowrie; Arbroath Sandstone (Plate 6), Auchmithie Conglomerate and Red Head Sandstone at Arbroath on the south-east limb of the Sidlaw Anticline; Finavon Conglomerate and Melgund Sandstone around Brechin and Forfar; Campsie Limestone, Dunblane Sandstone, Buttergask Flagstone and Sheriffmuir Sandstone in the Stirling to Perth area.

Callander–Aberfoyle area

4.3.8 Craig of Monievreckie Conglomerate Formation (CMVC)

Lithology:
The Craig of Monievreckie Conglomerate Formation consists of clast-supported, somewhat bimodally sorted, generally massive conglomerates. At lower stratigraphical levels, the coarse fraction comprises predominantly volcanic clasts (mainly vesicular andesite and basalt), with lesser amounts of felsite, psammite, quartzite and semipelite. The proportion of nonvolcanic clasts increases at higher stratigraphic levels and along strike to the south-west. Sandstones are subsidiary, but include the Bofrishlie Burn Sandstone Member, which is the lowest exposed component of the formation in the Aberfoyle district. The basaltic Balleich Lava Member conformably overlies this member, separating it from the succeeding conglomeratic facies. This lava is probably equivalent to the volcanic sequence exposed in the Callander area. The formation represents a series of coalesced alluvial fans.

Name derivation
Aitken (BGS Lexicon entry, 1996) introduced the name Craig of Monievreckie Conglomerate Formation in the Aberfoyle area for the 'Volcanic conglomerates' of Francis et al. (1970, pp. 88–90). The formation occurs on the north-west limb of the Strathmore Syncline from Maol Ruadh [NS 477 967] to north of Callander (Phillips and Aitken, 1998).

Type area:
The type area is Craig of Monievreckie in the Menteith Hills, in particular a gully [NN 5437 0187 to NN 5465 0164]. It is also exposed on the shoreline of Loch Venachar north of Tom Eoghainn [NN 5735 0502].

Upper and lower boundaries:
The base of the formation is faulted. The upper boundary is markedly diachronous and transitional with the sandstone facies of the Ruchill Flagstone Formation.

Thickness:
The formation is up to 1200 m thick.

4.3.9 Ruchill Flagstone Formation (RLF)

Lithology:
The Ruchill Flagstone Formation consists of grey to reddish grey, fine-, medium- to locally coarse-grained, massive sandstones with thinly interbedded dull purple, purplish brown and reddish brown silty mudstones and micaceous siltstones. These rocks are normally calcareous, with calcareous nodules in places, and the arenaceous ones exhibit small-scale cross-lamination. Some intercalations of poorly sorted, matrix-supported conglomerate, up to 150 m thick, (member names below) with quartzite, vein-quartz and volcanic clasts, are developed in association with pebbly medium- to coarse-grained sandstones. Intra-formational rip-up clasts of mudstone are common in the sandstones and suncrack polygons also occur. Pebbly bands and conglomerate beds occur throughout the sequence. Units of parallel bedded, reddish brown siltstone up to 8 m thick, are also common.

Name derivation:
The formation was introduced as the Ruchill Formation by Francis et al. (1970, pp. 66–68).

Type area:
The type area is in the Callander–Dunblane area in south-west Perthshire in the Water of Ruchill [NN 676 137].

Upper and lower boundaries:
The diachronous base of the formation is transitional from the underlying conglomerates of the Craig of Monievreckie Conglomerate Formation. The top is transitional with the overlying poorly sorted mudrocks of the Cromlix Mudstone Formation.

Thickness:
The thickness is between 400 m and 1750 m.

Members:
Conglomerate members which have been established (Phillips and Aitken, 1998) are the Callander Craig Conglomerate, Gartartan Conglomerate and the Inchmurrin Conglomerate (Figure 5).

4.4 STRATHMORE GROUP (SEG)

Lithology:
The Strathmore Group consists of mainly red or brown, in part pebbly, medium-grained, cross-bedded sandstones with important developments of moderately well-bedded, poorly-sorted, clast-supported conglomerate and also sandy mudstones. Particularly along the Highland Border, the Strathmore Group is characterised by rapid lateral variations in lithology, which reflect variations in depositional setting in relation to the location of local alluvial fans.

Name derivation:
Campbell (1913) first used the name, but Armstrong and Paterson (1970) included more strata within the group. They also recognised the two most widespread elements of the succession, as the Cromlix and Teith formations in the Dunblane–Callander area and therefore established the essential framework of the Strathmore Group lithostratigraphy.

Type section:
The type section is in the River Teith between Dunblane and Callander [NS 752 981 to NN 647 048] on the south-east limb of the Strathmore Syncline.

Upper and lower boundaries:
The base of the group is the base of the predominantly argillaceous succession belonging to the Cromlix Mudstone Formation. The top of the group is the unconformity with the Stratheden Group.

Thickness:
The thickness of the group is approximately 1800 m (Armstrong and Paterson, 1970)

Extent:
The Strathmore Group forms the bulk of the outcropping succession in the Strathmore Basin and it crops out on both limbs of the Strathmore Syncline. The group is also present on Arran (Section 5.2).

Stirling–Perth–Dundee area

4.4.1 Cromlix Mudstone Formation (CXF)

Lithology:
The Cromlix Mudstone Formation consists predominantly of bright red to brownish red, purplish brown, or green, poorly sorted, soft, sandy or silty mudstone, siltstone and subsidiary poorly sorted very fine-grained muddy sandstone, all commonly with green reduction spots (Plate 7). Typically the beds are massive with a blocky appearance as a result of pervasive fracturing due to the removal of overburden, although weak planar bedding is commonly developed.

In the north-east and by the Highland Border, the unit becomes more obviously thinly bedded and here is a mainly soft, micaceous, fine-grained or very fine-grained muddy sandstone, with mudstone laminations. Immediately below the base of the Teith Sandstone Formation in Strathmore around Fettercairn, the unit locally (Carroll, 1995e) consists of interbedded fine-

Plate 7 Blocky silty mudstones with thin channel-sandstone, Cromlix Mudstone Formation. East bank of River Almond, 100 m due south of Braehead (D3306).

grained, arkosic sandstone and very poorly sorted arkosic wacke. The better sorted sandstone is thickly bedded, forming units up to 5 m thick. Trough cross-bedding is commonly developed, the toes of which may be overlain by small lag deposits containing intraclasts of siltstone and mudstone. The sandstone is interbedded with thin to thick beds of very poorly sorted wacke. These typically occur in upward-fining thin bedded units commonly separated by layers of mudstone that contain polygonal desiccation cracks. The poorly sorted wacke beds have a moderately abundant ichnofauna including the genera *Skolithos*, *Arenicolites* and *Beaconichnus.* If correctly identified this implies a quasi-marine depositional facies.

While the Cromlix Mudstone Formation is predominantly fine-grained, it interfingers with sandstone and conglomerate both along strike and across strike in the Strathmore area. As such it can contain thin beds of medium- to coarse-grained sandstone or even laterally persistent gravel conglomerate units which pass into localised, very thick alluvial fan deposits such as the Malling Conglomerate and Tom Dubh Conglomerate members (see below). The poorly sorted, massive silty mudstone facies, typical of the formation, is comparable with aeolian clay pellet deposits (also known as parna) in landlocked basins, as found in parts of arid and semi-arid south-east Australia. (Dare-Edwards, 1984; Yang, 1997). The mudrocks are interspersed with substantial, local alluvial fans, represented by thick conglomerate units.

Name derivation:
The formational name was introduced by Francis et al. (1970) and refers to Cromlix House [NN 782 061].

Type section:
A type section is exposed in Bullie Burn [NN 816 104 (base) to 794–097(top)], north of Dunblane.

Upper and lower boundaries:
The base of the formation is transitional by interdigitation with the Arbuthnott-Garvock Group below. The Cromlix Mudstone Formation passes laterally and upwards into the Teith Sandstone Formation (Figure 5). The gradational nature of lithostratigraphical boundaries within the Strathmore Group is particularly evident on the north-west limb of the Strathmore Syncline.

Thickness:
The formation varies in thickness from less than 270 m to more than 1100 m (Carroll, 1995e).

Members:
In the Aberfoyle area, the following members have been established: Tom Dubh Conglomerate, Malling Conglomerate and Shannochill Sandstone (Phillips and Aitken, 1998). The conglomerate members are generally matrix supported, poorly sorted rocks that contain a wide range of clast sizes from sand to cobbles and small boulders. They are typically well-bedded, forming thin to medium (10–30 cm thick) planar beds, although beds of up to 3 m thick may be present. Thick conglomeratic units display normal (upward fining) grading. Trough and planar cross bedding are also widespread. Igneous lithologies (lava and microgranite) are usually less than 25%, with psammite, quartzite, schistose-pelite, semi-pelite, vein quartz and sandstone, forming the bulk of the ‘Highland'-dominated clast content.

4.4.2 Teith Sandstone Formation (THF)

Lithology:
The Teith Sandstone Formation consists predominantly of purple, purplish brown, greenish grey and sometimes red, fine- to coarse-grained, sometimes pebbly, cross-bedded, arkosic sandstones. ‘Flaggy’ thin-bedded sandstones are a local feature. Locally red mudstones with traces of roots also occur, especially towards the top of the formation. Conglomeratic members and interbeds are common in the Highland Border area.

Strong vertical and/or lateral facies changes occur within the Teith Sandstone Formation. In the ground between the Devilly Burn and the Burn Farm [NO 6080 7230], just north of Edzell, the formation rests directly on mudstone and fine-grained sandstone of the Cromlix Mudstone Formation. However, in Strathfinella and in the River North Esk, coarse, clast-supported conglomerate directly overlies the Cromlix Mudstone Formation. The coarse conglomerates of the Strathfinella Hill Conglomerate Member [NO 6906 7670, 6916 7675 and 6952 7658] and the Uamh Bheag Conglomerate Member [NN 691 119] are mapped separately.

The Teith Sandstone Formation, although characterised by fine- to medium-grained pebbly sandstone, is locally markedly heterolithic. It contains lenses of conglomerate and lenses or thick beds of mudstone and planar- or cross-bedded fine- to medium-grained sandstone. One extensive section in the Teith Sandstone occurs in the River North Esk at Gannochy Bridge [NO 6003 7089 to 6040 7000]. This section shows an upwards transition from trough cross-bedded, fine- to medium-grained, pebbly sandstone (included within the Gannochy Formation of Armstrong and Paterson, 1970) into thickly planar-bedded fine-grained sandstone and silty sandstone with very thin beds of laminated mudstone. The transition from pebbly sandstone to silty sandstone and mudstone occurs close to a major reduction in the dip of bedding, the section exposed in the River North Esk being near-horizontal and gently undulating for several kilometres downstream. This situation suggests that the relatively coarse-grained Teith Sandstone may be effectively restricted to the north-west limb of the Strathmore Syncline, passing into finer-grained sandstone and siltstone toward the south. In the Stirling district, Francis et al., (1970) divided the formation into three units: a ‘lower purple sandstone facies’, a middle ‘grey sandstone facies’, and an ‘upper purple sandstone facies’. The lowest unit is regarded as laterally equivalent to the Cromlix Mudstone Formation (Armstrong and Paterson, 1970; Phillips and Aitken, 1998). The middle and upper units of Francis et al., (1970) have been designated the Dalmary Sandstone and Buchlyvie Sandstone members, respectively. The former consist of greenish grey to pinkish grey (near the base), fine- to coarse-grained sandstones which typically occur in fining upward cycles interbedded with subordinate siltstone and pebbly sandstone, and rare beds of mudstone and conglomerate. Pebbles are mostly composed of vein-quartz with sparse quartzite and andesite. Mudstone and siltstone rip-up clasts are locally abundant, especially near the base of individual sedimentary cycles. The bedding surfaces of the sandstones are locally rich in fragmentary plant remains (Jack and Etheridge, 1877; Scott, Edwards and Rolfe, 1976) and this is a distictive feature of the formation. The Buchlyvie Sandstone Member represents the youngest Lower Devonian rocks exposed in the Forth valley. It comprises a mixed sequence of reddish grey, grey and reddish brown, lithic and sublithic, to feldspathic sandstones interbedded with red siltstone and mudstone units up to 7.0 m thick that represent overbank deposits.

Name derivation:
The name was introduced by Francis et al. (1970) and refers to the River Teith, south-west of Callander

Type section:
A partial type section through the lower part of the formation is exposed along the Keltie Water [NN 645 084 to 654 078] from the Bracklinn Falls south-eastwards for about 1 km.

Upper and lower boundaries:
The base of the formation is typically defined by a transition from poorly sorted, poorly bedded siltstone or sandstone of the Cromlix Mudstone Formation to well sorted, well-bedded sandstone characteristic of the Teith Sandstone Formation. In the Blairgowrie -Edzell area the formation overlies the Gannochy Conglomerate Formation (Figure 5). The top of the Teith Sandstone Formation is truncated either by faulting or by the unconformity with the Upper Devonian, commonly indicated by intense weathering (resulting in softening and reddening) of the Lower Devonian surface.

Thickness:
The Teith Sandstone Formation apparently occupies the highest stratigraphical level in the Lower Devonian succession of the Edzell area, as such it has a minimum thickness of about 1800 m in the north-west limb of the Strathmore Syncline.

Members:
The constituent members of the Teith Sandstone Formation in the Aberfoyle area are the Buchlyvie Sandstone, Dalmary Sandstone, Bracklinn Falls Conglomerate and Uamh Bheag Conglomerate (Phillips and Aitken, 1998). At Uamh Bheag [NN 696 117] and to the north of the Lake of Menteith, conglomerate deposition started within the Cromlix Mudstone Formation and continued into the Teith Sandstone Formation, resulting in the formation of the Bracklinn Falls Conglomerate Member (Appendix 1).

In the Strathfinella area (Carroll, 1995e) of Kincardineshire, the Strathfinella Hill Conglomerate Member consists of brown or purple, massive, poorly-sorted, clast-supported conglomerate containing well-rounded to rounded pebbles and cobbles in a matrix of poorly-sorted fine- to medium-grained arkosic sandstone. The coarse fraction contains a diverse assemblage of clast lithologies including psammite, quartzite, feldsparphyric andesite, leuco-feldsparphyric microgranite, schistose pelite and semi-pelite, vein quartz and sandstone. Igneous lithologies comprise more than 25% of the clast assemblage at most localities, but locally higher proportions are present.

The Strathfinella Hill Conglomerate is normally weakly cemented and weathers to a soft sandy gravel over much of its crop. It is a lenticular body which reaches a maximum thickness of about 1770 m on Strathfinella Hill. It rapidly thins along strike, such that about 3.5 km south-west of the hill, it has been reduced to 140 m and ultimately fades out in a further 1.5 km. It passes laterally into the Teith Sandstone Formation. It is a first cycle, laterally accreted fan conglomerate according to Haughton and Bluck (1988).

Age:
The formation contains spores (Richardson et al., 1984) which belong to the *Annulatus sextantii* Biozone (Emsian).
Fossil plants in a stream section at Ballanucater Farm [NN 630 019] and Auchensail Quarry [NS 345 795] near the Clyde estuary were described by Rayner (1983, 1984) and also in Cleal and Thomas (1995) as part of the Conservation Review of Palaeozoic Palaeobotany of Great Britain.

Blairgowrie- Edzell area

4.4.3 Gannochy Conglomerate Formation (GYF)

Lithology:
The Gannochy Conglomerate Formation consists of moderately well bedded, poorly-sorted, clast-supported conglomerate with pebbly sandstone interbeds and lenses. Quartzite is the most common pebble type but vein quartz, porphyry, andesite, granite, gneiss, felsite and sedimentary rock types are also present (MacGregor, 1968).

Name derivation:
It was originally defined by Armstrong and Paterson (1970) to extend from the base of the lowest conglomerate above the Loups Bridge [NO 5947 7165] to the highest pebbly sandstone beds below the Gannochy Bridge [NO 6020 7064] in the River North Esk section. The formation was considered by Carroll (1995e) to lens out along strike towards the north-east, whereas Armstrong and Paterson (1970) considered it to continue along strike and expand to form the mass of conglomerate underlying Strathfinella Hill.

Carroll (1995e) proposed that the definition be modified to place the top of the formation at the top of the clast-supported (ortho) conglomerate beds immediately downstream from the Loups Bridge [NO 5948 7164].

Type section:
The type section is in the River North Esk, north of Gannochy Bridge [NO 5947 7199 to 5948 7164(top)].

Upper and lower boundaries:
The Gannochy Conglomerate Formation rests conformably on poorly-sorted, fine- to medium-grained muddy sandstone considered to be a coarser-grained facies, of the Cromlix Mudstone Formation. It passes upwards into fine- to medium-grained pebbly sandstone of the Teith Sandstone Formation.

Thickness:
The modification of Carroll (1995e) reduced the thickness of the Gannochy Conglomerate Formation to about 250 metres (from 1400 m).

5 The Upper Silurian to Lower Devonian of Arran, Kintyre and Farland Head

In the western part of the MVS it is possible that the Strathmore and Lanark basins merged and continued southwestwards across the North Channel into Northern Ireland (Allen and Crowley, 1983; Simon and Bluck, 1982; Jackson et al., 1995). There are no great thicknesses of Lower Devonian lavas presently exposed in this area but evidence from volcaniclastic beds and vents (Friend et al., 1963; Friend and MacDonald, 1968) indicates contemporaneous volcanic activity.

5.1 ARBUTHNOTT-GARVOCK GROUP

Kintyre (mainland), Sanda and neighbouring islands

The Lower Devonian succession in the Kintyre area (Figure 6) is divided into three units, namely the Glenramskill Sandstone, New Orleans Conglomerate and The Bastard Sandstone formations (modified from Friend and Macdonald, 1968). It has an aggregate thickness of 1200 m and the whole succession probably belongs to the newly established Arbuthnott-Garvock Group on lithostratigraphical grounds. No fossil evidence has been found within the succession.

Sanda and the neighbouring islands (Figure 6) have not been surveyed in detail recently but are thought to be of Lower Old Red Sandstone lithofacies (McCallien, 1927). In the Campbeltown area these lithofacies were mapped (British Geological Survey, 1996a) without assigning them to formations. The presence of volcaniclastic sandstones and conglomerates overlain by interbedded sandstones, siltstones with cornstones and breccias suggests that the succession is part of the Arbuthnott-Garvock Group. Rocks on the west of the island have similarities with the New Orleans Conglomerate Formation on the mainland of Kintyre, but farther east the succession differs in detail from that on the mainland (Stephenson and Gould, 1995).

5.1.1 Glenramskill Sandstone Formation (GRK)

Lithology:
The Glenramskill Sandstone Formation comprises a Basal Breccia member, 110–150 m thick, and a Quartzite Conglomerate member 300–330 m thick. The Basal Breccia member, a poorly bedded unit 0–7 m thick, includes angular mica-schist, quartz-schist and vein quartz clasts up to 0.06 m long. The breccia fines up into sandstones succeeded by red siltstones. Most of the clasts are Dalradian in origin but towards the top of the member, lava fragments form up to 10% of the detritus. The Quartzite Conglomerate member comprises conglomerates, sandstones and siltstones. A thick (100 m) conglomerate at its base contains predominantly rounded pebbles and boulders of quartzite and other Dalradian lithologies although lava pebbles are also present. This conglomerate is succeeded by about 200 m of coarse-grained red to purple sandstones and red siltstones with some conglomeratic and volcanogenic beds. The facies in this formation has been interpreted as proximal fans fining up into floodplain deposits (Morton, 1979).

In the Campbeltown area (British Geological Survey, 1996a) this formation was placed within the Arbuthnott Group although Morton (1979) correlated it with the Stonehaven Group on lithological grounds as it contained mainly metamorphic clasts

Name derivation:
The formation was originally described by Friend and Macdonald (1968) as the Glenramskill Formation and named after Glenramskill village [NR 737 191].

Type section:
The type section is south of Campbeltown Loch, [NR 737 191 to 750 195].

Upper and lower boundaries:
The base of the formation lies unconformably on the Dalradian Supergroup. The top is transitional into volcanic-dominated conglomerates of the New Orleans Conglomerate Formation.

Thickness:
Its thickness is about 440 m in total.

5.1.2 New Orleans Conglomerate Formation (NWO)

Lithology:
The New Orleans Conglomerate Formation consists mainly of massive pebble to boulder conglomerates with rounded lava clasts although some conglomerates are bedded. Interbedded reddish sandstones and siltstones locally contain calcareous concretions, pumice lapilli and acidic tuffaceous beds. The few current-readings indicate palaeocurrents came from the north-west. The depositional environment is interpreted in terms of proximal alluvial fans (Morton, 1979). This formation includes the Southend Conglomerate Member exposed on the south coast of Kintyre (Friend and Macdonald, 1968). The formation is possibly equivalent to the Creag Mhor Conglomerates on the west side of Arran (Friend et al., 1963).

Name derivation:
The formation was named from New Orleans [NR 757 179], the house where the central conglomerate is best exposed. It was first described by Friend and Macdonald (1968).

Type section:
The type section is exposed along the coast from Davarr House to south of Achinhoan Head [NR 752 196 to 767 166].

Upper and lower boundaries:
The base of the New Orleans Conglomerate Formation is taken where volcanic-dominated conglomerates succeed the lithic sandstones and intercalated volcanogenic beds belonging to the Glenramskill Sandstone Formation. The top is drawn at the base of the predominantly sandstone succession of the Bastard Sandstone Formation.

Thickness:
The thickness of the formation is 890 m (Friend and Mcdonald, 1968).

5.1.3 The Bastard Sandstone Formation (BAT)

Lithology:
The Bastard Sandstone Formation consists of purple, homogeneous, quartzose sandstone interbedded with red siltstones. The beds are laminated, commonly flat bedded, but locally cross-bedded. Pumice lapilli occur in the lower part of the formation. Palaeocurrent evidence indicates a source to the north-west. The depositional environment has been interpreted as a complex cyclical floodplain (Morton, 1979).

The formation may be equivalent to the Machrie Burn Siltstones in the Machrie area of Arran (Friend et al., 1963).

Name derivation:
The formation's name is taken from the local hilltop, The Bastard [NR 758 166] (Friend and Macdonald, 1968).

Type section:
The type section occurs along the coast [base NR 767 166 — top faulted near Polliwilline Bay NR 742 097].

Upper and lower boundaries:
The base of the Bastard Sandstone Formation is taken where predominantly sandstone strata succeed the New Orleans Conglomerate Formation. The top of the formation is the unconformity with the overlying Upper Devonian Stratheden Group.

Thickness:
The maximum thickness of the formation is 100 m.

Farland Head (North Ayrshire)

5.1.4 Sandy's Creek Mudstone Formation (SACR)

Lithology:
The Sandy's Creek Mudstone Formation comprises greenish grey silty mudstones, siltstones and reddish brown sandstones, heavily sheared and contorted within a fault zone (Figure 6). The formation is only exposed in the Farland Head area.

Name derivation:
The strata were originally described as Sandy Creek Beds (Downie and Lister, 1969; Wellman, 1993b). The Sandy's Creek Formation was introduced by Monro (1999).

Type section:
The type locality is the coastal section just north of Farland Head [NS 176 485].

Upper and lower boundaries:
The lower boundary is faulted against Upper Devonian rocks and the upper boundary against the Portencross Sandstone Formation (see below).

Thickness:
The exposed thickness of the formation is up to 50 m and affected by deformation.

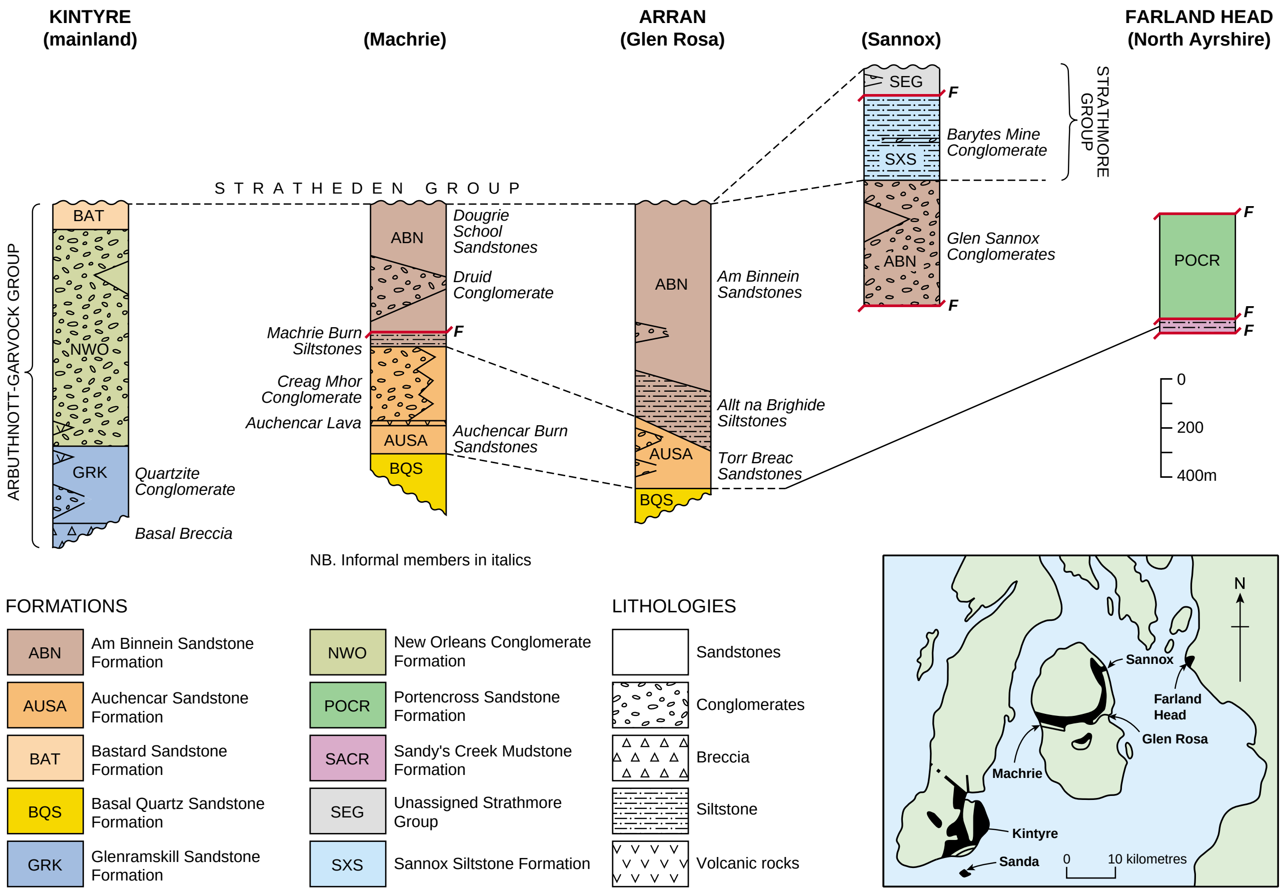

Figure 6 Lower Devonian lithostratigraphical correlation of Kintyre, Arran and Farland Head.

Age:
The historical debate as to whether these beds were Silurian or Devonian has been detailed in Wellman (1993b) and Downie and Lister (1969). The formation was assigned to the Arbuthnott Group (Wellman, 1993b) on the basis of spores and stratigraphical/palaeogeographical considerations. Previous work on the spores from this unit classified the formation as Lower Devonian (Downie and Lister, 1969) but some beds are possibly older (Cameron and Stephenson, 1985). Wellman (1993b) interpreted the continental spore assemblage as late-early to early-late Lochkovian in age. The change in the spore assemblage is attributed to small-scale regional variation in the composition of the vegetation on terrestrial floodplains or even lakes (Wellman, 1993b). A possible correlation was made with the grey siltstones and sandstones within the Basal Quartz Sandstone Formation on Arran (Downie and Lister, 1969).

5.1.5 Portencross Sandstone Formation (POCR)

Lithology:
The Portencross Sandstone Formation consists of mainly dark brown, hard sandstones with conglomerate lenses (Monro, 1999). The pebbles in the conglomerates are mainly of quartzite but also include chert, sandstone and lava. The oldest beds in the formation lie in the hanging wall of a fault north-west of the Sandy's Creek Mudstone Formation and therefore it is likely to be younger (Downie and Lister, 1969) than the Sandy’s Creek Mudstone Formation. No spores have been found to confirm its age. It probably correlates with the Arbuthnott-Garvock Group but it only occurs in the Farland Head area. A possible correlation with the Auchencar Sandstone Formation (Torr Breac Sandstones) on Arran was made by Downie and Lister (1969). The formation was deposited in a fluviatile environment with some fanglomerates.

Name derivation:
Originally described as Portencross Beds by Downie and Lister (1969), the formational name was introduced by Monro (1999).

Type section:
The type section is exposed along the coast north of Farland Head [NS 176 486 to 175 493] but the top and bottom of the formation are faulted.

Upper and lower boundaries:
The lower boundary is faulted against the Sandy’s Creek Mudstone Formation. The upper boundary is faulted against Upper Devonian rocks.

Thickness:
Its thickness is at least 450 m.

Bute

A single small exposure north of the Highland Boundary Fault at Scalpsie Bay, locally known as the ‘Haystack’, consists of coarse breccio-conglomerate and rests unconformably on Dalradian rocks (Hill and Buist, 1994, p. 22–23). It has been assigned to the Lower Old Red Sandstone and may equate to the Basal Breccia member of the Glenramskill Sandstone Formation on Kintyre and thus be part of the Arbuthnott-Garvock Group.

Arran

The lithostratigraphical classification on Arran is based on Friend et al. (1963) and since the authors have no more relevant data we have changed their terminology as little as possible; but the correlations of the British Geological Survey (1987) have been adopted.

5.16 Basal Quartz Sandstone Formation (BQS)

Lithology:
The Basal Quartz Sandstone Formation has a basal breccia of schist and vein quartz fragments. The breccia is overlain by coarse-grained, quartzose sandstones and white siltstones. Subordinate red mudstones and quartz-pebble conglomerates occur. The formation comprises fining- and coarsening-upward alluvial fans sourced from metamorphic basement.

Name derivation:
The term was first used by Friend et al. (1963).

Type section:
The type section is in Allt Mhic Gillegregish, a tributary of Garbh Allt [NR 938 366 to 939 364], the formation is also exposed in the Auchencar Burn.

Upper and lower boundaries:
The base is the unconformity with the Dalradian Supergroup. The upper boundary is the base of the Auchencar Sandstone Formation. In western Arran this is the base of the Auchencar Burn Sandstones; in south-east Arran, it is the base of the Torr Breac Sandstones. This basal Devonian formation is restricted to Arran (Figure 6)

Thickness:
The formation is up to 240 m thick.

5.1.7 Auchencar Sandstone Formation (AUSA)

Lithology:
The Auchencar Sandstone Formation is proposed (see Figure 6) to include as members the Auchencar Burn Sandstones, Auchencar Lava, and the Creag Mhor Conglomerate units in the Machrie area and the equivalent Torr Breac Sandstones in the Glen Rosa area (see Friend et al., 1963).

In the Machrie area, the lowest member of the Auchencar Sandstone Formation, the Auchencar Burn Sandstones, comprises about 100 m of red lithic sandstones with quartzite conglomerates. This member is followed by the Auchencar Lava Member, a grey pyroxene andesite (British Geological Survey, 1987) or hornblende- and olivine-andesite (Tyrrell, 1928) lava, up to 20 m thick, with an amygdaloidal upper zone. The succeeding Creag Mhor Conglomerate Member, up to 320 m thick, comprises mainly massive lava pebble to boulder conglomerate with some quartzite content towards the base. About one metre of red siltstone occurs at the base of the member above the irregular top of the Auchencar Lava (Friend et al., 1963). These conglomerates thin rapidly to the east; in Garbh Allt at Monyquil, lava and quartzite conglomerates are subordinate to coarse-grained lithic sandstones. The Torr Breac Sandstones in the Glen Rosa area (Friend et al., 1963) are a similar, but thinner, succession of lithic sandstones with subordinate quartzite-bearing conglomerates near the base; other conglomerate beds also include lava pebbles. The depositional environment of this formation is interpreted in terms of proximal fans including volcanic debris.

Name derivation:
The formation is named from the Auchencar Burn (cf. Friend et al., 1963) in which they describe the component informal members.

Type sections:
The lower part of the formation is exposed in Auchencar Burn [NR 902 367 to 891 367]; the upper part in Machrie Burn [NR 918 357 to 914 354]. The formation extends from the Machrie to Glen Rosa on Arran.

Upper and lower boundaries:
The lower boundary is transitional with the underlying Basal Quartz Sandstone Formation. The upper boundary of the formation is the base of the Am Binnein Sandstone Formation marked by a change to reddish siltstones and fine-grained sandstones.

Thickness:
The thickness of the formation is about 450 m.

5.1.8 Am Binnein Sandstone Formation (ABN)

Lithology:
The Am Binnein Sandstone Formation is defined in this report (Figure 6) to include as members, the Druid Conglomerates, the Glen Sannox Conglomerates, the Machrie Burn Siltstones, the Dougrie School Sandstones, and the Allt an Brighide Siltstones together with the Am Binnein Sandstones of Friend et al. (1963).

The Allt an Brighide Siltstones (and Machrie Siltstones) near the base of the Am Binnein Sandstone Formation comprise red, thinly bedded, fine-grained sandstones and siltstones which are locally micaceous. The succeeding thick sandstones are locally volcaniclastic with subordinate lava- and quartzite-bearing conglomerate beds. Minor red siltstones contain sparse calcareous concretions. Towards the top of the formation, on eastern Am Binnein, purple litho-feldspathic sandstones are characteristic (Friend et al., 1963).

In the west of Arran, the Druid Conglomerates (DRC) comprise pebble to boulder conglomerates with about 80% quartzite clasts interbedded with subordinate pebbly sandstones. The succeeding Dougrie School Sandstones are more quartzose than those below, are cross-bedded and have reduction spots. Minor conglomerates include much vein quartz.

In the Sannox area, the Glen Sannox Conglomerates have been correlated with the conglomerate facies in the Am Binnein Sandstone Formation (i.e. Druid Conglomerates, British Geological Survey, 1987). These thick conglomerates contain predominantly quartzite clasts but also lava and vein quartz. Red siltstones and sandstones are intercalated. The base of this succession is faulted against Arenig and Dalradian rocks. In this area the maximum thickness of the succession is 520 m (Friend et al., 1963) and it is overlain by Sannox Siltstone Formation (British Geological Survey, 1987). The Am Binnein Sandstone Formation was deposited in a complex of alluvial fans and floodplains with braided channels.

Name derivation:
The name derives from the type area, which is around Am Binnein [NR 997 374].

Type section:
The type section in Allt an Brighide [NR 986 371 to 990 369]. For type localities of the members, see Friend et al. (1963).

Upper and lower boundaries:
The base of the formation is transitional with the Auchencar Sandstone Formation. In the Machrie and Glen Rosa areas, the top of the formation is the unconformity with the overlying Stratheden Group. In the Sannox area, the formation is conformable with the overlying Sannox Siltstones Formation of the Strathmore Group.

Thickness:
In the Glen Rosa area, the total thickness of the formation is about 950 m (Allt an Brighide Siltstones 200 m, Am Binnein Sandstones 750 m). In the Machrie area to the west, the succession is thinner (around 670 m) comprising the Machrie Burn Siltstones 170 m, Druid Conglomerate 275 m and the Dougrie School Sandstones 226 m (Friend et al., 1963).

Age:
The plant fossil *Sawdonia ornata* (Dawson) Heuber [=*Psilophyton princeps* var. *ornatus*] has been identified from near the middle of the Am Binnein Sandstones (Gunn et al., 1903; Friend et al., 1963). It was stated to be typical of the flora found in (Emsian) Strathmore Group rocks (Morton, 1979; compare his fig. 1 and table1).

5.2 STRATHMORE GROUP ON ARRAN

5.2.1 Sannox Siltstone Formation (SXS)

Lithology:
The Sannox Siltstone Formation has red, slightly micaceous, siltstones with rare sandstones in its basal 210 m (the Allt na h' Ath Siltstones of Friend et al., 1963) (Figure 6). The siltstones contain some calcareous concretions and reworked cornstone pebbles. In the middle of the formation is the Barytes Mine Conglomerate Member (BMCG), about 8 m thick and consisting of subrounded quartz, quartzite and LORS sedimentary rock clasts. The overlying 130 m of strata (i.e. the lower part of the North Sannox Sandstones of Friend et al., 1963) consists of siltstones with subordinate sandstones and conglomerates. The formation was deposited on a terrestrial floodplain which included some sheeted fanglomerates. It probably correlates with the Cromlix Mudstone Formation in the MVS.

Name derivation:
The formation was originally termed Sannox Siltstones (British Geological Survey, 1987) and the strata were equated with the Am Binnein Formation by Friend et al. (1963) but is placed within the Strathmore Group mainly on lithostratigraphical grounds (Morton, 1979; British Geological Survey, 1987).

Type section:
The partial type section is exposed in Glen Sannox [NS 005 452 to 012 454; faulted top].

Upper and lower boundaries:
The lower boundary is conformable with the Glen Sannox Conglomerates Member of the Am Binnein Formation.

The upper boundary of the formation is faulted against sandstones of the Strathmore Group (British Geological Survey, 1987).

Thickness:
The thickness of the formation is over 350 m.

5.2.2 Unassigned Strathmore Group

Sandstones and fine conglomerates (British Geological Survey, 1987; Morton, 1979) overlie the Sannox Siltstone Formation although a fault separates the succession from the Sannox Siltstone Formation in the North Sannox section. The sandstones are lithic and litho-feldspathic in the lower part but higher up they become increasingly quartzose. The conglomerates are rich in vein quartz and contain very little quartzite. The succession is unconformably overlain by the Upper Devonian Stratheden Group.

The thickness of this succession is over 120 m as exposed in North Sannox Burn [NS 013 456]. It is equivalent to the upper part of the North Sannox Sandstones of Friend et al. (1963) and probably the Teith Sandstone Formation in the MVS.

6 The Upper Silurian to Lower Devonian rocks north of the Highland Boundary Fault

North of the Highland Boundary Fault and south of a line between Fort William and Aberdeen are several outliers of Lower Old Red Sandstone lithofacies. Small outliers of Arbuthnott-Garvock and Dunnottar-Crawton group rocks occur in the Kirriemuir and Blairgowrie areas (Figure 4). These can be correlated with rocks a short distance to the south across the fault and are described with them (see Section 4). However, note the views of Bluck, (2000) about these rocks being part of a distinct basin north of the Highland Boundary Fault.

The outliers of LORS at Rhynie, Cabrach and Towie are described as part of the separate Rhynie Group (Gould, 1997; Trewin and Rice, 1992).

The volcanic rocks in the outliers of Argyll, Glen Coe and Ben Nevis (Figure 7) are all described below and in the Caledonian Igneous Rocks of Great Britain (Durant, 1999b; McGarvie, 1999a, b).

Argyll

6.1 KERRERA SANDSTONE FORMATION (KESA)

Lithology:
On Kerrera and around Oban, exposures of Siluro-Devonian sedimentary strata (Stephenson and Gould, 1995) form a new formation, the Kerrera Sandstone Formation. The sedimentary strata comprise green conglomerates, green and red sandstones with subordinate siltstones, mudstones, and limestones. The flaggy grey mudstones have yielded *Cephalaspis lornensis, Kampecaris obanensis* and plant remains (Lee and Bailey, 1925) as well as other cephalaspids and an anaspid (Waterston, 1965).

The sedimentary strata accumulated in small isolated fault-bounded basins, which contained conglomeratic fans and scree breccias passing basinwards into fluvial sandstones and playa-lake siltstones and mudstones with thin beds of limestone. As the Kerrera Sandstone Formation contains andesite and olivine basalt clasts, there is evidence that the nearby volcanic area was already eroding prior to the final deposition of the sandstones. A former correlation of the sedimentary beds in the Oban area with the Arbuthnott Group of the Midland Valley was made (Waterston, 1965), however, the strata at Kerrera were formerly correlated with the Stonehaven Group on the basis of fish and arthropod fossils.

Name derivation:
The name is taken from the island of Kerrera, south-west of Oban.

Type area:
The type area is on the southern end of the island of Kerrera (Lee and Bailey, 1925; Morton, 1979) with a section along the coast from [NM 794 279] (top) to [NM 802 265] (base).

Upper and lower boundaries:
The base of the formation is the unconformity with the Dalradian metasedimentary basement and the top is the Lorn Plateau Volcanic Formation (see below), that locally interfingers with the sedimentary strata.

Thickness:
At its fullest on Kerrera (Lee and Bailey, 1925) the succession is up to 128 m thick, but it thins eastwards around Oban and is absent below the lavas farther east.

Age:
The late Silurian to early Devonian fossil fish at four sites within the formation; Ardmore on Kerrera, Gallanach, Selma Cottage Cliff and Dalintart are described in the Fossil Fishes of Great Britain Conservation Review (Dineley and Metcalf, 1999). Marshall (1991) produced palynological evidence that the sedimentary rocks below the lavas at Kerrera and Oban are latest Silurian to earliest Devonian in age (more specifically either in the *tripapillatus-spicula* or the overlying *micrornatus-newportenis* zones). This evidence is tied to radiometric dating of the overlying Lorn Plateau lavas (414–424 Ma, Thirlwall, 1988).

6.2 LORN PLATEAU VOLCANIC FORMATION (LPVO)

Lithology:
Lower Devonian volcanic rocks originally covered a large part of the Central Highlands but are now preserved mainly on the Lorn Plateau between Oban and Loch Awe (Figure 7). This volcanic succession is now established as the Lorn Plateau Volcanic Formation. The lavas are basalts and pyroxene-, hornblende- and biotite-andesites, forming flows 5 to 30 m thick, with rare rhyolite flows up to 2 m thick. Two intercalated rhyolitic ignimbrite flows are thought to have originated from the Glencoe centre (Roberts, 1974). The lavas are of potassic calc-alkaline type and show chemical similarities with the nearby lamprophyre intrusions. The lavas as a whole are richer in Sr, Ba, K, P and light rare-earth elements (LREE) than the lavas of equivalent age in the Midland Valley and Southern Uplands. The magmas are thought to be largely mantle-derived, with some contamination by crustal material possibly of mafic granulite composition (Groome and Hall, 1974; Thirlwall, 1981, 1982).

Name derivation:
The formational name is taken from the Lorn area of Argyll (Stephenson and Gould, 1995).

Type area:
The type area is on the Lorn Plateau, Argyll. The Lorn Plateau lavas, as described by Stephenson and Gould (1995), have a present extent of 300 km^2. The formation crops out on the island of Kerrera (Durant, 1999b) where its base is exposed [NS 7884 2743] above the Kerrera Sandstone Formation. Similar volcanic successions also occur in downfaulted blocks associated with the granitic complexes at Glen Coe and Ben Nevis (see below).

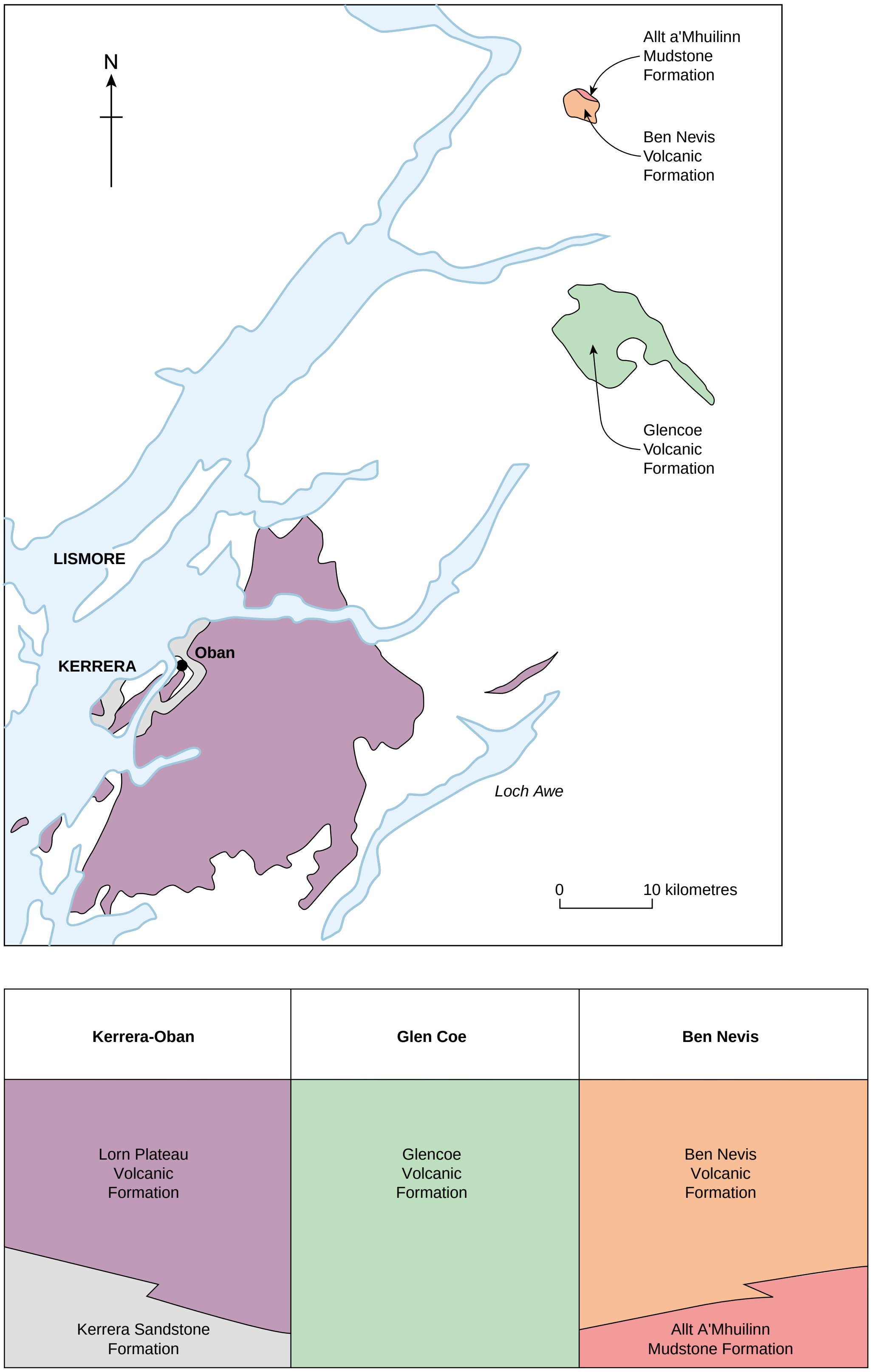

Figure 7 Siluro-Devonian lithostratigraphy of Argyll.

Upper and lower boundaries:
On Kerrera and near Oban, the base of the formation is the interfingering base of the lavas above the Kerrera Sandstone Formation. On the Lorn Plateau the formation oversteps the Kerrera Sandstone Formation to lie unconformably on the Dalradian Supergroup. The top of the volcanic succession is not seen owing to subsequent erosion.

Thickness:
The formation has a maximum preserved thickness of 800 m.

Age:
Clayburn et al. (1983) obtained a Rb/Sr isochron age of 400 ± 5 Ma (early Devonian) for the Lorn Plateau lavas, very similar to the 401 ± 6 and 396 ± 12 Ma obtained from the probably genetically related Etive granites.

However, Thirlwall (1988) has suggested, on the basis of Ar isotope work, that the Lorn Plateau lavas may be as old as 421 to 413 Ma, and that the Rb/Sr systematics of the lavas have been reset by the plutonic intrusions.

Glen Coe area

6.3 GLENCOE VOLCANIC FORMATION (GLVO)

Lithology:
The Lower Devonian volcanic sequence of lavas, tuffs, breccias and intercalated sedimentary rocks exposed in Glen Coe (Figure 7) is preserved in a downfaulted block (Bailey, 1960). It was recently described by Moore (1995) and Moore and Kokelaar (1997, 1998).

In the Ben Nevis area, (1:50 000 Sheet 53E, in prep) and the 1:25 000 Special Sheet of Glen Coe, the formation comprises six members:

Dalness Ignimbrite (youngest) (mainly welded tuff, breccia and lapilli tuff)
Bidean nam Bian Andesite (mainly andesitic lavas)
Cam Ghleann Clastic (mainly breccias and alluvial deposits)
Three Sisters Ignimbrite (mainly welded eutaxitic tuff with some breccias)
Etive Rhyolite (mainly flow-laminated rhyolites with tuffs and tuffaceous breccias)
Basal Andesite Sill complex (palaeocanyon infill mainly of sandstone and conglomerate intruded by sills with peperitic margins)

Name derivation:
The name derives from Glencoe [NN 100 588], the village at the foot of Glen Coe.

Type area:
The type area is around the Bidean nam Bian Geological Conservation site [NN 150 546] (McGarvie, 1999a),

Upper and lower boundaries:
The formation unconformably overlies Dalradian metasedimentary rocks including the Leven Schist Formation. The top of the volcanic succession has been removed by erosion.

Thickness:
The volcanic sequence has an aggregate thickness of over 1000 m.

Age:
A sporomorph assemblage recovered from the basal sedimentary strata of the Glen Coe succession was correlated with the *micrornatus-newportensis* Biozone despite being highly carbonised (Wellman, 1994). This indicates an early Devonian age for the strata which is younger than that suggested for the correlative, the Kerrera Sandstone Formation at Oban (Marshall, 1991). However, as stated by Wellman (1994) this may simply mean that the basal strata are diachronous. The overlying Glen Coe lavas (Thirlwall, 1988) were dated radiometrically at 421 $\pm$ 4 Ma.

Ben Nevis area

A downfaulted block of Lower Devonian sedimentary and volcaniclastic rocks (Figure 7) within the Ben Nevis igneous complex (cf. BNV — Ben Nevis Volcanic Series presently in the BGS Lexicon) can be divided into the Allt a' Mhuilinn Mudstone Formation and the Ben Nevis Volcanic Formation. Burt (1994), Burt and Brown (1997) and McGarvie (1999b) describe the volcanic and sedimentary rocks as resting on Dalradian metasedimentary rocks within the Inner Granite of the Ben Nevis complex. Burt (1994) divided the succession into four formations but the upper three are downgraded into members of the Ben Nevis Volcanic Formation (see below), as they are analogous to the subdivisions of the Glencoe Volcanic Formation.

6.4 ALLT A' MHUILINN MUDSTONE FORMATION (AMMU)

Lithology:
The Allt a' Mhuilinn Mudstone Formation (Burt, 1994; McGarvie, 1999b) comprises mainly mudstone and laminated siltstone with quartzite-dominated conglomerate intercalations. Burt (1994) interpreted the environment of deposition around Ben Nevis as a playa-lake during this time. The early non-volcaniclastic sediments gradually became replaced by volcaniclastic sediment and proximal calc-alkaline volcanic rocks. Sedimentary rock from Ben Nevis [NN 168 722] proved barren of spores (Wellman 1994).

Name derivation:
The name derives from Allt a' Mhuilinn, the burn draining the north of Ben Nevis.

Type section:
The type section is exposed in Allt a' Mhuilinn [around NN 140 757].

Upper and lower boundaries:
The formation rests unconformably on Dalradian metasedimentary rocks and is overlain by the predominantly igneous rocks of the Ben Nevis Volcanic Formation.

Thickness:
The thickness of the formation is about 15 m.

6.5 BEN NEVIS VOLCANIC FORMATION (BNVO)

Lithology:
The Ben Nevis Volcanic Formation (Plate 8) comprises three members (cf Burt, 1994). The oldest, the Coire na Ciste Member is composed of massive unsorted volcanic breccias including exotic clasts of welded ignimbrite, rhyolite, andesite, mudstone and some quartzite-dominated breccia. The succeeding Ledge Route Member, comprises volcanic, andesite-dominated, clast-supported breccia. At the top, the Summit Member contains autobrecciated andesite dominated sheets and sills with subordinate volcanic breccia beds.

Name derivation:
The name derives from Ben Nevis [NN 166 712].

Type section:
The type section lies near the summit of Ben Nevis [around NN 167 713] (Burt, 1994; McGarvie, 1999).

Upper and lower boundaries:
The base of the formation is the base of the massive volcanic breccia above the Allt a' Mhuilinn Mudstone Formation. The top is absent due to erosion.

Thickness:
The exposed thickness is estimated to be 630 m.

Aberdeen

6.6 BRIG O' BALGOWNIE CONGLOMERATE FORMATION (BOBC)

Lithology:
Rocks assigned to the new Brig o' Balgownie Conglomerate Formation occur in Aberdeen city (Munro 1986), and mainly comprise conglomerates containing well-rounded clasts of granite and psammite of local provenance. A patchy grey to red arenaceous matrix is common, but locally an argillaceous matrix or calcite cement is present. Similar rocks occur on the shore at Skelly Rock [NJ 967 145] and Eigie Links [NJ 962 163]. Conglomerate with some argillaceous and arenaceous rocks have been proved by drilling under much of Aberdeen city centre. It is not possible from the meagre evidence to assign them either to one of the MVS groups or to the Lower Devonian Crovie Group at the eastern margin of the Turriff inlier.

Name derivation:
The name derives from the Brig o' Balgownie, over the River Don, Aberdeen.

Type section:
The type section lies between Brig o' Balgownie and Bridge of Don, [NJ 940 094 to NJ 946 094] on the south side of the River Don in Aberdeen.

Upper and lower boundaries:
The base is the unconformity with the Dalradian Supergroup. The top is cut out by faulting but may occur offshore.

Plate 8 Cliff face of andesitic lavas, with contact of enclosing granite running up the stream and round behind the left end of the cliff. North face of Ben Nevis from Carn Dearg, looking south-west (D2132).

Thickness:
The thickness of the formation varies because of the irregular surface to the underlying unconformity but on the east side of Aberdeen, over 160 m of conglomerate was proved in a borehole.

7 The Upper Devonian Stratheden Group in the Midland Valley of Scotland

Lithology:
The Stratheden Group (SAG) consists mainly of red-brown sandstones with subordinate conglomerates, mudstones and one local volcanic interval on Arran. It is equivalent to most of the former Upper Old Red Sandstone lithofacies of the MVS except for the cornstone-bearing rocks of the Kinnesswood Formation which are now included in the Inverclyde Group (as defined by Paterson and Hall, 1986). Prior to the work of Chisholm and Dean (1974), Bluck (1978) and Paterson and Hall (1986), the Stratheden Group succession was not divided into formations and was included in the redundant Upper Old Red Sandstone succession.

Name derivation:
The group takes its name from the Stratheden area, Fife [NO 16 09].

Type area:
In the type area of Stratheden, Fife (Figure 8), the group comprises, in ascending sequence, the Burnside, Glenvale and Knox Pulpit sandstone formations.

Upper and lower boundaries:
In Fife the group is unconformable on the Ochil Volcanic Formation of the Lower Devonian Arbuthnott-Garvock Group and the top is transitional with the overlying Kinnesswood Formation. Elsewhere within the MVS the group lies unconformably above Lower Devonian (Plate 9) or older rocks (Figure 8).

Thickness:
The thickness of the group is very variable (from 0 up to 1500 m) but the component rock types are all of red-bed facies so that disparate outcrops of the group may be correlated throughout the MVS (and beyond).

Extent:
In the north-west of the MVS (Figure 8), north of the Clyde, the Stratheden Group comprises the Rosneath Conglomerate and the Stockiemuir Sandstone Formation. To the south of the Clyde, it contains two successions. The first, east of the 'Largs Ruck' which has the Fairlie Sandstone Formation at its top (Paterson et al., 1990) is conformably overlain by the Inverclyde Group. The second, west of the Largs Ruck, lacks the Fairlie Sandstone Formation and the top of the Stratheden Group is sharp and disconformable. The absence of the Fairlie Sandstone Formation is attributed to uplift and erosion west of the ruck prior to deposition of the Inverclyde Group. Farther west, the group as exposed on Bute is rudaceous, and on Arran it includes a relatively thin lava interval. In the south-west of the MVS, in Ayrshire, the Stratheden Group is thin and is not divided. It does not appear to be present in the area between Kilmarnock and the Pentland Hills and the Upper Old Red Sandstone lithofacies in this area (Paterson and Hall, 1986) is all assigned to the Kinnesswood Formation, Inverclyde Group (Carboniferous).

Likewise, in the Montrose area, the Upper Old Red Sandstone successions at Milton Ness (Trewin, 1987; Balin, 2000), and Boddin Point, are considered to belong to the Kinnesswood Formation because they include abundant developments of calcrete.

Age:
The scanty evidence of the age of the group suggests that it is probably all Late Devonian (House et al., 1977). More specifically in the type area, fish faunal data from the Glenvale Sandstone Formation and also from the Dura Den Member at the top of the Glenvale Sandstone Formation indicate a Famennian age for the group (Westoll in House et al., 1977). Comparable fish faunas have been described from the former Clashbenny Formation (now Glenvale Sandstone Formation) in the Perth area (Armstrong et al., 1985) and from the Stratheden Group in south Ayrshire. There is no other direct evidence of the age of the Stratheden Group within the MVS.

Fife and Firth of Tay areas

7.1 BURNSIDE SANDSTONE FORMATION (BRN)

Lithology:
The Burnside Sandstone Formation consists predominantly of fine- to very coarse-grained sandstones that are dull red or purplish in colour and contain a variable proportion of calcite cement. The formation is characterised by the presence in the sandstones of well-rounded, siliceous pebbles up to 0.15 m across; mainly quartzite and vein quartz of 'Highland' origin and of more locally derived pebbles of Ochil Volcanic Formation lavas. The lava pebbles are found predominantly at, or near, the base of the formation. Intraformational claystone pebbles are also present. The pebbles occur scattered throughout the sandstones and also form beds of conglomerate up to about 2 m thick. Planar bedding and trough cross-bedding are common but some conglomeratic beds are massive. Beds of red siltstone and silty mudstone up to 0.6 m thick are rare, but commonly disposed in upward fining cycles. Palaeocurrent flow in the fluvial environment was towards the east, northeast and southeast. The Burnside Sandstone Formation is normally poorly exposed. A probably equivalent conglomeratic facies is exposed in Broich Burn [NS 6337 9369] in the Stirling area (Francis et al., 1970) at the base of the Stockiemuir Sandstone Formation (formerly Gargunnock Sandstones, Figure 8)

Name derivation:
It was defined as the Burnside Formation by Chisholm and Dean (1974).

Type area:
Around Burnside [NO 166 080], near Lomond Hills, Fife.

Upper and lower boundaries:
The base of the formation is an unconformity which is seen in the Holton Burn [NO 112 062] by Milnathort. The upper contact with the Glenvale Sandstone Formation is transitional and is taken at the upward disappearance of the

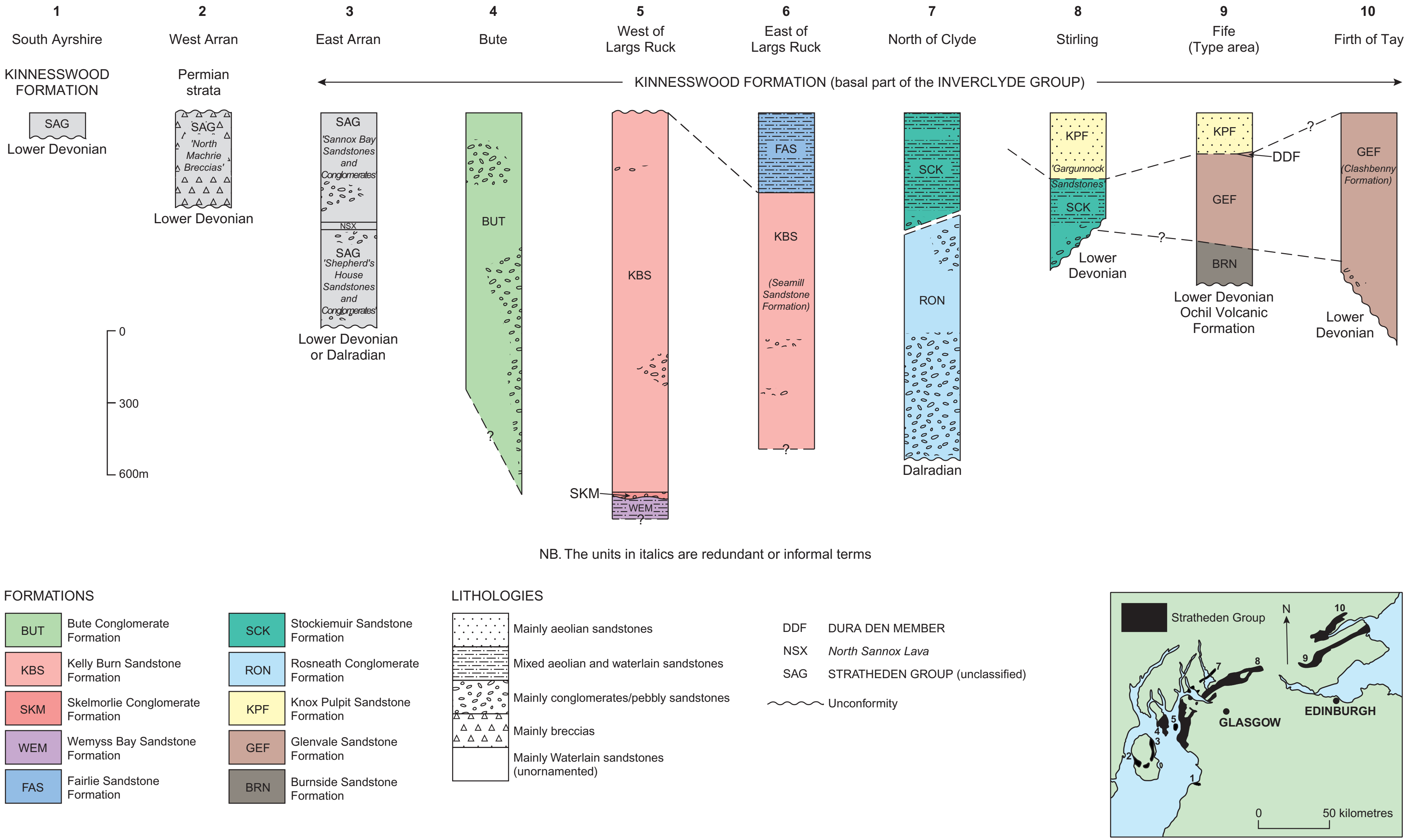

Figure 8 Stratheden Group within the Midland Valley of Scotland.

Plate 9 Basal conglomerate and sandstone of the Burnside Sandstone Formation lying unconformably on Lower Devonian Arbroath Sandstone Member, Whiting Ness, Arbroath (D2730).

siliceous pebbles and hence it is not known whether it forms a continuous sheet or isolated lenses. This also applies in the Firth of Tay area — see the description of the Glenvale Sandstone Formation below.

Thickness:
The formation is up to 160 m thick.

7.2 GLENVALE SANDSTONE FORMATION (GEF)

Lithology:
The Glenvale Sandstone Formation consists of white, yellow, brown, red and purple, fine- to coarse-grained, feldspathic sandstones, with rare siliceous pebbles. Pebbles of red, green and cream-coloured mudstone up to 0.15 m thick are common and fish fragments as well as complete *Holoptychius* are present. Large-scale trough cross-stratification, with sets up to 1.5 m thick, is the most common sedimentary structure but low-angle cross-bedding and planar lamination also are found. Palaeocurrent flow was towards the east. Subsidiary beds of greenish grey and red silty claystone and siltstone are also present, and some form the upper parts of upward fining cycles.

Name derivation:
The formation was defined as the Glenvale Formation by Chisholm and Dean (1974).

Type section:
The type section is in Glen Burn, north and east of Glenvale [NO 172 058].

Upper and lower boundaries:
In the type area, the transitional base with the underlying Burnside Sandstone Formation is exposed in the Glen Burn [NO 170 076] west of Lappie Farm. The transitional top with the overlying Knox Pulpit Sandstone Formation is partly faulted and poorly exposed in the same burn [NO 181 063] and taken at the incoming of sandstones showing significant amounts of characteristically aeolian pin-striped lamination.

Thickness:
The Glenvale Sandstone Formation is up to 350 m thick in Fife. The Stratheden Group in the Firth of Tay area is 600 to 900 m thick (Armstrong et al., 1985). No aeolian facies has been recorded from the area, so the Knox Pulpit Sandstone Formation may be absent (Browne, 1980) possibly because of lateral facies changes (or it may be faulted out). If so, it appears that the Glenvale Sandstone Formation equates to the whole of the Stratheden Group in the Firth of Tay area.

Member:
The Glenvale Sandstone Formation now includes the Dura Den Member which comprises red, green and cream-coloured micaceous very fine-grained sandstones and siltstones with irregular fine-grained sandstone interbeds. Mud-cracks are common and Skolithos-like burrows are present. The Dura Den Member which was originally established as a formation by Chisholm and Dean (1974) in the Dura Den area of Fife, contains the notable Dura Den Fish Bed (see below). The base of the member is not exposed, but the transitional top with the Knox Pulpit Sandstone Formation is exposed in the partial type section in Yoolfield Cliff [NO 417 146].

Extent:
The Glenvale Sandstone (formerly Clashbenny) Formation extends into the Firth of Tay area (Browne, 1980), where it consists mainly of reddish brown, but locally white or purple, cross-bedded sandstones. Towards the base of the succession they contain pebbles of quartz, quartzite and Lower Devonian lavas. Rare thin reddish brown silty mudstones were preserved in overbank deposits and silty mudstone rip-up clasts within the sandstones represent

penecontemporaneously eroded and redeposited overbank sediment. The base of the formation is locally a conglomeratic sandstone which rests unconformably on the Lower Devonian Scone Sandstone and Ochil Volcanic formations. The top of the formation here passes into the Kinnesswood Formation.

Age:
In the Dura Den Member, the fossil fish fauna contains besides *Holoptychius* and *Glyptopomus,* abundant *Bothriolepis* including B. *hydrophila* (Miles, 1968; Waterston, 1965). This indicates a Famennian age for the member (Westoll in House et al., 1977). In Clashbenny Quarry [NO 213 211], north of the Firth of Tay, a fish fauna including *Phyllolepis, Bothriolepis* and *Holoptychius* was recovered, which also indicates a Famennian age. Miles (1968) suggested a correlation between the Clashbenny and Dura Den strata.

7.3 KNOX PULPIT SANDSTONE FORMATION (KPF)

Lithology:
The Knox Pulpit Sandstone Formation comprises soft, weakly cemented, white and cream-coloured, very fine- to coarse-grained feldspathic sandstones. The most characteristic feature is a marked variation in grain-size between adjacent laminae which may be 1–10 mm thick. This is known as pin-stripe lamination and is aeolian in origin. The rarity of pebbles is another distinctive feature with small masses of ochreous decomposed cornstone near the top of the formation and greenish grey silty claystone near the base. A range of cross-stratification forms and flat lamination occur with reactivation surfaces within sets of cross-strata. Convolutions affect the larger scale sets (up to 2.5 m) found towards the base of the formation. Ripple lamination is rare except near the top. Well-rounded millet seed grains are common in coarser laminae. Palaeocurrent data from the Lomond Hills is bimodal suggesting an alternation of eastwards and westwards directed wind currents, a feature which is locally confirmed by the presence of the herringbone pattern of opposed foresets. In the Kemback area the direction of transport was consistently to the west (Armstrong et al., 1985). Trace fossils in the form of simple vertical tubes up to 15 mm across and 70–300 mm long are present and referred to the ichnogene *Skolithos* Haldeman. They are most common towards the top of the formation.

Name derivation:
The formation was established by Chisholm and Dean (1974) and the name taken from a crag, John Knox's Pulpit [NO 1891 0582].

Chisholm and Dean (1974) also set up the Kemback Formation in the Dura Den area, but this was equated directly to the Knox Pulpit Formation and hence the Kemback Formation name is redundant (Armstrong et al., 1985). Hall and Chisholm (1987, fig. 2) showed that the upper part (120 m) of the Gargunnock Sandstones (Francis et al., 1970) in the Stirling area is mainly aeolian and that it can also be correlated with the Knox Pulpit Sandstone Formation (Figure 8). Therefore the Gargunnock Sandstones (GKS) name is also redundant (see Stockiemuir Sandstone Formation).

Type section:
The most complete section through the formation occurs in Glen Burn, [NO 181 063 to 191 057] about 5 km north of Loch Leven. John Knox's Pulpit lies near the top of the section.

Upper and lower boundaries:
The transitional base of the formation is faulted and poorly seen in the Glen Burn [NO 181 063] where the lowest exposed strata have scattered laminae of greenish grey silty mudstone. The transitional top with the overlying Lower Carboniferous Kinnesswood Formation is taken arbitrarily at the highest significant occurrence of pin-stripe lamination. This contact is seen in the Glen Burn [NO 191 057] and was proved in the Glenrothes Borehole [NO 25615 03142] at a depth of about 450 m.

Thickness:
The formation ranges in thickness from about 130 m to 180 m.

North of the Clyde

7.4 ROSNEATH CONGLOMERATE FORMATION (RON)

Lithology:
The Rosneath Conglomerate Formation comprises conglomerate with clasts of quartz, quartzite and other metasedimentary rocks together with various intrusive and extrusive igneous rocks. In the Helensburgh–Dumbarton area, the formation consists of poorly sorted, mainly quartz-pebble conglomerate with sandstone and pebbly sandstone in its lower part, but near Rosneath Point, there is an intraformational unconformity above which the conglomerate contains numerous boulders of granite.

Cross-bedding measurements (see Paterson et al., 1990) indicate that the conglomerates were predominantly laid down by palaeocurrents flowing to the north-east but that some of the beds were deposited by palaeocurrents flowing to the south-east.

Earlier editions of the Greenock district map (Sheet 30W) assigned conglomerates at Cardross [NS 335 774] and Overtoun Muir [NS 370 800] and some of those on Ardmore peninsula [NS 315 785] to the Lower Devonian. However, at all these localities, the conglomerates have clast contents which more closely resemble the Rosneath Conglomerate than any Lower Devonian rocks in the vicinity. Accordingly Paterson et al. (1990) reassigned these conglomerates to the Rosneath Conglomerate.

Name derivation:
The Rosneath Conglomerate was defined (Paterson and Hall, 1986).

Type area:
Its type area lies west of Rosneath Point [NS 275 808] in Strathclyde Region.

Upper and lower boundaries:
The formation lies unconformably on the Dalradian Supergroup at Rosneath Point. A better exposed similar relationship on members of the Highland Border Complex is seen just south of Arrochymore Point, Loch Lomond [NS 410 917]. The top is not exposed but it is presumed to be overlain by the Stockiemuir Sandstone Formation.

Thickness:
A thickness of over 1000 m is exposed.

7.5 STOCKIEMUIR SANDSTONE FORMATION (SCK)

Lithology:
The Stockiemuir Sandstone Formation comprises red sandstones with scattered mudstone clasts and a few quartz pebbles in the lower part. In the Greenock district (Paterson et al., 1990), the lower part of the Stockiemuir Sandstone includes red-brown, fine-grained, quartzose sandstones with a few pebbly beds and mudstone intercalations. The upper part of the formation also contains interbedded cross-bedded sandstones considered to be of aeolian (Plate 10) rather than fluviatile origin (Hall and Chisholm, 1987). However, no separate formation of aeolian facies (i.e. equivalent of the Knox Pulpit Sandstone) has been established in this succession. The trace fossil *Planolites* has been recorded from this part of the formation (Aspen, 1974) as well as *Skolithos*-like burrows (Hall and Chisholm, 1987). These may have formed in wet interdune areas (Paterson et al., 1990).

The lower part of the Gargunnock Sandstones from the Stirling area (Read and Johnson, 1967; Francis et al., 1970) includes mixed aeolian and waterlain sandstones including pebbly sandstones and conglomerates. These are similar to beds in the Stockiemuir Sandstone Formation (Hall and Chisholm, 1987). Reassignment of the lower part of the Gargunnock Sandstones to the Stockiemuir Sandstone Formation makes the Gargunnock Sandstones a redundant term.

Name derivation:
The formation was introduced by Paterson and Hall (1986) and named after Stockiemuir in Strathclyde Region.

Type area:
The type area for this formation is around Stockiemuir [NS 476 820].

Upper and lower boundaries:
The base of the formation is not seen in its type area (Figure 8) as it is faulted against Lower Devonian strata. The relationship of the formation to the Rosneath Conglomerate is also not seen due to faulting, but it is assumed that the sandstones overlie the conglomerates and partly replace them laterally (Paterson et al., 1990). The top of the formation is a sharp change to the cornstone-bearing Kinnesswood Formation (Inverclyde Group).

Thickness:
The formation is over 400 m thick (Hall et al., 1998).

The Largs Ruck area and the Cumbraes

No biostratigraphical evidence has been found in the component formations of the Stratheden Group in this area.

7.6 WEMYSS BAY SANDSTONE FORMATION (WEM)

Lithology:
The Wemyss Bay Sandstone Formation occurs west of the Largs Ruck at the base of the Stratheden Group succession. It consists of red-brown sandstones that are fine- to medium-grained, lacking in pebbles and generally cross-bedded. The large-scale, low-angle, bipolar cross-bedding may be aeolian and the dominant transport direction is from the south-south-east (Bluck, 1978; Paterson et al., 1990).

Name derivation:
This name was first used by Bluck (1978) for the sandstone succession around Wemyss Bay.

Type area:
The type area lies on the coast at Wemyss Bay [NS 193 685].

Upper and lower boundaries:
The base of the succession is not seen but the top is an erosive contact overlain by the Skelmorlie Conglomerate. The Wemyss Bay Sandstone is thought to wedge out to the south-east against a contemporaneous fault (Bluck, 1978).

Plate 10 Aeolian cross-bedding in Stockiemuir Sandstone Formation, exposed in cliff at back of main postglacial shoreline. Havock Hole, near Dumbarton (D3605).

Thickness:
The thickness of the formation is at least 50 m.

7.7 SKELMORLIE CONGLOMERATE FORMATION (SKM)

Lithology:
The Skelmorlie Conglomerate Formation contains pebbles and cobbles up to 0.15 m long composed of quartz, low-grade schist, quartzite, sandstone and lava. The upper part tends to be finer grained with interbeds of pebbly sandstone. The formation is considered to have been deposited as an alluvial fan by braided rivers (Paterson et al., 1990) and the clast composition suggests that the source was the Arbuthnott-Garvock Group, in addition to Dalradian metasedimentary rocks.

Name derivation:
The Skelmorlie Conglomerate is named after the village of that name (Bluck, 1978).

Type area:
The type area is on the coast section near Skelmorlie [NS 192 675].

Upper and lower boundaries:
The base of the conglomerate lies disconformably on the Wemyss Bay Sandstone Formation (Plate 11), whereas the top is transitional to the Kelly Burn Sandstone.

Thickness:
The formation is 20 m thick in the type area.

7.8 KELLY BURN SANDSTONE FORMATION (KBS)

Lithology:
The Kelly Burn Sandstone Formation comprises mainly red-brown sandstones with subordinate conglomerate beds, including coarse- and medium-grained sandstones which are commonly cross-bedded and pebbly. The apparent source of the clasts is from Dalradian metasedimentary rocks and Lower Devonian strata or possibly recycled earlier deposits of the Stratheden Group (Paterson et al., 1990). The formation is thought to be fluviatile in origin.

Name derivation:
The formation was named after the Kelly Burn (Bluck, 1978).

Type section:
The formation was defined in the Kelly Burn section [NS 194 684 to NS 235 694] (Paterson and Hall, 1986).

Upper and lower boundaries:
In the type area, the base is transitional with the Skelmorlie Conglomerate Formation but the top is a sharp (?disconformable) junction with the cornstone-bearing Kinnesswood Formation (Figure 8).

To the east of the Largs Ruck, the Seamill Sandstone Formation is now a redundant term (Paterson and Hall, 1986) referring to a succession of red-brown, fine-grained sandstones with sporadic quartz pebbles and interbeds of quartz-pebble conglomerate. The latter succession is now assigned to the Kelly Burn Sandstone Formation. The sandstones are normally planar bedded but locally large-scale, low-angle cross-bedding is present. The base of this succession is not seen and its top is transitional into the white sandstones of the Fairlie Sandstone Formation.

Thickness:
The Kelly Burn Sandstone Formation is at least 1000 m thick.

7.9 FAIRLIE SANDSTONE FORMATION (FAS)

Lithology:
The Fairlie Sandstone Formation occurs east of the Largs Ruck. This formation comprises mainly white or cream-coloured, fine-grained sandstones with a few interbeds of pebbly sandstone and conglomerate. The pebbles mainly consist of quartz, with some quartzite and green siltstone. The sandstones are finely laminated (pin-stripe lamination) or cross-bedded. The formation includes both fluviatile and aeolian derived strata (Paterson et al., 1990). In the Largs Borehole [NS 2158 5936], white pebbly sandstones lying beneath the cornstone-bearing Kinnesswood Formation possibly also belong to the Fairlie Sandstone Formation (Paterson et al., 1990).

Name derivation:
The formational name is taken from Fairlie Glen (Paterson and Hall, 1986).

Plate 11 Erosive contact of Skelmorlie Conglomerate Formation on Wemyss Bay Sandstone Formation, Wemyss Bay (D1557).

Type area:
The type area is around Fairlie Glen [NS 220 548].

Upper and lower boundaries:
The base is transitional by alternation from the Kelly Burn Sandstone Formation below. The top is inferred to be unconformable under the Lower Carboniferous Clyde Plateau Volcanic Formation.

Thickness:
The estimated thickness of the formation is approximately 300 m.

Bute

7.10 BUTE CONGLOMERATE FORMATION (BUT)

Lithology:
The Bute Conglomerate Formation comprises a mainly conglomeratic succession with subordinate red pebbly sandstone. They are correlated on lithostratigraphical grounds with the Stratheden Group and no direct evidence of the age of these beds has been found.

Name derivation:
The formation was defined by Paterson and Hall (1986) and named for the island of Bute.

Type area:
Its type area lies in southern part of the island [NS 112 594].

Upper and lower boundaries:
The base is not exposed (Figure 8). The top of the formation is the sharp junction with the cornstone-bearing Kinnesswood Formation.

Thickness:
The thickness of the formation is at least 1000 m and possibly up to 1500 m.

Arran

7.11 UNDIVIDED STRATHEDEN GROUP ON ARRAN

The Special Sheet for Arran published by the British Geological Survey (1987), shows the Stratheden Group as a succession of sandstones and conglomerates with an intercalated basaltic lava. The strata remain informally named.

Only the North Sannox Lava (NSX) has been established (Paterson and Hall, 1986). The type area lies adjacent to North Sannox [NS 004 480]. The top and bottom of the lava are not seen but it lies within the Stratheden Group (Figure 8). The lavas are basalt to olivine andesite in composition but their volcanic setting is unknown and they are best referred to informally at present.

In the Sannox area, Friend et al. (1963) described the sequence below the North Sannox Lava, as the 'Shepherd's House Sandstones and Conglomerates'. This unit unconformably overlies Lower Devonian Strathmore Group. The sequence above the lava, the 'Sannox Bay Sandstones and Conglomerates' (Friend et al., 1963) is overlain by the cornstone-bearing Inverclyde Group. However, in the west of Arran (Figure 8), Friend et al. (1963) have described Upper Devonian 'North Machrie Breccias' from the shore section north of Machrie [NR 890 351]. The strata comprise mainly massive breccias of mostly quartzose and metamorphic clasts but with about 10% lava clasts in the lower part. These breccias are unconformably overlain by Permian strata.

The whole group is up to 750 m thick on Arran with the volcanic interval up to 30 m thick. The North Machrie Breccias are 373 m thick according to Friend et al. (1963).

South Ayrshire

7.12 UNDIVIDED STRATHEDEN GROUP IN SOUTH AYRSHIRE

To date the Stratheden Group (SAG) succession has not been subdivided in this area but since fossil fish scales *(Bothriolepis leptocheira* and *Holoptychius)* characteristic of the group have been found at Bracken Bay, south of Ayr, the group is considered to be present in the area. It is inferred to lie between the unconformity with the Lanark Group (LORS) and the base of the Inverclyde Group (the reddish sandstone succession containing cornstone beds). The mainly arenaceous strata could be assigned to the Kelly Burn Sandstone Formation.

At Bracken Bay, the group typically comprises mottled pink and white, massive sandstones which are locally greenish grey, pebbly and calcareous. It is from this section that the only fossil fish are recorded from central Ayrshire. In the 19th century, *Bothriolepis major* (Agassiz) was recorded and subsequently in the 20th century, fossil fish fragments were obtained which were considered more likely to be late Devonian than early Carboniferous in age (Eyles et al., 1949). A later reclassification of the fish has identified it as *Bothriolepis leptocheira* (Mykura in Craig, 1991). Since the remains of the specimen were described as representing a distinct species characterised by the length and slenderness of the appendages (see Eyles et al., 1949), it is unlikely that the fish remains are derived from older strata. Hence they are unlikely to lie within the basal part of the Kinnesswood Formation (cf. the fossil fish remains near Dumbarton described by Paterson and Hall, 1986).

Near the base of the group, in Carwinshoch Burn, south of the Heads of Ayr, are conglomerate interbeds containing chert, jasper, quartzite, greywacke and porphyrite pebbles. However, Lower Devonian lava pebbles are absent or very scarce although the lavas underlie the group c. 500 m to the south. It is likely that these pebbles are remnants of those eroded from the Lanark Group.

The group in south Ayrshire is estimated to be up to 80 m thick. As the succession is so much thinner and generally finer grained than the group as exposed on the north side of the MVS, it could be considered as a condensed deposit of the more distal part of a large alluvial system. There is possibly also an aeolian component.

The Upper Old Red Sandstone lithofacies farther south, between Dailly and Straiton is considered to belong to the Kinnesswood Formation (part of the Inverclyde Group of Paterson and Hall, 1986).

Mull of Kintyre

7.13 UNDIVIDED STRATHEDEN GROUP ON MULL OF KINTYRE

Around Campbeltown (British Geological Survey, 1996a), the red sandstones with beds of quartz-pebble conglomerate assigned to the Stratheden Group (SAG) are undivided. The group rests on Lower Devonian strata and is overlain by the Kinnesswood Formation. The strata could be assigned to the Kelly Burn Sandstone Formation.

8 The Upper Devonian rocks in the Southern Uplands Terrane

Little lithostratigraphical classification has been made of the Upper Old Red Sandstone lithofacies (Upper Devonian to Lower Carboniferous) in this area (see Figure 9) and it was taken to include red-bed clastic type lithologies including pedogenic carbonates. The top of the succession had been arbitrarily taken at the incoming of the lavas (Birrenswark or Kelso lavas) known to be Early Carboniferous in age but this has not been rigorously applied. On many recent BGS maps the succession has been shown as Devono-Carboniferous (cd) since it was known to cross the Devonian/Carboniferous System boundary. Where possible, as in the MVS, the succession has been divided into a lower red-bed clastic sequence without pedogenic carbonate (Upper Devonian Stratheden Group) and an upper sequence with pedogenic carbonate (Lower Carboniferous Kinnesswood Formation, Inverclyde Group). The best exposures of the Stratheden Group crop out along the east coast between Siccar Point and Cockburnspath and a lithostratigraphy for the group in the SUT is established here, based on these exposures.

The work of Smith (1967, 1968) and Leeder (1973, 1974) indicates that the deposits were laid down in a separate Scottish Border Basin in which a fluviatile system flowed and expanded north-eastwards. However, Paterson et al. (1976) produced evidence that the Scottish Border fluviatile system was confluent with that in the MVS, flowing to the north-east. With some difficulty, this relatively thin, muddy fluviatile succession may be divided into non-cornstone bearing and cornstone-bearing strata (cf. the Stratheden and Inverclyde groups of the MVS). The division is simpler in successions lying closer to the MVS. Leeder (1974, 1976) in his study of the Northumberland Basin, noted that there are several concretionary cornstone horizons (but not ubiquitous) in the few metres below the base of the lavas (Birrenswark Volcanic Formation) which has been traditionally taken as the base of the Carboniferous succession. Elsewhere in the UORS lithofacies, cornstones are comparatively thin, rare and usually occur as isolated nodules. Leeder concluded there was a break in fluvial deposition, best explained by isostatic upwarp at the onset of the partial melting that produced the lavas. Farther north, in Berwickshire, the UORS lithofacies is followed by the sedimentary Border (Cementstones) Group. Goodchild (1903, p.118) describing the UORS lithofacies, noted that an upper division termed the Cornstone Group could usually be distinguished in the lower Tweedside area. This group usually had a less pronounced red colour than the lower part of the lithofacies; it rarely contained aeolian sand grains and concretionary cornstones were common. Sun-cracks, rain imprints and a few obscure traces of plants were also recorded (Goodchild, 1903).

It is possible to conclude therefore that despite the reduced thickness of the succession, there are equivalents to the Stratheden Group and the lower part of the Inverclyde Group (i.e. Kinnesswood Formation) at least in the east of the SUT (Figure 9). However, the presence of pedogenic carbonate is facies dependant and good biostratigraphical control is generally lacking (see Lumsden et al., 1967). It is the case that *Bothriolepis sp.* is Frasnian/Famennian (not Tournaisian) so that strata containing it are Upper Devonian. On its own *Holoptychius* is less certainly Frasnian/Famennian and strata containing this fossil may be of earliest Carboniferous age. The Fossil Fishes of Great Britain Conservation Review for the Late Devonian of Scotland includes two sites in the SUT. These are at Oxendean Burn [NT 771 561] and at Hawk's Heugh, Pease Bay [NT 790 714] (Dineley and Metcalf, 1999).

Cockburnpath–Siccar Point area

The Stratheden Group and the lower part of the Inverclyde Group are included in this succession which is very variable in thickness (75–1000 m). The majority of it can be equated with the Stratheden Group (Figure 9) with only the uppermost 30 m correlated with the Kinnesswood Formation (Inverclyde Group) as they are essentially fluvitile sandstones with cornstone development. The Stratheden Group has been divided into the Redheugh Mudstone Formation and the Greenheugh Sandstone Formation based on the coastal exposures.

8.1 REDHEUGH MUDSTONE FORMATION (REMU)

Lithology:

The newly defined Redheugh Mudstone Formation comprises a basal conglomerate member overlain by shaly sandstones fining up generally into red sandy mudstones. Sandstones intercalated with the mudstones are usually thin but some beds are exceptionally 5 m thick.

A basal breccia or conglomerate, the Siccar Point Conglomerate Member, is locally up to 6 m thick, and exposed at Siccar Point, Hirst Rocks and one locality in Tower Burn; elsewhere the lowest rocks are red-brown sandstones (Greig, 1988). Pebbles in the conglomerate are all ‘greywacke’ and have an imbrication indicating fluvial palaeocurrents flowed to the south or south-east.

In the type section (see below), the basal conglomerate is succeeded by sandstones with pebbly layers. The succession passes up into red-brown sandy mudstones interbedded with mainly thin red-brown, pale yellowish grey, green, purple or cream-coloured sandstones that tend to be more numerous and massive upwards. One bed is described as having calcareous concretions up to 1 m in diameter (Greig, 1988). The proportion of mudstone to sandstone is of the order 3:1 at Meikle Poo Craig.

Inland, the succession of sandstone, siltstone and mudstone is mostly red with some paler beds towards the top.

Name derivation:

The formational name is taken from Redheugh Shore (Hirst Rocks) about 5 km east of Cockburnspath.

Type section:

The type section for the formation is taken at Redheugh Shore, from Hirst Rocks [NT 8267 7026] to Meikle Poo Craig [NT 822 708].

<table>
<tr><th colspan="2">SOUTHERN UPLANDS TERRANE
South-western part</th><th colspan="2">SOUTHERN UPLANDS TERRANE
North-eastern part</th></tr>
<tr><td colspan="2">BORDER GROUP (Birrenswark Volcanic Formation)</td><td colspan="2">INVERCLYDE GROUP (Ballagan Formation)</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="4">Upper Old Red Sandstone Lithofacies</td><td>INVERCLYDE GROUP
(Kinnesswood Formation: mainly cornstone-bearing sandstones)</td><td colspan="2">INVERCLYDE GROUP
(Kinnesswood Formation: mainly cornstone-bearing sandstones)</td></tr>
<tr><td rowspan="3">STRATHEDEN GROUP
(undivided reddish sandstone and conglomerate)</td><td rowspan="3">STRATHEDEN GROUP
(undivided reddish sandstone and conglomerate)</td><td>Cockburnspath area</td></tr>
<tr><td>Greenheugh Sandstone Formation</td></tr>
<tr><td>Redheugh Mudstone Formation</td></tr>
<tr><td colspan="4">Unconformity</td></tr>
</table>

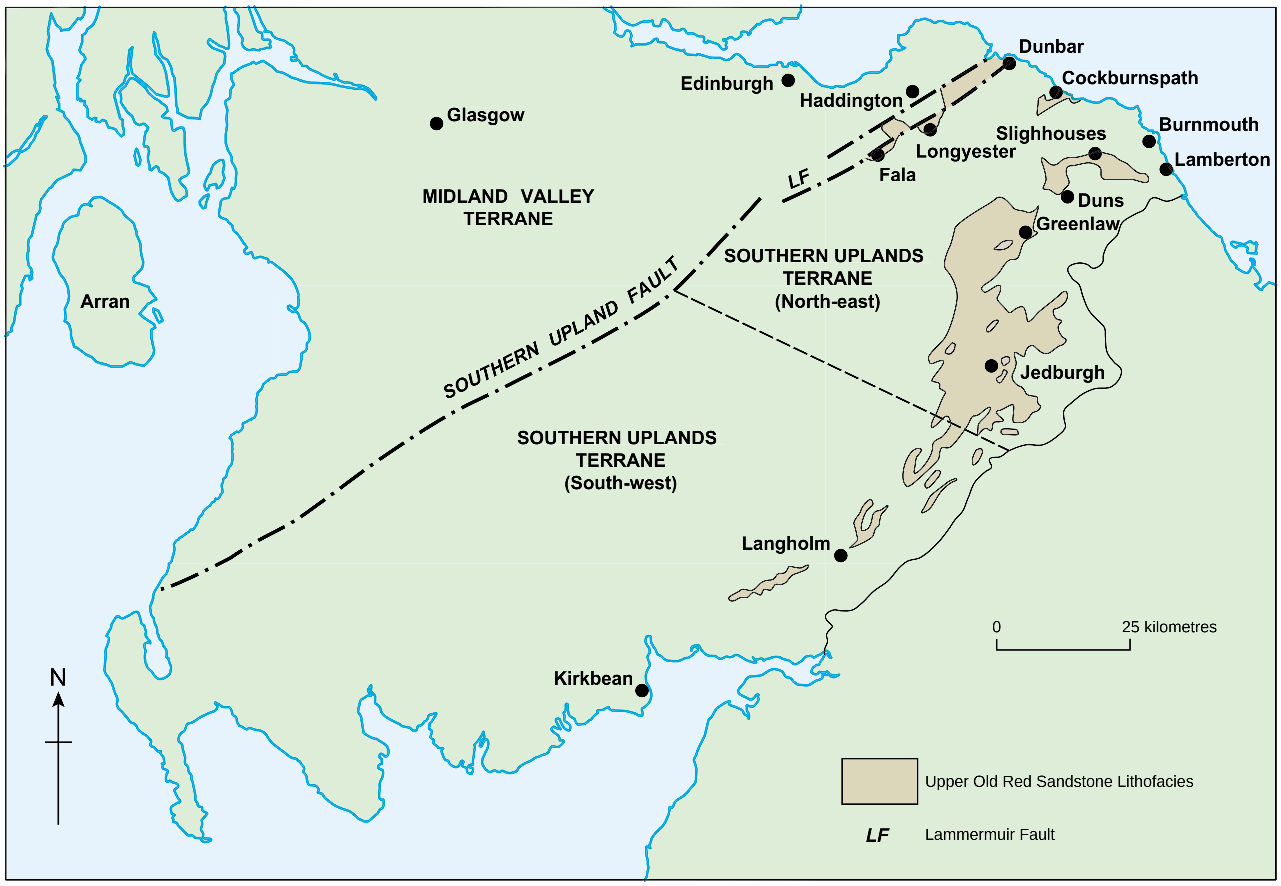

Figure 9 Lithostratigraphy for the Upper Old Red Sandstone lithofacies of the Southern Uplands Terrane.

Upper and lower boundaries:
The base of the formation is well exposed at Siccar Point (Plate 12) [NT 812 710] where it is famously unconformable (Playfair, 1805) on folded Llandovery rocks. The top is the incoming of the predominantly sandstone succession belonging to the Greenheugh Sandstone Formation.

Thickness:
The formation is estimated to be about 200 m thick.

Age:
Largely intact specimens of *Bothriolepis hicklingi* have been found in loose blocks between Meikle Poo Craig and Greenheugh Point (Miles, 1968). Inland, fragments of *Grossilepsis brandi; G.* sp., *Bothriolepis* sp. and *Holoptychius* sp. (Miles, 1968) have been found in Hazeldean Burn and indicate a Famennian age for the strata.

8.2 GREENHEUGH SANDSTONE FORMATION (GNSA)

Lithology:
The newly established Greenheugh Sandstone Formation comprises mainly medium- to coarse-grained red-brown

Plate 12 Siccar Point Conglomerate Member, basal breccio-conglomerate resting unconformably on vertical strata of Silurian (Llandovery) age. Siccar Point from the south-west (D2376).

sandstones with locally some pale yellow and green coloured beds. Thin red mudstones and siltstones are intercalated. The sandstones are commonly cross-bedded and both fluviatile and aeolian facies have been identified (Salter, 1992).

Name derivation:
The name is derived from Greenheugh Point, east of Pease Bay, 2 km east of Cockburnspath.

Type section:
The type section is from Greenheugh Point [NT 799 709] to Red Rock [NT 792 712], near Pease Bay.

Upper and lower boundaries:
The base of the formation is the top of the predominantly argillaceous Redheugh Mudstone Formation and the top is the incoming of cornstone development in sandstones of the Kinnesswood Formation.

Thickness:
The formation is estimated to be about 170 m thick.

Age:
Fragments of *Bothriolepis* sp. have been found in the lower, fluviatile sandstones of this formation.

Other areas in the Southern Uplands Terrane

8.3 UNDIVIDED STRATHEDEN GROUP

Slighhouses to Foulden area

This belt of red sandstone is poorly exposed but at several localities includes subordinate mudstone. The sandstones at Oxendean are generally thin bedded and fine-grained; more rarely massive and coarser grained. *Bothriolepis hayi* was collected (Miles, 1968) from exposures in the Oxendean area [NT 7706 5606 to 7709 5605], which places these beds in the Stratheden Group. Similar beds crop out near Whiteadder Water and also contain fragments of *Bothriolepis* spp. (Miles, 1968); at the base of these successions, above the unconformity with the Silurian turbidites, there are coarse-grained pebbly sandstones with pebbles of hornfelsed 'greywacke' and granite. The succession tends to fine upwards and near the top there are several exposures of white sandstone, rather than red (Greig, 1988).

In Harelaw Quarry [NT 883 572], north-east of Chirnside, red sandstones containing *Bothriolepis wilsoni* were reported (Miles, 1968; = B. *ornata* of Geikie, 1863). The medium-grained and locally coarse-grained, red sandstones around Chirnside are interbedded with conglomerate near the base of the succession and only about 17 m of red clay with cornstone nodules and pale grey calcareous sandstone (i.e. Kinnesswood Formation) is exposed underlying grey mudstone belonging to the Ballagan Formation.

In the Slighhouses–Billie Mains area, 20 m of calcareous sandstones and cornstones form the topmost beds of the UORS lithofacies in the section in Billie Burn (Greig, 1988). These upper beds belong to the Inverclyde Group (Kinnesswood Formation).

In a section in the Wheatland Burn, near Foulden, about 60 m of fine- and medium-grained reddish sandstones are commonly calcareous and contain cornstone nodules. They are interbedded with thin siltstones and lie below a thin cementstone [NT 9423 5510] taken as the base of the Ballagan Formation. To the east, the UORS lithofacies is overlapped by the Inverclyde Group, which rests directly on Llandovery rocks just over the border in England. It appears that the UORS lithofacies (in both the Stratheden and Inverclyde groups) form condensed sequences in the Border Region.

Burnmouth

The UORS lithofacies at Burnmouth [NT 958 610] (Figure 9) lies conformably below the Ballagan Formation (Cementstone Group of Greig, 1988; Smith, 1968). This succession which is the uppermost 50 m, contains red sandstones with subordinate mudstones and pedogenic carbonate. It is therefore correlated with the Kinnesswood Formation. Its base is faulted against Llandovery wacke sandstones.

Outliers around Burnmouth

The three outliers (Chester Hill [NT 947 600] north of Eyemouth [NT 943 649] and Lamberton [NT 968 592]) rest unconformably on Llandovery, or locally Lower Devonian rocks. They are mainly composed of conglomerate, that dominantly contains mainly wacke sandstone and Lower Devonian igneous rock clasts including dyke rocks and granite which appear to be locally derived. The matrix is reddish brown sandstone and interbeds of pebbly, cross-bedded sandstone and siltstone are exposed in the outlier north of Eyemouth. These three outliers are considered to belong to the Stratheden Group because they lack pedogenic carbonate and include Lower Devonian and older clasts.

Dunbar and Haddington area

There is no record of pedogenic carbonate in the Longyester or Fala outliers (Figure 9) which lie to the south-east of the Lammermuir Fault, but locally a basal conglomerate overlies the unconformable contact with the Ordovician (McAdam and Tulloch, 1985). These two outliers are therefore probably Stratheden Group.

North-west of the Lammermuir Fault, cornstone-bearing beds are present in the Upper Devonian to Lower Carboniferous strata in the Costerton and Humbie inliers. The Carfrae area is poorly exposed. Cornstone-bearing beds were also encountered at the base of the Spilmersford Borehole. These inliers are conformably overlain by Ballagan Formation (McAdam and Tulloch, 1985; Davies et al., 1986). The boundary with the Ballagan Formation is mostly conjectural; locally, a thin volcanic horizon in Humbie Water has been taken as the base of the Ballagan Formation. The Upper Devonian to Lower Carboniferous rocks exposed to the north-west of the Lammermuir Fault are therefore considered to belong to the Kinnesswood Formation.

Duns–Greenlaw–Jedburgh

The UORS lithofacies in this area (Figure 9) is not well known but from the descriptions of MacGregor and Eckford (1948), the component sandstones are bright red, deep red, red-brown, purplish, pink, buff, yellowish to almost white. Small dark red to pale green mudstone rip-up clasts are locally present. A study of the sandstone petrology shows a general lack of mica and presence of well-rounded grains. Numerous red-bed localities are listed in which fossil fish fragments have been found (MacGregor and Eckford, 1948). South of Melrose, some upper Devonian–lower Carboniferous strata are preserved around the Eildon Hills and comprise red, yellow and white sandstones, siltstones and marls. Goodchild (1903) notes that plant fragments of *Palaeopteris hibernica (Archaeopteris hibernica)* were found near Duns.

Most of these beds are considered part of the Stratheden Group. MacGregor and Eckford (1948) noted that white or yellow sandstones tend to occur in the higher parts of the succession. However, they found that this was not the case everywhere, e.g. at Greenlaw and near Makerston House on the Tweed, bright red sandstone was quarried just below the Kelso lavas (Birrenswark Volcanic Formation). They also noted that beds containing pedogenic carbonate had been recorded from near Robert's Linn Bridge, west of Wyndburgh Hill [NT 540 025] and from beneath 'greenstone' on the hill above Bedrule. A pedogenic carbonate bed has also been mapped along Wauchope Burn [NT 567 053] near the top of the sequence and it is estimated that there are at least 25–30 m of Kinnesswood Formation in this area. Farther east, below the Birrenswark Volcanic Formation in Caddroun Burn [NT 581 988] and Dawston Burn [NT 570 984], the uppermost beds contain thick dolomitised cornstone with pipe-like structures and can be equated with the Kinnesswood Formation (Inverclyde Group).

At Jedburgh, above a thin basal conglomerate, the succession is assigned as at Siccar Point (see sections 8.1; 8.2); namely lower fine-grained beds (Redheugh Mudstone Formation) passing upwards into sandstones with fossil fish remains (Greenheugh Sandstone Formation).

From Jedburgh, there is a faulted strip of UORS lithofacies running south-west towards Riccarton and Langholm and farther south-west, a strip between Lockerbie and Ecclefechan cropping out beneath the Birrenswark Volcanic Formation. The succession here comprises 30–200 m of pebbly sandstones, sandstones, siltstones and minor conglomerates. Towards Hawick a basal conglomerate unit overlies the Silurian rocks. Faunas are rare other than a few fish scales (see below). The UORS lithofacies appears to have originally covered a wider area as a large block of the sandstone is included in the Tudhope Vent [NT 982 432] which lies about four miles north of the main outcrop (Geikie, 1897). The main outcrop dips to the south-east below Lower Carboniferous rocks and may persist under the strata of the succeeding Northumberland Basin (Leeder, 1973). Peach and Horne (1903) recorded fish scales of *Holoptychius nobilissimus* from Dinely Burn, south of Hawick. The UORS lithofacies in the Scottish Border Basin (Leeder, 1973) is a wholly fluviatile succession unconformable on Silurian rocks and with an upper boundary which has been conveniently taken at the base of the Birrenswark Volcanic Formation. Leeder (1973) describes four fluviatile facies and where overbank siltstones were exposed to tropical weathering for a lengthy period, nodular pedogenic cornstones developed. The presence of scattered rounded millet seed grains in the sandstones suggests that they were derived from aeolian sands; these might be expected on semi-arid floodplains. However, no aeolian dune bedding has been recorded in the area.

Overall, Leeder (1973) found an upward trend to coarser-grained braided channel facies that may have resulted from uplift of the Galloway hinterland. Palaeocurrent measurements indicate persistent fluvial flow to the north-east. The pebble composition is consistent with a southerly source in Galloway. Leeder (1973) suggested that, with the evidence from Smith (1967), the Scottish Border Basin was one of interior drainage with its centre to the north-west of the Cheviot Hills (i.e. separate from that in the MVS, cf. Paterson et al., 1976). There is an equivalent to the Kinnesswood Formation in the Cheviot area in England (see the introduction to this section).

Langholm area

The UORS lithofacies in the Langholm area (Figure 9) rests unconformably on folded Lower Palaeozoic strata and is conformably overlain by the Birrenswark Volcanic Formation (Border Group). The succession varies in thickness between about 15 and 180 m (Lumsden et al., 1967). The strata comprise red sandstones, locally pebbly, with subordinate calcareous mudstones, siltstones and shales with calcareous nodules. At the base of the succession there is commonly a conglomerate of coarse Silurian fragments. *Holoptychius nobilissimus* has been recorded from red sandstones at the head of Wauchope Burn (Milne, 1843, pp. 435–9) and Dinely Burn (Peach and Horne, 1903; Lumsden et al., 1967). From the description of the Dinely Burn section (Lumsden et al., 1967), it is not possible to distinguish the cornstone-bearing facies from the beds bearing the fish remains. Lumsden et al. (1967) remained doubtful as to whether the red facies associated with *Holoptychius nobilissimus* necessarily implied that the beds were upper Devonian as opposed to lower Carboniferous.

Kirkbean area

The main, lower part of the UORS lithofacies in the Kirkbean area (British Geological Survey, 1993; 1998) (Figure 9) comprises breccias and sandstones similar in lithology to the Stockiemuir Sandstone Formation (Lintern and Floyd, 2000). The upper beds contain pedogenic carbonate and are therefore considered to belong to the Kinnesswood Formation (Inverclyde Group).

References

ALLEN, J R L, and CROWLEY, S F. 1983. Lower Old Red Sandstone fluvial dispersal systems in the British Isles. *Transactions of the Royal Society of Edinburgh. Earth Sciences,* Vol. 74, 61–68.

ARMSTRONG, H A, and OWEN, A W. 2000. Age and provenance of limestone clasts in the Lower Old Red sandstone conglomerates: implications for the geological history of the Midland Valley Terrane. 459–471 *in* New Perspectives on the Old Red Sandstone. FRIEND, P F, and WILLIAMS, B P J (editors). *Geological Society of London, Special Publications,* Vol. 180.

ARMSTRONG, M, and PATERSON, I B. 1970. The Lower Old Red Sandstone of the Strathmore Region. *Report of the Institute of Geological Sciences,* No. 70/12.

ARMSTRONG, M, PATERSON, I B, and BROWNE, M A E. 1985. Geology of the Perth and Dundee district. *Memoir of the British Geological Survey,* Sheets 48W, 48E and 49 (Scotland).

ASPEN, P. 1974. Fish and trace fossils from the Upper Old Red Sandstone of Dunbartonshire. *Proceedings of the Geological Society of Glasgow,* Session 113, 4–7.

ASTIN, T R. 1983. Discussion on implications for Caledonian plate tectonic models of chemical data from volcanic rocks of the British Old Red Standstone. *Journal of the Geological Society of London,* Vol. 140, 315–318.

BAILEY, E B. 1960. The geology of Ben Nevis and Glencoe and the surrounding country. (2nd edition). *Memoir of the Geological Survey of Great Britain,* Sheet 53 (Scotland).

BALIN, D F. 2000. Calcrete morphology and karst development in the Upper Old Red Sandstone at Milton Ness, Scotland. 485–501 *in* New Perspectives on the Old Red Sandstone. FRIEND, P F, and WILLIAMS, B P J (editors). *Geological Society of London, Special Publications,* Vol. 180.

BARRON, H F. 1998. Geology of the central Pentland Hills, 1:10 000 sheets NT16SE (Scald Law) and 1:10 560 sheets NT15NW (Baddinsgill) and part of NT15NE (Carlops) : part of 1:50 000 sheets 32W (Livingston), 32E (Edinburgh) and 24W (Biggar). *British Geological Survey Technical Report,* WA/98/41.

BLUCK, B J. 1978. Sedimentation in a late orogenic basin: the Old Red Sandstone of the Midland Valley of Scotland. 249–278 *in* Crustal evolution in northwestern Britain and adjacent regions. BOWES, D R, and LEAKE, B E (editors). *Special Issue of the Geological Journal,* No. 10.

BLUCK, B J. 1980. Evolution of a strike-slip fault-controlled basin, Upper Old Red Sandstone, Scotland. 63–78 *in* Sedimentation in oblique-slip mobile zones. BALLANCE, P F, and READING, H G (editors). *Special Publication of International Association of Sedimentologists,* No. 4.

BLUCK, B J. 1984. Pre-Carboniferous history of the Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* Vol. 75, 275–295.

BLUCK, B J, COPE, J C W, and SCRUTTON, C T. 1992. Devonian. 57–66 *in* Atlas of palaeogeography and lithofacies. COPE, J C W, INGHAM, J K, and RAWSON, P F (editors). *Geological Society of London Memoir,* No. 13.

BLUCK, B J. 2000. Old Red Sandstone basins and alluvial systems of Midland Scotland. 417–437 *in* New Perspectives on the Old Red Sandstone. FRIEND, P F, and WILLIAMS, B P J (editors). *Geological Society of London, Special Publications,* Vol. 180.

BRITISH GEOLOGICAL SURVEY. 1982. Eyemouth, Scotland Sheet 34. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1987. Arran, Scotland Sheet Special District. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1993. Dalbeattie, Scotland Sheet 5E. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1996a. Campbeltown, Scotland Sheet 12. Solid and Drift. 1:50 000. Provisional Series. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1996b. Carlops, Scotland Sheet NT15NE. Solid and Drift. 1:10 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1996c. Peebles, Scotland Sheet 24E. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1998. Kirkbean. Scotland Sheet 6W. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1999a. New Cumnock, Scotland Sheet 15W. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BRITISH GEOLOGICAL SURVEY. 1999b. Glen Shee, Scotland Sheet 56W. Solid. 1:50 000. (Keyworth, Nottingham: British Geological Survey.)

BROWNE, M A E. 1980. The Upper Devonian and Lower Carboniferous (Dinantian) of the Firth of Tay, Scotland. *Report of the Institute of Geological Sciences,* 80/9.

BROWNE, M A E. 1999. Balmerino to Wormit, Sheriffmuir Road to Menstrie Burn; Craig Rossie; Tilicoultry. 531–542 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series No. 17). STEPHENSON, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

BROWNE, M A E, and 5 others. 1999. A lithostratigraphical framework for the Carboniferous rocks of the Midland Valley of Scotland. Version 2. *British Geological Survey Research Report,* RR/99/07.

BURT, R M. 1994. The geology of Ben Nevis, Southwest Highlands, Scotland. Unpublished PhD thesis, University of St Andrews.

BURT, R M, and BROWN, P E. 1997. The Ben Nevis Intrusive Ring Tuff, Scotland: re-interpretation of the ‘Flinty Crush Rock’ as part of an ignimbrite conduit in the roots of an ancient caldera. *Scottish Journal of Geology*, Vol. 33, 149–155.

Cameron, I B, and Stephenson, D. 1985. *British Regional Geology: The Midland Valley of Scotland.* Third edition. (London: HMSO for British Geological Survey.)

Campbell, R. 1913. The geology of south-eastern Kincardineshire. *Transactions of the Royal Society of Edinburgh,* Vol. 48, 923–960.

Carroll, S. 1995a. Geology of the Stonehaven District. 1:10 000 sheets NO88NW, NO88NE, NO88SW and NO88SE (South of the Highland Boundary Fault). *British Geological Survey Technical Report,* WA/94/19.

Carroll, S. 1995b. Geology of the Inverbervie and Catterline District. 1:10 000 sheets NO87NW, NO87NE and NO87SW. *British Geological Survey Technical Report,* WA/94/20.

Carroll, S. 1995c. Solid geology of the Auchenblae District. 1:10 000 sheets NO78SW, NO78SE,NO77NW and NO77NE (South of the Highland Boundary Fault). *British Geological Survey Technical Report,* WA/95/80.

Carroll, S. 1995d. Geology of the Laurencekirk District. 1:10 000 sheets NO77SW and NO77SE. *British Geological Survey Technical Report,* WA/95/81.

Carroll, S. 1995e. Geology of the Fettercairn District. 1:10 000 sheets NO67NW, NO67NE, NO67SW, NO67SE and NO68SE (South of the Highland Boundary Fault). *British Geological Survey Technical Report,* WA/95/91.

Chisholm, J I, and Dean, J M. 1974. The Upper Old Red Sandstone of Fife and Kinross: a fluviatile sequence with evidence of marine incursion. *Scottish Journal of Geology,* Vol. 10, 1–30.

Clayburn, J A P, Harmon, R S, Pankhurst, R J, and Brown, J F. 1983. Sr, O and Pb isotope evidence for the origin and evolution of the Etive Igneous Complex, Scotland. *Nature, London,* Vol. 303, 492–497.

Cleal, C J, and Thomas, B A. 1995. *Palaeozoic palaeobotany of Great Britain.* (Geological Conservation Review Series: 9). (London: Chapman and Hall.)

Clough, C T, and 5 others. 1910. The geology of East Lothian. Second edition. *Memoir of the Geological Survey, Scotland* Sheets 33 and parts of 34 and 41.

Cope, J C W, Ingham, J K, and Rawson, P F. 1992. Atlas of Palaeogeography and Lithofacies. *Memoir of the Geological Society of London,* No. 13.

Craig, G Y. 1991. *Geology of Scotland.* Third edition. (London: The Geological Society of London.)

Dare-Edwards, A J. 1984. Aeolian clay deposits of south-eastern Australia; parna or loessic clay? *Transactions of the Institute of British Geographers,* Vol. 9, 337–344.

Davies, A, McAdam, A D, and Cameron, I B. 1986. Geology of the Dunbar district. *Memoir of the British Geological Survey,* Sheets 33E and part of 41 (Scotland).

Dineley, D L, and Metcalf, S J. 1999. *Fossil fishes of Great Britain.* Geological Conservation Review Series, No. 16. (Peterborough: Joint Nature Conservation Committee.)

Downie, C, and Lister, T R. 1969. The Sandy's Creek beds (Devonian) of Farland Head, Ayrshire. *Scottish Journal of Geology,* Vol. 5, 193–206.

Durant, G. 1999a. Port Schuchan to Dunure Castle; Culzean Harbour; Turnberry Lighthouse to Port Murray. 542–552 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). Stephenson, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

Durant, G. 1999b. South Kerrera. 489–492 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). Stephenson, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

Eyles, V A, Simpson, J B, and MacGregor, A G. 1949. Geology of Central Ayrshire. (2nd edition). *Memoir of the Geological Survey,* Sheet 14 (Scotland).

Francis, E H, Forsyth, I H, Read, W A, and Armstrong, M. 1970. The geology of the Stirling district. *Memoir of the Geological Survey of Great Britain,* Sheet 39 (Scotland).

Friend, P F, Harland, W D, and Hudson, J D. 1963. The Old Red Sandstone and the Highland Boundary in Arran, Scotland. *Transactions of the Edinburgh Geological Society,* Vol. 19, 363–425.

Friend, P F, and Macdonald, R. 1968. Volcanic sediments, stratigraphy and tectonic background of the Old Red Sandstone of Kintyre, W. Scotland. *Scottish Journal of Geology,* Vol. 4, 265–282.

Gatliff, R W, and 11 others. 1994. *United Kingdom offshore regional report: the geology of the central North Sea.* (London: HMSO for British Geological Survey).

Geikie, A. 1863. The geology of eastern Berwickshire. *Memoir of the Geological Survey of Great Britain,* Sheet 34 (Scotland).

Geikie, A. 1897. The ancient volcanoes of Great Britain. (London: Macmillan.)

Geikie, A, Geikie, J, Jack, R L, and Etheridge, R, Jun. 1872. Explanation of Sheet 22: Ayrshire (north part) with parts of Renfrewshire and Lanarkshire. *Memoir of the Geological Survey,* Scotland.

Geikie, A, Peach, B N, Jack, R L, Skae, H, and Horne, J. 1871. Explanation of Sheet 15. Dumfriesshire (North-West part); Lanarkshire (South part); Ayrshire (South-East part). *Memoir of the Geological Survey,* Scotland.

Gillen, C and Trewin, N H. 1987. Dunnottar to Stonehaven and the Highland Boundary Fault. 265–273 in *Excursion Guide to the Geology of the Aberdeen Area.* Trewin, N H, Kneller, B C and Gillen, C (editors). (Edinburgh: Scottish Academic Press.)

Goodchild, J G. 1903. The geological history of Lower Tweedside. *Proceedings of the Geologists' Association, London,* Vol. 18, 105–142.

Gould, D. 1997. Geology of the country around Inverurie and Alford. *Memoir of the British Geological Survey,* Sheets 76W and 76E (Scotland).

Greig, D C. 1971. British regional geology: the South of Scotland. Third edition. (Edinburgh: HMSO for Institute of Geological Sciences.)

Greig, D C. 1988. Geology of the Eyemouth district. *Memoir of the British Geological Survey of Great Britain,* Sheet 34 (Scotland).

Groome, D R, and Hall, A. 1974. The geochemistry of the Devonian lavas of the northern Lorne Plateau, Scotland. *Mineralogical Magazine,* Vol. 39, 621–640.

Gunn, W, Geikie, A, and Peach, B N. 1903. The geology of north Arran, south Bute and the Cumbraes with parts of Ayrshire and Kintyre. *Memoir of the Geological Survey of Great Britain,* Sheet 21 (Scotland).

Hall, I H S, Browne, M A E, and Forsyth, I H. 1998. Geology of the Glasgow district. *Memoir of the British Geological Survey,* Sheet 30E (Scotland).

Hall, I H S, and Chisholm, J I. 1987. Aeolian sediments in the late Devonian of the Scottish Midland Valley. *Scottish Journal of Geology,* Vol. 23, 203–208.

Haughton, P D W. 1988. A cryptic Caledonian flysch terrane in Scotland. *Journal of the Geological Society of London,* Vol. 145, 685–703.

Haughton, P D W. 1989. Structure of some Lower Old Red Sandstone conglomerates, Kincardineshire, Scotland: deposition from late-orogenic antecedent streams? *Journal of the Geological Society of London,* Vol. 146, 509–525.

Haughton, P D W, and Bluck, B J. 1988. Diverse alluvial sequences from the Lower Old Red Sandstone of the Strathmore region, Scotland — implications for the relationship between late Caledonian tectonics and sedimentation. 269–293 in *Devonian of the World. Volume 2: Sedimentation.* McMillan, N J, Embry, A F, and Glass, D J (editors). Vol. 2. (Calgary, Canada: Canadian Society of Petroleum Geologists.)

Haughton, P D W, Rogers, G, and Halliday, A N. 1990. Provenance of Lower Old Red Sandstone conglomerates, SE Kincardineshire: evidence of the timing of Caledonian terrane accretion in central Scotland. *Journal of the Geological Society of London,* Vol. 147, 105–120.

Henderson, W G, and Robertson, A H F. 1982. The Highland Border rocks and their relation to marginal basin development in the Scottish Caledonides. *Journal of the Geological Society of London,* Vol. 139, 433–450.

Hickling, G. 1908. The Old Red Sandstone of Forfarshire. *Geological Magazine,* Vol. 5 (new series), 396–408.

Hill, J, and Buist, D (editors). 1995. A geological field guide to the Island of Bute, Scotland. *Geologists' Association Guide,* No. 51.

House, M R, and 5 others. 1977. A correlation of the Devonian rocks in the British Isles. *Special Report of the Geological Society of London,* Vol. 7.

Howell, H H, Geikie, A, and Young, J. 1866. The geology of East Lothian including parts of the counties of Edinburgh and Berwick (Maps 33, 34 and 41). *Memoir of the Geological Survey of Great Britain.*

Jack, R L, and Etheridge, R J. 1877. On the discovery of plants in the Lower Old Red Sandstone of the neighbourhood of Callander. *Quarterly Journal of the Geological Society of London,* Vol. 33, 213–222.

Jackson, D I, and 5 others. 1995. *United Kingdom offshore regional report: the geology of the Irish Sea.* (London: HMSO for British Geological Survey.)

Kokelaar, B P. 1982. Fluidization of wet sediments during the emplacement and cooling of various igneous bodies. *Journal of the Geological Society of London,* Vol. 139, 21–34.

Lang, W H. 1927. Contributions to the study of the Old Red Sandstone flora of Scotland. VI. *Transactions of the Royal Society of Edinburgh,* Vol. 55, 443–452.

Le Maitre, R W (editor). 1989. *A Classification of Igneous Rocks and Glossary of Terms.* (Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks). (London: Blackwell Scientific Publications.)

Lee, G W, and Bailey, E B. 1925. The pre-Tertiary geology of Mull, Loch Aline and Oban. *Memoir of the Geological Survey of Great Britain,* Sheet 44 (Scotland).

Leeder, M R. 1973. Sedimentology and palaeogeography of the Upper Old Red Sandstone in the Scottish Border Basin. *Scottish Journal of Geology,* Vol. 9, 117–144.

Leeder, M R. 1974. Origin of the Northumberland Basin. *Scottish Journal of Geology,* Vol. 10, 283–296.

Leeder, M R. 1976. Palaeogeographic significance of pedogenic carbonates in the topmost Upper Old Red Sandstone of the Scottish Border Basin. *Geological Journal,* Vol. 11, 21–28.

Lintern, B C, and Floyd, J D. 2000. Geology of the Kirkcudbright-Dalbeattie district. *Memoir of the British Geological Survey*, Sheets 5W, 5E and part of Sheet 6W (Scotland).

Lumsden, G I, Tulloch, W, Howells, M F, and Davies, A. 1967. The geology of the neighbourhood of Langholm. *Memoir of the Geological Survey,* Sheet 11 (Scotland).

MacGregor, A G, and Eckford, R J A. 1948. The Upper Old Red and Lower Carboniferous sediments of Teviotdale and Tweedside, and the stones of the abbeys of the Scottish Borderland. *Transactions of the Edinburgh Geological Society,* Vol. 14, 230–252.

Marshall, J E A. 1991. Palynology of the Stonehaven Group, Scotland: evidence for a mid Silurian age and its geological implications. *Geological Magazine,* Vol. 128, 283–286.

Marshall, J E A, Haughton, P D W, and Hillier, S J. 1994. Vitrinite reflectivity and the structure and burial history of the Old Red Sandstone of the Midland Valley of Scotland. *Journal of the Geological Society of London,* Vol. 151, 425–438.

Marshall, J E A, Rogers, D A, and Whiteley, M J. 1996. Devonian marine incursions into the Orcadian Basin. *Journal of the Geological Society of London,* Vol. 153, 451–466.

McAdam, A D, and Tulloch, W. 1985. Geology of the Haddington district. *Memoir of the British Geological Survey,* Sheets 33W and part of 41 (Scotland).

McCallien, W J. 1927. Preliminary account of the post-Dalradian geology of Kintyre. *Transactions of the Geological Society of Glasgow,* Vol. 18, 40–126.

McGarvie, D W. 1999a. The Glencoe Volcano — an introduction to the GCR sites, Bidean nam Bian, Stob Dearg and Cam Ghleann, Buachaille Etive Beag, Stob Mhic Mhartuin and Loch Achtriochtan. 497–522 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). Stephenson, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

McGarvie, D W. 1999b. Ben Nevis and Allt a'Mhuilinn. 492–497 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series No. 17). Stephenson, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

McGiven, A. 1968. Sedimentation and provenance of post-Valentian conglomerates up to and including the basal conglomerate of the Lower Old Red Sandstone in the southern part of the Midland Valley of Scotland. Unpublished PhD thesis, University of Glasgow.

MacGregor, A R. 1968. Edzell and Glen Esk. 85–97. in *Fife and Angus Geology — an excursion guide.* (Edinburgh: Scottish Academic Press.)

Miles, R S. 1968. The Old Red Sandstone antiarchs of Scotland: Family *Bothriolepidae.* *Monograph of the Palaeontographical Society,* Vol. 122, No. 552, 1–130, plates 1–40.

Milne, D. 1843. Geological account of Roxburghshire. *Transactions of the Royal Society of Edinburgh,* Vol. 15, 433–502.

Mitchell, G H, and Mykura, W. 1962. The geology of the neighbourhood of Edinburgh. Third edition. *Memoir of the Geological Survey,* Sheet 32 (Scotland).

Monro, S K. 1999. Geology of the Irvine district. *Memoir of the British Geological Survey,* Sheet 22W and part of Sheet 21E (Scotland).

Moore, I. 1995. The early history of the Glencoe cauldron. Unpublished PhD thesis, University of Liverpool.

Moore, I, and Kokelaar, B P. 1997. Tectonic influences in piecemeal caldera collapse at Glencoe volcano, Scotland. *Journal of the Geological Society of London,* Vol. 154, 765–768.

Moore, I, and Kokelaar, B P. 1998. Tectonically controlled piecemeal caldera collapse; a case study of Glencoe Volcano, Scotland. *Geological Society of America Bulletin,* Vol. 110, Pt. 11, 1448–1466.

Morton, D J. 1979. Palaeogeographical evolution of the Lower Old Red Sandstone basin in the western Midland Valley. *Scottish Journal of Geology,* Vol. 15, 97–116.

Munro, M. 1986. Geology of the country around Aberdeen. *Memoir of the British Geological Survey,* Sheet 77 (Scotland).

Murchison, R I. 1859. On the sandstones of Morayshire containing reptilian remains, and on their relations to the Old Red Sandstone of that country. *Journal of the Geological Society of London,* Vol. 15, 419–423.

Mykura, W. 1960. The Lower Old Red Sandstone igneous rocks of the Pentland Hills. *Bulletin of the Geological Survey of Great Britain,* No. 16, 131–155.

Mykura, W. 1983. Old Red Sandstone. 205–251 in *Geology of Scotland.* Second edition. Craig, C Y (editor). (Edinburgh: Scottish Academic Press.)

Mykura, W. 1991. Old Red Sandstone. 297–344 in Geology of Scotland. Third edition. Craig, G Y (editor). (London: The Geological Society of London.)

North American Commission on Stratigraphic Nomenclature. 1983. North American Stratigraphic Code. *American Association of Petroleum Geologists Bulletin,* Vol. 67, 841–875.

Paterson, I B, Browne, M A E, and Armstrong, M. 1976. Letters to the Editors: Upper Old Red Sandstone Palaeogeography. *Scottish Journal of Geology,* Vol. 12, 89–91.

Paterson, I B, and Hall, I H S. 1986. Lithostratigraphy of the late Devonian and early Carboniferous rocks in the Midland Valley of Scotland. *Report of the British Geological Survey,* No. 3, 18.

Paterson, I B, Hall, I H S, and Stephenson, D. 1990. Geology of the Greenock district. *Memoir of the British Geological Survey,* Sheet 30W and part of Sheet 29E (Scotland).

Paterson, I B, and Harris, A L. 1969. Lower Old Red Sandstone ignimbrites from Dunkeld, Perthshire. *Report of the Institute of Geological Sciences,* No. 69/7.

Peach, B N, and Horne, J. 1899. The Silurian rocks of Britain, 1: Scotland. *Memoir of the Geological Survey of Great Britain.*

Peach, B N, and Horne, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the North of England and Central Scotland. *Transactions of the Royal Society of Edinburgh,* Vol. 40, 835–877.

Phillips, E R. 1994. Whole-rock geochemistry of the calc-alkaline Old Red Sandstone lavas, Sheet 15 (New Cumnock), Scotland. *British Geological Survey Mineralogy and Petrology Brief Report,* WG/94/1.

Phillips, E R, and Aitken, A M. 1998. The petrology and composition of the Lower Old Red Sandstone exposed in the Aberfoyle area (sheet 38E), Central Scotland. *British Geological Survey Technical Report,* WG/98/10.

Phillips, E R, Smith, R A, and Carroll, S. 1998. Strike-slip, terrane accretion and the pre-Carboniferous evolution of Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* Vol. 89, 209–224.

Phillips, E R, and Barron, H F. 2000. Provenance of the Silurian and Lower Old Red Sandstone sequences of the Southern Midland Valley, Scotland. *British Geological Survey Technical Report,* WG/00/6.

Playfair, J. 1805. Biographical account of the late Dr James Hutton. *Transactions of the Royal Society of Edinburgh,* Vol. 5, 39–99.

Rayner, D H. 1983. New observations on *Sawdonia ornata* from Scotland. *Transactions of the Royal Society of Edinburgh,* Vol. 74, 79–93.

Rayner, D H. 1984. New finds of *Drepanophycus spinaeformis* Goppert from the Lower Devonian of Scotland. *Transactions of the Royal Society of Edinburgh,* Vol. 75, 353–363.

Read, H H. 1927. The geology of the district around Edinburgh: The Tinto District. *Proceedings of the Geologists' Association,* London, Vol. 38, 499–504.

Read, W A, and Johnson, S R H. 1967. The sedimentology of sandstone formations within the Upper Old Red Sandstone and lowest Calciferous Sandstone Measures west of Stirling, Scotland. *Scottish Journal of Geology,* Vol. 3, 242–267.

Richardson, J B. 1967. Some British Lower Devonian spore assemblages and their stratigraphic significance. *Review of Palaeobotany and Palynology,* Vol.1, 111–129

Richardson, J B, Ford, J H, and Parker, J. 1984. Miospores, correlation and age of some Scottish Lower Old Red Sandstone sediments from the Strathmore region (Fife and Angus). *Journal of Micropalaeontology,* Vol. 3, 109–124.

Richey, J E, Anderson, E M, and MacGregor, A G. 1930. The geology of North Ayrshire. *Memoirs of the British Geological Survey* (Scotland).

Roberts, J L. 1974. The evolution of the Glencoe cauldron. *Scottish Journal of Geology,* Vol. 10, 269–282.

ROBINSON, R A J, RENNIE, C A, and OLIVER, G J H. 1998. Palaeocurrent data, source terrains and palaeogeographic setting of the Dalradian block: the Stonehaven-Dunnottar Groups revisited. *Tectonic Studies Group Annual General Meeting* (St Andrews).

ROCK, N M S, and RUNDLE, C C. 1986. Lower Devonian age for the 'Great (basal) Conglomerate', Scottish borders. *Scottish Journal of Geology,* Vol. 22, 285–288.

ROLFE, W D I. 1960. The Silurian Inlier of Carmichael, Lanarkshire. *Transactions of the Royal Society of Edinburgh,* Vol. 64, 245–260.

ROLFE, W D I. 1961. The geology of the Hagshaw Hills Silurian inlier, Lanarkshire. *Transactions of the Edinburgh Geological Society,* Vol. 18, 240–269.

SALTER, T. 1992. Facies, geometrical and palaeocurrent analysis of well-exposed alluvial reservoir analogues and applications to subsurface studies. Unpublished PhD thesis, University of Leeds.

SCOTT, A C, EDWARDS, D, and ROLFE, W D I. 1976. Fossiliferous Lower Old Red Sandstone near Cardross, Dunbartonshire. *Proceedings of the Geological Society of Glasgow,* Vol. 117, 4–5.

SIMON, J B, and BLUCK, B J. 1982. Palaeodrainage of the southern margin of the Caledonian mountain chain in the northern British Isles. *Transactions of the Royal Society of Edinburgh. Earth Sciences,* Vol. 73, 11–15.

SMITH, R A. 1993. Explanation for 1:10 000 Sheet NS72SE (Auchendaff). *British Geological Survey Technical Report,* WA/93/34.

SMITH, R A. 1994. Explanation for 1:10 000 Sheet NS72SW (Cairn Table). *British Geological Survey Technical Report,* WA/94/09.

SMITH, R A. 1995. The Siluro-Devonian evolution of the southern Midland Valley of Scotland. *Geological Magazine,* Vol. 132, 503-513.

SMITH, R A. 1996. Explanation for 1:10 000 Sheet NS62SE (Gass Water). *British Geological Survey Technical Report,* WA/96/22.

SMITH, R A. 1999a. Crawton Bay. 522–525 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). STEPHENSON, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

SMITH, R A. 1999b. Scurdie Ness to Usan Harbour; Black Rock to East Comb. 525–531 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). STEPHENSON, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

SMITH, R A. 2000. Geology of the Croy area. *British Geological Survey Technical Report,* WA/00/13.

SMITH, T E. 1967. A preliminary study of sandstone sedimentation in the Lower Carboniferous of the Tweed basin. *Scottish Journal of Geology,* Vol. 3, 282–305.

SMITH, T E. 1968. The Upper Old Red Sandstone-Carboniferous junction at Burnmouth, Berwickshire. *Scottish Journal of Geology,* Vol. 4, 349–354.

STEPHENSON, D. 1999. Pettico Wick to St Abb's Harbour. 552–556 in *Caledonian Igneous Rocks of Great Britain.* (Geological Conservation Review Series, No. 17). STEPHENSON, D, and 6 others (editors). (Peterborough: Joint Nature Conservation Committee.)

STEPHENSON, D, and GOULD, D. 1995. *British regional geology: the Grampian Highlands.* (4th edition). (London: HMSO for the British Geological Survey.)

SYBA, E. 1989. The sedimentation and provenance of the Lower Old Red Sandstone Greywacke Conglomerate, Southern Midland Valley, Scotland. Unpublished PhD thesis, University of Glasgow.

THIRLWALL, M F. 1979. The petrochemistry of the British Old Red Sandstone volcanic province. Unpublished PhD thesis, University of Edinburgh.

THIRLWALL, M F. 1981. Implications for Caledonian plate tectonic models of chemical data from volcanic rocks of the British Old Red Sandstone. *Journal of the Geological Society of London,* Vol. 138, 123–138.

THIRLWALL, M F. 1982. Systematic variation in chemistry and Nd-Sr isotopes across a Caledonian calc-alkaline volcanic arc: implications for source materials. *Earth and Planetary Science Letters,* Vol. 58, 27–50.

THIRLWALL, M F. 1983. Isotope geochemistry and origin of calc-alkaline lavas from a Caledonian continental margin volcanic arc. *Journal of Volcanology and Geothermal Research,* Vol. 18, 589–631.

THIRLWALL, M F. 1988. Geochronology of Late Caledonian magmatism in northern Britain. *Journal of the Geological Society of London,* Vol. 145, 951–967.

THIRLWALL, M F. 1989. Movement on proposed terrane boundaries in northern Britain: constraints from Ordovician-Devonian igneous rocks. *Journal of the Geological Society of London,* Vol. 146, 373–376.

TRENCH, A, and HAUGHTON, P D W. 1990. Palaeomagnetic and geochemical evaluation of a terrane-linking ignimbrite: evidence for the relative position of the Grampian and Midland Valley terranes in late Silurian times. *Geological Magazine,* Vol. 127, 241–357.

TREWIN, N H. 1987. Devonian of St. Cyrus and Milton Ness. 251–258 in *Excursion Guide to the Geology of the Aberdeen Area.* TREWIN, N H, KNELLER, B C, and GILLEN, C (editors). (Edinburgh: Scottish Academic Press)

TREWIN, N H, and RICE, C M. 1992. Stratigraphy and sedimentology of the Rhynie Chert locality. *Scottish Journal of Geology,* Vol. 28, 37–47.

TREWIN, N H, and DAVIDSON, R G. 1996. An early Devonian lake and its associated biota in the Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* Vol. 86, 233–246.

TUCKER, R D, and MCKERROW, W S. 1995. Early Paleozoic chronology: a review in light of new U-Pb zircon ages from Newfoundland and Britain. *Canadian Journal of Earth Sciences,* Vol. 32, 368–379.

TUCKER, R D, BRADLEY, D C, VER STRAETEN, C A, HARRIS, A G, EBERT, J R, and MCCUTCHEON, S R. 1998. New U-Pb zircon ages and the duration and division of Devonian time. *Earth and Planetary Science Letters,* Vol. 158, 175–186.

TYRRELL, G W. 1928. The Geology of Arran. *Memoir of the Geological Survey* (Scotland).

WALKER, E F. 1985. Arthropod ichnofauna of the Old Red Sandstone at Dunure and Montrose, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* Vol. 76, 287–297.

WATERSTON, C D. 1965. Old Red Sandstone. 269–308 in *The Geology of Scotland.* CRAIG, C Y (editor). (Edinburgh: Oliver & Boyd.)

WELLMAN, C H. 1993a. A land plant microfossil assemblage of Mid Silurian age from the Stonehaven Group, Scotland. *Journal of Micropalaeontology,* Vol. 12, 47–66.

WELLMAN, C H. 1993b. A Lower Devonian sporomorph assemblage from the Midland Valley of Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences,* Vol. 84, 117–136.

WELLMAN, C H. 1994. Palynology of the 'Lower Old Red Sandstone' at Glen Coe, Scotland. *Geological Magazine*, Vol. 131, 563–566.

WESTOLL, T S. 1951. A new cephalaspid fish from the Downtonian of Scotland, with notes on the structure and classification of ostracoderms. *Transactions of the Royal Society of Edinburgh,* Vol. 61, 341–357.

WESTOLL, T S. 1977. Northern Britain. in A correlation of Devonian rocks of the British Isles. HOUSE, M R, and 5 others (editors). *Special Report for the Geological Society of London,* Vol 7.

YANG, C X. 1997. Quaternary sedimentation, parna, landforms, and soil landscapes of the Wagga Wagga 1:100 000 map sheet, south-eastern Australia. *Australian Journal of Soil Research,* Vol. 35, Pt. 3, 643–668.

Appendix 1

Lithostratigraphy of Scotland south of a line from Fort William to Aberdeen

Group	*Formation*	*Code*	*Member*	*Area*
STRATHEDEN (SAG)	**Fairlie Sandstone**	**FAS**		Clyde
	Stockiemuir Sandstone	**SCK**		Clyde
	Knox Pulpit Sandstone	**KPF**		Fife
	Glenvale Sandstone	**GEF**	Dura Den	Fife
	Burnside Sandstone	**GEF**		Fife
	Rosneath Conglomerate	**RON**		Clyde
	Kelly Burn Sandstone	**KBS**		Clyde
	Skelmorlie Conglomerate	**SKM**		Clyde
	Wemyss Bay Sandstone	**WEM**		Clyde
	Bute Conglomerate	**BUT**		Bute
	Redheugh Mudstone	**REMU**		S Uplands Terrane
	Greenheugh Sandstone	**GNSA**		S Uplands Terrane
STRATHMORE (SEG)	**Teith Sandstone**	**THF**	Buchlyvie Sandstone	Aberfoyle
			Dalmary Sandstone	Aberfoyle
			Bracklinn Falls Conglomerate	Aberfoyle
			Uamh Beag Conglomerate	Aberfoyle
			Strathfinella Hill Conglomerate	Angus
	Gannochy Conglomerate	**GYF**		Angus
	Cromlix Mudstone	**CXF**	Tom Dubh Conglomerate	Aberfoyle
			Malling Conglomerate	Aberfoyle
			Shannochill Sandstone	Aberfoyle
	Sannox Siltstone	**SXS**	Barytes Mine Conglomerate	Arran
ARBUTHNOTT-GARVOCK (ATGK)	**Ruchill Flagstone**	**RLF**	Gartartan Conglomerate	Aberfoyle
			Callander Craig Conglomerate	Aberfoyle
			Inchmurrin Conglomerate	Aberfoyle
	Scone Sandstone	**SCN**	Campsie Limestone	Perth
			Dunblane Sandstone	Strathallan
			Buttergask Flagstone	Strathallan
			Sheriffmuir Sandstone	Strathallan
			Ashbank Sandstone	Angus
			Hatton Conglomerate	Angus
			Tannadice Sandstone	Angus
			Finavon Conglomerate	Angus
			Melgund Sandstone	Angus
			Arbroath Sandstone	SE Sidlaw
			Auchmithie Conglomerate	SE Sidlaw
			Red Head Sandstone	SE Sidlaw
	Craig of Monievreckie Conglomerate	**CMVC**	Bofrishlie Burn Sandstone	Aberfoyle
	Craighall Conglomerate	**CHCG**		Glen Shee
	Dundee Flagstone	**DEF**		Dundee
	Ochil Volcanic	**OVF**		Dundee
	Deep Conglomerate	**DECO**		Stonehaven
	Montrose Volcanic	**MVF**		Angus
	Catterline Conglomerate	**CATC**	Barras Conglomerate	Stonehaven
			Saint John's Knap Sandstone	Stonehaven
			Rouen Bay Sandstone	Stonehaven
	The Bastard Sandstone	**BAT**		Kintyre
	New Orleans Conglomerate	**NOW**		Kintyre
	Glenramskill Sandstone	**GRK**		Kintyre
	Am Binnein Sandstone	**ABN**	Dougrie School Sandstone	

			Druid Conglomerate	Arran
			Machrie Burn Siltstone	Arran
			Allt an Brighide Siltstone	Arran
			Glen Sannox Conglomerate	Arran
	Auchencar Sandstone	**AUSA**	Creag Mhor Conglomerate	Arran
			Auchencar Lava	Arran
			Auchencar Burn Sandstone	Arran
			Torr Breac Sandstone	Arran
	Basal Quartz Sandstone	**BQS**		Arran
	Portencross Sandstone	**POCR**		Farland Head
	Sandy's Creek Mudstone	**SACR**		Farland Head
DUNNOTTAR-CRAWTON (DRCR)	**Crawton Volcanic**	**CVF**	Lintrathen Tuff	Angus
	Whitehouse Conglomerate	**WCO**		Stonehaven
	Gourdon Sandstone	**GNF**	Rob's Cove Conglomerate	Stonehaven
			Doolie Ness Conglomerate	Stonehaven
	Tremuda Bay Volcanic	**TBVF**		Stonehaven
	Dunnottar Castle Conglomerate	**DRCC**	Castle Haven Conglomerate	Stonehaven
			Strathlethan Sandstone	Stonehaven
			Downie Point Conglomerate	Stonehaven
STONEHAVEN (SHG)	**Carron Sandstone**	**CRN**		Stonehaven
	Cowie Sandstone	**CWE**	Cowie Harbour Siltstone	Stonehaven
			Cowie Harbour Conglomerate	Stonehaven
			Castle of Cowie	Stonehaven
LANARK (LNK)	**Auchtitench Sandstone**	**AUC**		Lanark Basin
	Duneaton Volcanic	**DNV**		New Cumnock
	Biggar Volcanic	**BGRV**		Biggar
	Pentland Hills Volcanic	**PDH**		Lothians
	Carrick Volcanic	**CRKV**		W Ayrshire
	Swanshaw Sandstone	**SWAS**		Lanark Basin
	Greywacke Conglomerate	**GRWC**		Lanark Basin
RESTON (REST)	**Lamancha Conglomerate**	**LCHA**		S Uplands Terrane
	Auchencrow Burn Sandstone	**AUCR**		S Uplands Terrane
	Eyemouth Volcanic	**EYVO**		S Uplands Terrane
	Great Conglomerate	**GCGL**		S Uplands Terrane
	Cheviot Volcanic	**CHV**		S Uplands Terrane
	White Hill Sandstone	**WHIL**		S Uplands Terrane
UNCLASSIFIED	**Brig o' Balgownie Conglomerate**	**BOBC**		Aberdeen
	Lorn Volcanic	**LPVO**		Argyll
	Kerrera Sandstone	**KESA**		Argyll
	Glencoe Volcanic	**GLVO**		Glencoe
	Ben Nevis Volcanic	**BNVO**		Ben Nevis
	Allt a' Mhuilinn Mudstone	**AMMU**		Ben Nevis

Appendix 2

Obsolete lithostratigraphical terms in Scotland south of a line from Fort William to Aberdeen

Allermuir Group = Allermuir Volcanic Member
Arbuthnott Group = lower part of Arbuthnott-Garvock Group
Auchtitench Formation = Auchtitench Sandstone Formation
Ben Nevis Volcanic Series = Allt a' Mhuilinn Mudstone Formation and Ben Nevis Volcanic Formation
Blairgowrie Sandstone Formation = Scone Sandstone Formation
Bonaly Group = Bonaly Volcanic Member
Braidon Bay Conglomerate Member = Catterline Conglomerate Formation
Burnside Formation = Burnside Sandstone Formation
Carron Formation = Carron Sandstone Formation
Castle Hill Formation = Gourdon Sandstone Formation
Chapel Den Conglomerate Formation = Catterline Conglomerate Formation
Cheviot Volcanic Group/Series = Cheviot Volcanic Formation
Clashbenny Formation = Glenvale Sandstone Formation
Cowie Formation = Cowie Sandstone Formation
Crawton Group = upper part of Dunnottar-Crawton Group
Cromlix Formation = Cromlix Mudstone Formation
Dundee Formation = Dundee Flagstone Formation
Dunnottar Group = lower part of Dunnottar-Crawton Group
Edzell Mudstone Formation = Cromlix Mudstone Formation
Edzell Sandstone Formation = Teith Sandstone Formation
Fowls Heugh Conglomerate Formation = Whitehouse Conglomerate Formation
Gannochy Formation = Gannochy Conglomerate and Teith Sandstone formations
Gargunnock Sandstone Formation = Stockiemuir Sandstone and Knox Pulpit Sandstone formations
Garvock Group = upper part of Arbuthnott-Garvock Group
Glen Coe Sedimentary Series = lowest part of Glencoe Volcanic Formation
Glen Coe Volcanic Series = Glencoe Volcanic Formation
Glenramskill Formation = Glenramskill Sandstone Formation
Glenvale Formation = Glenvale Sandstone Formation
Gourdie Conglomerate Formation = Hatton Conglomerate Member
Gourdon Formation = Gourdon Sandstone Formation
Johnshaven Formation = Catterline Conglomerate Formation
Kemback Formation = Knox Pulpit Sandstone Formation
Knox Pulpit Formation = Knox Pulpit Sandstone Formation
Lanark Sandstone Formation = Swanshaw Sandstone Formation
Laurencekirk Mudstone Formation = Cromlix Mudstone Formation
Lorn Plateau Lavas = Lorn Plateau Volcanic Formation
Lorne Sedimentary Series = Kerrera Sandstone Formation
Portencross Formation = Portencross Sandstone Formation
Rouen Formation = Whitehouse Conglomerate Formation
Ruchill Formation = Ruchill Flagstone Formation
Sannox Siltstones = Sannox Siltstone Formation
Scone Formation = Scone Sandstone Formation
Seamill Sandstone Formation = Kelly Burn Sandstone Formation
Sandy's Creek Formation = Sandy's Creek Mudstone Formation
Stirling Group = Inverclyde Group
Swanshaw Formation = Swanshaw Sandstone Formation
Teith Formation = Teith Sandstone Formation
Three Wells Sandstone Formation = Three Wells Sandstone Member
Woodhouselee and Braid Hills Group = Woodhouselee Volcanic Member

Formerly formations now reduced to member status

Arbroath Sandstone Member AHS
Auchencar Burn Sandstones Member ABS
Auchmithie Conglomerate Member ACO
Barras Conglomerate Member BACO
Bofrishlie Burn Sandstone Member BBSA
Buttergask Flagstone Member BTG
Campsie Limestone Member
Creag Mhor Conglomerates Member CMC
Doolie Ness Conglomerate Member
Downie Point Conglomerate Member DPCO
Druid Conglomerates Member DRC
Dunblane Sandstone Member DUF
Dura Den Member DDF
Finavon Conglomerate Member FCO
Hatton Conglomerate Member HCF
Inchmurrin Conglomerate Member IMC
Melgund Sandstone Member MDF
Red Head Sandstone Member RHF
Rob's Cove Conglomerate Member
Sheriffmuir Sandstone Member SRF
St John's Knap Sandstone Member SJKS
Strathfinella Hill Conglomerate Member
Strathlethan Sandstone Member SNF
Tannadice Sandstone Member TEF

Informal terms

North Sannox Lava NSX
Sannox Bay Sandstones and Conglomerates
Shepherd's Bay Sandstones and Conglomerates
North Machrie Breccias
Basal Breccia
Quartzite Conglomerate
Morphie-Bruxie Hill member
St Cyrus member