# 1 Introduction

## Geodiversity Cairngorms National Park

Geodiversity is the variety of rocks, minerals, fossils, landforms sediments and soils, together with the natural processes which form and alter them (Gordon and Barron, 2010). Geodiversity also links people, landscapes and their culture through the interactions of biodiversity, soils, minerals, rocks, fossils, active processes and the built environment (Stanley, 2004).

### 1.1 The Cairngorms National Park

Established in 2003 as Scotland's second national park, the 4,528 $km^2$ Cairngorms National Park (CNP) is the UK's largest national park, and is over twice the size of both the Loch Lomond and the Trossachs and the Lake District parks.

It is a mountainous area with 36% of the land area over 800 metres and 2% over 1000 metres in altitude. Four of Scotland's five highest mountains are within the Park and there are 55 summits over 900 metres. It contains the largest area of arctic mountain landscape in the British Isles. Currently 39 % of the area of the Park is designated for nature conservation; of this 25 % is designated as being of European importance for nature conservation.

Geological, geomorphological and climatic processes underpin and shape the Park's outstanding landscapes of arctic mountains, hills, glens and straths (Gordon and Wignall, 2006). The Cairngorms contains one of the world's finest assemblage of pre-glacial and glacial landforms; assemblages rarely seen outside arctic Canada. This international significance of the Cairngorm's geodiversity is recognised in their inclusion in the UK Tentative List of World Heritage sites for their exceptional physical features.

### 1.2 Cairngorms National Park Plan

The 2007 Cairngorms National Park Plan includes the following vision for geodiversity:

*'The important geodiversity record in the Park will be widely recognised and will be well managed and conserved'.*

Supporting this geodiversity vision are four strategic objectives that provide a long-term framework for managing the Park:

1. Safeguard the geological and geomorphological features and associated processes that contribute to the landscape of the Park.
2. Raise awareness of the outstanding geology and geomorphology in the Park.
3. Prevent degradation and erosion of soils, particularly vulnerable montane and organic soils.
4. Safeguard against large-scale extraction and removal of mineral resource from the National Park.

In 2009, the British Geological Survey (BGS) and the Cairngorms National Park Authority (CNPA) agreed to prepare a jointly-funded geodiversity audit of the Cairngorms National Park to support these strategic objectives and help realise this long-term vision. At the same time, BGS also contributed to a new Landscape Character Assessment (LCA) of the CNP (Barron et al., 2011)

The outputs of this wholly desk-based audit will be used to inform land management activities in the Park and serve as a future resource for interpretation work. The project covered the entire Park area and a full range of geodiversity topics, but was biased towards:

- Geodiversity sites and landforms that represent the best examples within the Park;
- sites and landforms on lower ground nearer centres of population.

## 2 Why geodiversity matters

Geodiversity links people, landscape, biodiversity and culture. It exerts a profound influence on the distribution of habitats and species, and is an important control on the economic activities and history of settlement in any given place (Gordon & Barron, 2011). The geodiversity of a region is as important a facet of its natural heritage as its wildlife interests, and it can be one of the most significant areas of heritage interest, especially in areas of high landscape value. Conservation, sustainable management, educational use and interpretation of geodiversity are as important as those of biodiversity and archaeology, and geodiversity interests should be integrated into the management and conservation strategies for such related or parallel interests. Geodiversity information should make a significant contribution to the formation of a wide range of planning and environmental policies.

Considering the impact of geology on our local landscapes and heritage, few geological and landscape features in Scotland have any protection other than those designated as Sites of Special Scientific Interest (SSSIs). Geodiversity is an important environmental asset but is one of the least recognised and appreciated.

The geodiversity of an area is vulnerable to a wide range of threats: forests may be planted; quarries can be infilled; natural overgrowing by vegetation can completely obscure an exposure; and features within an urban environment may be built over.

The general public, Local Authorities, industries and schools have for many years been made aware of the importance of conserving archaeological and wildlife sites for future generations; it is equally important that geodiversity sites are understood, protected and explained to others.

Geoconservation activities in Scotland, and elsewhere in the UK, have traditionally focused mainly on the assessment and management of statutory protected sites (e.g. Ellis et al., 1996; Prosser et al., 2006) and interpretation of the links between geology and landscape (e.g. Gordon et al., 2004).

Increasingly, geodiversity is being recognised to have much wider relevance in a number of key policy areas and, in effect, to form a core element of ecosystem services (e.g. Gordon and Leys, 2001; Gray, 2004; Stanley, 2004; Gordon and Barron, 2010; Birch et al., 2010):

- it provides the physical basis for our varied landscapes (both rural and urban) and scenery, and has a profound influence on habitats and wildlife;
- it provides the basis for many aspects of economic development, including geotourism-based activities;
- it is a strong influence on our cultural heritage as a source of inspiration for art, sculpture, music, poetry and literature, and on the character of our urban areas through the use of different building stones;
- it provides a resource for a variety of recreation and outdoor activities, and therefore delivers benefits for people’s health and well-being;
- sustainable management of the land, river catchments and the coast; and
- it can help society to develop adaptations to climate change and to mitigate natural hazards through better understanding of natural processes.

In the past, geodiversity has suffered from a sectoral approach to conservation in which biodiversity and geodiversity have tended to be treated as separate entities, and with a dominant focus on the former (Gordon & Barron, 2011). However, the value of more integrated approaches is now becoming widely recognized at a strategic level; for example, the Convention on Biodiversity and the European Landscape Convention call for a more integrated approach to the conservation of natural resources and landscapes, both within and beyond protected areas.

This is reflected in the growing emphasis on an ‘ecosystem approach’ in conservation management and, at a more practical level, in Integrated Catchment Management/Sustainable Flood Management (Gordon & Barron, 2011).

Soil conservation and sustainable management of soil resources have become increasingly a priority issue through the European Soil Thematic Strategy and the proposed Soil Framework Directive.

Scotland's geodiversity forms the essential foundation upon which plants, animals and human beings live and interact. The active geomorphological processes that shape our mountains, rivers and coasts also maintain dynamic habitats and ecosystems. Scotland's biodiversity depends on the continued operation of these processes. It is increasingly recognised, therefore, that conservation management of the non-living parts of the natural world is crucial for sustaining living species and habitats.

Geodiversity also links the Earth, its people and their culture. Through the Global Geoparks Network, the cultural and economic importance of geodiversity is being increasingly adopted by UNESCO as a means to deliver geoconservation as part of a wider strategy for regionally sustainable socio-economic and cultural development that safeguards the environment (Eder and Patzak, 2004). There is therefore growing acceptance that geodiversity has a vital place in all aspects of the natural heritage and that it impacts on many sectors in economic development and historical and cultural heritage.

Geodiversity also has key relevance for other strategic issues/programmes, most notably climate change. Potentially important contributions include:

- river basin management plans and sustainable flood management through restoration of natural processes and an understanding of floodplain histories from sedimentary records; and
- understanding carbon dynamics in organic (peat) soils (Scotland's soils contain the majority of the UK soil carbon stock – Chapman et al., 2009)

Many different activities and sectors interact with geodiversity and have an impact on it – agriculture, forestry, industry, transport, recreation, tourism, development planning and flood protection along rivers. The challenge is to raise wider understanding and awareness of geodiversity and that its protection, enhancement and sustainable management are not only relevant, but essential to the people of Scotland and, through the provision of a range of vital services and benefits, how they live their lives.

## 3 Methodology

The project was divided into four key stages:

1. Literature and data review
2. Compile database and GIS of potential geodiversity sites and landforms
3. Select Potential Local Geodiversity Sites
4. Compilation of this report

### 3.1 Literature and data review

Information on potential sites was gathered from:

1. Specialist and general geological literature
2. Geological Conservation Review (GCR) database from SNH
3. SNH SSSI site documentation; SNH Commissioned Report No. 348, The geomorphological heritage of the Cairngorm Mountains (Kirkbride & Gordon, 2010); SNH Commissioned Report No. 064, Geological structure and landscape of the Cairngorm Mountains,( Thomas et al., 2004).
4. BGS 1:10k and 1:25k scanned maps, field slips, and other information such as digital aerial photography and NEXTMap® Britain data from Intermap Technologies

### 3.2 Site database and GIS compilation

The information gathered during the literature and data review was compiled in Excel tables and plotted as layers within a Geographic Information System (GIS) to give a reasonably comprehensive (within the resource limits of the project) database of sites.

### 3.3 Selection of potential local geodiversity sites for the cnp

Initially it was intended to apply scientific quality/rarity value scoring (Table 1) to sites and landforms to allow selection of the best sites for selection as potential Local Geodiversity Sites. However, this proved difficult to apply objectively in the absence of site visits and the selection of sites and landforms was left to the geologist's expert judgement.

Table 1 Geodiversity Site selection criteria – Geoscientific Merit

| **Geodiversity Site selection criteria ? Geoscientific Merit** | | |
|---|---|---|
| **Rarity** | **Rating** | |
| The abundance or significance of the feature of the site in the global context.Is the rarity such that the feature is one of only a few in the world, in the UK or in the regional area or is it one of many examples and only of reference or educational significance (because it is on the doorstep)? | | World<br>UK<br>Regional<br>Local (LGAP)<br>Educational / Reference<br>Not Present / Relevant |
| **Quality** | **Rating** | |
| | 10 | World |
| | 8 | UK |
| The extent to which a feature is typical or demonstrates 'text-book' features. | 6 | Regional |
| | 4 | Local (LGAP) |
| | 2 | Educational / Reference |
| | 0 | Not Present / Relevant |
| **Literature/Collections** | | **Rating** |
| | 10 | Detailed Studies |
| | 8 | Interpretations |
| The detail of written literature or material collections relating to the feature. | 6 | Descriptions |
| | 4 | Collected Material |
| | 2 | Referenced |
| | 0 | No Data |

Other geodiversity criteria such as access, current site value, community value, educational value, fragility and potential use are also included but not normally scored.

## 4 Bedrock geodiversity of the Cairngorms National Park

### 4.1 Background

The Cairngorms National Park contains representatives of a remarkably high proportion of the main bedrock geology units that crop out within the Grampian Highlands of Scotland – in many respects the Park presents a microcosm of the entire swathe of bedrock geology that crops out between the Great Glen Fault and the Highland Boundary Fault.

The age of bedrock units in the CNP spans approximately 600 million years; from around 1,000 million years ago to 400 million years ago. In simple terms there are two main components: (i) layers of sedimentary materials that were deposited at Earth's surface and subsequently buried, lithified, metamorphosed and folded; and (ii) numerous bodies of igneous rock that were injected into the metasedimentary rocks from deep within the Earth's crust. The metamorphosed sedimentary rocks consist of an older unit, the Badenoch Group, and a much thicker and more diverse younger unit, the Dalradian Supergroup. The igneous rocks consist of a small number of older granite intrusions, the Vuirich Suite, and a large number of younger and more diverse intrusions of the Caledonian Supersuite. The latter formed in association with the Caledonian Orogeny, a period of major geological upheaval caused by the collision of continents and smaller crustal units during closure of the Iapetus Ocean between 500 and 400 million years ago). The orogeny caused much of the folding and metamorphism that has affected the (meta)sedimentary rocks of the district. The Park also contains a small area of non-metamorphosed sedimentary rocks deposited during the early part of the Devonian Period, which represents a relict of widespread terrestrial deposits that originally blanketed much of the district when the land was uplifted and eroded at the end of the Caledonian Orogeny.

### 4.2 Recommended bedrock geodiverstiy sites

Thirty-five sites are proposed to represent the bedrock geodiversity within the CNP (Table1, Figure 1). These are biased towards lower ground nearer centres of population at the request of the CNPA, and to a large extent, on the local knowledge of BGS geologists. Bedrock mapping in the CNP by BGS over the last 40 years or so has concentrated on the Dalradian rocks to the east and south of the Park. One exception to this was the joint study by SNH and BGS on the geological evolution of the Cairngorms Mountains (Thomas et al., 2004). However this concentrated on landscape evolution of the Cairngorm Granite using lithological and structural data, rather than geodiversity.

More than half (twenty-two) of these are existing or proposed GCR sites (sites described in the Geological Conservation Review series (Ellis et al., 1996) that have been considered for notification as SSSI's on the basis of their national or international Earth science significance). The sites fall into several informal categories depending on the type of feature they represent. Most numerous are sites presenting good examples of a particular part of the stratigraphy, and in some cases important structural or depositional relationships. Other categories are: examples of the main families of intrusions, landforms reflecting strong bedrock controls, and sites of historical or cultural relevance (for example quarries that have made an important contribution to the local built heritage). The list of proposed sites is not exhaustive, but should form a framework to which additional sites can be added in future.

A summary of the age, nomenclature and sequence of the major stratigraphical and intrusive divisions in the bedrock geology of the CNP is presented in Figure 1. Many of the proposed bedrock geodiversity sites represent a particular part of the geological record - for example a distinct segment of the lithostratigraphy, or one of the main families of intrusive units. Where this is the case it is indicated on Figure 1. A small number of the main bedrock divisions highlighted on Figure 1 is not represented in the list of proposed sites, namely: the Southern Highland Group (Dalradian Supergroup), the Northeast Grampian Granitic Subsuite and Northwest Grampian Granitic Subsuite. Additional sites could be identified to represent these units and thereby complete a 'set' of geodiversity sites that encompasses all of the major bedrock divisions in the park.

## 5 Quaternary landforms and deposits of the Cairngorm National Park

### 5.1 Background

The Cairngorm National Park is an area of outstanding geomorphological interest, comprising an exceptional assemblage of pre-glacial, glacial, glaciofluvial, periglacial and paraglacial landforms and deposits. These include planation surfaces, tors and pockets of deeply weathered bedrock that have survived several periods of glaciation, illustrating aspects of longer-term landscape development. It contains a striking assemblage of landforms created by selective glacial erosion, including vast corries, arêtes and breaches, together with those related to the retreat and decay of glacier ice, including moraines, deep drainage channels and deposits formed in temporary ice-dammed lakes. In addition, the Park includes a wide range of periglacial phenomena, both active and relict, that result from repeated freezing and thawing of rocks and soil under the influence of gravity.

The last major glaciation of the Cairngorm National Park occurred between 29 000 and 15 000 BP (calendar years ago). During this 'Main Late Devensian' glaciation, an ice sheet expanded quickly to cover the whole of the Scottish mainland. Ice on the plateaux is believed to have been relatively thin, dry and cold-based. It caused minimal glacial erosion as it flowed predominantly by internal deformation. In contrast, convergent flow within the major glens and across bealachs was wet based, promoting basal sliding and enhancing rates of glacial erosion. The Park includes classic examples of such 'selective linear erosion'.

Following the Last Glacial Maximum at about 22 000 BP there followed a slow glacial retreat under ‘Siberian’ conditions, especially in the north-east of the Park. Ice sourced in the western Highlands retreated in a general westerly direction, exposing mountaintops and glens in the east before those in the west. There were complex interactions between this actively retreating ice sheet and ice sourced locally over the Cairngorms, Lochnagar and Gaick. Retreat was punctuated by at least one major glacial readvance or stillstand involving Strathspey ice, evidenced by extensive lateral moraines in Glen More. Ice-marginal lakes were ponded up at this time within Gleann Einich and the Lairig Ghru, between active Strathspey ice occupying Rothiemurchus, and local glaciers.

The climate warmed abruptly 14 700 years ago when tundra vegetation was replaced by one of birch and juniper scrubland. However, the climatic amelioration was short-lived and Arctic conditions returned about 12 500 years ago. During the ensuing ‘Loch Lomond Readvance’ (or ‘Younger Dryas’) ice caps developed over the Gaick and the West Drumochter Hills, and small glaciers formed in the high corries of the Cairngorms, Lochnagar and Monadhliath mountains. Most of the district remained unglaciated, but repeated freezing and thawing destabilised cohesive glacial deposits, causing them to creep and slip downslope into the glens. The present warm, interglacial climate of the Holocene began abruptly 11 500 years ago. Birch woodland had returned by 10 000 BP, followed later by pine. Though relatively stable, the climate has varied sporadically and has become colder and wetter since 4 300 BP.

### 5.2 The landforms and deposits

The imprint of glaciation remains dominant in the Park, from the enormous glacial troughs and corries, to nearly every hump and bump in the landscape. The most widespread deposit laid down directly by the last ice sheet was glacial till. It generally rests on bedrock, covers much of the low ground and extends into the upland glens. Till generally consists of cobbles, boulders and pebbles mixed with clayey sand and silt. Although tills in the Park are very sandy, particularly on granite bedrock, they are nonetheless relatively impermeable because they have been extremely compacted beneath ice.

Mounds and ridges of more heterogeneous, bouldery gravel and till were laid down as ‘recessional’ moraines at the margins of the ice sheet and outlet glaciers as they retreated. They are ubiquitous in the glens and straths, where they are generally composed of poorly consolidated, sandy and permeable deposits. The recessional moraines are commonly associated with ‘glacial drainage channels’ that were cut into the underlying till and bedrock at the retreating ice margins during summer thaws. Most of the channels contain some modern drainage, but most of them are clearly ‘misfits’.

Seasonal glacial meltwaters laid down deposits of glaciofluvial sand and gravel during deglaciation that now occur as plateaux, mounds (kames) and ridges (eskers). Glaciofluvial deposits are most common within valleys that have for some reason been protected from subsequent fluvial erosion. The glacial, morainic and glaciofluvial deposits once formed were commonly subsequently ‘reworked’ by outwash streams to form widespread terraces in many valleys, similar to sandar in Iceland. These terraces are generally underlain by densely-packed, cobble gravel. They are generally distinguished from younger, ‘alluvial’ terraces by the presence of enclosed hollows (kettleholes) that were formed by the melting of blocks of ice trapped within the sediment. The lower-lying alluvial terraces were formed by braided rivers during the final retreat of the last ice sheet and during the subsequent Loch Lomond Readvance.

Post-glacial processes have superimposed subtle, but distinctive, modifications on the glacial landscape. Steep mountain sides have been modified by rockfalls, soil creep and debris flows, whereas valley floors have been affected by rivers and by the accumulation of alluvial fans at the mouths of tributary streams. Once dense vegetation had become established by about 10 000

BP, most major rivers changed from ‘braided’ systems to their present, ‘single-thread’ style. Gravelly alluvium underlies the floodplains of most upland streams in the Park, which are commonly bordered by steep, relatively unstable bluffs up to 25 m high. Most upland streams are fast flowing with beds of cobble and boulder gravel, bifurcating channels and shifting linear bars of shingle. The floodplains of the major rivers of the Park are generally underlain by up to 2.5m of ‘overbank deposits’ that consist of coarsely laminated, humic, micaceous loam. Former meander channels and ox-bow lakes are filled with organic mud and peat.

### 5.3 Recommended Quaternary geodiversity sites

Fifty-four sites are proposed to represent the Quaternary geodiversity within the CNP (Table 1). Some sixteen of them are pre-existing or proposed GCR sites that have been described in the Geological Conservation Review series (Ellis et al., 1996) and that have been considered for notification as (SSSI's) on the basis of their national or international Earth science significance. The sites fall into several informal categories depending on the type of deposit or feature they represent.

The list of proposed sites is certainly not exhaustive, but should form a framework to which additional sites can be added in future. Unlike the Bedrock geology, which has been re-surveyed in the past forty years or so, only the western half of the Park is covered by modern Superficial mapping. Most of the proposed sites fall within this area, where BGS geologists have walked the ground systematically and have either discovered phenomena that have not been described hitherto, or have been able to reinvestigate ones previously described in the literature. Sites are also biased towards lower ground nearer centres of population at the request of the CNPA. For more detail on the geomorphology of the Cairngorm Mountains and sites with palaeoenvironmental records see Kirkbride & Gordon (2010).

## 6 Conclusions and recommendations

This desk study is a first pass at selecting the most important localities for Local Geodiversity Sites in the Cairngorms National Park, based on available information and knowledge of BGS geologists. The 35 bedrock and 54 Quaternary sites selected should not be regarded as the final definitive list, but as a framework to which additional sites can be added as more information becomes available and field work is undertaken.

6.1 Bedrock geodiversity

Additional sites could be identified within the Southern Highland Group, the Northeast Grampian Granitic Subsuite and Northwest Grampian Granitic Subsuite to give complete coverage of all of the major bedrock divisions in the Park. Also, site coverage is poor in the western half of the Park and could be improved by some targeted fieldwork. There may also be potential to incorporate some localities reported in Thomas et al. (2004).

### 6.2 Quaternary geodiversity

The eastern half of the Park is not covered by modern BGS Superficial mapping and a targeted survey is recommended (Glen Clova in particular). There is also potential to select additional sites in the core mountain area from Kirkbride & Gordon (2010).

**References**