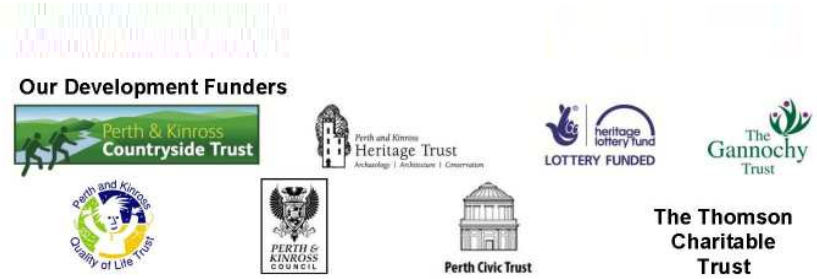
Tayside Geodiversity

Geodiversity of the Tay Landscape Partnership Area

Tay Landscape Partnership



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Tayside Geodiversity is affiliated to the Edinburgh Geological Society (Scottish Charity no. SC008011) and a member of Geoconservation UK.

Tayside Geodiversity is a voluntary group that is interested in making Tayside's geology and landscape better known. The group aims to produce leaflets and information boards about local geology and geomorphology sites and to protect and improve these sites in the three council areas (Angus, Perth & Kinross, and Dundee) that make up Tayside.

Local Geodiversity Sites can be important for educational purposes, scientific study, historical value, and for public awareness and appreciation of landscape and geology.

Contents

A The Geology of the Tay Landscape Partnership Area

Introduction

The aim of this report is to present the geological story of the Tay Landscape Project area succinctly and non-technically. It describes over 400 million years of Earth History, concentrating on those time periods where there is local evidence in the rocks and subsoils of the climate and environments. It will also mention where the area was on the globe as 'Scotland' journeyed northwards from near to the South Pole about 580 million years ago by plate tectonic movements. The full scope includes many aspects of geodiversity such as the rocks, landforms, landscapes, soils and subsoils, fossils, mineral resources and links to built heritage.

Bedrock Geology

The rocks of the Tay Landscape area have a pronounced influence on its landscapes. The oldest rocks are over 400 million years old (Early Devonian) and consist of volcanic (Ochil Volcanic Formation) and sedimentary (Dundee Flagstone and Scone Sandstone formations) strata belonging to the Arbuthnott-Garvock Group. These rocks formed when the area was located about 30° to 20° south of the Equator as part of a continent known as Laurussia. The volcanic rocks are the dominating upland element of the local landscapes, forming a horseshoe shaped backdrop to the lowlands breached by the Tay and Earn. In the south, they form the Ochil Hills and to the north, the Sidlaw Hills. The volcanic strata consist mainly of andesitic lavas, interbedded with sandstone and conglomerate composed of lava detritus. Lava flows are metres to tens of metres thick and autobrecciation is common; some flows contain abundant mm-sized crystals of feldspar. It is possible that these volcanic rocks formed stratovolcanoes like those of the Andes today but this is not certain. What is certain is that little life would have existed on this volcanic terrain that could be preserved as fossils. When volcanic activity was limited, some lake and river sediments were laid down on lava flow tops. In such mudstones and siltstones, primitive plants such as *Parka decipiens* are preserved as fossils. This plant is named after Parkhill at Newburgh where it may have been first found. In addition worm trails and trackways of small arthropods occur as in Friarton Quarry at Perth.

Semi-contemporaneous sedimentary strata (Dundee Flagstone Formation) are only at or near surface in the eastern fringe of the area around Longforgan. They were laid down as river and deltaic sands and lake silt and mud. A major, mainly braided, river system flowed southwest through the Perth-Angus area with the sediment possibly derived ultimately from Scandinavia (and perhaps also southern Scotland) rather than from the remnants of mountains in the Scottish Highlands. Lakes also formed from time to time, apparently as the lava flows from the erupting volcanoes blocked the primary drainage. Both fossil fish and plants have been found in these rocks, especially in Angus, and it can be accepted that algae, fungi and cyanobacteria formed part of the flora along with the earliest known Scottish vascular plants (known from rocks of similar age from Rhynie in Aberdeenshire, where spiders and insects also occur). The presence of plants suggest that the climate was not particularly arid but was probably warmer than today's. Indeed as the sedimentary rocks are grey (and not red) wetter conditions are most likely and raindrop impressions are found in the finest grained sediments. Locally, quite primitive fossil vascular plants and roots have been found in the Dunning and Forteviot area with simple and apparently branching straps more than 60cm long and 3cm wide.

The youngest Lower Devonian strata (Scone Sandstone Formation) were laid down on top of the volcanic rocks as river sands (and gravel) with some beds of red mud representing the floodplain of a largely braided but also possibly meandering major river system flowing

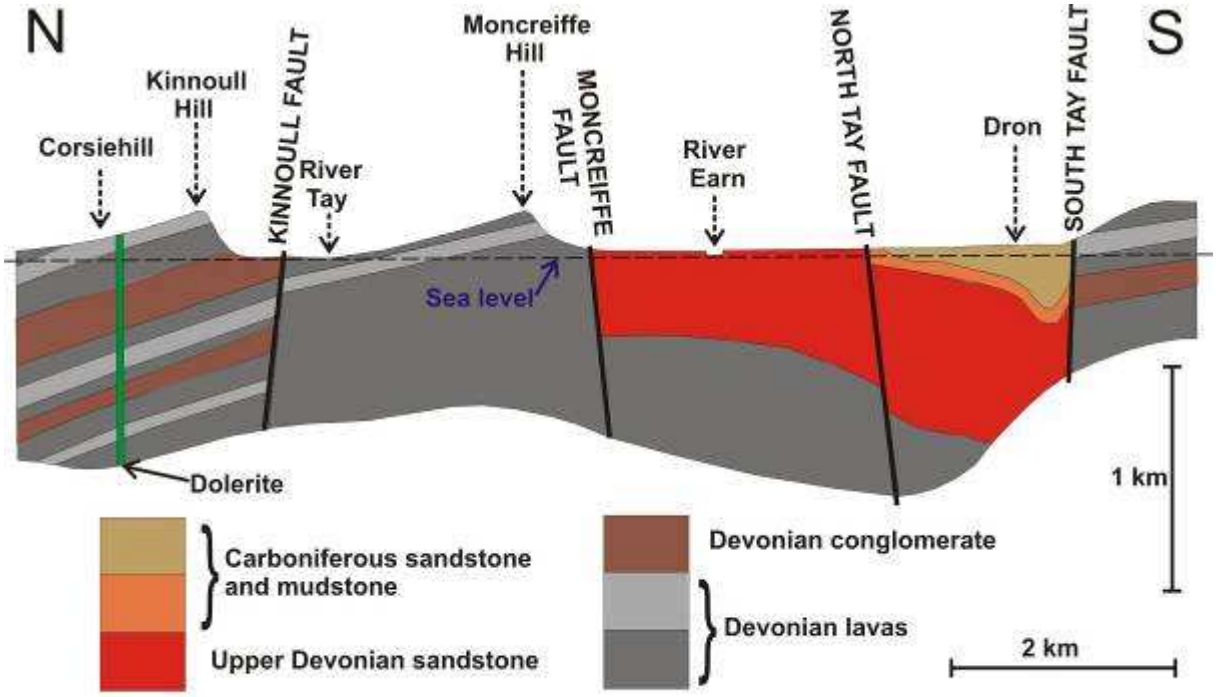
southwest. The presence of many limestone nodules apparently devoid of fossil roots and stems (calcrete soils mediated by vegetation) in these red and purple coloured sandstones clearly indicates that the local climate was hot and semi-arid with marked dry and wet seasons. No local evidence has yet been found in these rocks for wind blown sand dunes but as there is also little or no evidence of life, this remains a possibility. These strata are at surface in the lower ground around Perth and Scone, as at Quarrymill, and on the A9 roadside at Crossgates and also by the old Burghmuir sandstone quarries.

During the mid-Devonian, major Earth plate collision (Acadian Orogeny) far to the south folded and faulted these rocks, and arched them up to form the Sidlaw-Ochil Anticline (with the Strathmore Syncline to the north of this area). The Sidlaw Hills are on the north side of the arch and the Ochils on the south, emphasising the presence of this fold in the present landscape. Much erosion of the local rocks took place in the mid-Devonian leaving a very subdued landscape possibly largely devoid of life.

About 370 million years ago (Upper Devonian), more sedimentary rocks (Glenvale Sandstone Formation of the Stratheden Group) were laid down resting unconformably on the Lower Devonian strata. This contact was formerly visible in a building stone quarry at Dunbarney, Bridge of Earn. These are both braided and meandering river sediments laid down in a hot, semi arid climate so they are characteristically bright red and orange. Similar sandstone strata in Fife are partly of wind blown desert origin and it is likely that is also the case around Errol and Dron. The area was probably about 20° to 10° south of the Equator. Clashbenny Quarry near Errol is justifiably famous for the fossil fish found there when it was still working in the 19th century. Species of primitive armoured freshwater fish including *Holoptychius*, *Bothriolepis* and *Phyllolepis* have been found mainly as isolated bony scales. These fossils have been compared with those found at the very famous Dura Den, Fife locality.

The Glenvale Sandstone strata pass seamlessly up into the oldest Lower Carboniferous (Kinnesswood Formation of the Inverclyde Group) that is about 355 million years old. These are also river sediments but characterised by the presence of many nodules and even beds of limestone (calcrete soils) indicating a hot climate again with pronounced dry and wet seasons. The youngest strata (Ballagan Formation, also of the Inverclyde Group) present in the area (around East Dron, Mains of Errol and Newburgh) are mudstones with thin beds of dolostone and limestone and also gypsum nodules and veins. These strata were laid down on a low-lying coastal alluvial plain subject to storm surges bringing seawater inland from the east; bivalves and ostracod fossils are found in these strata but little evidence of plants apart from pollen and some evidence for rooting. The mineral gypsum was precipitated from the evaporating water and is further evidence for the arid climate at this time.

Further major earth movements about 300 million years ago (Variscan Orogeny) driven by plate collisions to the south of England completely eroded the remaining Carboniferous strata in this area, removing the evidence they would have provided of tropical seas and equatorial ever wet forests (coal seams) as Scotland sat across the Equator. Around this time, a period of igneous activity not associated with any volcanoes produced the quartz-dolerite dykes seen at Corsiehill Quarry SSSI, Perth and at Campsie Linn, Stanley that are intruded into the Lower Devonian rocks. A much more profound effect was the faulting of the strata with two particularly important lines being the North and South Tay Faults. North of the Carse of Gowrie is the steep southern fault-face of the Braes of the Carse. South of Strathearn and the Firth of Tay, the ground rises abruptly across a north-facing fault scarp which delimits the Lower Devonian volcanic rocks of the Ochil Hills. As the result of these ancient movements, the softer Upper Devonian and Lower Carboniferous strata were down-faulted and are now preserved under the low ground of Strathearn and the Carse of Gowrie and under the Tay estuary. The topographic effect is as if the lower ground was in a ‘rift valley’ formed along the axis of the arch of the Sidlaw-Ochil Anticline. As a result, the landscapes of the two estuaries and surrounding lowlands of the Tay and Earn are very much a consequence of the local bedrock geology and its earth movement history.



Cross section from Corsiehill to Dron.
Simplified from British Geological Survey (1984a).

It is now generally accepted that deposits of Permo-Triassic desert sand dunes and rivers, Jurassic and Cretaceous seas and deltas and even possibly Palaeocene were laid down in central Scotland. Scotland's journey northwards north of the Equator through low latitudes is not recorded in the Tay area. However the major volcanic events (seen on Mull, Skye, Rum and Arran) marking the opening of the Atlantic Ocean about 55 million years ago caused uplift and further major erosion in central Scotland with estimates of 500-1000m of rock removed.

Quaternary (Superficial deposits)

Ice ages in Scotland and Western Europe reflect the result of long continued plate movements to northern mid latitudes (56° at Perth) and significant rapid cooling of the world climate about two and half million years ago. As a result, Scotland was glaciated on a number of occasions resulting in significant changes to the landscape. The glacial landforms of the area are attributed to the late Devensian Stadial ice-sheet starting from about 33,000 years ago, although the ice-moulded bedrock features probably owe their form to the accumulated effects of more than one glaciation. All of the evidence from glacial striae, erratic boulders and drumlins (ice-eroded streamlined mounds of till) shows that the late Devensian ice advancing from the west Highlands fanned out over east central Scotland, moving eastward across this area. This ice sheet probably merged with the Scandinavian ice sheet somewhere in the central North Sea. Glacial deposits in the Tay area also appear to relate exclusively to the last (Devensian) glaciation during which till (boulder clay), a mixture of clay, silt, sand and stones, was laid down extensively at the base of the ice sheet.

About 20,000 years ago the ice started to retreat, pulling back westwards from its most easterly extent. In this retreat, the emergence of high ground confined active glaciers to the major valleys and glacial melt-waters released by the wasting glacier in the Tay valley laid down the sand and gravel deposits which form the sub-soils in the higher fields around Newburgh and Abernethy, and also laid down the Lindores esker in the Newburgh Gap. These deposits were formed either beside or within stagnant ice and usually rest on the glacial till. Melt-waters also deposited sands and gravels, at and in front of the ice-margins in the Perth area mainly as glaciofluvial spreads and one or two glaciomarine deltas. Altimetric

levelling of some of the terraced features, both fluvial and marine, has lead to recognition of positions of ice termini in the Tay valley. One of these termini at Almondbank associated with the 'Perth Re-Advance' has generated much scientific debate over the years as to when it may have formed or indeed if it marks a significant event.

Marine deposits laid down during the glacial retreat from about 15,000 years ago now occur well above present sea level as a consequence of the uplift of the land, a glacio-isostatic response to the rapid removal of the weight of about one kilometre of ice. At this time, local sea level was over 40m higher than present so that the sites of farms like Jamesfield and Culfargie were submerged. The Tay and Earn valleys were fjords initially with icebergs and then later, as the glaciers withered, only with winter ice. Evidence of these arctic waters is reflected in the presence of red plastic clay that was deposited by melt-water plumes in the fjord. This red deposit, the Errol Clay, has long been known for the arctic shells and seal bones found in it in claypits around Inchcoonans and in more silty deposits in temporary sections at Almondbank SSSI. The fauna includes bivalves, foraminifera and ostracods, some of which no longer live in British (boreal) waters.

In the deeper bedrock depressions under the Tay and Earn valleys, the Errol Clay is generally buried by a thick succession of younger clays (the Powgavie Clay with a boreal aspect fauna) and silts and sands. The commercial drilling associated with the construction of the major M90 bridges provided much of this evidence along with scientific boreholes sunk in the 1980s. On the fringes of the valley sides, pink sand and silt, and occasionally gravel, cover the Errol Clay and were laid down as estuarine and beach deposits. From 15,000 to about 11,000 years ago, local sea level fell from 40m to about present level. This fall is evident in the landscape from the presence of benches and breaks in hill-slope that mark the positions of former coastlines.

Another period of fully arctic climatic conditions known as the Loch Lomond Stadial lasted from about 12,800 to 11,600 years ago. Although glaciers returned to parts of the Highlands and some of the Central Lowlands north of Glasgow and west and northwest of Stirling, they were distant from Perth. The response in this area to this climatic event was the loss of vegetation and destruction of soils. Periglacial activity probably took place but little evidence of such features (*e.g.* solifluction deposits and ice wedge casts) exists. The local sea level was possibly 3m below OD, reflected by the sand and gravel filled channel now buried under younger deposits, discovered during the drilling of site investigation boreholes for the M90 Bridge over the River Earn.

Subsequently the climate improved at the beginning of the Holocene and the sea rose again depositing the mainly grey silt and clay of the 'buried beaches' (Carey Beds). The presence of the Sub-Carse Peat that subsequently formed on these exposed beach deposits approximately 8,000 years ago records a further fall in sea level in part associated with the development of partly buried minor valleys (*e.g.* Pitlowie SSSI) with complex fills with more than one bed of peat. The last significant marine transgression culminated about 6,000 years ago, the deposits of this episode forming the widespread carselands of lower Strathearn and the Carse of Gowrie. The Carse Clay formed as inter-tidal mudflats. The local sea level reached a maximum of about 9m above OD when the Carse Clay was laid down. At least one bed of sand in the Carse Clay has been linked to the tsunami caused by the largest known submarine slope collapse in the North Sea.

In the last 6,000 years, sea level has fallen to that of present times. There are, however, fields where a lower Carse terrace is preserved above the level of the present, partly reclaimed, inter-tidal flats of the Earn and the Tay. This intermediate level was formed by about 4,000 years ago and the Carpow Logboat is about 1,000 years younger than these estuarine deposits.

Soils

The Soil Survey's mapping of the area recognises several soil types: Alluvium Association (Marine Saltings Series), Stirling Association (Stirling Series of estuarine silts and clays of the 'low raised beach'), and Carpow Association (Carpow Series of the upper terrace deposits mainly of sand and gravel; Carey Series of the upper terrace deposits but mainly of sand and silt). The Stirling Series is the soil type developed on the Carse Clay, and the Carey Series is developed on the raised estuarine sediments that are more than 11,000 years old. The Carpow Series is developed on the glacial melt-water sand and gravel deposits.

Mineral Resources

The bedrock geology is also reflected in the built heritage, with older buildings in Perth constructed in local Lower Devonian sandstone from quarries on the Burghmuir, at Huntingtower and Quarrymill. Local lavas and dolerite also were used both in buildings, walls and road aggregate. Bridge of Earn has many old buildings constructed with red Upper Devonian sandstone from Dunbarney and Glenearn; similarly Errol from Clashbenny. Limited amounts of sand and gravel have been extracted just downstream of Perth and Errol Clay was used for brick, pipe and tile around Errol. Near Broombarns, Carse Clay was also dug. Culturally, the Stone of Scone almost certainly was sourced locally either at Quarrymill or from the banks of the Tay.

Table of rock units in the TLP area, with ages in thousands of years (ka) or millions of years (Ma)

6 ka	Carse Clay		Quaternary
8 ka	Sub-Carse Peat		
	Carey Beds		
	Powgavie Clay		
15 ka	Errol Clays		
	Glaciofluvial sand and gravel		
33-20 ka	Till	Devensian glaciation	
2.5 Ma			Start of ice ages
300 Ma	Quartz-dolerite dykes		Carboniferous
	Ballagan Formation	Inverclyde Group	
355 Ma	Kinnesswood Formation		
370 Ma	Glenvale Sandstone Formation	Stratheden Group	Upper Devonian
			Unconformity
	Scone Sandstone Formation	Arbuthnott-Garvock Group	Lower Devonian
	Dundee Flagstone Formation		
>400 Ma	Ochil Volcanic Formation		

B Accessible Summary: From Desert to Ice – the Making of a Landscape

Climb to the top of Moncrieffe Hill, near Perth and look down at the landscape where the Rivers Tay and Earn meet. This is the focus of a 200 kilometre square area that includes the low ground of the Carse of Gowrie, Lower Strathearn and the Tay estuary and is flanked by the higher ground of the Sidlaw and Ochil Hills. The landscape that you see today has been shaped by 400 million years of Earth history. The evidence for this can be found in the underlying rocks. Around 400 million years ago, in a time period called the Devonian, this part of Scotland was part of a large continent located in the tropical zone to the south of the Equator. The rock strata laid down during this time were mainly sandstones and volcanic rocks.

Up to the north-east of this area were high mountains, while closer by were towering volcanoes, erupting lava and debris that now forms the Ochil and Sidlaw Hills. The climate was semi-arid and a large river system flowed southwest through the Perth and Dundee area. The rivers deposited sand and pebbles to build layers of grey sandstone and conglomerate rocks. Mud was also deposited on floodplains and in lakes. The resulting sandstone and mudstone occasionally contains fossils, and provides evidence of primitive plants growing on the wet margins of the rivers, and fish living in lakes.

The Earth's surface is constantly in motion, driven by the forces of plate tectonics. The colliding of the Earth's plates far away affected this area. The rock layers were arched upwards with the centre of the arch running along the line of the present Tay estuary. As a result the rock layers on Kinnoull Hill slope towards the north with a south-facing scarp. The same layers in Fife slope towards the south with a north-facing scarp.

By the end of the Devonian, 370 million years ago, Scotland was still located in the tropical zone to the south of the equator. It had moved north so was closer to the equator than before. The environment was a wide coastal plain with extensive areas of sand dunes implying hot desert conditions. Fossils show that the rivers contained abundant fish as big as salmon. In this desert climate the sandstones formed were red and yellow in colour.

Colliding earth plates again affected the area about 300 million years ago. The curved rock layers of the central arch broke along fault lines, the North and South Tay faults, which today form the edges of the Ochil & Sidlaw Hills. The oldest rocks form these hills and in between a rift valley exposes relatively younger rocks (see diagram in section A). Molten rock was squeezed up through the sandstone in giant vertical sheets and did not erupt at the surface. It solidified as the rock which is called dolerite.

Over the following 300 million years the land was uplifted and worn down to its present level by wind, rain and latterly ice and frost. Thousands of feet of rock have been removed by erosion to expose the rocks we see today. Throughout this time plate movements were carrying Scotland northwards to its present position in the Northern Hemisphere.

The Earth entered an Ice Age about two and a half million years ago. Since then Scotland has been repeatedly covered by thick ice sheets up to one kilometre in thickness. The ice, carrying rock debris, scoured and eroded the land surface, leaving the more resistant hard volcanic rocks as prominent high ground. The last time this area was buried beneath an ice sheet began about 33,000 years ago, when ice was moving eastward, out of the Highlands and into the North Sea. By 20,000 years ago the ice sheet was retreating and leaving deposits of till, a mix of clay, silt and stones, across the area. Around Perth, melt water from the ice deposited extensive areas of sand and gravel.

As the climate became warmer the ice began to retreat and melt. Sea level was high due to the weight of the ice sheet pushing down the land surface. As the ice retreated back into the Highlands, the Tay and Earn estuary contained a glacier that flowed into the sea. The ice

breaking from the glacier created icebergs. In the Carse of Gowrie, the Errol clay was deposited in this estuary and contains stones dropped from the icebergs and fossil shells of species found nowadays in high Arctic waters.

As the ice sheet melted, the land surface pushed back up and from 15,000 to 11,000 years ago, sea level fell within the Tay and Earn estuary. This has resulted in the formation of raised beaches, marked by distinctive breaks of slopes along the Tay and Earn that show the former positions of the shoreline. The melting ice sheet released water to the sea. At about 6,000 years ago this resulted in a higher sea level than today. The Carse of Gowrie became an area of extensive intertidal mudflats and the Carse Clay was deposited. From that time to today the sea level fell to its present position and the Lower Tay and Earn Valleys became boggy ground with woodland of birch and oak growing in the drier places. The land was later drained to provide fertile farmland.

The rocks of this area have been quarried and extracted for building stone and construction materials. Devonian sandstones were quarried at places such as Burghmuir and Quarrymill to provide the building stone that is present in the older buildings in Perth. Local lavas and dolerite were used in both walls of buildings and to build roads and railways. Red sandstones from near Glenearn give the buildings of Bridge of Earn a distinctive character. The Errol Clay was used for brick making, tiles and field drains.

C Site list

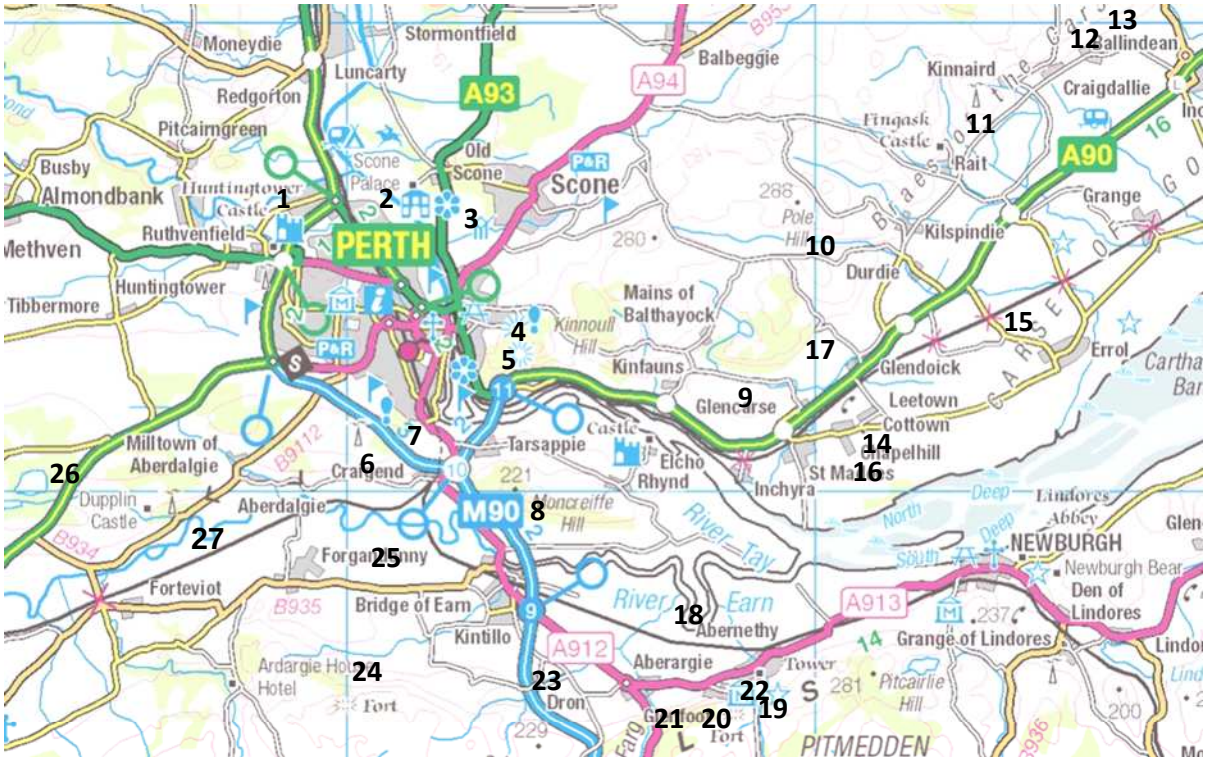
No	Location	NO	Geology	Feature
1	Almondbank SSSI	084262	Quaternary	Evidence of the "Perth Re-advance"
2	River Tay at Scone	114257	Lower Devonian sandstone	Sandstone features
3	Quarrymill Den, Scone	125254	Lower Devonian sandstone	Possible origin of the Stone of Destiny
4	Corsiehill Quarry SSSI, Kinnoull Hill	135235	Permo-Carboniferous dyke	Dyke contact
5	Kinnoull Hill (partly SSSI)	134229	Lower Devonian Ochil Volcanic Formation	Geological history and agates
6	Kirkton Hill and St Magdalene's Hill	103205 110211	Lower Devonian Ochil Volcanic Formation	Pyroxene andesite lavas, dolerite dykes, conglomerates
7	Friarton Quarry, Perth	115211	Lower Devonian Ochil Volcanic Formation, Permo-Carboniferous dyke	Geological history
8	Moncreiffe Hill	133198	Lower Devonian Ochil Volcanic Formation	Andesite lavas, agates
9	Pepperknowes Quarry, Glencarse	183222	Lower Devonian Ochil Volcanic Formation	Andesite lava and conglomerate
10	Pitroddie Den	205252	Lower Devonian Ochil Volcanic Formation, dyke	Meltwater channel
11	Flawcraig and Craighead Quarries	240280	Lower Devonian Ochil Volcanic Formation	Dolerite dyke and andesite lava
12	Wester Ballindean Quarry	258294	Upper Devonian Glenvale Sandstone Formation	Sandstone features
13	Tinkletop Hill, Ballindean	260304	Porphyritic intrusion	Agates
14	Clashbenny Quarry	213213	Upper Devonian Glenvale Sandstone Formation	Fossil fish
15	Inchcoonans SSSI	236235	Quaternary	Late-glacial climate and sea level changes
16	Gallowflat SSSI	211208	Quaternary	Late-glacial climate and sea level changes
17	Pitlowie SSSI	203228	Quaternary	Dating post-glacial sea level changes
18	Carey SSSI and Rhynd, River Earn	173171	Quaternary	Dating post-glacial sea level changes
19	Loanhead Quarry, Abernethy	190157	Lower Devonian Ochil Volcanic Formation	Andesite lava
20	Castle Law, Abernethy	178152	Lower Devonian Ochil Volcanic Formation	Different lava types, sandstone, conglomerate
21	Ayton Quarry	168151	Lower Devonian volcanics	Porphyritic felsite intrusion
22	Rough Den, Abernethy	188160	Lower Carboniferous Kinnesswood Formation	Carboniferous sediments
23	Dron Burn	137153 141158	Lower Carboniferous Ballagan Formation	Carboniferous sediments
24	Pitkeathly and Glenearn Quarries	114160 108161	Upper Devonian Glenvale Sandstone Formation	Source of local building stone
25	Dunbarney Quarry	112182	Upper Devonian Glenvale Sandstone Formation	Source of Bridge of Earn building stone
26	Crossgates Road Cutting (A9)	046208	Lower Devonian sandstone	Sedimentary structures and dyke
27	Broombarns, River Earn	068189	Quaternary	Post-glacial sea level change

D Field Survey of Geodiversity Sites

The sites were examined over nine days from August 18th to Sept 23rd, 2012. Although each survey took place in good weather, the summer of 2012 had been exceptionally wet in eastern Scotland, and many sites were therefore more overgrown than usual. The solid and drift geology sites are described first, followed by geomorphological sites (Quaternary and modern glacial and fluvial features) which are generally clearer when viewed from a nearby hill or using satellite images such as Google Earth.

Grid references (generally 8-figure) are all within square NO. All sites can be reached on foot, though a small boat provides a better view of the sections along the River Earn. Only sites which are normally accessible to the general public were visited; interesting sites known to exist on private land, e.g. Rossie Den, Ballindean Quarry and the Water of May were omitted. The usual scale in outcrop photographs is a walking pole 1m long. The photographs were all taken by Carol Pudsey except where otherwise credited. The field maps, notebook and digital photographs will be archived at Perth Museum (Natural History Collections).

The map below shows the approximate position of each site. Contains Ordnance Survey data © Crown copyright and database right 2011.



E Desktop study

The following organisations were contacted to determine whether any archival material or specimens from the survey sites were held:

Scottish Natural Heritage
British Geological Survey
Perth Museum and Art Gallery (abbreviated to PMAG in the text)
AK Bell Library, Perth – Archives and Local Studies
National Museums of Scotland
Hunterian Museum and Art Gallery
The McManus Art Gallery and Museum
Dundee University
St Andrews University
Abertay University

The majority of the information was held in the site files and literature of the geological archive at PMAG. A particularly useful resource to researchers here is a card index of geological papers on articles of local interest from the early 1800s to the mid 1990s. Quite a few of these references are from more local journals that have not been referenced in the wider scientific literature. In the archives here there is also an extensive collection of site files on sites of minor geological importance in the Perthshire area. The geological collection here holds the most comprehensive collection of reference specimens. The photography collection at the Museum also holds some relevant images.

The Archive and Local Studies departments at the AK Bell Library in Perth hold some useful material relating to several of the sites.

The McManus Museum collection at Dundee holds a significant set of specimens from the Errol Beds of the Carse of Gowrie.

Sources of additional information:

Details of the SSSI citations, management statements, operations requiring consent and an outline map of each site can be found on the Scottish Natural Heritage website.

The British Geological Survey (Edinburgh) was contacted as part of the study, but it became apparent that the only way of obtaining data would be to pay for individual site searches for each locality, for which we do not have the resources.

A useful website that contains information on some of the sites, including a few aerial photographs is the Scotland's Places website (www.scotlandsplaces.gov.uk), although it is mainly geared towards archaeology and history.

The National Library of Scotland has published all of the first and second series Ordnance Survey maps online and these are viewable through an interactive map screen (www.geo.nls.uk/search).

We thank Dr Wishart Mitchell for helpful comments on parts of this report.

F Geodiversity Sites

1. Almondbank SSSI

SSSI Citation: The site consists of a key section used as part of the evidence for the so-called "Perth Re-advance" which was formerly believed to have interrupted the final wastage of the last ice sheet to cover Scotland. The exposure shows a basal red-brown till overlain by laminated marine silts and clays and succeeded by an outwash deposit with kettle holes in its surface nearby. The marine sediments are believed to have accumulated by repeated discharge of material, in a marine delta advancing down the Tay Valley and extending westwards into the lower Almond Valley, which was still occupied by stagnant ice. The ice-front position near Almondbank, where the outwash grades into ice-contact fluvio-glacial deposits, probably represents only a temporary halt in the progressive wastage of the last ice sheet westwards from the east coast. This site is of considerable interest in historical and sedimentological contexts and for the light it throws on the decay of the last ice sheet.

Historically this site has been seen as providing important evidence for the 'Perth Readvance'; however, a more recent interpretation is that the site represents deltaic sedimentation into the Tay estuary and a transition to marine conditions following progressive ice retreat (Gordon & Sutherland, 1993). A detailed study of these sediments can be found in Paterson (1974).

The site consists of a section of riverbank cut through late Devensian deposits by the River Almond. The lowest exposed bed consists of a minimum of 3.7m of red brown till. This is overlain by 7.2m of laminated silts and clays deposited in glaciomarine conditions. This sediment is capped by 4.6m of sand and gravels marking continued deltaic advance into the Tay valley downstream.

The steeply sloping bank is indicated on the first series Ordnance Survey map.

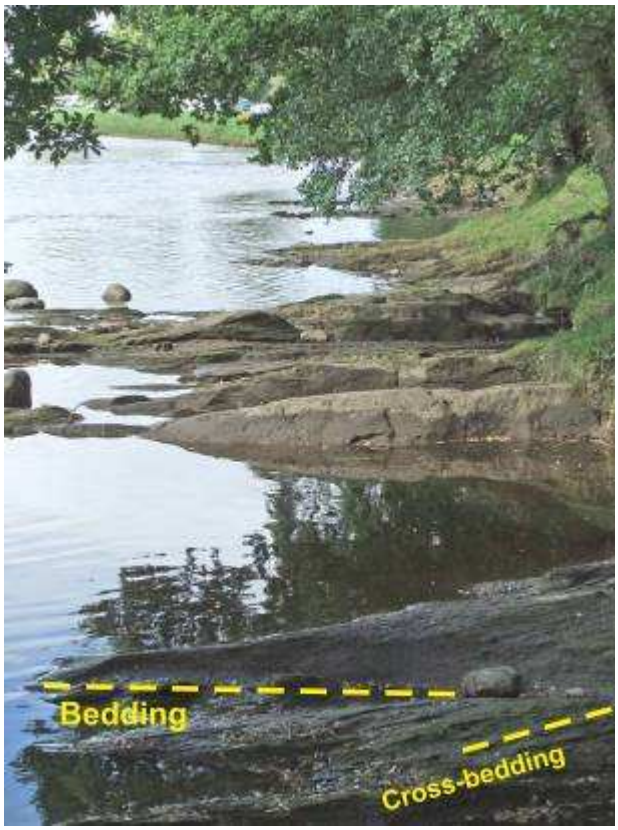
The Almondbank section is easily accessible from Ruthvenfield Place, Inveralmond Industrial Estate. An excellent path leads upstream (west) along the river Almond; after about 350m turn right to the riverbank. A large shingle bank affords a spectacular view of the Quaternary section in the cliff on the north side. At the base are 2m of reddish brown till, then about 4m of sand and silt with large-scale cross-bedding, i.e. delta foresets, dipping east. This observation may contradict the accepted interpretation of a delta advancing westwards into the Almond valley, making the site of even more interest. At the top there is 2m of poorly exposed outwash sand and gravel.

The Almondbank river section. This is a prime site with excellent access. No improvement is required but may need management of vegetation and spoil in the future.

2. River Tay at Scone

The sandstones at this site belong to the Lower Devonian Arbuthnott-Garvock Group. They were deposited by a major river system flowing southwest through the area when the environment was semi-arid according to McIntyre (2000). A detailed stratigraphical analysis can be found in Armstrong & Paterson (1970) and much changed and updated in Browne *et al.* (2002).

These outcrops are not indicated on the first series Ordnance Survey map.



The northeast bank of the River Tay in front of Scone Palace exposes some 50m of sandstone of the Scone Sandstone Formation (Arbuthnott-Garvock Group). It is reached by walking or cycling from the minor road at 11362734 (good layby) west along the Scone Parklands road to a fishing bothy, then some 1.3km SE along the riverbank. Except when events are being held in the Scone Parklands it may be possible to obtain permission to drive as far as the end of the surfaced track at NO11332587. Rocky ledges along the edge of the river from NO11412580 to NO11542554 consist of reddish purple sandstone with some pebbly beds. Many of the pebbles are of redeposited calcrete (calcareous concretions indicating seasonally repeated wetting and drying of the sediment), with scarce lava and quartz and more common mudstone. Plane bedding in the sandstones dips 15° to WNW and trough cross bedding is directed to the west (photo below).

Sandstone beds dipping north, east bank of the River Tay near Scone.

Trough cross-bedding in sandstone, east bank of the River Tay near Scone. Pebbles marked by yellow rings.

This is the most extensive exposure of the Scone Sandstone in the Perth area and the quality of the exposure is much better than at Quarrymill (see below). It is only visible when

the River Tay is flowing at a low level. The level at Ballathie, some 15km upstream, can be viewed at http://www.fishpal.com/Scotland/Tay/RiverLevels4.asp?dom=Pal, and should be 2ft or less. No action is required to maintain access to this section, the riverside path being maintained by salmon fishing interests.

3. Quarrymill Den, Scone

This site is of sandstones of the Scone Sandstone Formation (Arbuthnott-Garvock Group) deposited in a similar environment to those at the Scone site.

This site is historically interesting as it had been proposed as the most likely source of the Stone of Scone (also known as the Stone of Destiny) (Fortey *et al.*, 1998).

Stone has been quarried here since at least the 14th century, early names for the site being recorded as Balcormoc and Balchormack. The first reference to a quarry here is a letter dated 4th July 1328 from King Robert I (the Bruce) to Scone Abbey requesting permission to use stone from here for the Kirk of Perth and the bridges of Perth and Earn. A more detailed history of the site can be found on the Woodland Park page of the Gannochy Trust website.

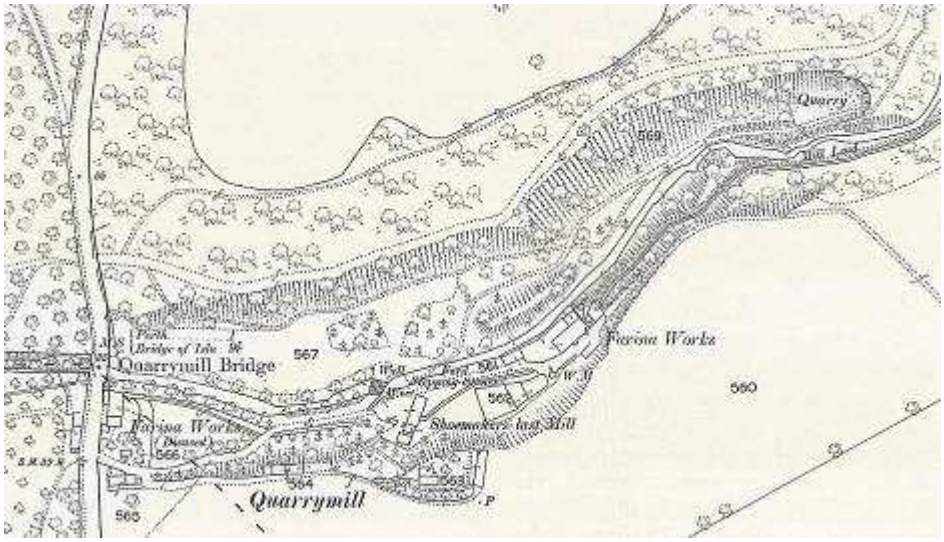
The archive at the AK Bell Library holds a series of papers dating from 1766 to 1771 on the building of Smeaton's Bridge in Perth that contain reference to the quarry, although it is seldom explicitly named (references: PE23/bundles 5, 14, 63, 69 and 73). Although a small quarry is indicated on the first series Ordnance Survey map the amount of material extracted from this site over many hundreds of years means that it must have been more extensive. It is likely that the entire north bank of the stream from Quarrymill Bridge was progressively worked upstream, quarry waste (some mounds still visible) obscuring the previous workings. This is quite obvious on the 1866 25-inch Ordnance Survey map.

Two postcards of generic views up Quarrymill Den are present in the Local Studies collection of the AK Bell Library (references: P5158, P5159).

Quarrymill Woodland Park has excellent parking and facilities, and good paths suitable for all abilities. The same cannot be said for the outcrops of Scone Sandstone which are overgrown and heavily shaded (below, left). The only good exposures are now those in the bed of the Annaty Burn, which are only safe to examine in very dry conditions (below, right). The old quarry itself, at NO12422539 (see map), is barely visible for trees.

Overgrown exposure of Scone Sandstone, Quarrymill 12322531.

Scone Sandstone in the Annaty Burn, Quarrymill, taken from 3rd footbridge.



Ordnance Survey first series 25-inch map showing indication of workings along the northern bank of the Burn with the 'Quarry' at its head.

While this is managed as a woodland park, some light felling and tree pruning to let the light in would improve the variety of habitats from a biodiversity aspect, as well as improving the view of the rocks. The Stone of Destiny may have come from here, so the site deserves better treatment.

4. Corsiehill Quarry SSSI, Kinnoull Hill

SSSI citation: The rock exposures in Corsiehill Quarry are of national importance in representing part of Scotland's geological history. Quarrying has exposed hard, medium-grained igneous rock (formed through the cooling and crystallisation of molten rock or magma). A sheet of magma was intruded through pre-existing rocks close to the Earth's surface. This magma solidified and formed a vertical rock feature called a dyke. Millions of years ago, during the Carboniferous period, volcanic activity was widespread in mid and south Scotland, and around 306 million years ago a major group of dykes was formed in the Midland Valley. The dyke in Corsiehill Quarry has been selected as one of the best and most accessible exposures to represent this feature.

The geology of Corsiehill Quarry consists of a Permo-Carboniferous tholeiitic basalt dyke intruded into basic-pyroxene andesite with conspicuous feldspar phenocrysts of the Ochil Volcanic Formation. The site is a particularly good example as the quarrying has exposed the contact in several places. A useful leaflet about the quarry, its geology and its history has been produced by Tayside Geodiversity; it is currently out of print but is available online as a PDF.

Numerous specimens of the various rock types at the quarry are held in the collection at PMAG. Some very interesting minerals have also been found here and there are specimens of agates, aragonite, calcite, chlorite, garnet, goethite, grossular, porphyrite and quartz (including rose quartz and rock crystal) in the collection.

The only known photograph of the quarry in operation appears in Macnair (1908, Figure 50), the original glass plate appears to be lost. A photograph of a thin section of dolerite from the centre of the also appears as Figure 42 in the book. The original glass plate for this image is held in the PMAG photographic collection (accession number XIV.I3). PMAG also hold a photograph of a rock showing the junction between amygdaloidal andesite and tuff from this quarry (accession number IV.D1) and this specimen is in the geological collection (accession number 1991.273.171). Another two photographs in the collection (IV.D13 and IV.D14) show glacially scratched rocks from Corsiehill, though these are presumably from the hill itself rather than the quarry; one of these specimens still exists but it has not yet been accessioned.

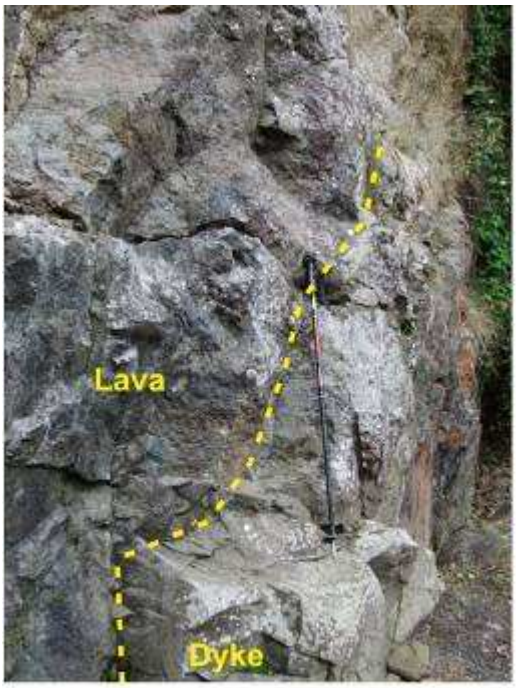
Corsiehill Quarry, by William Ellison, around 1890 (From Macnair, 1908).

While the precise date that quarrying operations began at this site is unknown, a series of documents at the AK Bell Library Archives may shed some light on the matter. A package of accounts and receipts for the Perth Burgh Bridge Commissioners from 1841-51 show the origin of the road metal used to surface the bridge (reference: PE23/Bundle 82). In 1841 this was brought from Muirhall Quarry (NO139241), however, by 1843 it was being brought from

Corsiehill, which is approximately 500m nearer the bridge. A detailed account of the history of the quarry can be found in Abernethy (1990). It continued to be quarried, mainly for road metal up until about 1938.

Other articles mentioning the quarry are a notice in the Perth Courier from 1876 on 'Dynamite experiments' (Anon, 1876) and a more recent article on the history of the quarry appears in the Perthshire Advertiser (Anon, 2007b). The quarry appears on the first series Ordnance Survey map where it is called 'Kinnoullhill Quarry'.

Corsiehill Quarry, now partly surfaced as a car park, exposes a dolerite dyke at least 10m wide and its near-vertical contacts with andesite lavas. The lavas and the dyke contact on the south side are well exposed (below, left) but the section across the dyke by the steps is now heavily shaded by trees (below, right).



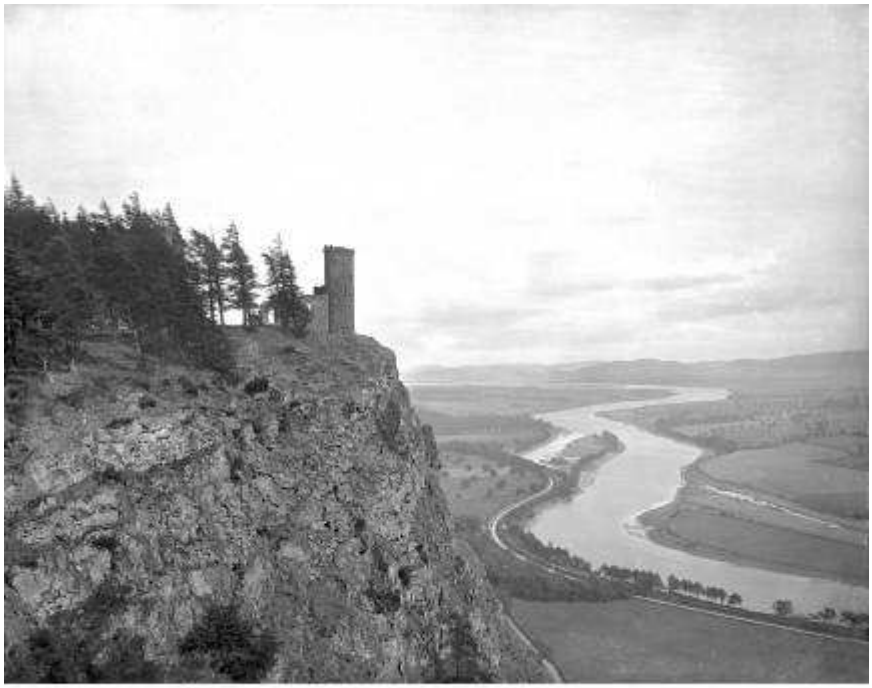
Yellow dotted line marks the contact between andesite lava and dolerite dyke.

At the western end of Corsiehill Quarry, somewhere under the tree branches, is a dolerite dyke.

The rock faces on the north and south sides of the quarry are in good condition and the area is clean and tidy. The trees by the steps should be cut back regularly to allow examination of the full width of the dyke.

5. Kinnoull Hill (partly SSSI)

The rocks at the base of the cliffs on the south side of the hill are conglomerates of the Ochil Volcanic Formation, overlain by andesitic lavas. The lowest members consist of aphyric lavas with minor feldspar-phyric flows; these are overlain by feldspar-phyric basic pyroxene-andesites which form the steep cliffs on the south face of the hill (Armstrong *et al.*, 1985, p. 32). The uppermost flows present are aphyric and occur on the northern slopes of the hill.



Kinnoull Hill and the Tay Estuary in 1903 (PMAG image W0154)

Agates from Kinnoull Hill were mostly found in the rocks at the foot of the cliffs and at one time were quite abundant (Macpherson, 1989); large specimens, however, are now quite scarce and the site is difficult to access. There are many specimens held in the collection at PMAG. In addition to numerous samples of rock from the hill in this collection there are also specimens of graphite, idocrase, porphyrite and quartz (including carnelian, chalcedony, heliotrope and jasper). In the McManus Gallery and Museum collection there is a 'quartz stalactite' from this site.

PMAG holds several geologically interesting photographs of this site in its collection. There are several versions of the iconic view of Kinnoull Tower and the Tay estuary that is used as the TLP logo (accession numbers MJ1045, W22, W153, W154, W653, W703 and II.E7). There is also a photograph of vesicular andesite from Kinfauns (accession number IV.D2); although this specimen could not be located, there is a similar example in the collection.

Car parking is available at Corsiehill (roadside or in the quarry) or the Millennium car park by the Aitken arboretum. There is no significant exposure on Deuchny Hill. From Corsiehill a choice of waymarked paths leads to the summit. The upper part of the hill is a thick series of stacked lava flows forming sheer cliff faces on the south side, best seen looking west from the tower (below, left). The top of each flow is brecciated and these layers, some 20-30cm thick, tend to weather out making the flow boundaries visible. There is a good example at the foot of the tower (below, right), but for those without a head for heights a small quarry some 50m to the west has a 3m thick flow with a crumbly brecciated top.

View west from Kinnoull Hill Tower, showing stacked lava flows in the cliffs.

Top of an andesite lava flow at the foot of Kinnoull Hill Tower outer wall.

Access to the path along the foot of the slope is not easy. It is possible to walk from the Branklyn Garden car park, which is quite a long way and involves walking along and crossing the busy A85 road. There is an interesting road cutting at NO12572226 exposing two lava flows, the lower with an undulating, brecciated top, but this is not recommended for public access. Informally one can leave the main road at West Lodge, turn right along a lane and park at NO13142222 behind a shed. Continuing ENE along this lane, the conglomerate forming the lower part of Kinnoull Hill is seen in crags at about NO136225, dipping north at 10^{o} (below, left). Rockfall debris at the edge of the lane and on the lower hillslopes consists of vesicular and amygdaloidal lava with veins and nodules of agate (below, right).

Conglomerate just above lane at the base of Kinnoull Hill, about 136225.

Fallen blocks of andesite lava with small agates (pink), base of Kinnoull Hill, about 137225.

If better arrangements could be made for parking, or a path could be made through from Barnhill, it would greatly facilitate access.

6. Kirkton Hill and St Magdalene's Hill

The rocks of St Magdalene's Hill are of the Ochil Volcanic Formation and consist of conglomerates of rounded lava clasts of an acid type not found in the local igneous sequence, interfingered with andesitic lavas. They are described in detail in Davidson (1932b), and his conclusions are critically re-examined in Armstrong *et al.* (1985, p. 38-9). It is concluded that the source of these acid rocks was probably somewhere between Perth and the Highland Border, but that its eroded remnant is deeply buried under later strata.

The lavas of Kirkton Hill are of the same sequence of aphyric basic andesite found at other nearby sites. They are penetrated here by two Permo-Carboniferous dolerite dykes identified as being tholeiitic in the PMAG site file. A detailed discussion of this dyke swarm can be found in Armstrong *et al.* (1985, p. 57-61).

St Magdalene's Hill is named after St Magdalene's Hospital which was in existence in 1327. A quarry named 'St Magdalene's' (both then and later) was used at this time to provide building material for the Hospital and apparently was in operation for several hundred years (Fenn, 1998). This quarry was actually located on the west side of Friarton Hill. It is shown on the first series Ordnance Survey map and had been enlarged considerably by the time of surveying for the 1947 6-inch map. Comparison of this and the present 1:25,000 map indicates that it has been subsumed into Friarton Quarry.

There are two specimens of andesite from Kirkton Hill in the PMAG collection.

This locality includes the area west of Friarton comprising St Magdalene's Hill, Hilton Hill, Mailer Hill and Kirkton Hill itself. Good parking is available at the top of Glendevon Road and a well-surfaced core path leads up to a motorway footbridge then SW across the area and down to the Craigend-Aberdalgie road. There are good exposures of Ochil Volcanic Formation (Arbuthnott-Garvock Group) lavas and conglomerates, and two large dolerite dykes cross Kirkton Hill. There are also excellent views east up Strathearn, west to Kinnoull and Moncreiffe Hills, and north to the Highlands.

Directly northeast of the viewpoint on St. Magdalene's Hill, the slope exposes flat outcrops of conglomerate (below left; the slope is a bedding plane). Interestingly, the pebbles are mainly of pinkish lava of a more acid composition (microgranitic) than the surrounding grey andesitic lavas. There are a few grey lava pebbles and some quartzites. Similar conglomerates dipping gently NW can be seen from the footbridge across the M90 (below, right; photo from Google Streetview).

Conglomerate near the viewpoint on Kirkton Hill, 10992121. The hillside here is a bedding plane.

Conglomerate and sandstone beds dipping gently NW, from M90 footbridge10792123.

Rusty-weathering dolerite dyke, SW side of Mailer Hill 10192083.

Close-up of dolerite dyke.

The northern of the two dykes forms an east-west ridge, slightly offset by two faults. It is best seen on the southern slopes of Mailer Hill, reached by walking up the track to the masts and continuing southwest through a gap in the fence to about NO10212083. It is a coarse dolerite showing typical rusty weathering (above, left), and crystals of feldspar and ferromagnesian minerals can be seen in fresh surfaces (above, right).

Mailer Hill and Kirkton Hill (below) have many small outcrops and cliffs of andesite lava, the freshest exposures being on the south-facing slopes. The outcrops are in fields grazed by sheep and cattle, but there are pedestrian gates.

This would be an excellent area for a self-guided walk with a leaflet. The landowner's views should be sought on access to pasture fields.

Grey andesite lava, south side of Kirkton Hill.

7. Friarton Quarry, Perth

The rocks in Friarton Quarry are aphyric basic andesite overlying grey siltstone which passes down into coarse volcanic material (Armstrong *et al.*, 1985, p. 32, 39). As St Magdalene's Quarry has, in turn, been quarried out by Friarton Quarry, the dyke described at St. Magdalene's and now exposed here is described as being a 35m wide intrusion of quartz-dolerite with a tholeiitic margin and a 0.5m chill zone (*ibid.*, p. 58).

In the geological collection at PMAG there are two samples from the quarry (basalt and andesite).

According to a petition for compensation of 1802 in the archives at the AK Bell Library the quarry at Friarton was in operation from 'Michaelmas 1800' and was used for 'stone to pave the streets [of Perth]' (reference: PE15/Bundle 2). This quarry is marked as being disused on the first series Ordnance Survey 25 inch map of 1866. A new quarry above the original one is shown on the 1931 map. According to Fenn (1998) this new quarry was opened by James Deas in the 1920s, but the operation failed after a few years. The third attempt to quarry the site was begun in 1930 when the Perth Quarry Company was formed by Arthur Miller. In 1986 it passed to Wimpey, and passed again to Tarmac Heavy Building Materials in 1986. In the archives at the AK Bell Library there is an undated town plan of Perth (probably 1940s) that shows a planned area of quarry expansion (reference: PE/P448).

There is an interesting article in the Perthshire Advertiser about a large blast in the quarry that dislodged 70,000 tons of rock in a single firing (Anon, 1941).

It should be noted that the Perth 'Town Quarry' referred to in some literature is actually the small quarry indicated on the older large scale Ordnance Survey maps in the Woodlands area south of Westerhill Road at NO09462287.

The dolerite dyke in a disused face in the west wall of the quarry.

Close-up of a lava-breccia boulder. The clasts are very angular and show narrow zones of chilling against the matrix. Subsequent mineralisation of the matrix includes crystal growth into cavities.

This is the only major working quarry in the area and is owned by Tarmac, from whom

permission should be sought prior to any visit. It provides extensive, fresh exposures of lavas and sedimentary rocks of the Ochil Volcanic Formation, with a 30-40m wide dolerite dyke.

The section dips to the NW at 16° and consists mainly of massive, aphyric andesite lava flows in units 15-20m thick. A 10m unit of well-bedded sandstones, siltstones and mudstones overlie a thick lava breccia in the quarry face currently being worked. The breccia is most easily examined in large blocks used to mark out areas of the quarry floor; it may result from autobrecciation or more likely from interaction of magma (hot liquid lava) with wet sediment to form peperite. The sediments exhibit ripple cross-lamination, desiccation cracks and mud clasts, while plant fragments and rare ?arthropod trackways have been found. A quartz-dolerite dyke some 35m wide trends E-W across the quarry, dipping steeply south. It is being worked for armouring blocks (sea defences etc) while the andesite is used for general aggregate.

An unusual dyke-like feature is exposed in the main working face and also high on the east wall of the quarry. It is ~5m wide, vertical and filled with volcanic conglomerate/breccia which is strongly reddened and much more friable than the breccia mentioned above. On either side a basalt dyke ~1m wide separates this breccia from the lava/sediment sequence. This feature, which coincides with a normal fault downthrowing about 3m to the north, is not presently understood but is likely to be peperite.

The dyke-like feature, here labelled as a conglomerate fissure fill, in the working face of Friarton Quarry. The face is 15m high.

8. Moncreiffe Hill

The rocks of Moncrieffe Hill include some of the lowest members of the Ochil Volcanic Formation and are summarised in Armstrong *et al.* (1985, p. 32). The oldest members of the Formation in the Perth area are to be found around Rhynd, younger feldspar-phyric basic pyroxene-andesites form the crags on the south side of the hill and these are in turn overlain by aphyric basic andesite which can be found on the summit and north-west slopes. The contact between these last two members can be traced on the south side of the hill and be seen in the east side of the M90 motorway cutting through the westernmost end of the hill where the boundary can be seen to be markedly uneven (old lava landscape). A more detailed account of the geology is given in Davidson (1932b), although it must be noted that Armstrong *et al.* (1985) point out that some of his terminology lacks precision.

The collection at PMAG holds numerous specimens of rock from the hill and mineral specimens include calcite, goethite, haematite and dendritic pyrolusite.

There are car parks on the north and south sides of the hill. There are few good exposures and nowhere along the paths are the field relations of different lava flows seen, though trap topography is seen in places on the northern slopes. Fine-grained, aphyric andesite occurs around Moredun Top hill fort (below, left) and exhibits glacial striations oriented NW-SE in a ditch at NO13324999. Porphyritic andesite is fairly well exposed in road cuttings near the bottom of the steps at NO13251983 (below, right). At the foot of the slope in the SW corner of the wood, fallen blocks of strongly amygdaloidal lava include some small agates.

Massive, aphyric andesite lava, 13412004, Moncreiffe Hill near Moredun Top hill fort.

Andesite lava with phenocrysts of white feldspar, 13251983, forest road cutting, Moncreiffe Hill.

The road cutting above the M90 at the west end of Moncreiffe Hill exposes some 50m of stacked lava flows. This is one of the best exposures of any rock formation in the whole area, but is unfortunately inaccessible. It may be viewed through binoculars from the fields of Hilton Farm to the SW.

The Woodland Trust manages Moncreiffe Hill, with the published leaflet emphasising archaeology as well as natural history. The rock outcrops are less dramatic than Kinnoull Hill, and to improve the exposures would probably conflict with woodland management, so it is recommended that no action be taken other than to supply some geological information for future updates to the existing leaflet.

Lava flows at the west end of Moncreiffe Hill above the M90 motorway, viewed from the SW. The face is some 50m high. Each terrace is the top of a flow and there is another flow top within the middle terrace, indicated by the dotted line.

9. Pepperknowes Quarry, Glencarse

The rocks in this quarry are of the Ochil Volcanic Formation and consist of feldspar-phyric lavas; these are overlain (above the quarry) by aphyric basic pyroxene-andesite (Armstrong *et al.*, 1985, p. 32).

The quarry is named on the first series Ordnance Survey map; other than this there appears to be no other documentary information on the site.

Limited parking is available at NO18202242 some 200m to the east. Access to the quarry is rather poor: one must negotiate tall vegetation and a steep slope, the original zigzag access road being completely overgrown. Once in, the quarry still has plenty of good exposure of massive aphyric lava. Most interesting is the old road cutting at the NE end, below the main lava flow. This exposes about 4m of volcanic conglomerate with clasts of laminated mudstone and heavily weathered lava in a crumbly sandy matrix. There has been a little interest in re-opening this quarry.

Massive andesite lava, west corner of Pepperknowes Quarry.

Volcanic conglomerate, old entrance to Pepperknowes Quarry.

10. Pitroddie Den

The geology here consists of a dolerite dyke intruded into lavas of the Ochil Volcanic Formation. This dyke is one of the few in the Permo-Carboniferous swarm that follows a pre-existing fault (Armstrong *et al.*, 1985, p. 57) and is described as being of the 'Corsiehill Type' (*ibid.*, p. 58).

The first evidence of the quarry being in operation is in the 1851 census which contains information that it was owned by Donald McDonald and there were 7 men working there (Abbot, 2000). The quarry was not being worked in 1915-16, presumably as a result of the First World War, and appears never to have been reopened thereafter.

There is a historic view of the Den in the photographic collection at PMAG (accession number III.A13) and a black and white lantern slide of a thin section of dolerite taken down a microscope (XIV.I2), this is reproduced in Macnair (1908, figure 47). A legal document of 1881 in the archives at the AK Bell Library dealing with the disposal of spoil on adjacent land states that its main purpose was the supply of paving stones for the streets of Dundee (reference: MS169/3/1/2(996-997).

There are several samples of dolerite in the PMAG collection, however, although Macpherson (1989) reports that agates have been found in the area there are no known specimens in the collection.

The quarry is named on the Ordnance Survey First Series map.

Pitroddie Den, late 19th century (PMAG image III.A13)

Contact between andesite lava and dolerite dyke, Pitroddie Den, about 203252

This is a site particularly badly obscured by dense vegetation. Roadside parking is available just SE of Pitroddie farm. The track up Pitroddie Den has been partly washed out by recent flooding and disappears altogether before the main quarry area is reached. There are some interesting brecciated lavas, and a good intrusive contact between andesite lava and a dolerite dyke (above, right), but both these features can be better seen elsewhere, *e.g.* Corsiehill Quarry. The main interest of Pitroddie Den is its morphology as a major meltwater channel.

11. Flawcraig and Craighead Quarries

The rocks here represent some of the oldest known of the Ochil Volcanic Formation, the basal lava flow being of feldspar-phyric rock with only a few olivine pseudomorphs at NO24102814 (Armstrong *et. al.*, 1985, p. 30).

Craighead Quarry is named on the first series Ordnance survey map. The AK Bell Library Archive holds accounts for the Fingask Estate from 1882-1917 that gives details of the rent paid for the Flawcraig quarry for 1915-17 (reference: MS169/3/1/2(996-997)). No other documentary evidence could be found.

These quarries are easily accessed from the Carse road between Rait and Kinnaird, with limited roadside parking available close by. The western one exposes a fresh dolerite dyke (below, left) and the eastern one massive aphyric andesite lava (below, right).

Both these sites are in good condition. As they are unlikely to be visited by the general public and only rarely by geologists, no action is recommended.

Fresh exposure of a dolerite dyke, 23882784 Flawcraig Quarry.

Massive andesite lava with vertical joints, 24112803 Craighead Quarry

Ballindean area

Parking for Ballindean is available at NO25952925 or NO26302932.

12. Wester Ballindean Quarry

The rocks at this quarry are described as being bright red sandstones typical of the Upper Devonian Clashbenny Formation (Armstrong *et. al.*, 1985, p. 51), now termed the Glenvale Sandstone Formation.

The quarry is indicated on Ordnance Survey from the first series maps to the present day. No other documentary information could be found on it.

There is pedestrian access between houses and a large shed. The quarry, last worked in about 1969, has recently been used as a dump for garden debris, but still exposes bright red plane-bedded and cross-bedded quartzose sandstone: the Glenvale Sandstone Formation of the Stratheden Group (Upper Old Red Sandstone).

Bright red, moss-stained sandstone showing cross-bedding, Wester Ballindean Quarry.

Close-up of sandstone.

13. Tinkletop Hill, Ballindean

The agates this site is famous for were found at Agate Knowe, Ballindean Farm, Tinkletop Hill and Inchture (Macpherson, 1989). It is believed that the majority of the specimens were recovered from fields after ploughing; as nearly all of these are now put to grazing land it is unlikely that many more will be found.

There is a specimen of haematite and one agate from Ballindean in the PMAG collection; however, it should be noted that there are many agates without locality data in the collection and some of these may be from this site.

There is pedestrian access from the farm track through Hilltown. A small quarry at NO25953038 exposes porphyritic microdiorite (below, left). This sill is a small outlier of a larger intrusion occupying the easternmost part of the Braes of the Carse (including the hill Castle Huntly is built on).

The only place agate-bearing lava can now be seen is in the surface of the farm road leading east from Hilltown (below). It is not clear how much of this is in-situ.

Agate in surface of farm track, 26252978 Ballindean.

Porphyritic microdiorite, 25953038 west side of Tinkletop Hill.

14. Clashbenny Quarry

The sandstones here were previously assigned to the Clashbenny Formation, a redundant stratigraphic name, they are now included in the Glenvale Sandstone Formation of the Stratheden Group. This site is famous for the discovery of well preserved fossil fish in the nineteenth century. Three species were described from here: *Holoptychius noblissimus* Agassiz, *Holoptychius* sp. and *Phyllolepis concentrica* Agassiz. Unfortunately the collection at PMAG contains none of these; the known specimens from this site are at:

- Natural History Museum, London, 14 specimens
- National Museum of Scotland, Edinburgh, 11 specimens
- St Andrews Museum, 1 specimen
- Elgin Museum, 2 specimens
- Dundee Museum, 2 specimens
- Cockburn Museum, University of Edinburgh, 1 specimen
- British Geological Survey, Keyworth, 1 specimen
- Muséum d'Histoire Naturelle, Neuchâtel, Switzerland, 1 specimen

According to the New Statistical Account of Scotland (1843) the quarry was opened 'more than twenty years ago and the excavation is now pretty extensive. The strata have in some places been quarried to the depth of 25 or 30 feet.' The entry goes on to give an interesting early history of the discovery of the first fossil fish to be found at the site. Further information towards the end of the account notes that between 4,000 and 5,000 tons were of stone were currently being extracted annually. Noble (1843) provides additional information on the fossil fish. The quarry is named on the first series Ordnance Survey map and labelled disused on the 1901 map.

Clashbenny Quarry, late 19th century
(PMAG image IV.D6).

A photograph taken in the quarry in the late nineteenth century is held in the PMAG photographic collection (accession number IV.D6). In the PMAG site file there are also seven colour slides taken in 1982 and five black and white slides taken around 1990.

Consent was issued to infill the quarry once traffic safety issued had been addressed in 2007 (Anon, 2007a), although this has not taken place and the planning consent expired in April 2012.

The quarry is now flooded, and so overgrown as to be almost inaccessible (below, left). There is parking for one car at the end of the lane to the north. It is possible to walk round the field edge, over a wire fence and through the nettles to gain access to the southern corner of the quarry where there is a small sandstone outcrop (below, right). The main working face can only be reached by boat and is densely overhung by trees.

15. Inchcoonans SSSI

SSSI Citation: Inchcoonans is the type locality for the Errol Beds, a sequence of fossil-bearing marine sediments which occur on the east coast of Scotland in the Forth, Tay and South Esk estuaries, and offshore along the coast from the Forth to Aberdeen. These sediments were deposited during the waning of the last major ice sheet to cover the country.

Typical species present include the bivalves Portlandia arctica, Palliolum groenlandicum and the ostracod Rabilimis mirabilis*, all of which are now present only in the Arctic Seas showing that the seas on the east coast of Scotland were much colder then than they are now. These sediments are raised above the coast, as relative sea level is now lower than when the sediments were deposited. This is therefore a key site for interpreting relative sea level and environmental conditions during the early part of the Lateglacial period – around 13000 -10000 years ago.*

The brick and tile industry associated with the Errol Clays is one of the most interesting and important parts of the geoheritage of the Tay Landscape Partnership area.

This site was historically the best exposure of the late Devensian clays of the Errol Beds. A detailed description and interpretation of this site is given in Browne *et al.* (1995); this is summarised and the site is compared with Gallowflat by Sutherland (1993). The site is described and discussed in relation to the other Quaternary deposits in the Tay-Earn area in Paterson *et al.* (1981).

Browne *et al.* (1995) differentiate four layers in the sequence, which was deposited between 17,000 and 13,000 years ago. The lowest bed of reddish-brown clay, 1.3m thick, is deposited on glacial sand and gravel. This is overlain by 0.9-1.5m of brownish-grey clay and 1.25-2.9m of yellowish-grey silty clay. The sequence is capped by 1.0-1.75m of yellowish-grey sandy clay separated from the bed below by an erosion surface.

The numerous fossils recovered from the site came mainly from the second and third layers although it is suspected that decalcification during soil formation may have resulted in their loss from the upper portion. The fauna consists of two species of gastropod, eight bivalves, 21 foraminiferans and 12 ostracods. Browne *et al.* (1995) assess the foraminiferan and ostracod assemblage as representing an arctic fauna indicating a near-shore shallow-water habitat with a sandy or silty substrate; although the diversity is low numbers are generally quite high. The salinity was somewhat variable but towards the marine end of the spectrum. One ostracod (*Krithe glacialis*) that is only found towards the bottom of the sequence is very seldom found in water less than 27m deep. The estuary became shallower and more mixed as relative sea level fell. Additional information on the fossil assemblage can be found in Graham & Gregory (1981).

The geological collection at PMAG holds an extensive series of fossils from this site, these include:

- Mammal – 1 species (a Harbour Seal bone)
- Fossil wood – 1 species (*Quercus* sp.)
- Gastropod – 4 species
- Bivalves – 13 species
- Brittle star – 1 species
- Barnacle – 1 species
- Foraminifera – 4 species
- Ostracods – 9 species

In the McManus Gallery and Museum collection there are 75 fossils from this site, mostly bivalves, but also including three barnacles, a brittle star and a gastropod; seven species of bivalve and the brittle star are named. There are a further 19 specimens from the ‘Kinnaird Collection’ from the ‘Errol clay’ that could have come from this site; curiously they include three fossil Fig leaves (*Ficus* sp.).

The quarry is not shown on the first series Ordnance Survey map, but there is another nearby quarry indicated immediately south of the brickworks at NO238233. No mention is made of clay extraction in the parish in the New Statistical Account of Scotland (Grierson, 1843). On the 1901 map clay is shown as being extracted to the north-west of the brick and tile works and this site is still undeveloped.

In the Third Statistical Account of Scotland (Hutchinson, 1979) it is stated that the industry was established to manufacture pottery, brick and tile in 1855 but the pottery business was discontinued after a short time. Brick and tile manufacture continued up to the time of writing (1953) where business was still said to be good. About 20 men were employed at the time of writing, these being employed in a shift system so that the furnace could be kept up to temperature and some new machinery had been installed recently. Following abandonment of the clay pit in the 1960s for another site at Gallowhills, a planning application to extract 325,000 tonnes of clay per year for 16 years was granted (Anon, 1996) without objection by SNH.

Parking is available at the southern entrance to the site, NO23942333.The old brickworks still has two chimneys and two round kilns (below, left). The former clay pit to the NW of the site has been almost entirely filled in. The group of pits east of the site, the SSSI, is reached on foot along a lane. The pits are flooded (below, right) and only the deepest of the pits preserves about 2m of inaccessible clay section (bottom right).

16. Gallowflat SSSI

SSSI Citation: *Gallowflat provides the only notable exposures in the Errol Beds in their type area. These marine sediments with their Arctic-type fossils are only known to occur in eastern Scotland and provide significant evidence for relative sea level and environmental conditions during the Lateglacial. Gallowflat is an important reference site for demonstrating the lower part of the Errol Beds and complements the interest of the type locality at Inchcoonans where there is a complete sequence of deposits, but there are no exposures.*

The sediments at Gallowflat are similar to those at Inchcoonans and belong to the Errol Beds. A detailed description and interpretation of this site is given in Sutherland (1993). McManus (1972) describes the sediments as being composed of laminated silty clay with thin layers of sand. In the lower part there are multiple beds of silty clays or clayey silts with the upper part composed of fine and medium sands. Numerous drop stones up to a diameter of 1.3m have been found, these being of dolerite, metamorphic rock and Old Red Sandstone.

The only macrofossils recovered from this site belonged to the bivalve Portlandia sp. (family Yoldiidae), the only microfossils being a single species each of an ostracod and a foraminiferan. The fauna is indicative of an arctic environment.

These sediments were deposited during the last Ice Age, between about 17,000 and 13,000 years ago. They were deposited by flocculation in a strongly stratified water body; coarser silts and sands were deposited as sea level dropped and the water column became more mixed (Duck, 1990). The site is briefly described in Armstrong *et al.* (1985, p. 83).

No workings are indicated on the first series Ordnance Survey map or mentioned in the New Statistical Account of Scotland (Noble, 1843). Pitfour Clay Pit (NO208207) and the associated brick and tile works are shown on the 1901 map, but the Gallowflat site is still undeveloped.

A late nineteenth century photograph of workings at Pitfour Clay Pit is held in the photographic collection at PMAG (accession number IV.D12). A series of 12 black and white slides taken on a field visit to the site around 1990 are in the PMAG geology site file.

Pitfour Clay Pit photographed by Alex Roger on 20th June 1908 (PMAG image IV.D12)

Only two specimens from the site are held in the collection at PMAG, these both being of Upper Devonian red sandstone, presumably drop stones. Also within the collection there are two fossil bivalves, a fossil gastropod and a concretion from Pitfour.

There is ample parking at Gallowflat Farm, then a very muddy walk along farm roads to the pits. These are flooded (below, left) though the water is not very deep, generally <1m. Apart from a bit of surface wash obscuring the clay faces, this site is in very good condition. The SSSI boundary needs to be updated as the pit has been enlarged. One of the best sections is at the NE end where dropstones up to cobble size are clearly visible above a 20cm thick layer of stiffer clay (below, right).

Satellite image of the Gallowflat area, from Google Maps.

For both Inchcoonans and Gallowflat a strategy needs to be agreed with the landowners, SNH and Tayside Geodiversity on preservation of and access to the sites. This assumes a new importance with the final closure of the Errol Brickworks.

17. Pitlowie SSSI

SSSI Citation: *Pitlowie is important for a sequence of Flandrian peat and estuarine deposits that occur in part of a system of gullies formed during the Late Devensian. It forms part of a network of sites that provide evidence for Flandrian relative sea-level change in eastern Scotland. Detailed studies encompassing lithostratigraphy, pollen stratigraphy, geochemistry and radiocarbon dating have shown that the Main Postglacial Transgression at Pitlowie was initially rapid, but then slowed and culminated before 6000 BP (Before Present).*

This site provides important information on post glacial sea level changes in the Tay estuary. The site is entirely subsurface, the sediments having been investigated with a 'Russian type peat borer' (Morrison *et al.*, 1981).

A detailed description and interpretation of this site is given in Smith (1993). This paper details how peat began to accumulate in the early Holocene. In the Late Devensian as sea levels rose, a gully system was cut into the peat and grey silty clay deposited within the gullies. Sea levels then fell again and peat returned and buried the clay-filled gullies. The radiocarbon date from the peat at the bottom of the gully at Hole of Clein was 7500 ±90 BP and the date for the first overlying peat was 6170 ±90 BP. At Glencarse these figures are 6679 ±40 BP and 6083 ±40 BP respectively. Pollen recovered from the clay in the gullies indicates that they were marine in origin. The site records the history of the Main Postglacial Transgression and subsequent regression, recorded in detail over a period of about 2,000 years, making it one of the most important of its type in eastern Scotland.

Outlines of the channel system are visible in a contour on the first series Ordnance Survey map and can also be seen on the modern 1:25,000 map.

As this site is entirely subsurface and is reported by SNH to be in favourable condition, it was not visited during the fieldwork.

18. Carey SSSI and Rhynd

SSSI Citation: *Carey forms part of a network of sites demonstrating relative sea-level change in eastern Scotland during the Flandrian. It provides an exposed riverbank section showing a layer of peat overlying sand and in turn succeeded by carse clays. Analysis of pollen and diatoms together with radiocarbon dating indicates abandonment of a buried early Flandrian estuarine flat about 9,600 years BP (Before Present), then a period of lower relative sea level at the site until the Main Postglacial Transgression deposited the carse clays after about 7,600 years BP.*

The sediments deposited here provide important evidence for interpreting sea level changes at the start of the Holocene. A detailed description and interpretation of this site is given in Cullingford (1993). The base of the sequence consists of coarse sand and fine gravel of unknown thickness and believed to be of fluvial origin. These are overlain by 0.9m of fine- to medium-grained micaceous sand representing estuarine beach deposits. The third bed is by far the most important feature at this site and consists of 0.59m of terrestrial peat with abundant woody debris.

Organic remains within the peat include sedges, broom, horsetails, alder, hazel, birch, pine, willows and oak. Cullingford (1993) also quotes unpublished pollen analysis by P.E. Gotts. This found that the lowest 0.1m was most probably a typical reed swamp environment with no evidence for a transition from salt- to freshwater. Grasses dominated the remainder of the sequence with few other herbaceous plants represented. At the lower transition there is a peak in birch and willow pollen; the presence of juniper here indicates that it was a marginal environment, but the juniper disappears with the arrival of hazel and bog myrtle. At the peat to silt-clay transition at the top of the sequence, oak pollen appears for the first time, indicating the beginning of succession to a drier woodland habitat.

The base of the peat has been dated twice to 9640 ±140 BP and 9524 ±67 BP and the top has been dated twice to 7605 ±180 BP and 7778 ±55 BP (Cullingford *et al.*, 1980). Intermediate radiocarbon dates were also taken to date changes through the section. In addition to this work a later investigation on the other side of the Earn at Wester Rhynd (Cullingford *et al.*, 1989) has further raised the importance of lower Strathearn for dating sea level changes in eastern Scotland in the early Holocene.

A broader discussion of the site and its regional and stratigraphic significance is given in Armstrong *et al.* (1985, p. 89).

These are sections through Quaternary sediments in the banks of the tidal River Earn. For Carey, parking may be available at Broadwell but permission should be sought, otherwise park at Aberargie and cycle down the farm road as far as the railway bridge. Like most Quaternary sections it relies on natural landslipping and river erosion to expose the sediments. At the time of this visit (at low tide) dense riverbank vegetation and soggy, unharvested cereal fields made it a rather strenuous walk to the riverbank. Only the top 3m of Carse clay was clearly visible (right), though a small disturbed section of Sub-carse peat could be made out beneath a fallen tree (dark material, photo below).

The tidal River Earn sections are more easily examined from a small boat. The best exposures are currently on the north side of the river just east and west of Wester Rhynd. Photo below at NO17861842 shows the Carey Beds (estuarine sand and silt with thin clay layers) overlain by 0.3m of black Sub-Carse Peat and then several metres of Carse Clay which extends to the top of the bank section.

19. Loanhead Quarry, Abernethy

The rock exposed in this quarry is of the Ochil Volcanic Formation, the main workings were into the face of a single lava flow at least 30m thick. This flow has an irregular top and an autobrecciated zone at the base (Armstrong *et al.*, 1985, p. 33).

The quarry is named on the first series Ordnance Survey map, and there is also an adjacent unnamed quarry. Although not specifically mentioned in the New Statistical Account of Scotland (Duncan, 1843), it does say that quarries in the Ochil range are used for road-metal and sometimes for coarse building.

Free parking is available in Abernethy village and the core paths are well signposted. From the village Loanhead Quarry is reached by walking south up ‘Witches Road’, the quarry face being visible above the fields. The quarry floor is dry but densely overgrown with trees, nettles etc (below, left). The quarry face is a single lava flow at least 30m thick with an uneven, brecciated top. Fallen blocks are mainly aphyric andesite with some amygdaloidal and vesicular blocks (below, right). Most of the face is weathered with vertical joints but at the east end a fresh rockfall reveals curved joints (bottom right).

20. Castle Law, Abernethy

At this site rocks of the Ochil Volcanic Formation include sandstones that are overlain by about 40 m of volcanic conglomerate varying from fine- to coarse-grained; although most of the clasts are basic in origin some acidic material is present (Armstrong *et al.*, 1985, p. 38). The summit and the south side of the hill are composed of a hypersthene-andesite lava flow up to 90 m thick (*ibid.*, 1985, p. 35). In general the conglomerates and lavas are poorly exposed except along the forest roads.

21. Ayton Quarry

This site consists of a small plug of orange-coloured porphyry that has been intruded into volcaniclastic sedimentary rock (Armstrong *et al.*, 1985, p. 95). The site file at PMAG contains three slides probably taken in the early 1980s.

In the New Statistical Account of Scotland it is stated that 'In the Glenfarg quarry, near Ayton, have been discovered fragments of scales of those extraordinary *ichthyolites*, which have been found in abundance at Clashbenny' (Duncan, 1843). This site is now lost but must have been somewhere in the vicinity of Glenfarg House, on the low ground below the hill face. On the first series Ordnance Survey 25-inch map a quarry is shown 150m south east of Ayton house.

The quarry just above the hamlet of Ayton (NO16801524), still in occasional use, exposes microgranite (acid intrusive rock) which extends up the hill to a forest road cutting at NO16801515 but is seen nowhere else in the area. Its contact with the grey andesite lava to the east is gradational and almost vertical, *i.e.* the intrusion has the form of a stock or dyke.

22. Rough Den, Abernethy

The rocks exposed in the bed of the Ballo Burn are the only exposure of the Lower Carboniferous Kinnesswood Formation (Inverclyde Group) in the TLP area (Armstrong *et al.* (1985, p. 53). The rocks consist of a series of grey, purple and reddish-brown cross-bedded sandstones with occasional beds and nodules of concretionary limestone (calcrete). They were deposited on broad alluvial plains that gently subsided allowing minor transgressions of the sea and the deposition of the Ballagan Formation (Inverclyde Group) which is found at Dron (see *23* below).

From the path in the glen there are good views of the Kinnesswood Formation sandstones in the Ballo Burn, dating from the Devonian/Carboniferous boundary. Flaggy, micaceous red sandstones dip southwest at ~30°. Calcareous veins and nodules have been reported from here (high water level at the time of my visit; could not verify).

The Abernethy area would be an ideal place for a geological trail, along the lines of the following sketch. The paths already exist but a leaflet would be required. There are opportunities for volunteers to clear vegetation from several of the sites.

23. Dron Burn

This is the only recorded exposure of Lower Carboniferous Ballagan Formation in the TLP area (Armstrong *et al.* 1985, p. 53). It was first described by Smith (1876); however, the site report at PMAG states that no exposures were visible in 1982. The majority of our knowledge comes from five boreholes drilled by the British Geological Survey in 1972 (Browne, 1980) which show the site to have been a coastal alluvial plain across which an extremely shallow sea flowed in storm conditions from time to time. Sabkha-like conditions formed by the subsidence of the broad alluvial plain in a semi-arid climate resulted in the deposition of evaporite salts like gypsum, anhydrite and some halite. The borehole at East Dron (NO13601572) provided the most complete record and was used to correlate stratigraphy in the other boreholes. Another exposure of this formation in the railway cutting near Dron, a photograph of which appears in Macnair (1908, figure 13) was destroyed during construction of the M90. An original albumen print of this image is present in the photographic collection at PMAG (accession number 2012.330.16).

The site report at PMAG states that no exposures were visible during a site visit by M.A. Taylor in 1982. At present the Ballagan Formation is nowhere accessible or visible, though there is red sandstone almost in place in a silage pit/farm store at NO13601575 near the motorway bridge.

Lower Carboniferous Ballagan Formation exposed in the railway cutting at Dron c.1908. The site was destroyed when the M90 was built. (PMAG 2012.330.16)

24. Pitkeathly and Glenearn Quarries

A series of small quarries in the Upper Devonian Glenvale Sandstone Formation were formerly worked along the foot of the Braes of Abernethy southwest of Bridge of Earn. Pitkeathly is mentioned as being typical of the Clashbenny Formation (name now superseded as above) in Armstrong *et al.* (1985, p. 51). The rocks consisted of reddish-brown cross-bedded sandstones. The outline of the quarry/spoil area nearest Pitkeathly Mains shown on the modern 1:25,000 map is present on the first series Ordnance Survey map. The quarry 250m west of Pitkeathly Mains is not shown at this time, but Glenearn Quarry is present. All three are shown on the 1902 map, although it appears the one nearest Pitkeathly Mains may be disused.

Park at NO11431623 or NO11141628, go through a gate at NO11431623 and walk up a pasture field, cross the fence at the far side and continue through young trees. Pitkeathly Quarry, although containing a good deal of farm rubbish including tyres, provides the best local exposure of several metres of the Glenvale sandstone (left). The faces are fresh except for a little surface wash, bedding and cross-bedding are clear (below) and about 30m is visible laterally.

A further small quarry at Glenearn 650m to the west is less typical, having quartz pebbles within the matrix. Photo below by Mike Browne.

25. Dunbarney Quarry

The only documentation associated with this quarry is a summary site report at PMAG. This states that Upper Old Red Sandstone of the Clashbenny Formation (now Glenvale Sandstone Formation) consisting of sandstone and mudstone is exposed. Macnair (1908) mentions quartz and lava pebbles in the sandstone and Lower Devonian lavas (Ochil Volcanic Formation). This site is called Quarry Hall in Armstrong *et al.* (1985).

The quarry is named on the first series Ordnance survey map and is marked as disused on the 1902 map. There is an entry for the site on the Scotland's Places website but this adds no new information.

Dunbarney can be reached via core paths from the south (no parking) or west (park at end of lane NO10641798 and walk up to the windmill then east to the quarry). Formerly a large (150x100m) quarry, this has been disused for many years and is largely overgrown with trees; it is also being gradually filled in from an entrance on the north side. At the east end at the base of an old vehicle ramp, two small exposures of sandstone survive.

26. Crossgates Road Cutting (A9)

Information on the geology of this section in the Scone Sandstone Formation (Arbuthnott-Garvock Group) was derived from the site report at PMAG (record NO02/5); M.A. Taylor completed this while the road was under construction in July 1982. The cutting passes through flaggy and micaceous sandstones with excellent bedding and discontinuous thin beds of red mudstone; a dolerite dyke, which appears to be narrower on the south side of the cutting, cuts this. There are 17 photographic slides in the site file at PMAG taken during this field visit. The planning department of Perth and Kinross Council may hold additional information.

The south side of the cutting exposes a downstream orientated section along a large sand bar in a major river channel with a dolerite dyke cutting it at the western end of exposure (below; image from Google Streetview).

Towards the northeastern end of the section there is a flexure in the generally almost horizontal bedding in the Scone Sandstone. This has been alternatively interpreted as a monocline or much more likely as a large-scale river channel fill (below; image from Google Streetview).

These localities cannot safely be visited by the general public.

27. Broombarns, R. Earn

The River Earn between Bridge of Earn and Forteviot exposes several interesting sections of Quaternary sediments on the outer sides of meander bends. The sites at Eastfield Farm and Freeland Farm are rather overgrown, but the site near Broombarns is in excellent condition and easily the best Quaternary section on the whole river. It is accessed from near the entrance to Dupplin Castle walled garden where there is a layby at NO06391950. A farm track leaves the road via a gate at NO06611961 and leads down past a fishing hut to the riverbank. The main Postglacial Shoreline is clearly visible to the east. Continue through pasture fields to a shingle beach at NO06851896 which gives an excellent view of the river cliff opposite. Some 100m of the cliffs are visible, and there is more to the east opposite the SE corner of the meander loop. The variability of the sandy Carey Beds below the Sub-Carse Peat is better displayed here than anywhere else.

This site should proceed to LGS designation as it scores highly on scientific interest and ease of access.

Quaternary and Recent landforms

Glacial and fluvial erosion and deposition, combined with changes in relative sea level, have created some spectacular landforms in the Tay-Earn confluence area. On a large scale the major river valleys were created first by glacial erosion followed by meltwater erosion, over several glacial episodes in the last two million years. Valleys that cut deeply through the Braes of the Carse but now contain only minor streams were incised mainly by glacial meltwater, *e.g.* Pitroddie Den, the Glen of Rait and the Fingask Glen.

The village of Errol lies at the eastern end of a group of drumlins, low streamlined ridges of till moulded by eastward ice flow along the Tay valley. On an outcrop scale, glacial striations on Kirkton Hill (Armstrong *et al.* 1985, p. 68), Moncreiffe Hill (see section 8 above) and Corsiehill (photo, right) show the former direction of ice flow across the hilltops.

The notably flat areas of the Carse of Gowrie and lowermost Strathearn owe their form to inundation by the sea as the last ice sheets retreated. As the balance shifted between glacio-isostatic rising of the land surface and glacio-eustatic changes in global sea level, several different shorelines were formed (Armstrong *et al.*, 1985, p. 72-4). The Main Postglacial Shoreline can be seen on the south side of Friarton Bridge, and also east of Bridge of Earn.

Meanders and oxbow lakes are beautifully developed between Forteviot and Bridge of Earn. Modern river sediments may also be examined in the River Tay, from the gravel bars below Scone Palace to the extensive tidal mudflats and reedbeds in the firth.

The meandering course of the River Earn south of Perth; image from Google Maps.

G Bibliography

Abbot, D.M. 2000. *Pitroddie and its quarry: an element of social history*. Unpublished report at the AK Bell Library Local Studies Section.

Abernethy, A. 1990. *Corsiehill Quarry, Kinnoull Hill, Perthshire*. Unpublished report, Perth Museum and Art Gallery.

Anderson, J. 1841. On the geology of Fifeshire. *Transactions of the Highlands Agricultural Society*, **7**(ns):376-431.

Anon. 1876. Dynamite experiments. *Perth Courier*, August 1, p. 3.

Anon. 1941. Big blast dislodges 70,000 tons of rock. *Perthshire Advertiser*, May 31, p. 7.

Anon. 1996. Approval for Carse clay extraction. *Perthshire Advertiser*, August 8.

Anon. 2007a. Consent given to infill quarry once traffic safety addrressed. *Perth Courier*, March 16, p. 4.

Anon. 2007b. Corsiehill Quarry. *Perthshire Advertiser*, November 30, p. 18.

Armstrong, M. & 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. & Browne, M.A.E. 1985. *Geology of the Perth and Dundee district*. Memoir for 1:50,000 geological sheets 48W, 48E, 49. Her Majesty's Stationary Office, London. ISBN 0 11 884368 0.

Brady, G.S., Crosskey, H.W. & Robertson, D. 1874. *A Monograph of the Post Tertiary Entomostraca of Scotland*. Palaeontological Society Monograph, London.

Bloodworth, A.J., Cowley, J.F., Highley, D.E. & Bowler, G.K. 2001. *Brick Clays: Issues for planning*. British Geological Survey Commissioned Report CR/01/117N.

British Geological Survey. 1984a. *Perth*. 1:50,000 Solid Map.

British Geological Survey. 1984b. *Perth*. 1:50,000 Drift Map.

British Geological Survey. 1984c. *Dundee*. 1:50,000 Solid Map.

British Geological Survey. 1984d. *Dundee*. 1:50,000 Drift Map.

Brown, T. 1867. On the arctic shell-clay of Elie and Errol, viewed in connection with our other glacial and more recent deposits. *Transactions of the Royal Society of Edinburgh*, **24**:617-633.

Browne, M.A.B. 1980. *Late Devensian marine limits and the pattern of deglaciation of the Strathearn area*. Report for the Institute for Geological Science, No. 80/9.

Browne, M.A.E., Paterson, I.B. & Wilkinson, I.P. 1995. *Report on the Geological Survey of the SSSI at Inchcoonans Claypit, Errol*. British Geological Survey Technical Report WA/95/67.

Browne, M.A.E., McKirdy, A. & McAdam, A.D. 2001. *Fife and Tayside: A Landscape fashioned by Geology*. Scottish Natural Heritage and British Geological Survey.

Clark, J.H. 1980. The Parish of Abernethy. Pp. 328-334. In: *The Third Statistical Account of Scotland*. Culross the Printers, Coupar Angus. ISBN 0 903589 38 9. [Note: the original entry was written in 1980 and updated by T.K. Potts in 1962].

Cullingford, R.A. 1972. *Lateglacial and postglacial shoreline displacement in the Earn-Tay area and eastern Fife*. PhD Thesis, University of Edinburgh.

Cullingford, R.A. 1977. Lateglacial raised shorelines and deglaciation in the Earn-Tay area. In: Gray, J.M. & Lowe, J.J. *Studies in the Scottish lateglacial environment*. Pergamon, Oxford.

Cullingford, R.A. 1993. Carey (GCR ID: 2023). In: Gordon, J.E. & Sutherland, D.G. (Eds.). Quaternary of Scotland. *Geological Conservation Review*, **6**(15): Fife and Lower Tay.

Cullingford, R.A. & Smith, D.E. 1966. Late-glacial shorelines in eastern Fife. *Transactions of the Institute of British Geographers*, **39**:31-51.

Cullingford, R.A., Caseldine, C.J. & Gotts, P.E. 1980. Early Flandrian land and sea-level changes in lower Strathearn. *Nature*, **184**:159-161.

Cullingford, R.A., Caseldine, C.J. & Gotts, P.E. 1989. Evidence of early Flandrian tidal surges in lower Strathearn, Scotland. *Journal of Quaternary Science*, **4**:51-60.

Davidson, C.F. 1932a. The arctic clay of Errol, Perthshire. *Transactions of the Perthshire Society of Natural Science*, 9(2):55-68.

Davidson, C.F. 1932b. The geology of Moncreiffe Hill, Perthshire. *Geological Magazine*, **69**:452-464.

Davidson, C.F. 1935. Geology. In: Melville, T. *Errol: its Legend, Lands and People*. Thomas Hunter and Sons, Perth.

Davidson, C.F. 1937. The geology of the Coronation Stone. *Transactions of the Perthshire Society of Natural Science*, **9**:210-212.

Duck, R.W. 1990. S.E.M. study of clastic fabrics preserved in calcareous concretions from the Errol Beds, Tayside. *Scottish Journal of Geology*, **26**:33-9.

Duck, R.W. 1999. Geology and Landscape. In: Omand, D. (Ed). *The Perthshire Book*. Birlinn , Edinburgh.

Duncan, D.D. 1845. Parish of Abernethy. In: *New Statistical Account of Scotland*, **10**:838-862. William Blackwood and Sons, Edinburgh.

Duncan, J. 1997. *Perth and Kinross: the Big County*. John Donald Publishers, Edinburgh.

Duncan, W. 1794. Parish of Abernethy. In: *The Statistical Account of Scotland*, **11**: 435-448. William Creech, Edinburgh.

Fleming, J. 1831. On the occurrence of scales of vertebrated animals in the Old Red Sandstone of Fifeshire. *Edinburgh Journal of Natural Science*, **3**:81-86.

Fortey, N.J., Phillips, E.R., McMillan, A.A. & Browne, M.A.E. 1998. A geological perspective on the Stone of Destiny. *Scottish Journal of Geology*, **34**:145-152.

Geikie, A. 1900. *The geology of central and western Fife and Kinross-shire*. Memoir of the Geological Survey, Great Britain.

Gemmell, A.M.D. (Ed). 1975. *Quaternary studies in north east Scotland*. Department of Geography, Aberdeen University.

Gordon, J.E. & Sutherland, D.G. 1993. Almondbank (GCR ID: 185). In: Gordon, J.E. & Sutherland, D.G. (Eds.). Quaternary of Scotland. *Geological Conservation Review*, **6**(14): Eastern Highland Boundary.

Graham, D.K. & Gregory, D.M. 1981. A revision of C.F. Davidson's arctic fauna from Inchcoonans Claypit, Errol, held by the Museum and Art Gallery, Perth. *Scottish Journal of Geology*, **17**:15-222.

Grierson, J. 1845. Parish of Errol. In: *New Statistical Account of Scotland*, **10**:367-405. William Blackwood and Sons, Edinburgh.

Harry, W.T. 1956. The Old Red Sandstone lavas of the western Sidlaws. *Geological Magazine*, **93**:43-56.

Hutchinson, A.S. 1980. The Parish of Errol. Pp. 360-369. In: *The Third Statistical Account of Scotland*. Culross the Printers, Coupar Angus. ISBN 0 903589 38 9. [Note: the original entry was written in 1953 and updated by T.K. Potts in 1962].

Jackson, N.P.D. 1967. *Record of wells in the areas of Scottish one-inch geological sheets Kinross (40), North Berwick (41), Perth (48) and Dundee (49)*. Water Supply Papers Geological Survey Great Britain, Well Catalogue Series.

Jamieson, T.F. 1865. On the history of the last geological changes in Scotland. *Quarterly Journal of the Geological Society of London*, **21**:161-203.

Long, D., Smith, D.E. & Dawson, A.G. 1989. A Holocene tsunami deposit in eastern Scotland. *Journal of Quaternary Science*, **4**:61-66.

Macdonald, R., Gottfried, D., Farrington, M.J., Brown, F.W. & Skinner, N.G. 1981. The geochemistry of a continental tholeiitic suite: late Palaeozoic quartz-dolerite dykes of Scotland. *Transactions of the Royal Society of Edinburgh*, **72**:57-74.

MacGregor, A.R. 1996. *Fife and Angus Geology*. Pentland Press, Edinburgh.

McIntyre, D.B. 2000. *The building stones of Perth*. Unpublished report, Perth Museum and Art Gallery.

McManus, J. 1971. The geological settings of the bridges of the lower Tay estuary with particular reference to the fill of the buried channel. *Quarterly Journal of Engineering Geology*, **3**:197-205.

McManus, J. 1972. Estuarine development and sediment distribution, with particular reference to the Tay. *Proceedings of the Royal Society of Edinburgh*, **71**:97-113.

Macnair, P. 1908. *The geology and scenery of the Grampians and the valley of Strathmore*. Volume 2. James MacLehose and Sons, Glasgow.

Macpherson, H.G. 1989. *Agates*. British Museum (Natural History), London. ISBN 0 565 01100 6.

Melville, L. 1939. *The fair land of Gowrie*. Culross, Coupar Angus.

Morrison, J., Smith, D.E., Cullingford, R.A. & Jones, R.L. 1981. The culmination of the main postglacial transgression in the Firth of Tay area, Scotland. *Proceedings of the Geologist's Association*, **92**:197-209.

Noble, J. 1845. Parish of St Madoes. In: *New Statistical Account of Scotland*, **10**:607-636. William Blackwood and Sons, Edinburgh.

Paterson, I.B. 1974. The supposed Perth Readvance in the Perth district. *Scottish Journal of Geology*, **10**:53-66.

Paterson, I.B. 1977. *Sand and Gravel resources of the Tayside Region*. Report of the Institute of Geological Sciences, No. 77/6.

Paterson, I.B., Armstrong, M. & Browne, M.A.E. 1981. Quaternary estuarine deposits in the Tay-Earn area, Scotland. *Report for the Institute for Geological Science*, No. 81/7.

Peacock, J.D. & Browne, M.A.E. 1998. Radiocarbon dates from the Errol Beds (Pre-Windermere Interstadial Raised Marine Deposits) in eastern Scotland. *Quaternary Newsletter*, **86**:1-7.

Simpson, J.B. 1933. The late-glacial Readvance moraines of the Highland Border, west of the River Tay. *Transactions of the Royal Society of Edinburgh*, **57**:633-646.

Sissons, J.B. 1963. The Perth Readvance in central Scotland. Part I. *Scottish Geographical Magazine*, **79**:151-163.

Sissons, J.B., Cullingford, R.A. & Smith, D.E. 1965. Some pre-carse valleys in the Forth and Tay basins. *Scottish Geographical Magazine*, **81**:115-124.

Sissons, J.B., Smith, D.E. & Cullingford, R.A. 1966. Late-glacial and post-glacial shorelines in south east Scotland. *Transactions of the Institute of British Geographers*, **39**:9-18.

Smith, J. 1876. The Earn Valley. The Dron beds and Dunning borings. *Scottish Naturalist*, **3**:113-121.

Smith, D.E. 1993. Pitlowie (GCR ID: 1959). In: Gordon, J.E. & Sutherland, D.G. (Eds.). Quaternary of Scotland. *Geological Conservation Review*, **6(15)**: Fife and Lower Tay.

Smith, D.E., Dawson, A.G., Cullingford, R.A. & Harkness, D.D. 1985. The stratigraphy of the Flandrian relative sea-level changes at a site in Tayside, Scotland. *Earth Surface Processes and Landforms*, **10**:17-25.

Stephenson, D., Loughlin, S.C., Millward, D., Waters, C.N. & Williamson, I.T. 2003. Corsiehill Quarry. pp. 246-249. In: *Geological Conservation Review*, **27**.

Strachan, D. 2010. *Carpow in Context: a Late Bronze Age Logboat from the Tay*. Society of Antiquaries of Scotland, Edinburgh.

Sutherland, D.G. 1993. Inchcoonans and Gallowflat (GCR ID: 1184). In: Gordon, J.E. & Sutherland, D.G. (Eds.). Quaternary of Scotland. *Geological Conservation Review*, **6(15)**: Fife and Lower Tay.

Taylor, W. 1792. Parish of Rynd. In: *The Statistical Account of Scotland*, **4**. William Creech, Edinburgh, pp. 178-184.

Walker, F. 1934a. A preliminary account of the quartz-dolerite dykes of Perthshire. *Transactions and Proceedings of the Perthshire Society of Natural Science*, 9:109-117.

Walker, F. 1934b. *The geology of Strathearn*. Dundee Museum and Art Gallery, Dundee.

Walker, F. 1961. *Tayside Geology*. Dundee Museum and Art Gallery, Dundee.

H Summary of Recommendations

1. Almondbank

This is a prime site with excellent access. No site improvement is currently required, but may need management of vegetation and spoil in the future.

2. River Tay at Scone

No action is required to maintain access to this section, the riverside path being maintained by salmon fishing interests.

3. Quarrymill Den

Access is excellent but the rocks are very overgrown and heavily shaded. While this is managed as a woodland park, some light felling and tree pruning to let the light in would improve the variety of habitats from a biodiversity aspect, as well as improving the view of the rocks. Some of the rock faces have been covered in steel mesh; this treatment should be discouraged.

4. Corsiehill Quarry SSSI

The rock faces on the north and south sides of the quarry are in good condition and the area is clean and tidy. The trees by the steps should be cut back regularly to allow examination of the full width of the dyke. We also hope to reprint the leaflet.

5. Kinnoull Hill SSSI

No action is required on the paths on the upper part of the hill beyond the maintenance already undertaken by P&KC. If better arrangements could be made for parking at the bottom of the hill, or a path could be made through from Barnhill above the main road, it would greatly facilitate access. Tayside Geodiversity could supply some geological information to be incorporated into future editions of the trail leaflet.

6. Kirkton Hill and St. Magdalene's Hill

A good network of core and other paths exists here but the dyke outcrops may require some clearance of vegetation. The site will go forward for LGS designation. It is a good area for a self-guided walk, so requires a leaflet. The landowner must be consulted on access to outcrops in pasture fields.

7. Friarton Quarry

It would be very desirable to conserve sections of the quarry including the unusual dyke-like feature; this would require discussions with the owners and action including stabilisation of the faces at a safe angle.

8. Moncreiffe Hill

This is managed by the Woodland Trust, with the published leaflet emphasising archaeology as well as natural history. The rock outcrops are less dramatic than Kinnoull Hill, and to improve the exposures could conflict with woodland management, so it is recommended that

no action be taken other than to supply some geological information for future updates to the existing leaflet.

9. Pepperknowes Quarry, Glencarse

This site is in reasonable condition. As it is unlikely to be visited by the general public and only rarely by geologists, no action is recommended. If the quarry is ever reopened Tayside Geodiversity would like to be kept in touch with the planning process.

10. Pitroddie Den

As this site is unlikely to be visited by the general public and only rarely by geologists, no action is recommended for now.

11. Flawcraig and Craighead Quarries

Both these sites are in good condition. As they are unlikely to be visited by the general public and only rarely by geologists, no action is recommended for now.

12. Wester Ballindean Quarry

The house adjacent to the access is presently for sale and the estate agent's particulars mention historic access to the quarry. The estate agent has already been contacted about possible geodiversity interest in the quarry.

13. Tinkletop Hill

This site is in good condition. As it is unlikely to be visited by the general public and only rarely by geologists, no action is recommended for now.

14. Clashbenny Quarry

The geodiversity value of this site has been badly degraded by flooding of the quarry and dense tree growth; it is currently of more value as a wildlife site than a sandstone/fossil locality. Because of its fossils we might wish to propose it as a LGS eventually. It would require serious work even to provide limited access, deal with the vegetation, rubbish, and not withstanding these the flooding too (presumably the level of the local water table). In the future, it might possibly be re-opened as a borrow pit to mend local properties. If so, rescue conservation if not anything else might be carried out. This might also apply to landfill.

15. Inchcoonans SSSI & 16. Gallowflat SSSI

For both Inchcoonans and Gallowflat a strategy needs to be agreed with the landowners, SNH and Tayside Geodiversity on preservation of and access to the sites. This assumed a new importance with the final closure of the Errol Brickworks.

17. Pitlowie SSSI

This site is reported by SNH to be in favourable condition. No action is recommended.

18. Carey SSSI and Rhynd

SNH state that as long as the river banks continue to erode naturally, there should always be a certain amount of bank slippage which creates new exposures. Action to reveal new exposures would only be considered if developments along the river hinder natural erosion.

19. Loanhead Quarry, Abernethy

Most of the quarry floor is densely overgrown; if a geological trail is created (see below), part of it should be cleared to allow access to view a safe part of the face.

20. Castle Law, Abernethy

Routine maintenance of core paths and forest roads should continue to allow access.

21. Ayton Quarry

The landowner needs to be contacted to agree access and interpretation.

22. Rough Den, Abernethy

Routine maintenance of core paths should continue to allow access.

The Abernethy area would be an ideal place for a geological trail (see section 22 above). The paths already exist but a leaflet would be required. There are opportunities for volunteers to clear vegetation from several of the sites.

23. Dron Burn

The geodiversity value of this site has already been lost. No action is recommended.

24. Pitkeathly and Glenearn Quarries

One or both of these should become a Local Geodiversity Site. The landowner(s) must be approached first to agree details of access. Rubbish/scrub clearance will be necessary.

25. Dunbarney Quarry

Most of the geodiversity value of this site has been lost. No action is recommended, the same rocks being better exposed at Pitkeathly and Glenearn. In the unlikely event of the unconformity section becoming re-exposed Tayside Geodiversity would like to be kept informed.

26. Crossgates Road Cutting (A9)

This site is not safely accessible by the general public. No action is recommended at the moment. However here and at other nearby road cuts to the west, the use of steel mesh is damaging the value of the exposures which are of great value academically.

27. Broombarns, River Earn.

This site is in excellent condition on account of recent bank erosion. It will go forward for LGS designation. The landowners need to be consulted to agree details of access and to ensure that natural bank erosion is not impeded.

Resources will therefore be sought for the following, subject to the consent of the landowners:

Tree pruning at Quarrymill, Corsiehill Quarry and Loanhead Quarry

Rubbish/scrub clearance at Wester Ballindean and Kirkton Hill

Writing, design and printing of leaflets for Abernethy and Kirkton Hill

Making a new footpath and/or improving car parking at the foot of Kinnoull Hill

Improving safe access to disused quarry faces at Friarton Quarry

Maintaining sections at Inchcoonans and Gallowflat clay pits.