GEOMORPHOLOGY OF THE ALYTH BURN CATCHMENT

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Introduction

The Alyth Burn occupies a small catchment in the eastern Grampians (historically, these mountains are also called The Mounth) constrained between the more extensive catchments drained by the River Ericht to the west and the River Isla to the east, of which it is a tributary. The landscape of this part of the Mounth can be described as a dissected plateau of considerable geological antiquity with gently sloping upland areas that are incised by valleys eroded first by rivers and since modified further by glacial ice and then meltwater during the multiple climatic changes that occurred during the Quaternary Period (last 2.58 Ma (million years) of geological time with a particular emphasis on the impact of last glaciation and deglaciation during the last 30 ka (thousand years)).

The catchment size has calculated by SEPA (Scottish Environmental Protection Agency) as 36.28 sq. km to its confluence with the River Isla. Figure 1 shows its extent on a DTM (Digital Terrain Model).

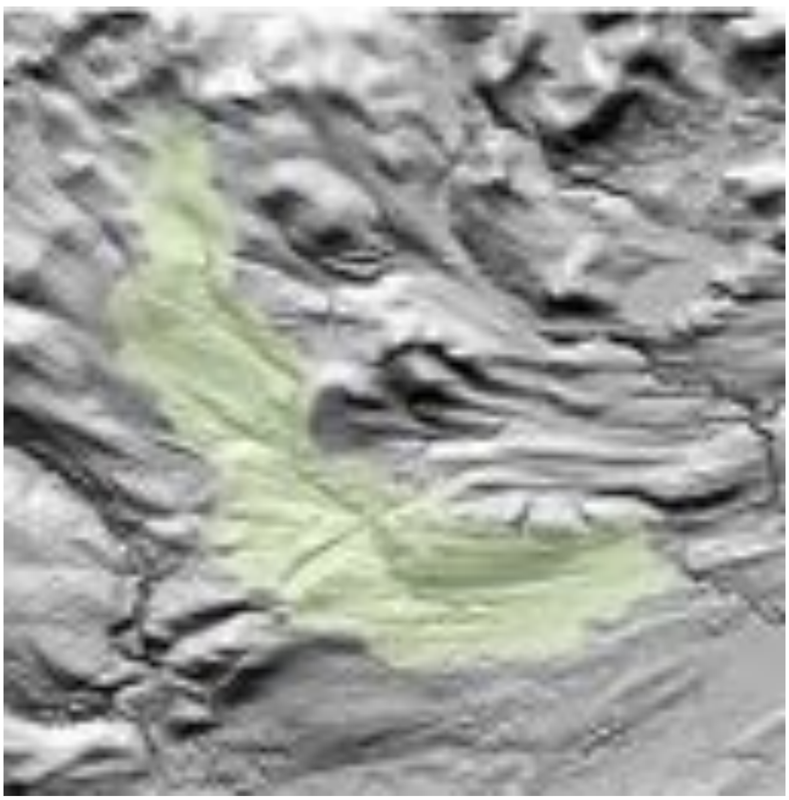

Figure 1. Hill-shaded DTM © NEXTMap showing the extent the Alyth Burn catchment.

These hill shaded models of the ground surface are formed from aerial radar survey data that can be processed in a GIS (Geographical Information System) to create an impression of the ground surface; this one has a resolution of 5m. As can be seen from Figure 1, the catchment has a distinctive topographic appearance of clear moulding (or lineation) from right to left across the image. This reflects the regional impact of the last ice sheet which eroded/ deformed bedrock and sediments in the subglacial environment (at the base of the ice) to create a streamlined landscape across the Alyth Burn catchment and wider area. This can be interpreted as indicating that the former ice sheet flowed from the north-west and can be traced back to a source area over the Gaick Plateau, to the west of the Cairngorms. However, the streamlining also shows that in the vicinity of Blairgowrie and Alyth, this ice converged with ice moving north-east along Strathmore from a source area in the Western Grampians (the main centre of the Scottish Ice Sheet (SIS). At its maximum extent, this SIS completely buried the landscape and extended into the North Sea basin (more details are discussed below).

Topographical differences across the Alyth Burn catchment from the northern hills to the lowland of Strathmore are a result of differential erosion of diverse types of bedrock (lithology) exposed in the area (discussed below). The DTM also shows distinct linear features aligned south-west to north-east which are related to these elevational changes. These are related to the geological structural changes associated with a further set of linear features which traverse the catchment and mark the surface expression of a number of faults, particularly the trend of the most important, the Highland Boundary Fault (HBF). However, it should be stressed that it is not one single fault but a series of faults that occur within a narrow, complex structural zone which divides the landscape into two important geological terranes (developed below).

The catchment only occupies a small area of this upland area locally called the Forest of Alyth. It is notable narrow in its upper part being about 1km in breadth in its upper reaches, where it rises to modest elevations of around 400 m on the southern slopes of Cairn Gibbs (521m OD) with two burns that drain Culponach Moss at elevations of 410m OD. These combine to form the Alyth Burn flowing south-southeast at the edge of Runnaguman Forest becoming more incised towards Tullymurdoch where the catchment width is over 2km. Around here, there are several small tributaries draining the south-eastern slopes of Drumderg (423m OD), now occupied by a wind farm and extending the catchment to the west towards the River Ericht catchment. Here, the Olies Burn extends towards High Rannagulzion where the actual drainage divide becomes ambiguous on the OS 1:25,000 map. Some of these tributaries are interpreted as occupying former meltwater channels cut by water during the melting of the ice sheet (which are discussed in more detail later). Below the confluence of the Olies Burn, the Alyth Burn occupies a more open valley towards Fyal where it crossed the Highland Boundary Fault and joins the stream flowing down the Den of Welton and a small stream draining the western part of the Bamff Estate. In this area, the interfluve (the area between the Ericht and Alyth Burn catchments) is complicated and related to bedrock geology and deglaciation.

Downstream of this confluence, the Alyth Burn becomes confined in a major bedrock channel called the Den of Alyth which extends about 3km towards the town of Alyth with one major tributary at Bridge of Tully that drains the slopes west of the Alyth Burn which are part of the catchment. The Den is a former meltwater channel; however, it is only the most northerly and deepest of a series of former meltwater channels which occupy the slopes west of the town towards St Fink (see below). Once in Alyth, the burn is no longer bedrock controlled and enters Strathmore flowing across gentle slopes of glacifluvial deposits in an easterly direction towards its confluence with the River Isla at Inverqueich. This section of the channel downstream of Alyth is remarkable by being very slightly incised in comparison to the deep bedrock channel upstream of the town. To the south, this part of the catchment is poorly defined within the glacifluvial sediments (sands and gravels deposited by meltwater during deglaciation) on which the town is built and mark the area from the golf course towards the River Isla. To the north, the steep slopes of the conglomerate bedrock ridge Hill of Alyth, Hill of Loyal and Barry Hill allow the interfluve to be well defined along the summit of the ridge.

The topography of the present catchment of the Alyth Burn can be described in terms of three distinct sub-regions which reflects the control bedrock geology and in particular tectonic structure and the subsequent glacial inheritance has had on the present drainage. These will be described in more detail to help explain the present catchment.

Geological Structure and Bedrock

As mentioned in the description of the DTM in Figure 1, an obvious linear feature can be identified across the middle of the catchment, particularly along the Den of Welton-Bruckly Burn (Figure 2).

This defines the Highland Boundary Fault (HBF) which is of primary geological significance in this area and across Scotland having been identified trending from Arran in the west to Stonehaven on the east coast. This marks the southern edge of the older, harder rocks of the Grampian Terrane of the Scottish Highlands from younger, softer rocks of the Midland Valley Terrane. (A terrane is a distinct crustal fragment that is bounded by faults with a distinct geological history in terms of lithology and tectonics). The Highlands Terrane is marked by complex rocks that were originally deposited as sedimentary rocks in a marine basin and which have subsequently been buried and deformed by multiple tectonic deformation and regional metamorphic events associated during the Grampian (Caledonian) Orogeny of Ordovician age. At some stage, this also resulted in the physical uplift of the area to form a high mountain range which has since been deeply eroded with the remnants forming the present Grampians. These rocks are classified as the Dalradian Supergroup which formed over a long period of time during the late Neoproterozoic (Late Precambrian) and Cambrian and can be distinguished across the HBF from the younger sedimentary rocks of Old Red Sandstone age (Devonian) exposed in Strathmore (Figure 2).

Figure 2. Geological Map of the Alyth Burn Catchment (1:50,000; Geological Map Data © BGS UKRI 2023).

The present elevational change in the catchment reflects this change of geology with the older Dalradian rocks forming the higher ground north of the HBF. However, this is not a simple relationship in this area. Erosional resistance from some of the Devonian conglomerates have formed high ridges such as Hill of Alyth which lies south of the HBF but also Hilton Hill and Balduff Hill which lie north of the accepted HBF. In fact, in this area, the lithological changes to Dalradian rocks do not occur at the main, widely recognised HBF but at a further fault to the north of Balduff Hill. It is now realised that the HBF is not a single fault but a zone of a number of fault strike-parallel to the main fault and define a distinct geological zone now called the Highland Boundary Complex.

The older rocks of the Dalradian Supergroup occupy the main part of the catchment (Fig. 2) and was originally mapped by the Scottish Geological Survey and the map published in 1870. This mapping only identified a limited number of faults, and their complex pattern was not yet appreciated as was the significance of the HBF within the now accepted paradigm of plate tectonics. The area along the HBF was also studied by Douglas Allan in the 1920's and interpreted in the understanding of geology at that time. Later BGS maps have improved our understanding of the rocks and structures in this area (Fig.2).

Within the present lithostratigraphical sequence established by the British Geological Survey (BGS) and the wider scientific literature, the bedrock in the upper catchment of the Alyth Burn is dominated by a widespread but poor exposure of a complex sequence of metamorphosed sandstones (psammites) and mudstones (pelites). The original rocks were deposited from deep marine bottom current flows as turbidites which became involved in later orogenic (mountain building) events which subjected the rocks to compression and heat leading to a number of folding events) (4 major episodes of ductile deformation (D1-4) are recognised during the Ordovician Grampian (or Caledonian) Orogeny which transformed the sedimentary rocks into a mountain range similar to the present Himalayas. During this period of crustal compression and intense deformation, these rocks were also metamorphosed to different degrees related to presence of regional geothermal heat which resulted in the formation of a number of metamorphic zones during the orogeny at a wide regional scale covering the whole present area of The Mounth and beyond. Beyond this present catchment, crustal melting resulted in the emplacement of a number of granite bodies within the Eastern Grampians.

Within the upper Alyth Burn catchment, bedrock reflects this sequence of geological events. The main rock types exposed are a sequence of psammites and pelites of low metamorphic (greenschist facies) grade. These are presently classified as the Southern Highland Group and form the uppermost (youngest) of the Dalradian rocks These rocks are interbedded and gradational with a series of mineralogically distinct rocks termed 'Green Beds' which indicate a volcanic input into the original turbidite sequence, and which have distinct mineralogy.

These are thought to be of younger age within the sedimentary pile and it is events late in the orogeny that are recorded in the Alyth Burn catchment with tectonic disturbance becomes more notable towards the HBF Zone. The first of these tectonic changes is a marked steeping of the general dip of the rocks into the Highland Border Downbend with its axial trace parallel to the HBF which is now thought to be a late stage deformation event and represents a ductile response to crustal changes with the HBF reflecting later brittle behaviour. In the Alyth Burn catchment, this is marked by a steepening of dip towards the HBF zone from the Flat Belt that marks a laterally extensive stretch of the ground of the Eastern Grampians to include the structural domain of the upper catchment. The Downbend appears to only occur as a narrow zone stretching northeast across the catchment, probably around the Hill of Three Cairns.

Towards the HBF, there is a distinct zone marked by a number of faults that have split the country rock into discrete fault slices, some of which are occupied by rock types that are only found in along this zone which has been termed the Highland Boundary Complex (Fig. 2); this is thought to be of Cambrian age but unconnected to events in the Grampian Terrane. Debate is still ongoing about this complex, but it is now regarded as a distinct geological setting with rocks derived from a separate tectonic basin on the northern margin of the Midland Valley terrane possibly in associated with a former island-arc that became trapped between the two major terranes. Fault movements, both at depth and along strike have disrupted the bedrock breaking it up into a series of fault-controlled blocks, with distinctive rocks that occur as a series of fault-bounded slivers along the HBF zone.

These rock types are of volcanic and sedimentary types which in places, have formed fault-breccias as a result of brittle fracture of the rocks caught up with the faulting. Alongside the brittle failure, deformation also resulted in many of the rocks having a steep and variable dip along the HBF. Although the tectonic movement of the fault is complex, it is thought to have been the result of transpressive (compression leading to shearing) movement (both along strike and dip) related to movement along the fault. It appears that the brittle behaviour of the HBF was late-stage tectonic behaviour as activity continued to be an active strike-slip fault until Silurian times and even after into Mid-Devonian since it cuts deposition of the lower ORS rocks acting at this stage, as a high-angle reverse fault during Mid-Devonian compressive earth movements. It appears that tectonic movement along the HBF zone ceased as later Carboniferous dykes are not displaced.

As has already been noted, the HBF forms the main division between the Highland Dalradian rocks and the younger rocks of the Midland Valley terrane. The younger rocks of the Midland Terrane are sedimentary and originated as deposits of major rivers that flowed southwest in Strathmore reflecting the high amounts of erosion in the high mountains that resulted from the Grampian (Caledonian) Orogeny. These now form a series of conglomerates (cemented gravels) and sandstones that were originally described as the Old Red Sandstone and are now known to be of Devonian age. Igneous rocks are also found in association with these clastic rocks suggesting on-going volcanic activity allowing lava production at the same time. Two types of conglomerates have been mapped and classified according to the rock type of the constituent pebbles; one type is characterised by pebbles of volcanic rock and the other of Highland igneous and metamorphic rocks. This reflects erosional style with the older eroding volcanic rocks deposited at the same time as the conglomerates and sandstone and then deeper erosion of the orogenic belt.

The great period of deep time following these events is not recorded in the Eastern Grampians as isostasy (the ability of lithospheric crust thickness to balance geothermal heat and rock density to form relief) allowed the area to remain above sea level as a positive topographic upland which experienced surface erosion rather than deposition. There has been much debate as to why this should and much conjecture to explain the high-level flat surfaces that characterise The Mounth in comparison to the western Scottish mountains. A number of such planation surfaces have been proposed with the Alyth Burn catchment occupying a small extent of a low-level surface at about 400m OD. Suffice to say that during the long periods of available time, very little erosion occurred in this area, but it was able to maintain a positive topography.

Glaciation and Present Landscape

In the Scottish Highlands, because they remained an area of positive relief, albeit at variable elevations through time as an area of net erosion, there is no physical record of geological events after the deposition of the Old Red Sandstone, but much conjecture as to how the mountains evolved through time until the global climatic changes that triggered the Ice Ages of the Late Cenozoic (2.58 Ma to 11,700 years ago). In Scotland, glaciers have formed on many occasions, both as topographically constrained corrie and valley glaciers and more topographically independent plateau ice caps and ice sheets that completely submerged the landscape. However, because ice is an exceptionally effective agent of erosion, the evidence of earlier glacial events is most often removed, and it is only the evidence of later events that can be found in the present landscape. Thus, the landscape of Eastern Scotland most clearly records the impact of the last glaciation on the landscape and the manner of its melting away during deglaciation. During each successive glaciation, the emphasis is firstly, on the impact of glacier ice on the landscape; however, as the ice margins receded during deglaciation, the role of the meltwater became dominant in the development of the landscape. Glacier ice and meltwater affected the landscape in two ways; firstly, by eroding the landscape into a series of landforms and secondly, by creating sediment that was transported and deposited leaving a geomorphological and sedimentological record that still can be seen in the present landscape. The last British Ice Sheet is thought to have reached a maximum extent more than 25 ka (thousands of years) when it extended into the centre of the North Sea (which was dry because of sea level fall) and then began to melt back to its source areas in the Scottish Highlands and had disappeared by 15 ka.

It is also important to understand that during a cold, glacial period, except at the maximum extent of the ice sheet, glacier ice would not have covered the land surface all of the time. The land surface would be notably ice free at the beginning of a glacial period and then during build up when glaciers grew to cover the land and later during deglaciation when land became progressively ice free. However, the climate remained cold and cold non-glacial conditions would have prevailed allowing the formation of a suite of distinct periglacial processes and landform even over the lowlands. The climate only began to warm after 14.7 ka and for a while the temperatures matched the present; however, the climate quicky returned to glacial conditions about 12.8 ka returning the Scottish landscape to a distinct short glacial period before returning to 'normal' more temperature conditions at about 11.7 ka. This warming and subsequent glacial event mark the Lateglacial Period with the warm period termed the Windermere Interstadial and the glacial event named as the Loch Lomond Stadial. During this short glacial event, glaciers re-formed in the highest corries and plateau across the eastern Grampians. After this short glacial event, the climate became warmer but with variations in temperature and precipitation through the Holocene (the present interglacial). At present, while the overall sequence of these climatic changes, very little detail is known about these environmental changes within the Alyth Burn catchment. It is important to emphasise this temporal cyclicity of the glacial-interglacial cycle with short periods of cold and warm periods of shorter duration demonstrating the complexity of understanding climate change at a variety of spatial and temporal scales.

Within the area of the Eastern Grampians, the present landscape reveals a complex sequence of landforms and sedimentological evidence that reflects the passage of the last ice sheet. The DTM (Fig. 1) shows a landform pattern that can be best explained by the passage of the ice. Within the area of the Alyth Burn and adjacent area, the surface is marked by a series of sub-parallel linear ridges that are best explained by deformation of the ground surface at the base of the ice sheet. These are termed mega-scale subglacial lineations (MSGL) which are interpreted as forming at the base of the ice sheet and indicating former ice flow directions. Across the Alyth Burn catchment this clearly shows former ice sheet flow from the north-west/west/ to the east. The mega-lineations cover the entire catchment and are found along many of the slopes of the Grampians and indicate that the landscape was completely inundated by the ice sheet as can be exemplified by the smoothed profiles of the major summits such as Balduff Hill to the east of the catchment. In fact, the whole profile of the conglomerate ridge of the Hill of Alyth shows ice streamlining and morphology. It also demonstrates the control of the present river system that cuts across the regional topography. Further, it can be shown that long drift tails (a particular type of MSGL) can form down-ice of summits such as Balduff Hill extending eastwards towards and beyond Incheoch marking the reach to the south of the Burn of Auchrannie. The widespread occurrence of these landforms across Scotland has been mapped as part of a major project to understand the entire British Ice Sheet, termed BRITICE (Figure 3). This was constructed within a GIS with individual landform types described as separate layers. Figure 4 has selected the layer for subglacial landforms (MSGL) showing the former SE ice flow from a source area to the northwest over the White Mounth. It is also clear that this ice has been deflected eastwards by ice flowing along Strathmore in a north-east direction from the Western Highlands with these two ice flows converging in Strathmore near Alyth. Such reconstructed flow patterns are often complex and crosscut each other resulting from internal changes in flow regime. This does not seem to be apparent in the upper Alyth Burn catchment but is observed in Strathmore. Such landforms are found to be typical of the beds of former ice streams – internal components of an ice sheet which move faster than other areas of the ice sheet. Strathmore formed a major ice stream conduit during the last glaciation with the multiple directions recording flow changes with a retreating ice margin.

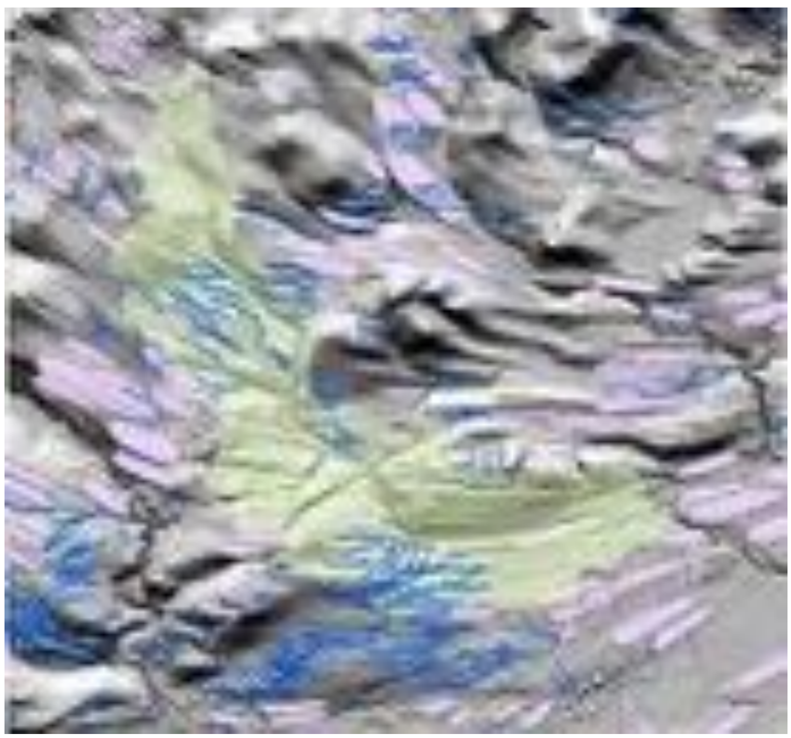

Figure 3. DTM of the Alyth Burn catchment with selected BRITICE layers showing the subglacial lineations (grey); meltwater channels (blue). From Clark et al (2018).

At some point in the last glaciation, the ice sheet began to melt and receded back towards its source area in the Grampian Highlands. There are a number of reasons, and it appears to have been driven primarily due by internal factors as it appears that it wasn't warming of the global climate that triggered initial melting as the climate remained polar through much of deglaciation. Rather, it seems that ice sheets have in-built destructive capabilities; they can be become unstable by becoming too thick and extensive, extending so far offshore that they establish an ice margin in contact with the ocean. Even although the sea level had fallen as water was converted to form the ice sheet, such marine margins are inherently unstable allowing for increased mass loss from the ice sheet by increased melting (ablation) into the ocean forming icebergs. Such mass loss destabilises the ice margin and may result in accelerated ablation triggering deglaciation if new mass can no longer be added to the ice sheet. When this happens in association with temperature increases in the climate and also significantly the marine environment, it can trigger the catastrophic collapse of the ice sheet.

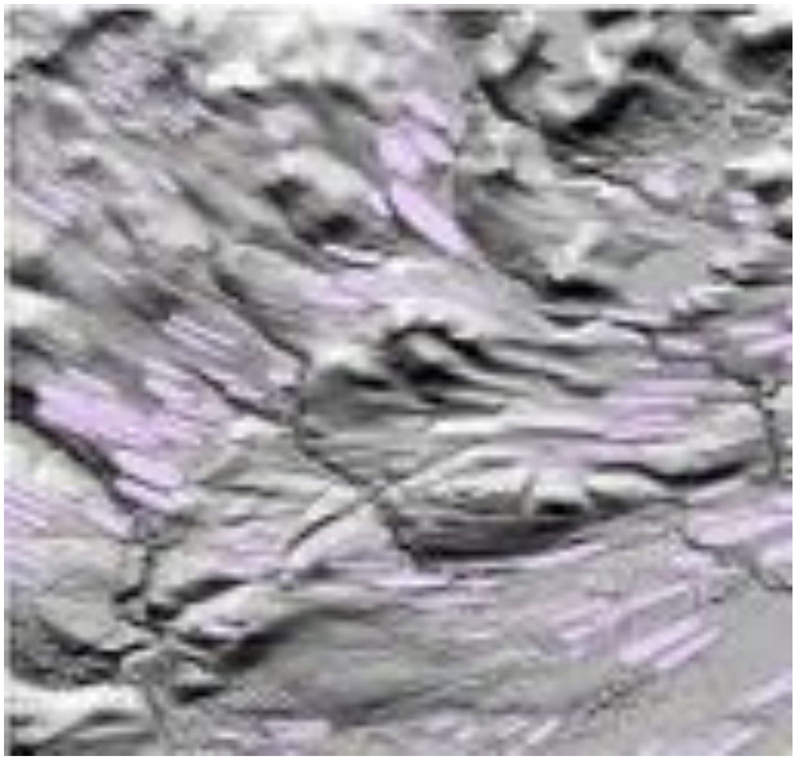

Figure 4. DTM of the Alyth Burn catchment with select BRITICE layer showing the subglacial lineations (grey). From Clark et al 2018).

During deglaciation, the ice sheet appears to have developed two different modes of glaciological behaviour. Firstly, it remained active (continuing to flow from source areas, that is the ice remained dynamic continuing to flow towards ever changing ice margins, both laterally and vertically as the ice volume declined, as is happening at present day glaciers. Alternatively, the ice mass was cut off from its source areas and stagnated in place, leaving ice blocks to subsequently melt and form kettle-hole lakes. This can be seen in the present-day lochs towards Dunkeld, but many have dried up to form peat bogs within glacifluvial sediments as seen around Blairgowrie and in Strathmore. Conversely, melting of the Scottish ice sheet allowed the creation of enormous quantities of meltwater which has had an important impact on the now deglaciated Scottish landscape by creating meltwater channels (Fig. 5) that formed in two distinct environments. Whilst the routes taken by the meltwater were initially controlled by the ice sheet and the channels formed subglacially, a further type of meltwater channel formed when ice had not only laterally stepped back but also thinned down to be topographically controlled in valleys allowing meltwater flow along the former ice margins creating lateral marginal or sub-marginal channels.

Many of these subglacial channels can still be seen in the present landscape but many are now separated from the present drainage system and no longer carry water, while others are still in use as the present drainage. Many of the former channels are marked as a GIS layer in BRITICE (Fig. 5); it is clear that others have not, and the area needs to be re-mapped. Where such channels encountered topographic divides, they just eroded through the divide, for example, outside the Alyth Burn, the Holm of Needs which carries the road to Glen Isla, is a major meltwater channel as is the spectacular Craig of Balloch channel system between the Backwater and Glen Quharity. It seems clear that such channels were also controlled by geological structure such as the Den of Welton channel along the HBF before entering the Den of Alyth which appear to have been formed by subglacial meltwater during deglaciation. The Den of Alyth continued to be utilised in a marginal environment as Alyth occupied a poorly defined small fan of glacifluvial deposits. A large meltwater channel can also be seen at Burnieshed of Bamff which becomes the Burn of Achrannie which flows east confined in a depression between two long drift tails.

In the upper part of the catchment, there are a number of former meltwater channels no longer part of the present-day drainage, particularly on the east side of the catchment which cross or begin near the drainage divide into the River Isla catchment. Good examples can be seen east on the Hill of Three Cairns /Hill of Craighead which end near Little Kilry. The hillslopes between High Rannagulzion and Tullymurdoch have a number of former meltwater channels orientated by the mega-scale subglacial lineaments that formed with regional ice flow. It would appear the Alyth Burn and Olies Burn are not identified as a former meltwater channels as are others in the ambiguous interfluve area around Burnside of Drimmie around the burn that flows to the Ericht catchment at Glenericht House. Further channels appear to occupy the eastern slopes of the Hill of Drimmie towards Welton of Creuchies where there are present tributaries of the Alyth Burn. Given the control of the MSGL on the location of these meltwater channels it is likely that they originated in the subglacial environment as opposed to former ice margins.

Conversely, many meltwater channels were formed along former ice margins where the topography allowed surface meltwater to drain along the ice margin in contact with the topography. These marginal or sub-marginal channels are often cut into glacial sediments and occur as discontinuous sub-parallel channels cut obliquely across hillslopes reflecting former margins which would have changed rapidly as the ice melted back across the slope and down the slope as the ice thinned. Such lateral channels have the ability of deciphering the pattern of deglaciation in certain valleys. This seems to be the case on the hillslopes from Alyth towards the Hill of St Finks where a high density of channels has been identified on the DTM and by BRITICE (Figure 5). Many of these drain into the Alyth Burn in the vicinity of the town; for example, the track to Johnshill Farm where they may indicate small changes in a lateral margin extending along this slope. There is a notable change at the larger channel of McSourie's Den which drains from Glendams about 1 km from the top of the Den of Welton channel southeast into a different catchment in Strathmore and appears to mark a more significant former ice margin which cut off the meltwater source of the eastern channels towards Alyth with a further set of meltwater channels eroded on the slope as Strathmore ice retreated west towards Blairgowrie.

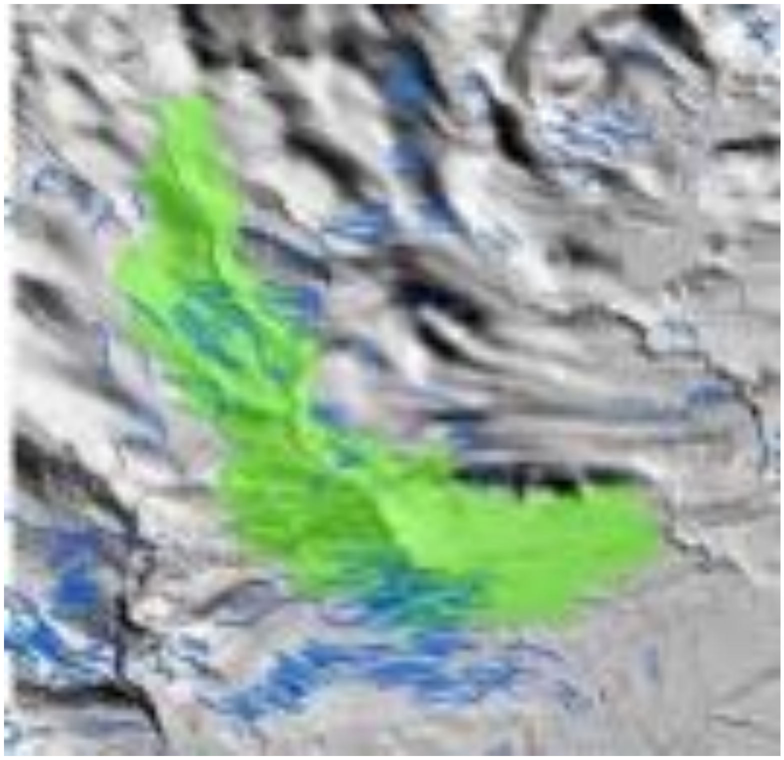

Figure 5. DTM of the Alyth Burn catchment with selected BRITICE layers showing the meltwater channels (blue) in relationship to the present catchment. From Clark et al 2018).

Subsequent events following the global increase in temperature into the present interglacial (called the Holocene) is not dealt with here as there is local paleo-environmental site that give detailed environmental changes within the Alyth Burn catchment. Reference is made to the excellent set of poster boards that are on the new fence at the sawmill in Alyth produced by Dr Richard Tipping.

Further Reading

There will be no surprise to find that there is an enormous set of information sources that covers this topic both in the printed literature and on-line. The few references given below have been used in the above account as being particularly pertinent to the study area. There are also a number of books that cover all aspects of Scottish geology.

Bedrock Geology

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Glaciation and Present Landscape

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