The Brecon Beacons

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Abstract

The Brecon Beacons of central and southern Wales offer the opportunity to explore a range of geomorphological processes, particularly those relating to the rapid climate changes associated with the period subsequent to the Last Glacial Maximum. The mountains present some of the best preserved evidence in the British Isles of the interplay between glacial, periglacial and paraglacial processes, associated with conditions of marginal glaciation, and provide the most southerly evidence of Younger Dryas/ Loch Lomond Stadial glaciation of Britain. The absence of evidence for landscape evolution in the region prior to the Last Glacial Maximum has recently begun to be addressed through insights derived from the subterranean geomorphology of limestone found in the south of the region. As one of the key sites of the early Industrial Revolution, the Brecon Beacons also preserve a unique landscape of anthropogenic (or even anthropocenic) geomorphology associated with large scale coal and iron extraction.

Keywords

Brecon Beacons, Sandstone, Limestone, Glaciation, Paraglacial, Periglacial and Anthropogenic Landforms.

1: Introduction

The Brecon Beacons are perhaps some of the most easily accessible mountains in the British Isles, and offer a dramatic landscape particularly when viewed from the Usk valley, described by Symonds (1872) as '*waves poised to crash over the lowlands of Brecknock*'. Located in south-central Wales (Figure 1), the Brecon Beacons was designated a National Park in 1954, with the western area of the park becoming a UNESCO Global Geopark (the Fforest Fawr Geopark) in 2005, based upon its rich geological and geomorphological heritage (Ramsay 2017).

The geomorphology of the Brecon Beacons is dominated by four distinct upland areas forming a generally east-west trending escarpment, comprising mainly of Devonian Old Red Sandstone. The scarp faces northwards, and has been shaped into a series of dramatic glacial trough-heads (Figure 2a), with shallower valleys on the dip slope of the escarpment (Figure 2b). The Black Mountains are the exception, where long south-easterly trending troughs reflect a structural control in the Old Red Sandstone as the escarpment bends toward the north-east. The River Usk cuts through the main escarpment, separating the eastern Black Mountains from the other three areas of upland (Brecon Beacons, Fforest Fawr and Black Mountain/Mynydd Du) to the west. Other than the Usk, most of the rivers drain from the watershed of the escarpment, with the northern rivers feeding into the Usk catchment, and the southward flowing rivers feeding the Tawe, Neath, Taff and Rhymeny basins (Figure 1).

This region holds particular significance in the development of our understanding of Earth history since ~500 million years ago, with figures such as Adam Sedgewick and Roderick

Murchison undertaking pioneering work in the Brecon Beacons to define the Ordovician, Silurian and Devonian periods, establishing key foundations for the modern geological time-scale. The landscape of the Brecon Beacons is also well-known for the historical development of the Glacial Theory in the British Isles, with the Rev. William Symonds first suggesting that the region had experienced past glaciation in 1872. Subsequently, Thomas Mellard Reade presented in 1894 the first detailed study of the moraines found at many trough-heads in the area, and which offer the most southerly evidence of glaciation in the British Isles during the Younger Dryas (Shakesby and Matthews 1993; Bickerdike et al. 2018). Finally, along the southern boundaries of the National Park, the Brecon Beacons preserves classic landscapes associated with coal and iron extraction and processing marking the onset of the Industrial Revolution, and offers an historical insight into the developing Anthropocenic geomorphology of the British Isles.

2: Geology

The bedrock geology of the Brecon Beacons comprises entirely of sedimentary rocks, and preserves an almost complete succession extending from the Late Ordovician through to the Carboniferous (Figure 3), representing the infill of a deep ocean basin, and are associated with the emergence of life on land, and at least two phases of mountain building (Howells 2007; Humpage 2007; Ramsay 2017). In general, the geology of the Brecon Beacons dips and youngs towards the south. From a historical perspective, the region has importance due to the Silurian period being named by Murchison (1839) after the Celtic *Silures* tribe that occupied south-east Wales and Fforest Fawr and whom fiercely resisted the Roman invasion of Wales in around AD 48, and also the region is known as the type site of the lowest epoch of the Silurian System (the Llandovery Series; Cocks et al. 1984) just to the northwest of the Brecon Beacons.

The oldest Ordovician and Early Silurian sequences are located at the north-western flank of the Black Mountain, and fine-grained mudstones and siltstones represent deposition under deep marine conditions in the Rheic Ocean (Barclay et al. 2005). Subsequent uplift associated with the Caledonian Orogeny through the mid- to late Silurian and early Devonian results in a transition from progressively shallower marine and near shore-tidal environments, into the fluvial red-beds known as the (Lower) Old Red Sandstone (Barclay et al. 2005). These, at up to 1000 m thick, make up the bulk of the escarpment, and formed an alluvial plain with multiple fluvial styles extending from the Caledonian Mountains to the north (Owen 1995; 2017; Wellman et al. 1998; Marriott and Hillier 2014; Kendall 2017). The extensive tabular sheets of the Lower Old Red Sandstone (St Maughans, Senni and Brownstone Formations) are magnificently exposed on the north-facing slopes of the Brecon Beacons, Fforest Fawr and Black Mountain (Figure 2). The Senni Formation preserves fossil traces of small, primitive vascular plants (Edwards and Richardson 2004; Ramsay 2017) as well as early aquatic vertebrates (jawless fish; Blieck and Elliott 2017). The Acadian Unconformity, considered to represent uplift at the culmination of the Caledonian Orogeny, truncates this lower sedimentary succession. Above this unconformity, the Upper Old Red Sandstone (Plateau Beds Formation, Grey Grits Formation) are found as pebbly conglomerates that form the distinctive summit caps of many of the mountains of the Brecon Beacons. These reflect deposition during the Late Devonian under a combination of aeolian, fluvial (braidplain) and tidal conditions associated with a major marine transgression associated with significant regional subsidence (Barclay et al. 2005; Humpage 2007; Ramsay 2017).

During the Carboniferous, the Brecon Beacons were located on the southern margin of the Wales – Brabant High (Howells 2007; Ramsay 2017), and sedimentation of limestones and sandstones are associated with cycles of marine transgression and regression in a shallow tropical sea resulting in a thickening ramp of sedimentation on the southern flank of the Brecon Beacons. The Carboniferous limestones (Avon Group, Pembroke Group, both of Dinantian age) are characterized by siliciclastic mudrocks and thin beds of fossiliferous limestone, punctuated by thin palaeosols representing periodic marine regression (Humpage 2007; Ramsay 2017). These cycles of sea level rise and fall are speculated to reflect eustatic sea level change associated with the growth and decay of a major southern polar ice sheet (Wright and Vanstone 2001). Unconformably overlying grits and sandstones characterize interbeds of marine, nearshore deltaic and fluvial sedimentation within the Namurian (Twrch Sandstone and Bishopstone Mudstone Formations) offer further evidence of ongoing glacio-eustatic sea level change during the Carboniferous. Finally, in the south of the region, Westphalian coal measures (South Wales Coal Measures Group) are found, comprising mudrocks (including beds and nodules of sideritic ironstone), sandstones and interbeds of anthracite coal deposited in a fluvially dominated delta plain (Howells 2007; Humpage 2007; Ramsay 2017). From the late Carboniferous and into the Permian, the Brecon Beacons were significantly influenced by the tectonics of the Variscan Orogeny, which uplifted and imparted the southerly dips to the bedrock sequence seen today, and imparted some low-grade metamorphism within the Coal Measures group to create spatial variation in the rank of coal present (Bevins et al. 1996). The uplift associated with Variscan Orogeny results in a regional erosional unconformity and stratigraphic hiatus which persisted through until the Late Quaternary. Extensive swallow holes and sinks in the Carboniferous Limestone are attributed to Tertiary weathering (Humpage 2007), although these and other karst features seem to have also been actively formed through the Quaternary (Farrant et al. 2014).

There is a rich economic geology within the Brecon Beacons, which has had a substantial impact upon the geomorphology of the region, which can be considered one of the cradles of the Industrial Revolution. The co-location of both high-quality anthracite coal measures and iron ores means that South Wales became a major global centre for the production of iron and steel (Howells 2007; Ramsay 2017). Additionally, limestone quarrying and lime-burning, present in the region since the middle-ages, dramatically increased in the 19th and 20th Centuries to supply both the network of ironworks in South Wales and for agricultural purposes. The scale of modification of some of these landscapes, such as the Blaenau Valley is such that these represent some of the earliest examples of Anthropocenic landscapes, where human imprint dominates the valley geomorphology.

3: The Quaternary

The large-scale structure and geomorphology of the Brecon Beacons was probably established during the Tertiary, prior to the onset of the Quaternary Period, but it is also clear that the pre-Quaternary landscape has undergone significant modification during successive glacial-interglacial cycles (Lewis and Thomas 2005; Shakesby et al. 2007), particularly through glacial, periglacial and paraglacial processes. Fascinating insight into long-term landscape evolution in the region have emerged from the extensive Ogof Draenen cave system near Blaenavon (Simms and Farrant 2011; Farrant et al. 2014). The changing geometry and sediment infill of the cave systems have been interpreted as reflecting subglacial drainage conduits, probably active during the Anglian (MIS 12) glaciation, and Farrant et al. (2014) suggest that landscape modification in subsequent glaciations has been minimal. However, there is little direct surface evidence preserved for these events across Wales, with only inference of the glacial modification of pre-existing fluvial valleys (e.g. Sahlin et al. 2009), prior to the events associated with the Last Glacial Maximum (Late Devensian/ Dimlington Stadial) and subsequent events (Figure 4).

During the Late Quaternary, there is a wealth of geomorphological evidence in the Brecon Beacons of the maximum extent and retreat of the last (Late Devensian) British-Irish Ice Sheet, as well as subsequent events associated with the Last Glacial-Interglacial Transition (LGIT). Whilst traditionally regarded as a regional ice-dispersal centre during Quaternary glaciations, a re-interpretation of selected glacial geomorphology by Jansson and Glasser (2008) suggests the region was more peripheral and marginal compared to the ice sheet scale glaciation that influenced much of mid- and north-Wales during the Devensian. This more restricted view of local glaciation has been strongly challenged by Shakesby and Matthews (2009), and is discussed in more detail below.

There is an extensive, high-resolution record of landscape and environmental change in the Brecon Beacons during the LGIT (Figure 4), with the most southerly evidence in the British Isles for mountain glaciation during the Younger Dryas period (Carr 2001; Shakesby 2002; Carr et al. 2007; 2010; Bickerdike et al. 2016; 2018). In addition, long Lateglacial palaeoenvironmental records extracted from Traeth Mawr, Llanilid and Llangorse Lake (Walker 1982, Walker et al. 2003, Palmer et al. 2008) provide a detailed record of vegetation and climate change through this dynamic period of landscape evolution. The marginally glacial environments in the Brecon Beacons during the LGIT have resulted in a complex landscape whereby glacial, periglacial and paraglacial geomorphology is spatially and temporally closely associated, leading to uncertainty and ambiguity in their interpretation and palaeoenvironmental implications (Shakesby 2002; Shakesby and Matthews 2007, Carr et al. 2007, Coleman and Carr 2008). This results in a fascinating and complex record of landform and landscape evolution that is challenging to interpret.

4: Glacial Geomorphology

The main Brecon Beacons mountain belt would likely have acted as an ice accumulation and dispersal centre during multiple Quaternary glaciations, inferred by the spectacular northern face of the mountains, deeply sculpted by glacier erosion into the dramatic trough heads described by Symonds (1872). The southern slope of the mountains is less deeply eroded (Figure 2b) and suggests that the geological structure of the Brecon Beacons over-emphasise the actual volume of Quaternary glacial erosion, and that much of the Brecon Beacons preserves a largely fluvial landscape (see for example Jansson and Glasser 2008). However, over-deepening of the upper reaches of the north-facing trough heads (Shakesby and Matthews 2009), and the breaches that divide the four main massifs of the Brecon Beacons are testament to active ice sheet glaciation and the migration of regional ice-divide across the mountain belt resulting in the formation of transection glaciers throughout multiple Quaternary glaciations (Shakesby et al. 2007).

During the Last Glaciation (Late Devensian), it would appear that the Brecon Beacons were peripheral to the overall British-Irish ice sheet (Lewis and Thomas 2005; Jansson and Glasser 2008; Evans 2016), and that compared with ice-centres in Mid- and North Wales, The Brecon Beacons contributed relatively little to the volume of the Welsh ice cap during this period (Patton et al. 2013). Controversially, Jansson and Glasser (2008) propose that some of the erosional and depositional features identified in the trough heads of the central and western Brecon Beacons represent features generated by ice extending southwards from mid-Wales flowing up-valley into and over the escarpment of the Brecon Beacons during the Last Glaciation, rather than moraines and associated landforms of restricted glaciation during the Younger Dryas (Figure 5). This view has been strongly critiqued by Shakesby and Matthews (2009), noting the selective use of previously published geomorphological, sedimentary and chronological evidence by Jansson and Glasser (2008) in arriving at their interpretations, and Shakesby and Matthews (2009) assert that the absence of mid-Wales erratics south of Trecastle and Llangorse indicates that locally-sourced ice from the Brecon Beacons deflected mid-Wales ice largely out of the Usk Valley (Figure 5). The actual form of the most recent ice-sheet scale glaciation has not yet been adequately reconstructed, but it is likely that local plateau icefields on the main escarpment of the Brecon Beacons fed a series of outlet glaciers flowing down the main valleys, rather than there being a single large ice dome over the entire region, and some of the higher mountains are likely to have remained ice-free throughout the LGM (Lewis and Thomas 2005; Patton et al. 2013).

On the northern side of the Brecon Beacons escarpment, the LGM Usk Glacier drained the majority of the ice-dispersal centre, forming a significant, highly-active and erosive outlet glacier extending eastwards beyond Abergavenny (Thomas and Humpage 2007; Coleman 2007). Shorter and less erosive outlet glaciers drained to the south of the escarpment along the Taff, Tawe and Neath valley systems, with additional ice source areas evidenced by lower-altitude cirques and glacial trough-heads within the South Wales coalfield, particularly the Rhondda valley, contributing to the South Wales End Moraine complex (Bowen 1973; Lewis and Thomas 2005). The main outlet glacier of the region, the Usk Glacier, terminated in a piedmont glacier lobe forming a kame-moraine complex extending beyond the mountain front from Pontypool in the south across to Raglan in the east, becoming confluent with the Wye Glacier in the north, an outlet glacier draining central Mid-Wales (Humpage 1992; Thomas 1997; Lewis and Thomas 2005; Thomas and Humpage 2007). Thomas and Humpage (2007), and Coleman (2007) identify a suite of moraines, kame deposits and associated outwash sediments and landforms that record the progressive retreat, punctuated by occasional re-advances through the middle- and upper Usk valley (Figure 6), and Coleman (2007) highlights the importance of the disconnection of small peripheral icefields, such as that on the Llangattwg plateau, in controlling the rate and dynamics of the retreat of the Usk Glacier. At Llangorse Lake, the contribution of ice from both the Wye and Usk Glaciers is recorded in a high-resolution lake sediment record (Palmer et al. 2008), which although currently floating in terms of geochronology, has yielded a detailed annually-resolved picture of the retreat and dynamics of these glaciers during deglaciation.

During the LGIT, a short-lived reversion to extreme cold conditions during the Younger Dryas Stadial led to re-occupation of the high mountain trough-heads of all four sections of the Brecon Beacons by small mountain glaciers (Ellis-Gruffydd 1977; Carr 2001; Shakesby 2002; Coleman and Carr 2008). It is widely recognised that small lateral and terminal moraine ridges, typically lying at around 500-600 m elevations (Figure 7) represent the most southerly evidence of Younger Dryas glaciation in the British Isles. The extremely marginal conditions for glaciation during this period have led to much discussion over the potential range of glacial and non-glacial origins of these scarp-foot ridges in the Brecon Beacons, with particular focus on sites where the glaciation level was much lower, such as the features in the head of Glyn Tarell (Shakesby and Matthews 1996; Shakesby 2002; Shakesby and

Matthews 2007; Carr et al. 2007). In these instances, a combination of geomorphology, sedimentology, glacier reconstruction and local climate modelling highlights the role of local topoclimatic influences (for example shading or the influence of snowblow from adjacent plateaux) in conditioning whether a valley head experienced glaciation or other cold-climate processes during the LGIT (Coleman et al. 2009).

5: Periglacial and Paraglacial Geomorphology

As noted above, the marginal nature of glaciation of the Brecon Beacons during the LGM and through the LGIT has resulted in a suite of landforms in both the uplands and lowlands that reflect a diverse range of glacial, periglacial (cold climate, but non-glacial) and paraglacial (non-glacial processes conditioned by destabilisation of landscapes by glaciation) environments, such, that particularly for the uplands, it has often proven challenging to adequately interpret the geomorphological record.

Some of the upland scarp-foot ridge features in the Brecon Beacons have been interpreted by different authors as both moraines reflecting highly localised glaciation and as pronival ramparts associated with perennial snowbank formation under periglacial conditions during the Younger Dryas. A classic example of this confusion is demonstrated by the ridge at Fan Hir (Figure 7a), which has been interpreted as a Younger Dryas terminal moraine (Shakesby and Matthews 1993), an LGM lateral moraine (Jansson and Glasser 2008) and a pronival rampart (Ellis-Gruffydd 1977). This reflects the challenge of interpreting the geomorphology of such marginal glacial and periglacial environments, and highlights the importance of collecting sedimentological data as well as using climate and physical modelling approaches to inform geomorphological interpretations. The value of this integrated approach is demonstrated by Coleman and Carr (2008) who interpret the various scarp-foot ridges within the neighbouring trough heads of Cwm Oergwm (Figure 7b) and Cwm Cwareli as a combination of pre-Younger Dryas and Younger Dryas terminal moraines, a pronival rampart, and a subsequent small paraglacial rock-slope failure through a combination of geomorphological methods. However, sites such as the nine scarp-foot features identified beneath the Mynydd Du escarpment (Figure 7c) continue to be enigmatic and may represent hybrid periglacial and glacial features dating from the LGIT. Beyond these scarp-foot ridges, the widespread presence of gelifluction lobes and terraces on the uplands of the Brecon Beacons, particularly well-preserved on Torpantau and near Fan Gyhirych is evidence of periglacial activity, assumed to be of Younger Dryas age (Lewis and Thomas 2005), although the absence of pingo ramparts and ice wedge casts is suggested to reflect marginal periglacial conditions, rather than permafrost environments.

During the LGIT, the influence of glaciation as a mechanism of destabilisation of slopes, is frequently preserved as large scale mass-movements in the Brecon Beacons (Figure 8), and in particular there is a rich geomorphological record of paraglacial slope modification (Shakesby and Matthews 1996; Shakesby 2002; Curry and Morris 2004; Coleman and Carr 2008). In some cases, such as below the scarp of Craig Cerrig-Gleisiad in Glyn Tarell, it is possible to construct a morphostratigraphic sequence of deglaciation, paraglacial landslide development and subsequent modification of the landslide debris by a Younger Dryas glacier (Shakesby and Matthews 1996). However, at the majority of locations where rock-slope failures and other paraglacial slope modifications have been identified (Figure 8), it has proven difficult to establish whether these relate to landscape instability during the LGIT or within the early Holocene. However, detailed work on the talus accumulations along the escarpment of

Mynydd Du (Curry and Morris 2004: see Figure 7c) suggests that rapid rock-wall retreat during the LGIT, was associated with highly effective diurnal-style freeze thaw weathering of unstable, paraglacial rock slopes resulting in rockwall retreat rates some two orders of magnitude greater than present-day levels.

6: Fluvial Geomorphology

As noted earlier, whilst the northern escarpment of the Brecon Beacons is striking, with clearly glacially-modified trough heads, the overall landscape of the mountains is predominantly one of moderate relief, and it has been suggested (albeit controversially) that the overall form and geometry of the Brecon Beacons is fluvial in origin (Jansson and Glasser 2008; Sahlin et al. 2009; Shakesby and Matthews 2009). As such, the valley systems of the Brecon Beacons may imply a persistent landscape preserved throughout multiple Quaternary glaciations. However, even if this is the case, there is little direct geomorphological evidence of sediments or landforms of fluvial origin prior to the Holocene.

There has been little formal geomorphological research published on the modern fluvial catchments associated with the Brecon Beacons. The dominant modern river catchment of the Brecon Beacons is that of the Usk, which at ~120 km in length, and a catchment of 1358 km^2 is one of the largest in Wales (Larsen et al. 2009). The catchment experiences modest baseflow (~15% of discharge), and consequently discharge and sediment load is subject to significant fluctuations associated with stormflow (Environment Agency 1998). For much of its course within the Brecon Beacons, the River Usk is a single-thread bedrock river channel, which has also eroded into the Quaternary glacial landscapes, with modest floodplain development in the middle reaches. Once beyond the mountain front at Abergavenny, the Lower Usk extends across a large alluvial floodplain, with a complex suite of migrating meander loops, cut-off and backwater features.

Where the underlying bedrock geology comprises Carboniferous Limestone, mainly in the south and east of the Brecon Beacons, particularly the upper reaches of the Tawe and Neath catchments, the hydrology and fluvial behaviour of catchments is strongly affected by karst processes.

7: Karst Geomorphology

The presence of Carboniferous Limestone results in the some surface karst geomorphology and much more extensive sub-surface karst cave systems within the Brecon Beacons. The limited surface exposure of limestone in a narrow band extending across the southern part of the Brecon Beacons restricts the exposure of classic limestone pavements, which only cover approximately 20 hectares in total, comprising numerous isolated patches, many of which have been degraded by quarrying and removal of limestone blocks for building stone (Figure 9). Dolines can be found throughout the limestone belt of the Brecon Beacons, some of which are ephemerally flooded, such as the feature at Pwell-y-Felin (Farr et al. 2016), or the numerous examples on the Mynyndd Llangynidr (Gunn 2012) which demonstrate different behaviour including both water retention or acting as stream sinks to subsurface karst. These dolines thus reflect complex hydrological behaviour reflecting the balance of input of surface water and subterranean conduits associated with the structure of the Carboniferous Limestone, particularly the role of small scale localised variations in water solubility associated with the presence of interstratal karst (Farr et al. 2016).

However, the subsurface karst geomorphology of the Brecon Beacons is much more extensive and dramatic, with some of the longest surveyed cavern systems in the world, including over 70 km of passages in the Ogof Draenen and Mynydd Llangatwg cave systems near Blaenavon (Simms and Farrant 2011) as well as the well-known tourist showcaves at Porth yr Ogof and Dan yr Ogof near Ystradfellte. Perhaps the most striking example of sub-surface karst geomorphology is the cavern system at Ogof Draenen, which comprise four linked, vertically-stacked, but genetically separate cave systems (Farrant et al. 2014), of which only the lowest is currently hydrologically active. Cave survey, sediment analysis and U-series dating of speleothem is utilised by Farrant et al. (2014) to infer a complex series of surface topography and drainage changes over the past ca. 0.5 Ma. In particular, massive influxes of sediment, sufficient to choke the upper passages of Ogof Draenen, are interpreted as flushes of glacifluvial sediments emplaced during the Anglian (MIS 12) glaciation, when the cave systems acted as subglacial meltwater 'underspill' systems. Critically, Farrant et al. (2014) infer substantial changes to the surface topography occurred in the Brecon Beacons during this early glaciation, and that glaciations subsequent to the Anglian have done little to further change the overall relief and regional scale geomorphology of the Brecon Beacons.

The findings of the research in the Ogof Draenen demonstrate the importance of sub-surface geomorphology as a key form of evidence to inform the development of reconstructions of long term landscape evolution, particularly where human impact on the landscape may have substantially altered surface geomorphology.

8: Anthropogenic Geomorphology

The geomorphology of the Brecon Beacons, as with most other areas of the British Isles, is a palimpsest landscape of shared natural and cultural elements associated with persistent human occupation and modification of the pre-existing, post-glacial environment. The climatic amelioration at the end of the LGIT is associated with the first arrival of Mesolithic hunter-gatherers into the Brecon Beacons, for whom the clearance of the wooded landscape of the region by fire provides the first cultural imprint on the landscape (Leighton 2012; Ramsay 2017). The impact of these, and subsequent waves of agricultural settlers in the early Neolithic through to the Iron Age, is recorded in the substantial decline in woodland cover, replaced by upland heather moorland and blanket bogs, permanently changing the vegetation, ecology and hydrology of the region (Leighton 2012). Expansion of agriculture, particularly of sheep grazing since the Medieval period, has seen a further transition from heather moorland to acid grassland. The indirect geomorphological legacy of pre-industrial human occupation of the Brecon Beacons is thus considerable and pervasive, in terms of accelerating erosion and sedimentation, particularly of soils, and changing the significance of chemical weathering through acidification. This perhaps marks the start of a transition towards an anthropocenic landscape whereby geomorphological processes are dominated by human agency.

The onset of extensive production of iron in South Wales during the mid-18th Century, utilising the rich iron and coal reserves located in the southern part of the Brecon Beacons (Morgan 2005; Ramsay 2017) represents some of the earliest global evidence of the Industrial Revolution. The direct anthropogeomorphological signature of large scale mining, particularly associated with the deposition of mining spoil tips, is considerable in the vicinity of Blaenavon, such that Haigh (1979) suggests the landscape is dominated by artificial landforms. The anthropogeomorphology of these spoil tips (Figure 10) reflects the evolution of different processes of sediment transport, from flat-topped fan and plateau tips resulting from use of rail wagons to move spoil, through to more recent ridge and conical tips deposited by aerial bucketways and conveyor belt systems. Whilst the large-scale extraction of coal and iron in South Wales has largely ended, the geomorphological legacy of such modification of the landscape is still recorded in monitoring of soil and water quality, erodibility and localised sediment transport (Haigh 1980; 2000).

9: Conclusions

The Brecon Beacons, defined by the boundary of the Brecon Beacons National Park, is dominated by the mainly Devonian Old Red Sandstone escarpment, which is itself part of a regional sequence that Sedgewick and Murchison used to define and establish Earth's history over the past ~500 million years. The main escarpment, split into four main upland areas, offers a wealth of glacial, periglacial and paraglacial evidence of the geomorphological impact of Late Quaternary environmental change, and offers the most southerly evidence of glaciation of the British Isles during the Younger Dryas. Whilst there is ongoing tension between researchers with regard the significance of Quaternary glaciation in shaping the surface landscape of the Brecon Beacons, it is perhaps the hidden record of subterranean karst in the south of the region that is yielding the most exciting and tantalising information about the long-term landscape evolution of the region. Whilst post-glacial landscape development in the Brecon Beacons has perhaps been less dramatic, the pervasive impact of humans as a geomorphological agent are particularly well represented in the region since pre-historic times, with localities such as Blaenavon illustrating the significance, or even the dominance of humans over the physical landscape.

Figures

Figure 1: Map of the Brecon Beacons: Boundary of the national park overlain on Digimap shaded relief model. Main settlements, mountain areas and river catchments are illustrated, as well as key sites mentioned in the text. Digital Terrain Map image licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Contains Ordnance Survey data © Crown copyright and database right.

Figure 2: Physiography of the Brecon Beacons. a) View of the north-facing escarpment, looking westwards toward Cribyn and Pen y Fan. Moraines associated with former mountain glaciation during the LGIT are typically found below these steep scarps, where local microclimates (enhanced shading from solar insolation, adjacent plateau areas to contribute accumulation by snowblow) permit. b) More subdued topography on the south-facing dip slope of the Brecon Beacons, looking northwards to the peaks of Corn Du and Pen y Fan. Extensive plateau surfaces with only moderate fluvial and glacial incision offer a significant contrast with the dramatic north-facing slopes.

Figure 3: Geological map and column (© Brecon Beacons NPA, Crown copyright 100019322. 2010). Source: Brecon Beacons National Park [online]. Available at: http://www.breconbeacons.org/geology.

Figure 4: Synthesis of the palaeoenvironmental record from Llanilid (adapted from Walker et al., 2003), showing the dramatic temperature shifts (derived from *coleoptera* mutual climatic range data), vegetation and ecology of South Wales and the Brecon Beacons associated with the Last Glacial-Interglacial Transition (LGIT).

Figure 5: Photograph of valley head and moraine at Cwm Llwch (photograph by C. A. Lewis), suggested to illustrate flow of mid-Wales ice southwards, up the valley, overtopping the Brecon Beacons. Number 2 shows features interpreted by Janssen and Glasser (2008)

as glacial lineations and feature 3 is inferred to have been a moraine formed during ice flow into valley head. This interpretation is robustly rejected by Shakesby and Matthews (2009), who demonstrate that features 2 and 3 represent Younger Dryas/Loch Lomond Stadial mountain glaciation. The lake is approximately 100 m across (image from from Jansson and Glasser, 2008)

Figure 6: Retreat stages and changing glacifluvial landsystem for the deglaciation of the Usk Valley subsequent to the LGM (Coleman, 2007). A total of 28 stages of ice retreat and readvance are identified from sedimentological and geomorphological evidence. Bold black lines mark moraines. Active glacier retreat is marked by diagonal lines, and rapid wastage or stagnation is marked by cross-hatches.

Figure 7: Upland geomorphology associated with the LGIT. a) Long ridge running north-south beneath Fan Hir. This feature continues to be of interest, having been interpreted as a pronival rampart or terminal moraine of Younger Dryas age and even as a lateral moraine emplaced during the LGM. The consensus is that this feature is a Younger Dryas terminal moraine. b) Series of ridges within Cwm Oergwm interpreted by Coleman and Carr (2008) as terminal moraines associated with the maximum (feature 1) retreat phases (features 2) of a Younger Dryas glacier, and a contemporaneous pronival rampart (feature 3). c) Complex of ridges within Cwm Sychlwch, beneath Fan Foel, Mynydd Du. Note also the well-developed talus accumulations described by Curry and Morris (2004).

Figure 8: Un-named and previously unreported rock slope failure beneath the Waun Rydd plateau, central Brecon Beacons. Image taken looking northeast from Craig y Fan Ddu. It is evident that large-scale paraglacial mass-movements are common in the region, albeit not commonly reported.

Figure 9: Fragment of limestone pavement, Garwnant Fawr, Taff Valley. Image taken looking north. To the southwest of this pavement, dolines and sink-holes are common to the summit of Cadair Fawr.

Figure 10: Aerial photo of fan-type and conical spoil tips at Garn-yr-erw, northwest of Blaenavon. The entire landscape of the upper Blaenau valley and those surrounding it are dominated by such artificial landforms, relating to the extraction of coal and iron in the valleys extending south of the Brecon Beacons. Aerial imagery © Getmapping Plc, with Ordnance Survey grid © Crown copyright and database right.

References

Barclay WJ, Davies JR, Humpage AJ, Waters RA, Wilby PR, Williams M, Wilson D (2005) *Geology of the Brecon district – a brief explanation of the geological map.* Sheet Explanation of the British Geological Survey. 1:50 000 Sheet 213 Brecon (England and Wales). 38pp.

Bickerdike HL, Evans DJA, Ó Cofaigh C, Stokes CR (2016) The glacial geomorphology of the Loch Lomond Stadial in Britain: a map and geographic information system resource of published evidence. *Journal of Maps*, *12*(5), 1178–1186.

Bickerdike HL, Evans DJA, Stokes CR, Ó Cofaigh C (2018) The glacial geomorphology of the Loch Lomond (Younger Dryas) Stadial in Britain: a review. *Journal of Quaternary Science*, 33(1), 1–54.

Bevins RE, White S.C, Robinson D (1996) The South Wales Coalfield: Low grade metamorphism in a foreland basin setting? *Geological Magazine*, 133(6), 739–749.

Blieck A, Elliott DK (2017) Pteraspidomorphs (Vertebrata), the Old Red Sandstone, and the special case of the Brecon Beacons National Park, Wales, U.K. *Proceedings of the Geologists' Association*, 128(3), 438–446.

Bowen DQ (1973) The Pleistocene history of Wales and the borderland. *Geological Journal* 8, 207-224.

Carr S (2001). A glaciological approach for the discrimination of Loch Lomond Stadial glacial landforms in the Brecon Beacons, South Wales. *Proceedings of the Geologists' Association*, *112*(3), 253–262,

Carr SJ, Coleman CG, Evans DJA, Porter EM, Rea BR. (2007) An alternative interpretation of Craig y Fro based on mass-balance and radiation modelling . In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) *Quaternary of the Brecon Beacons: Field Guide*. Quaternary Research Association, London, 120-127.

Carr SJ, Lukas S, Mills SC (2010). Glacier reconstruction and mass-balance modelling as a geomorphic and palaeoclimatic tool. *Earth Surface Processes and Landforms*, *35*(9) 1103-1115.

Cocks LRM, Woodcock NH, Rickards RB, Temple JT, Lane RD (1984) The Llandovery Series of the type area. *Bulletin of the British Museum (Natural History), Geology* 38, 131-182

Coleman CG (2007) *Landscape interaction with climate change: The Lateglacial of the Usk Valley, South Wales*. Unpublished PhD thesis, Oxford Brookes University. 453pp

Coleman CG, Carr SJ (2007) Deglaciation of the middle Usk valley and the role of tributary glaciers. In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) *Quaternary of the Brecon Beacons: Field Guide*. Quaternary Research Association, London, 201-211.

Coleman CG, Carr SJ (2008). Complex relationships between younger dryas glacial, periglacial and paraglacial landforms, Brecon Beacons, South Wales. *Proceedings of the Geologists' Association*, 119(3–4), 259–276.

Coleman CG, Carr SJ, Parker AG (2009) Modelling topoclimatic controls on palaeoglaciers: implications for inferring palaeoclimate from geomorphic evidence. *Quaternary Science Reviews* 28, 249-259.

Curry AM, Morris CJ (2004). Lateglacial and Holocene talus slope development and rockwall retreat on Mynydd Du , UK. *Geomorphology*, *58*, 85–106.

Edwards D, Richardson JB (2004) Silurian and Lower Devonian plant assemblages from the Anglo-Welsh Basin: a palaeobotanical and palynological synthesis. *Geological Journal* 39, 375-402.

Ellis-Gruffydd ID (1977) Late Devensian glaciation in the upper Usk basin. *Cambria*, 4, 46-55.

Environment Agency (1998) *Rural Usk LEAP Consultation Report*. Environment Agency Wales, Cardiff, 41pp.

Evans DJA (2016). Landscapes at the Periphery of Glacierization – Retrospect and Prospect. *Scottish Geographical Journal*, *2541*(March), 1–24.

Farr G, Naughton O, Sadasivam S, Kendall R, Saville J, Bowring A (2016) The hydrology of an ephemerally flooded doline: Pwll-y-Felin, South Wales, UK. *Cave and Karst Science* 43, 41-47

Farrant AR, Smith CJM, Noble SR, Simms MJ, Richards DA (2014) Speleogenetic evidence for a pre-Devensian glaciation in the Brecon Beacons, South Wales, UK. *Journal of Quaternary Science* 29, 815-826.

Gunn J (2012) *Assessment of Mynydd Langynidr as a potential Site of Special Scientific Interest. Limestone Research and Consultancy Ltd. Report 2012/13*. Commissioned by the Countryside Council for Wales, Contract Number ES01700. 35pp

Haigh MJ (1979) Ground retreat and slope evolution on plateau-type colliery spoil mounds at Blaenavon, Gwent. *Transactions of the Institute of British Geographers* 4, 321-328.

Haigh MJ (1980). Slope retreat and gullying on revegetated surface-mine dumps, Waun Hoscyn, Gwent. *Earth Surface Processes* 5, 79-82.

Haigh MJ (2000). Soil stewardship on reclaimed coal-lands. In: Haigh MJ (ed). *Reclaimed Land: Erosion Control, Soils & Ecology*. Balkema, Rotterdam 165-274

Howells MF (2007) *British Regional Geology: Wales.* British Geological Survey, Keyworth, 230pp.

Humpage AJ (2007) The bedrock geology of the Brecon Beacons and Usk Valley. In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) *Quaternary of the Brecon Beacons: Field Guide.* Quaternary Research Association, London, 2-13.

Jansson KN, Glasser NF (2008) Modification of peripheral mountain ranges by former ice sheets: the Brecon Beacons, southern UK. *Geomorphology* 97, 178-189.

Kendall RS (2017). The Old Red Sandstone of Britain and Ireland — a review. *Proceedings of the Geologists' Association*, 128(3), 409–421.

Larsen S, Vaughan IP, Ormerod SJ (2009) Scale-dependent effects of fine sediments on temperate headwater invertebrates. *Freshwater Biology* 54, 203-219.

Leighton D (2012) *The Western Brecon Beacons. The Archaeology of Mynydd Du and Fforest Fawr.* Royal Commission on the Ancient and Historical Monuments of Wales, 2nd Edition. Cambrian Printers, Cardiff, 180pp.

Lewis CA, Thomas GSP (2005) The Upper Wye and Usk Regions. In Lewis CA, Richards, AE (eds.) *The Glaciations of Wales and Adjacent Areas*. Logaston Press, Herefordshire, Chapter 8, 101-128.

Marriott SB, Hillier RD (2014). Fluvial style in the Lower Old Red Sandstone: Examples from southwest Wales, UK. *Proceedings of the Geologists' Association*, 125(5–6), 534–547.

Morgan P (2005) *Wales: an illustrated history (2nd Edition)*. The History Press, Stroud, 360pp.

Murchison (1839)

Owen G (1995). Senni Beds of the Devonian Old Red Sandstone, Dyfed, Wales: anatomy of a semi-arid floodplain. *Sedimentary Geology*, 95(3–4), 221–235.

Owen G (2017). Origin and significance of soft-sediment deformation in the Old Red Sandstone of central South Wales, UK. *Proceedings of the Geologists' Association*, 128(3), 422–430.

Patton H, Hubbard A, Glasser NF, Bradwell T, Golledge NR (2013). The last Welsh Ice Cap: Part 1 - Modelling its evolution, sensitivity and associated climate. *Boreas*, *42*(3), 471–490.

Palmer AP, Rose J, Lowe JJ, Walker MJC(2008). Annually laminated Late Pleistocene sediments from Llangorse Lake, South Wales, UK: a chronology for the pattern of ice wastage. *Proceedings of the Geologists' Association*, 119(3–4), 245–258.

Ramsay T (2017). Fforest Fawr Geopark—a UNESCO Global Geopark distinguished by its geological, industrial and cultural heritage. *Proceedings of the Geologists' Association*, 128(3), 500–509.

Sahlin EAU, Glasser NF, Jansson KN, Hambrey, MJ (2009). Connectivity analyses of valley patterns indicate preservation of a preglacial fluvial valley system in the Dyfi basin, Wales. *Proceedings of the Geologists' Association*, 120(4), 245–255.

Shakesby RA (2002) *Classic Landforms of the Brecon Beacons (Classic Landforms Guide 13)*. Geographical Association, Sheffield, 48 pp.

Shakesby RA, Matthews JA (1996) Glacial activity and paraglacial landsliding in the Devensian Lateglacial: evidence from Craig Cerrig-gleisiad and Fan Dringarth, Fforest Fawr (Brecon Beacons), South Wales. *Geological Journal* 31, 143-157.

Shakesby RA, Coleman CG, Carr SJ (2007) Quaternary Landscape Evolution. In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) *Quaternary of the Brecon Beacons: Field Guide.* Quaternary Research Association, London, 14-22.

Shakesby RA, Matthews JA (2007) Craig y Fro: origin of the depositional features. In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) *Quaternary of the Brecon Beacons: Field Guide.* Quaternary Research Association, London, 114-119.

Shakesby RA, Matthews JA (2009) Comments on Jansson, K.N., and Glasser, N.F. (2008) Modification of peripheral mountain ranges by former ice sheets: the Brecon Beacons, southern UK. Geomorphology 97, 178-189. *Geomorphology* 110, 217-225.

Simms MJ, Farrant AR (2011) Landscape evolution in southeast Wales; evidence from aquifer geometry and surface topography associated with Ogof Draenen cave system. *Cave and Karst Science* 38, 7-16/

Symonds WS (1872) Records of the Rocks: or notes on the geology, natural history and antiquities of North and South Wales, Devon and Cornwall. John Murray, London, 433pp.

Thomas GSP (1997) Geomorphology of the Middle Usk Valley. In Lewis SG, Maddy D. (eds). *The Quaternary of the South Midlands and the Welsh Marches: Field Guide*, Quaternary Research Association, Cambridge, 49- 60.

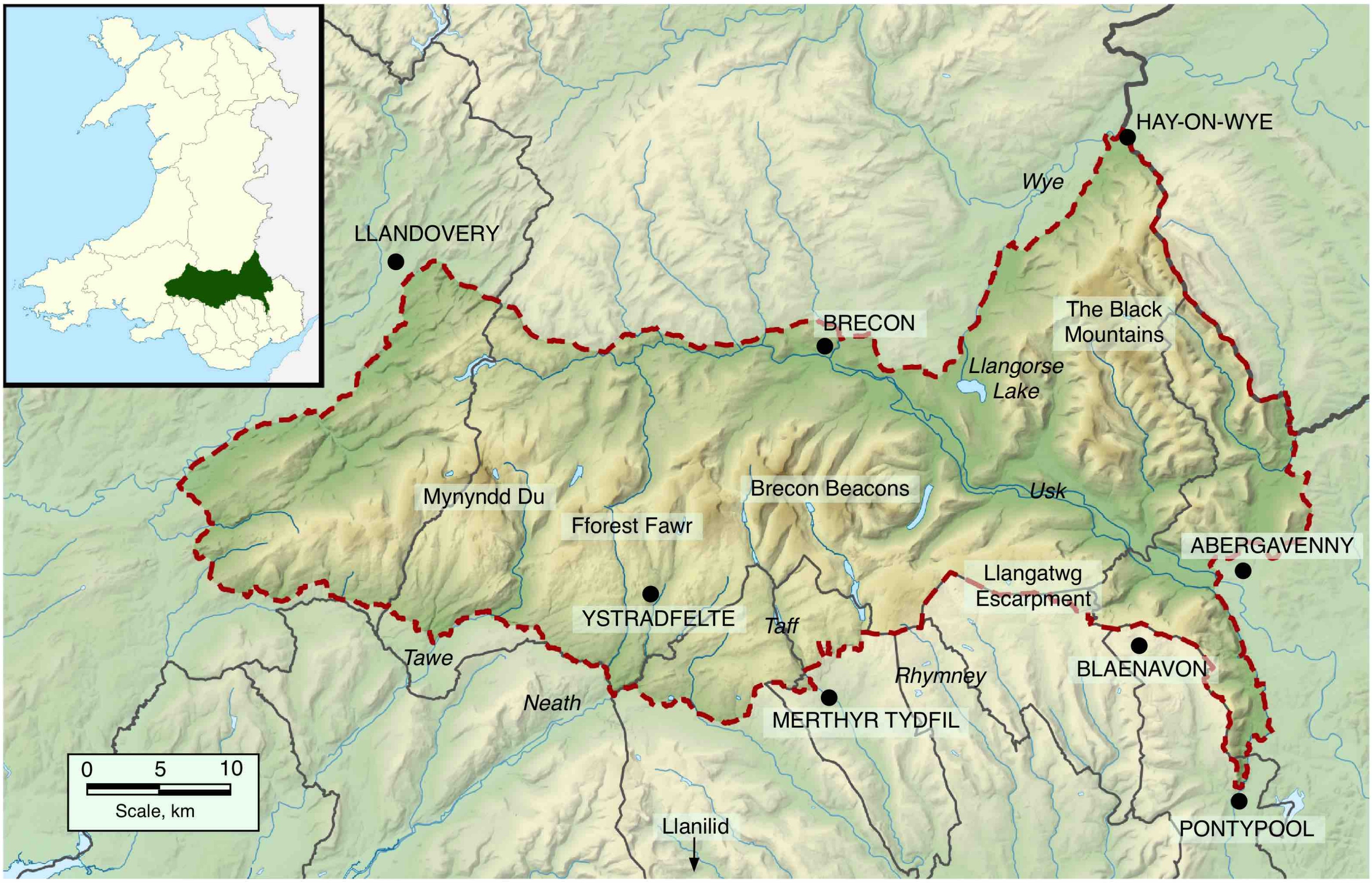
Thomas GSP, Humpage, AJ (2007) The Glacial geomorphology of the lower and middle Usk valley. In Carr SJ, Coleman CG, Humpage AJ, Shakesby RA (eds.) Quaternary of the Brecon Beacons: Field Guide. Quaternary Research Association, London, 161-173.

Walker MJC (1982) The Lateglacial and Early Flandrian deposits at Traeth Mawr, Brecon Beacons, South Wales. New Phytologist 90, 177-194.

Walker MJC, Coope GR, Sheldrick C., Turney CSM, Lowe JJ, Blockley SPE, Harkness DD (2003) Devensian Lateglacial environmental changes in Britain: a multi-proxy record from Llanilid, South Wales, UK. *Quaternary Science Reviews* 22, 475-520.

Wellman CH, Thomas RG, Edwards D, Kenrick P (1998). The Cosheston Group (Lower Old Red Sandstone) in southwest Wales: Age, correlation and palaeobotanical significance. *Geological Magazine*, 135(3), 397–412.

Wright VP, Vanstone SD (2001) Onset of Late Palaeozoic glacio-eustasy and evolving climates of low latitude areas: a synthesis of current understanding. *Journal of the Geological Society, London* 158, 579-582.



HAY-ON-WYE
Wye
LLANDOVERY
BRECON
The Black
Mountains
Llangorse
Lake
Mynyndd Du
Brecon Beacons
Usk
Fforest Fawr
ABERGAVENNY
Llangatwg
Escarpment
YSTRADFELTE
Taff
BLAENAVON
Tawe
Rhymney
Neath
MERTHYR TYDFIL
0
5
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Scale, km
Llanilid
PONTYPOOL

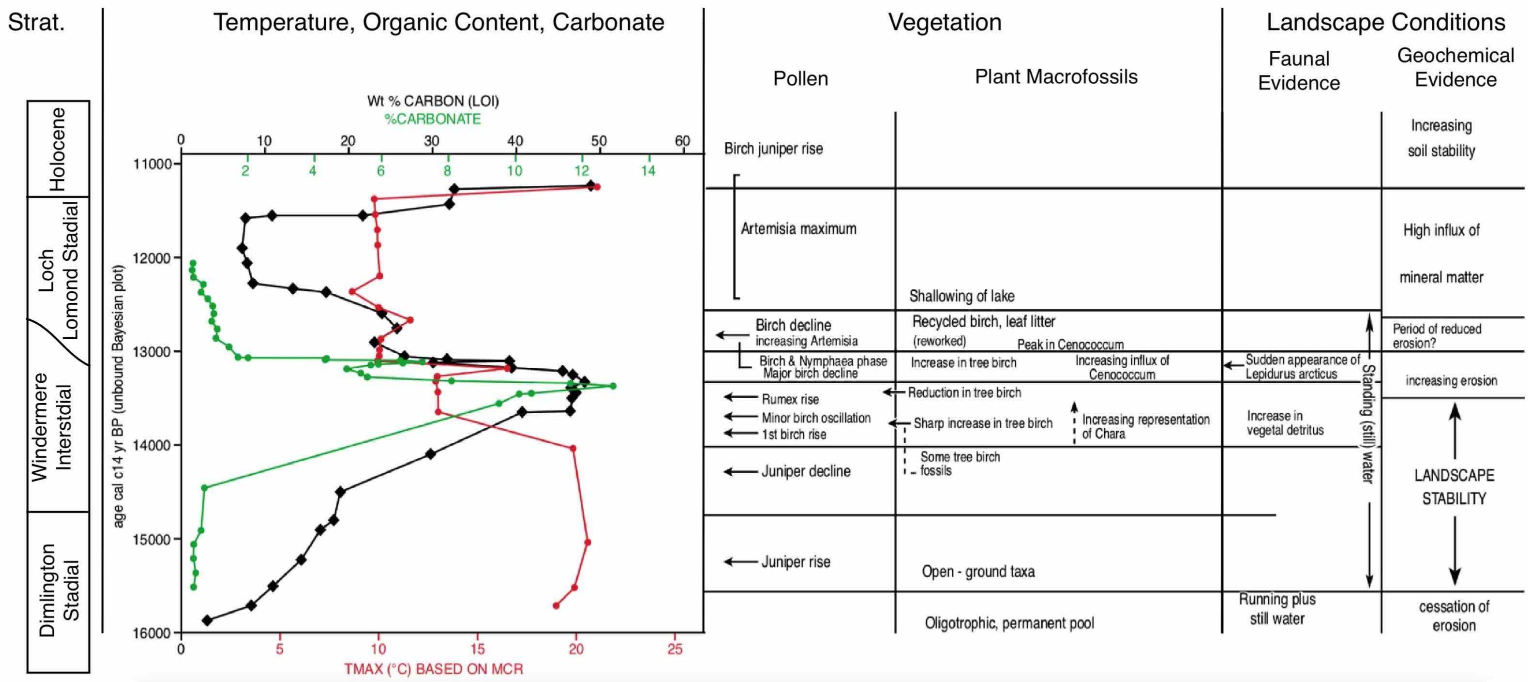
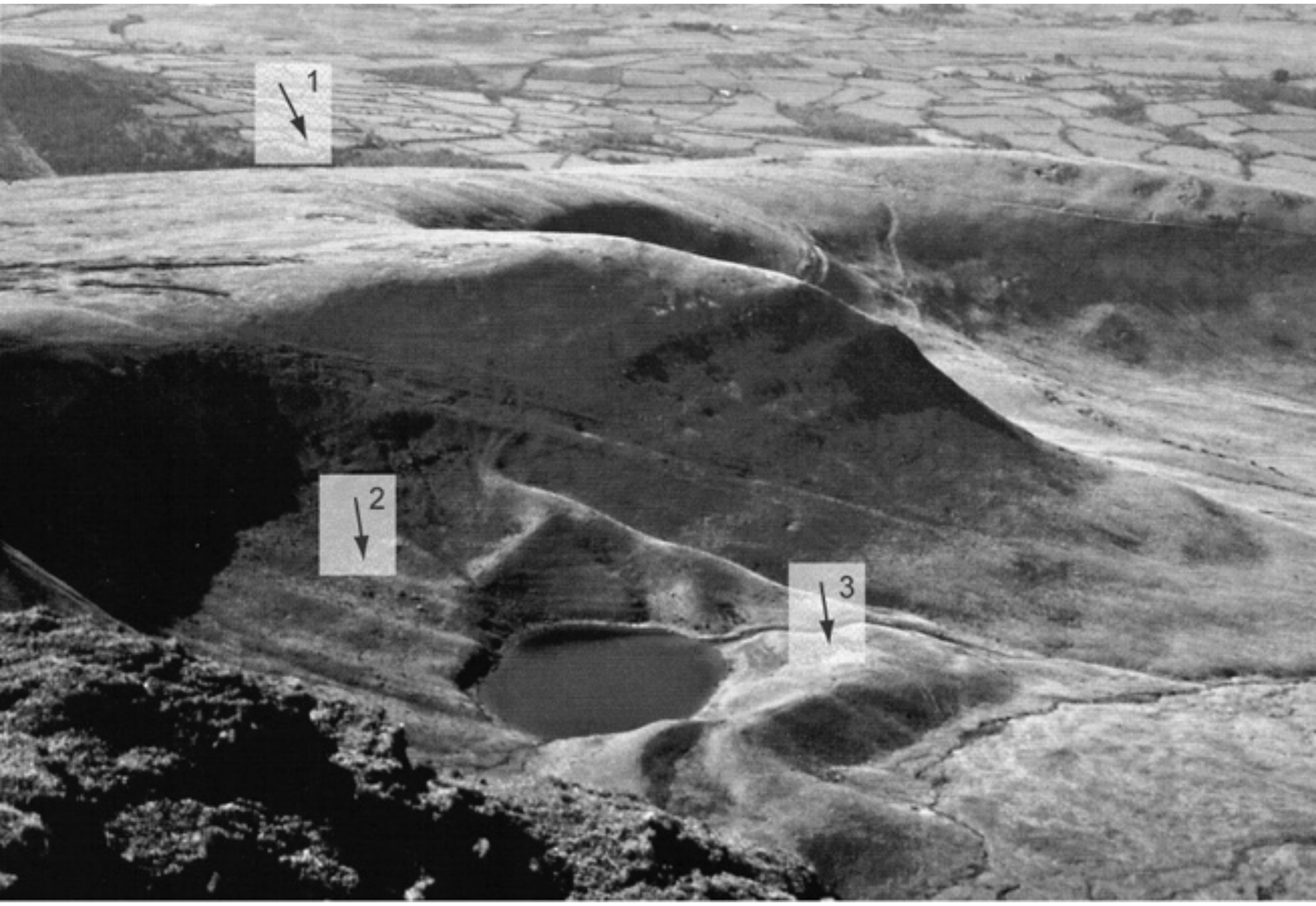

Strat.
Temperature, Organic Content, Carbonate
Vegetation
Landscape Conditions
Holocene
Loch Lomond Stadial
Windermere Interstdial
Dimlington Stadial
Wt % CARBON (LOI)
%CARBONATE
age cal c14 yr BP (unbound Bayesian plot)
TMAX (°C) BASED ON MCR
Pollen
Plant Macrofossils
Faunal Evidence
Geochemical Evidence
Birch juniper rise
Artemisia maximum
Birch decline
increasing Artemisia
Birch & Nymphaea phase
Major birch decline
Rumex rise
Minor birch oscillation
1st birch rise
Juniper decline
Juniper rise
Shallowing of lake
Recycled birch, leaf litter
(reworked)
Peak in Cenococcum
Increase in tree birch
Increasing influx of Cenococcum
Reduction in tree birch
Sharp increase in tree birch
Increasing representation of Chara
Some tree birch fossils
Open - ground taxa
Oligotrophic, permanent pool
Sudden appearance of Lepidurus arcticus
Increase in vegetal detritus
Standing (still) water
Running plus still water
Increasing soil stability
High influx of mineral matter
Period of reduced erosion?
increasing erosion
LANDSCAPE STABILITY
cessation of erosion

Figure 4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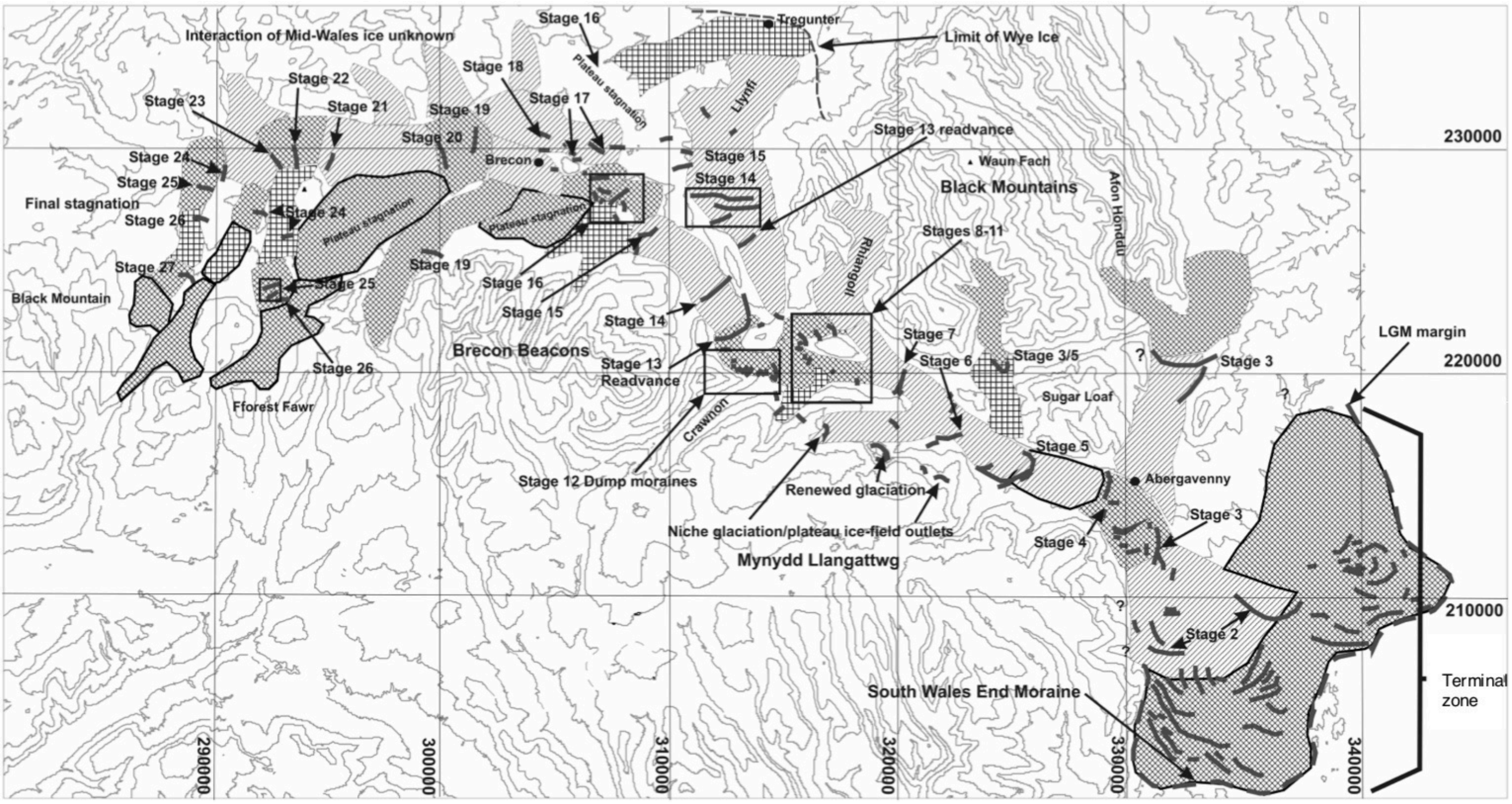
Interaction of Mid-Wales ice unknown
Stage 16
Tregunter
Limit of Wye Ice
Plateau stagnation
Stage 18
Stage 22
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Stage 19
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Stage 13 readvance
Stage 20
230000
Stage 24
Brecon
Stage 15
Waun Fach
Stage 25
Stage 14
Black Mountains
Final stagnation
Stage 24
Plateau stagnation
Plateau stagnation
Stage 26
Afon Honddu
Rhiangoll
Stages 8-11
Stage 27
Stage 19
Stage 25
Stage 16
Black Mountain
Stage 15
Stage 14
LGM margin
Stage 7
Brecon Beacons
Stage 3/5
Stage 6
?
Stage 3
Stage 13
Readvance
220000
Stage 26
Sugar Loaf
Crawnon
Fforest Fawr
Stage 5
Abergavenny
Stage 12 Dump moraines
Renewed glaciation
Niche glaciation/plateau ice-field outlets
Stage 3
Stage 4
Mynydd Llangattwg
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Stage 2
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290000
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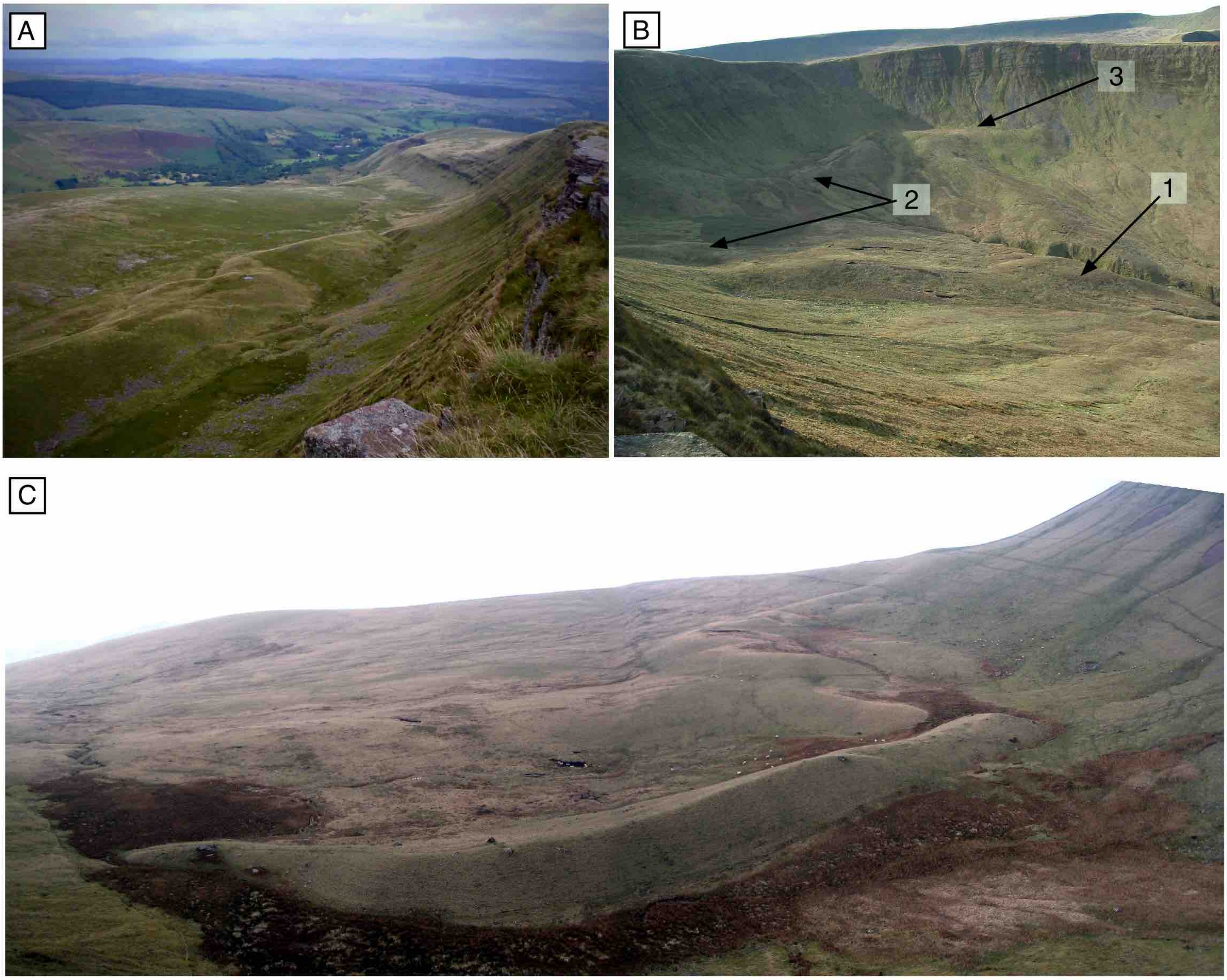
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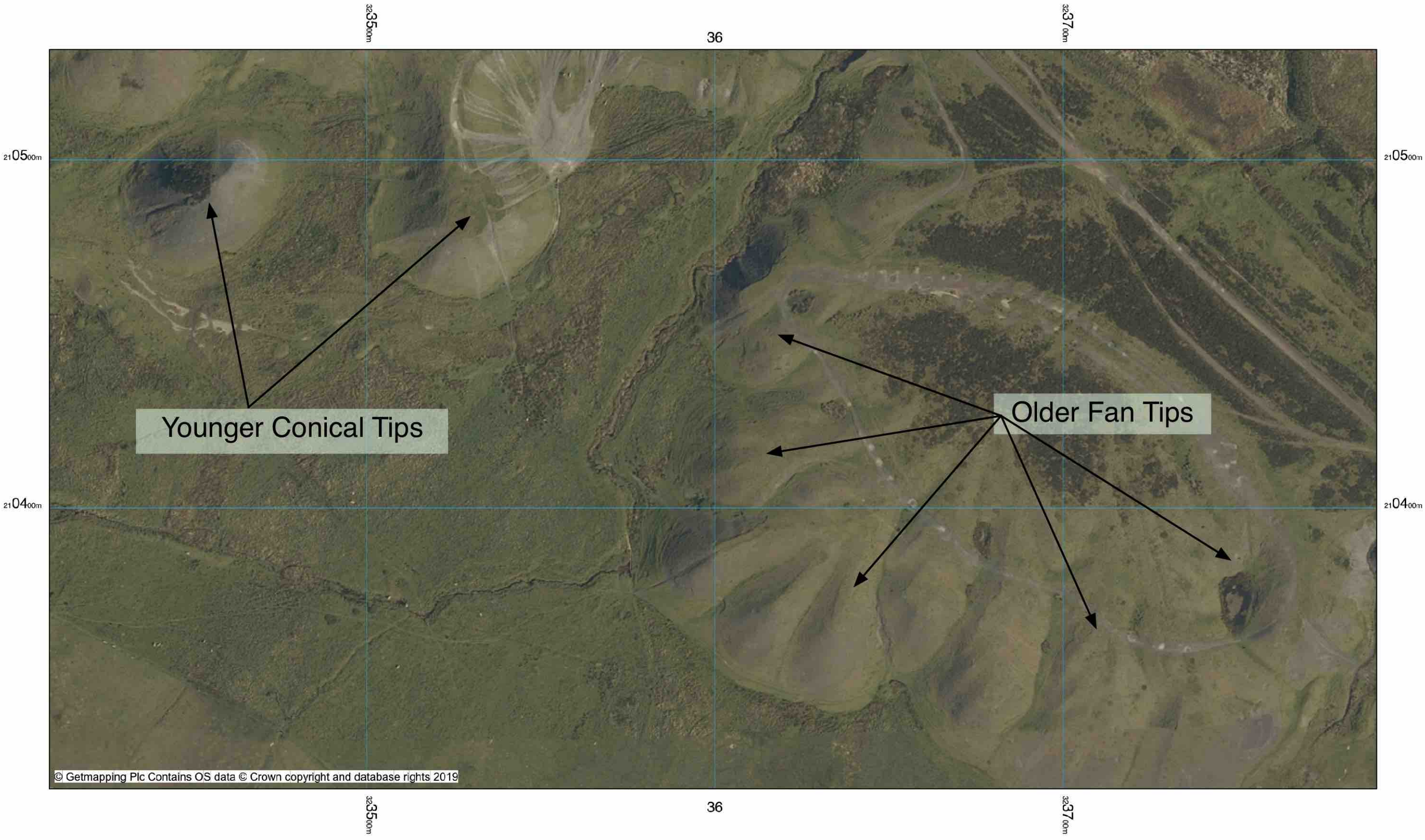
Scar exposed by Rock Slope Failure
Rock Slope Failure



323500m
36
323700m
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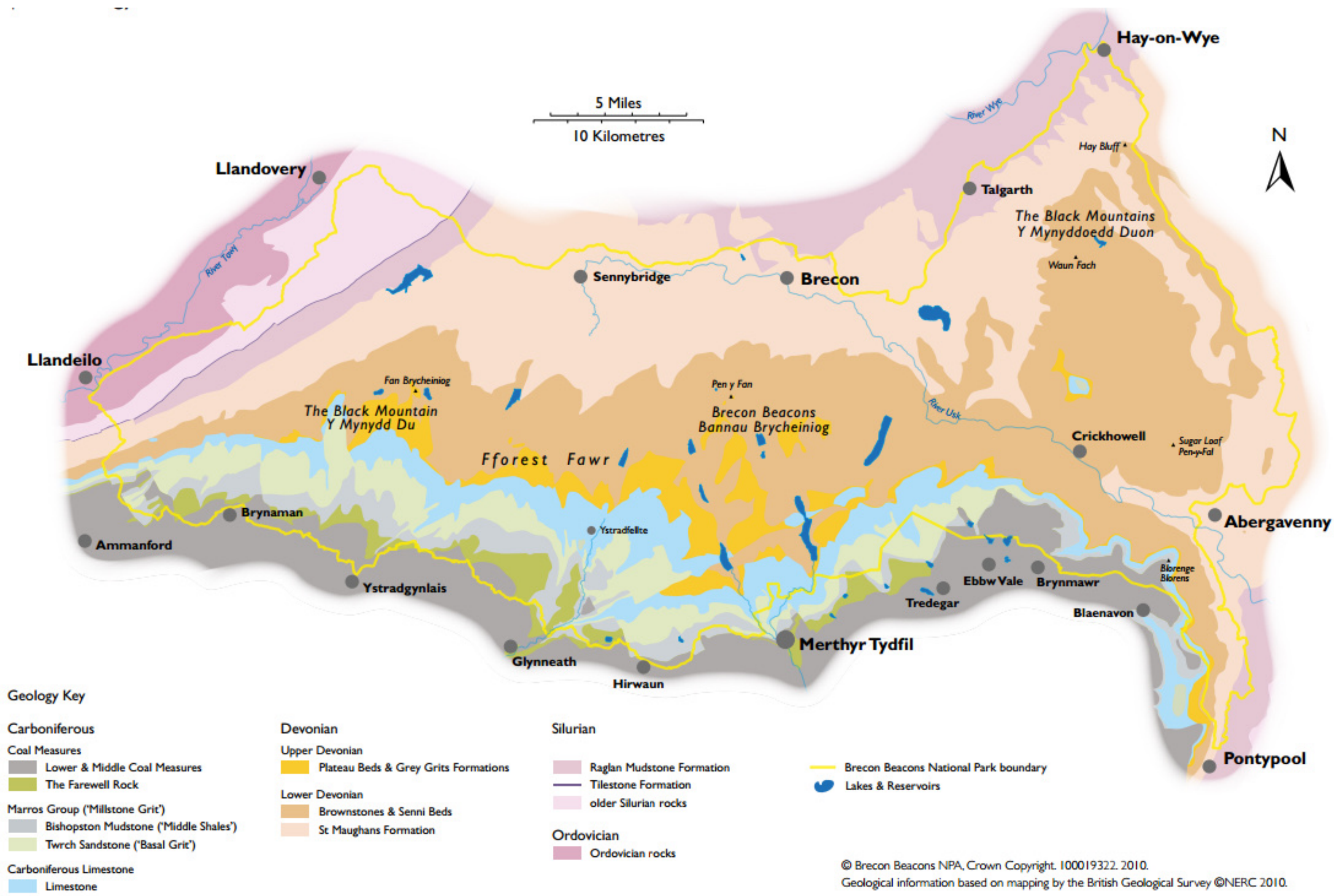
210400m
Younger Conical Tips
Older Fan Tips
© Getmapping Plc Contains OS data © Crown copyright and database rights 2019


5 Miles
10 Kilometres
N
Hay-on-Wye
River Wye
Hay Bluff
Llandovery
Talgarth
River Tywi
The Black Mountains
Y Mynyddoedd Duon
Waun Fach
Sennybridge
Brecon
Llandeilo
Fan Brycheiniog
The Black Mountain
Y Mynydd Du
Pen y Fan
Brecon Beacons
Bannau Brycheiniog
River Usk
Crickhowell
Sugar Loaf
Pen-y-Fal
Fforest Fawr
Abergavenny
Brynaman
Ammanford
Ystradfellte
Blorenge
Blorens
Ebbw Vale
Brynmawr
Ystradgynlais
Tredegar
Blaenavon
Glynneath
Merthyr Tydfil
Hirwaun
Pontypool
Geology Key
Carboniferous
Coal Measures
Lower & Middle Coal Measures
The Farewell Rock
Marros Group ('Millstone Grit')
Bishopston Mudstone ('Middle Shales')
Twrch Sandstone ('Basal Grit')
Carboniferous Limestone
Limestone
Devonian
Upper Devonian
Plateau Beds & Grey Grits Formations
Lower Devonian
Brownstones & Senni Beds
St Maughans Formation
Silurian
Raglan Mudstone Formation
Tilestone Formation
older Silurian rocks
Ordovician
Ordovician rocks
Brecon Beacons National Park boundary
Lakes & Reservoirs