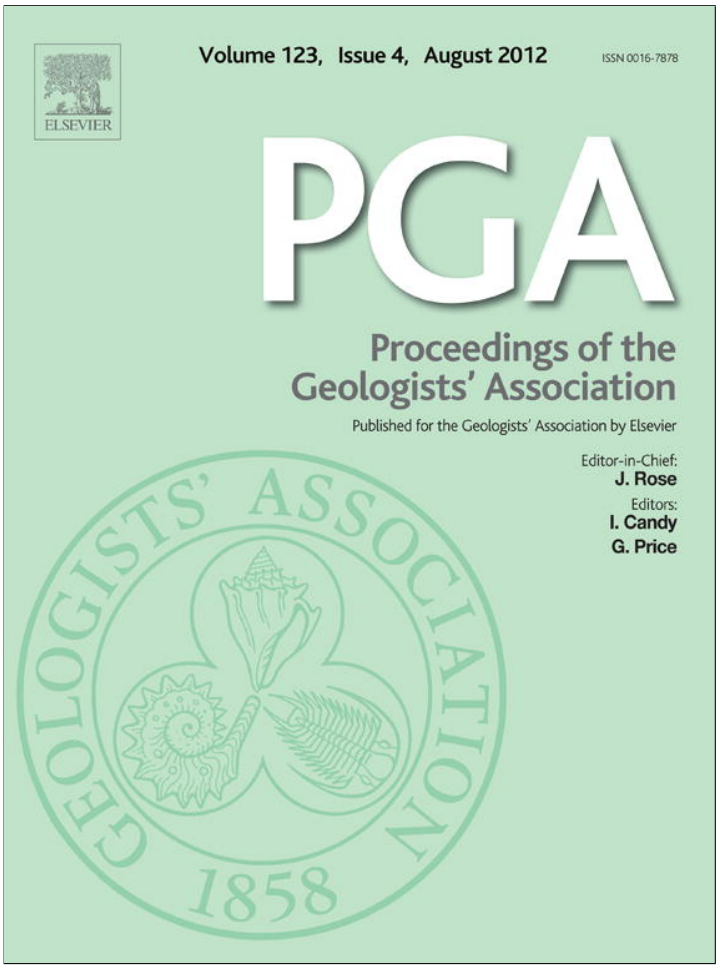

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Buckland, Darwin and the attempted recognition of an Ice Age in Wales, 1837–1842☆

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ABSTRACT

The concept of a former Ice Age was introduced to Britain by Agassiz, first, through Buckland in 1838 and then by his tour of Britain in 1840. The reception was mixed due to the Iceberg theory, which was held by Darwin, Lyell and Murchison and others. After 1840, Murchison looked for a compromise between Glaciers and Icebergs and this came in the work of Bowman and Buckland in 1841 and Darwin during 1842 in Snowdonia and the Marches. There were three geologists visiting Wales, all familiar with glaciation; Bowman failed to find any glaciation and Buckland and Darwin, who identified both alpine-glacier and "ice-berg" glaciation and reinterpreted their previous work. Thus both a Catastrophist and a Uniformitarian came to similar conclusions, but it was several decades before a consensus was found, which was delayed by Darwin's emphasis on submergence.

1. Introduction

Evidences of former glaciation in Snowdonia and North Wales were discovered in the two years following Agassiz's visit to Britain in 1840 (Agassiz, 1842; Davies, 1968, 1969; North, 1943), when, along with Buckland (1842a) and Lyell, he made known the basic features of former glaciation in Scotland and Northern England. By the end of 1840 Darwin's interpretation of the "Parallel Roads" of Glen Roy (Darwin, 1839a) was under severe question and he wrote to Buckland between November 1840 and February 1841, "*I should much like to hear yours' and Agassiz's opinion on the parallel roads, though I guess its outline*" (Burkhardt et al., 2002, pp. 356–357).

The work on supposed glaciation in North Wales and the Marches of John Eddowes Bowman (1785–1841)[1] (ODNB, vol. 6, 977) and Buckland in 1841, and Darwin in 1842 (the centre-piece of Darwin's work was in Cwm Idwal and Nant Francon, Fig. 1), along with Murchison's fleeting visit, has an importance beyond a purely local interest for two main reasons. First, it highlights the equivocal nature of glacial phenomena as shown by Bowman's scepticism of former glaciation, later shared by Murchison. Secondly, both Buckland and Darwin realised that alpine or terrestrial glaciation was insufficient to explain all glacial features, and each gave a different interpretation of the drift deposits found in an arc from Shrewsbury through the northern end of the Vale of Clwyd to the coast near Caernarfon. This opened the way for a rapprochement between the terrestrial glaciation of Agassiz, which emphasised that glaciers and ice-sheets emanated from mountains and the Iceberg Hypothesis, which explained erratic blocks and other features by transportation by icebergs. The latter was Darwin's explanation of glacial erratic at the upper reaches of the Santa Cruz river of Patagonia some 60 miles from the Corderilla (C.R. Darwin, 1839, vol. 1, p. 124, 279ff).[2] However his observations of glaciers descending to the sea and calving in the Straits of Magellan seemed to confirm this hypothesis.

The discovery of evidence for former glaciation in Wales may conveniently be considered to have begun at Neuchâtel in 1838, although one must consider observations going back another 20 years. First, Buckland toured the Oberland in the autumn and like Agassiz and Charpentier before him, Buckland was slow to be convinced of a former Ice Age (Rupke, 99). Secondly, in the autumn of 1838 Darwin added an appendix on to the delayed manuscript of

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[1] John Eddowes Bowman (1785–1841) a businessman and banker from Wrexham and Manchester was a competent, amateur, geologist and botanist, who had previously worked on the Silurian in Wales. There is a monument to him in the Unitarian chapel in Shrewsbury opposite that of Darwin.

[2] Dr. Robert Wesson suggested to me that if Darwin continued up the Santa Cruz he may have not adopted the Iceberg Hypothesis.

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Fig. 1. The central focus of Darwin's glacial work. The view from the summit of the Glyderau looking down the classic u-shaped valley of Nant Francon. The lake in the middle ground is Llyn Idwal.

his *Journal of Researches*, in which he argued that an arm of the sea went up southward of Neuchatel and that the erratics on the Jura had been transported by icebergs. In the appendix, which was omitted in the 2nd edition of 1845, he made an explicit rejection of Agassiz's idea of a massive continental glaciations (C.R. Darwin, 1839, pp. 617–625).

In the years before 1841 many features, later to be recognised as glacial in origin, had been observed in Britain. The layers of drift covering much of Britain were seen as diluvium and regarded as the deposits of the last great catastrophe – the Noachian Deluge. The rejection of diluvialism, or some kind of catastrophism and the Deluge has been studied but often in an exaggerated way. What is overlooked is that many geologists were not convinced by fluvialist, or uniformitarian arguments and this is best illustrated by de la Beche's water-colour cartoon of 1831 (Fig. 2) when he drew little Frank Buckland piddling at the head of a glacial valley to the admiration of his nanny for producing such a large valley. De la Beche's serious point was that little rivers could not make such large valleys, no matter how long they operated. By selecting a glacial valley, de la Beche highlighted a major problem of Lyell's uniformitarianism.

The relationship of the Deluge, diluvialism and the Ice Age has recently been discussed by Rudwick (2009). Erratic boulders were well known and in his *Autobiography* Darwin mentions the Bellstone, a one metre erratic in the centre of Shrewsbury. The aged Richard Cotton (d1839) told him, in about 1822, that it had come from Cumberland and, "*solemnly assured me that the world would come to an end before anyone would be able to explain how this stone came where it now lay*" (Darwin and Huxley, 1983, p. 28). This apocalyptic statement reflects the popularity of Millenarianism and biblical prophecy at that time.

At about the same time Buckland was gathering material for his treatise *Reliquiae Diluvianae*, which as well as describing many cave deposits presented striae and erratics as "*effects of diluvial action*". He reported some "*diluvial scratches and scorings on the surface of slate-rock*" to the east of Betws-y-Coed below Dinas Mawr, which had been observed by Thomas Underwood (1772–1835) a painter and geologist with a fascinating life history (ODNB, vol. 55, p. 900). Underwood made several sketches of these and similar "diluvial scratches" in the Llanberis Pass (Buckland, 1823, p. 206) and near Edinburgh for an intended second volume of his Reliquiae. Most of these sketches refer to "Diluvial action". Several of the prints are to found in the Buckland Papers at Oxford,[3] but the two annotated prints of the Conwy Valley near Betws y Coed are only to be found at the University of Neuchâtel. This is because in 1841 Buckland re-interpreted outcrops as glacial, which he had previously designated as diluvial, and Buckland later referred to these sketches of the striae in the Conwy valley (Buckland, 1842c). At Neuchâtel Underwood's sketches sometimes have the word "diluvial" replaced by "glacier" or "glacial" but are not in Buckland's illegible hand (Fig. 3) (Archives de Louis Agassiz, 35/1.1).

Buckland revisited these "*flutings and striae*" in the upper Conwy valley in October 1841and re-interpreted them as of glacial origin (Buckland, 1842c). These striae were uncovered by road-building before 1815 and have probably been removed by further road-widening.[4] It is also highly likely that Buckland re-intrepreted outcrops as glacial, which he had previously designated as diluvial. At Neuchâtel there are also sketches of Craig Leath quarry and Calton Hill, near Edinburgh, similarly annotated to allow a glacial rather than diluvial interpretation. In 1831 Sedgwick commented on the skull-shaped rocks near Llanberis

[3] Sketchs, Buckland Papers, Glacial Theory File, Buckland Files, Oxford University Museum.

[4] From the descriptions of both Buckland and Bowman these ought to be close to the junction of the B4406 and the A5 by the Conwy Falls.

Fig. 2. de la Beche's anti-uniformitarian cartoon of 1831 (Haile, 1997) (Martin Rudwick reckons that the valley in de la Beche's cartoon is probably in the Auvergne).

(Adam Sedgwick Journal no. XXI, 21 August 1831), which a decade later were seen to have been rounded off by ice. By the 1830s most geologists rejected Diluvialism.

After the demise of Diluvialism, there were two rival explanations of erratic blocks and drift. First was the transport of erratics by icebergs and secondly, after 1837, by terrestrial glaciers. The two ideas are not mutually exclusive and came together in the work of Darwin, whose uniformitarianism is often seen as hindering his acceptance of a *catastrophic* Ice Age, *and* in Buckland, who attempted to coalesce the Ice Age with the Deluge. Icebergs containing large angular blocks had been seen in polar regions, and some were found in the Southern Hemisphere at similar latitudes to Geneva thus lending credence to the iceberg hypothesis (Darwin, 1839b).

When Agassiz visited Britain in 1840 there was a mixed reaction to ideas of a former Ice Age. Buckland and Lyell were the main converts, though Lyell later changed his mind. Many geologists were unconvinced, as was William Conybeare who wrote to Buckland in November 1840, "*As to the Glacial Theory, I you know am a Sceptic if not an infidel*" (Sharpe and McCartney, 1998, p. 34). Almost prophetically the sceptic Murchison wrote to Sedgwick on 26 September 1840: "*Agassiz gave us a great field-day on Glaciers, and I think we shall end in having a compromise between himself and us of the floating icebergs. I spoke against the general application of his theory*" (cited Davies, 1969, p. 134).

Buckland himself had began to work out that compromise when he presented his Presidential Address to the Geological Society of London five months later on 19 February 1841 and tentatively combined the marine iceberg theory with the Ice Age. He suggested: "*a middle way between these two opinions will probably be found in the hypothesis, that large portions of the northern hemisphere . . . have . . . been so much colder. . ., and that the melting of this ice and snow was accompanied by great debacles. . .*" (Buckland, 1842b, p. 516). The work of Buckland and Darwin in Wales in 1841 and 1842 provided the key to effect that compromise but by then many in the Geological Society had rejected the glacial theory.

2. The pre-glacial studies of Buckland and Darwin in 1836–1838

However, before considering the work of Bowman, Buckland and Darwin in 1841 and 1842 mention must be made of Buckland's visit to North Wales with Joshua Trimmer (1795–1857) (ODNB, vol. 55, p. 381) in 1836, when neither could conceive of the glacial origin of "drift" and Darwin's fieldwork in the drift around Shrewsbury in 1837 and 1838. Information on Buckland's visit to Wales is sparse and is gleaned from references in the paper he wrote on glaciation five years later. There appear to be no extant notes to this visit[5] and thus the description is obtained from his glacial paper in which there are numerous references to his visit in October 1836. Buckland and Trimmer visited areas of drift at Cefn Caves, 4½ km SSW of St Asaph, Moel Faban and Moel Tryfan, two rounded drift-covered hills of 400 m on the edge of Snowdonia and finally the contorted beds of gravel and clay of the low coastal hill at Dinas Dindlle. In 1841 Buckland considered the drift at Moel Faban and Moel Tryfan to be "*due to a great diluvial or marine current, advancing from the north*" (Buckland, 1842c, p. 584) and the contorted strata at Dinas Dindlle as "*due to the lateral pressure of icebergs*" but in 1836 he found the contorted strata "*inexplicable*". Allowing for the fact that this paper was summarised by an editor rather than written by Buckland it demonstrates that in 1836 Buckland was not even considering glacial origin of drift.

While in Patagonia, Darwin had studied glaciers at first hand and explained many deposits, especially erratic and boulder trains, as transported by icebergs, Darwin's researches have been studied closely by Evenson et al. (2009). Darwin regarded the boulder trains at Bahia San Sebastian had been carried down by icebergs from the Corderilla Darwin some 50 miles to the west. Evenson and colleagues presented the arguments that they were transported by a glacier. However this conviction of transport by icebergs and of considerable uplift of land gained in South America coloured his future understanding of glacial deposits (C.R. Darwin, 1839; Herbert, 1999). In the two years after he returned from his Beagle voyage, Darwin made a close study of the drift around Shrewsbury. During 1837, probably between June and September, Darwin explored the riverbanks of the Severn below his family home, the Mount, and several gravel quarries in the vicinity. He made several cross-sections and recorded several stages of deposition (CUL DAR 5, fols 24–32).[6] He found some shells, notably *turritella*, and also laminae and "*current*" (cross)-bedding. He concluded that the sandy stratified deposits were deposited in quiet conditions and others in a "*deluge*", but clearly not the Deluge. He recorded the clasts but made little of their angularity.

In June 1838 Darwin went to Glen Roy and extended ideas of uplift to explain the terraces, interpreting them as non-glacial. This

[5] Patrick Boylan, personal communication.

[6] Darwin's geological notes, with other manuscripts are in the Darwin Archive at Cambridge University Library. "CUL DAR" numbers represent manuscript volumes; they alone will be cited in subsequent references.

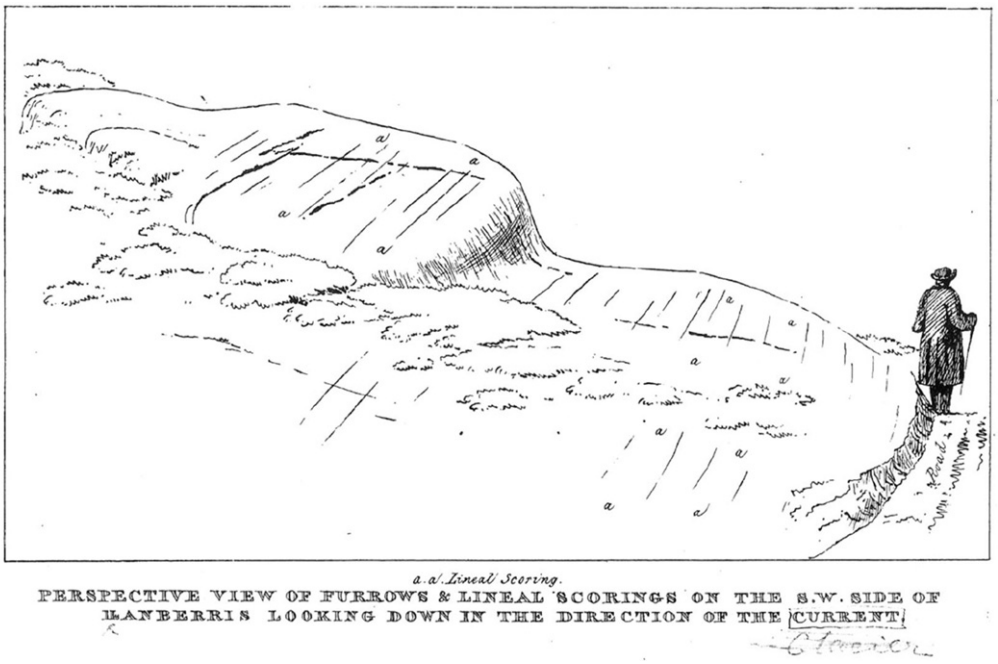

Fig. 3. Underwood's sketches of scorings in Llanberis, with the linear scorings regarded as caused by currents. Note pencil rubbings in bottom right-hand corner. The copy of this print at Neuchatel (Archives de Louis Agassiz, 35/1.1.,Université de Neuchatel.) has the word "current" removed and replaced by "glacier", indicating a re-interpretation.

was based on his own observations of glaciers and uplift in South America (Rudwick, 1974). If Darwin's visit to Glen Roy is studied in isolation, a clear impression is gained that Darwin's ultra-uniformitarianism prevented him from even considering the possibility of glaciation. This was not entirely the case.

Darwin was always the master of self-depreciation and in his journal dismissed his fortnight in Shrewsbury after he returned from Glen Roy as "*very idle at Shrewsbury*" (Burkhardt and Smith, 1986, p. 432). He was anything but idle and opened two notebooks on 15th July; notebook D and notebook M and wrote numerous pages on transmutation and related topics (Barrett et al., 1987). The next day he began several days' fieldwork around Shrewsbury, on the gravels and Wenlock (Silurian) Limestone at Wenlock Edge, in connection with his work on *Coral Reefs*, as well as considering drift and "elevation". He re-visited most of the sites around Shrewsbury and concluded the presence of a glacier in estuarine areas. On Monday 16 July, he went to the gravel pit (probably at GR 474108), which he had visited on at least four occasions between 1831 (Darwin and Huxley, 1983, p. 39) and 1842. He wrote: "*this deposit reminds me strongly of Pampas substance. except presence of pebbles + absence of concretions. ____ I do not doubt in all these cases it will turn not to be estuary. That with glaciers acting. ____ In this + other pits in neighbourhood of <illeg> pebbles less well rounded excepting that of slate.*" (CUL DAR 5, fol 19ii.)

Two days later he visited Shelton Rough (1½ km west of *The Mount*), a steep 15–20 m overgrown embankment above the River Severn and recorded: "*Wednesday. _ Shelton Rough it is not to be questioned. the small pebbles, which form beds full of broken bits of shells, are more rounded + have different character ... In upper alluvium fragments bigger more angular more slaty, __ estuary round with glacier bringing fragments. ... I cannot doubt the distinct formations*" (CUL DAR 5, fol 20ii).

Darwin made a distinction between round and angular clasts, with the latter indicating transport by ice rather than water. However the fossil shells have not been found since, though Trimmer recorded some (Trimmer, 1831) and Murchison found shells of living species in Central England (Murchison, 1839, p. 532). Murchison cited Darwin's observations and it was probably part of the more extensive fieldwork he did for Murchison from 1836, which he mentioned in a letter to his sister, Caroline, on 9 November 1836 (Burkhardt and Smith, 1985, p. 518). Darwin likened these deposits to Pampas formations and used these observations for his 1842 paper. Darwin revisited the first quarry in July 1842 after his Snowdonia trip and recorded, "*gravel pit – marine shells – fragments (entangled in coast ice?)*" (CUL DAR 27, unnumbered page before fol 1). Thus in his reconsideration he regarded the environment at Shrewsbury to be similar to that of Moel Faban and Moel Tryfan.

In the absence of publication exactly what Darwin intended when he wrote these notes is not clear. Perhaps these notes indicate that Darwin was sympathetic to a former Ice Age but this was lost in the writing up of Glen Roy researches and the Beagle voyage, not to mention marriage and illness. However, he recognised the gravels as estuarine where they contained rounded boulders, but considered that angular boulders must have a glacial origin. In his volume on South American geology, he used rounded pebbles as demonstration of either fluvial or marine transportation (Darwin, 1890, p. 335). He likened the angular pebbles to those by Loch Dochart, near Crianlarich and by Spean Bridge, near Fort William. However he did not suggest glaciation while in Scotland and his glacial insights were not developed. In these notes "Glacier" is possibly shorthand for boulders dropped by icebergs and this agrees with the argument developed in the appendix to the first edition of the *Journal of Researches* (C.R. Darwin, 1839, pp. 617–25). Here he noted that in the Southern Hemisphere icebergs were found at the same latitude as Geneva, thus icebergs at Shrewsbury were not unexpected. Thus, the references to "*glacier*" in his 1838 notes probably means icebergs rather than a former Ice Age.

Meanwhile in autumn 1838 William and Mary Buckland were travelling around Switzerland and, initially, were far from convinced of an Ice Age. As Mary wrote to Agassiz, "*We have made a good tour of the Oberland, and have seen glaciers, etc., but Dr Buckland is as far as ever from agreeing with you*" (Gordon, 1894, p. 141). On their return to Neuchâtel, Agassiz convinced Buckland of the glacial origin of erratics in the Jura like *le pierre a bot* and

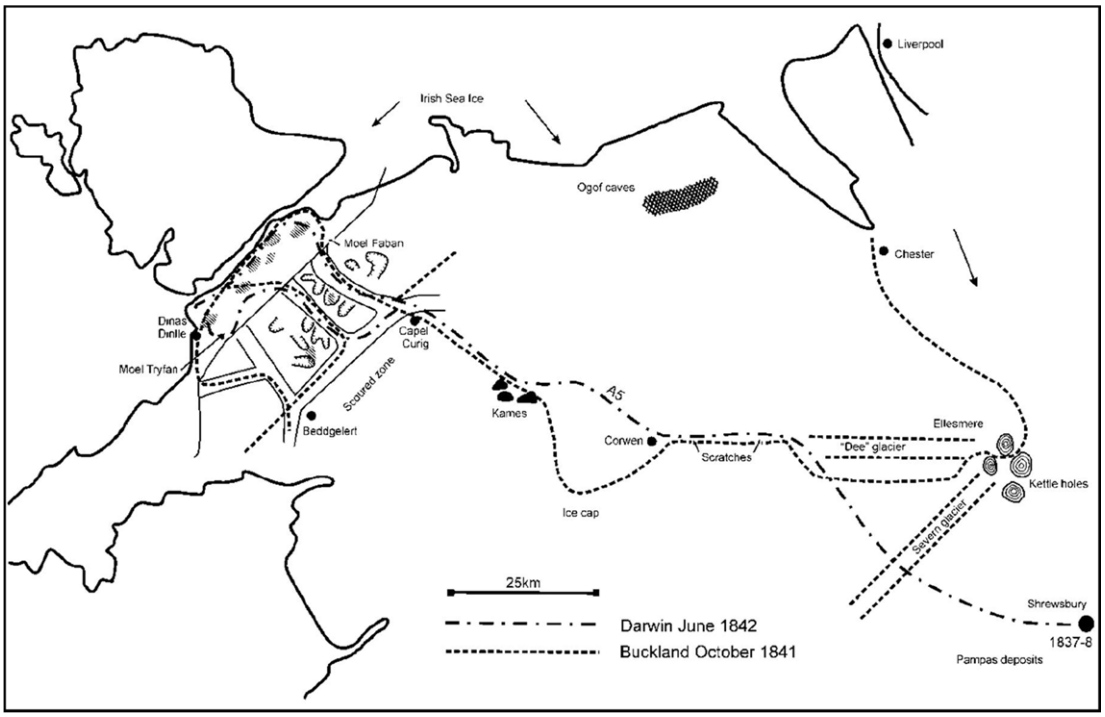

Fig. 4. Map showing the routes of Buckland and Darwin in North Wales.

Buckland publicised his new convictions on his return to Britain. In 1840 Agassiz visited Britain and demonstrated glaciation in Scotland and Northern England. Thus within two years Darwin's paper on Glen Roy was badly mauled by Agassiz and Buckland during their Scottish tour in 1840, when they argued that the Parallel Roads were caused by different levels of a lake similar to the Marlen See. Darwin's concern for this is to be seen in his letter to Buckland on November <!– no-mfc –>1840"<!– /no-mfc –> (Burkhardt et al., 2002, pp. 356–357).

In 1840 and 1841 Scotland and Northern England was the focus of attention for glacial theorists, and Wales was not visited until mid-1841 when three geologists, Bowman, Buckland and Darwin, visited it within a year.

3. Glaciers come to Wales 1841–1842

In the 12 months from June 1841 to June 1842, three geologists visited North Wales to ascertain whether there had been a time of glaciation. Bowman and Buckland followed similar routes. Bowman concluded there had never been glaciation, but Buckland demonstrated conclusively that there had been an Ice Age as in the Alps. The following year Darwin came, in-between two bouts of illness and while writing his first essay on Natural Selection, and was also convinced and rejected some of his previous convictions. Fig. 4 shows the routes that Buckland and Darwin took. Bowman followed the same route as Buckland from Llangollen to Snowdonia.

3.1. John Eddows Bowman 1841

The first geologist who published his findings on Welsh glaciation was Bowman, who had visited the Alps some years previously. In 1841, the year of his death, he traversed North Wales from Llangollen to Bangor looking for traces of glaciation. In the rolling hills above Llangollen none were forthcoming – or least to his perception – and the only possible trace of glaciation, which he considered – and dismissed – were the "bossified" rocks at Ogwen. Bowman followed the Dee valley to Bala and then passed below Arenig Fawr, over a mountain road to Pentrefoelas and thence to Betws y Coed and Ogwen (Fig. 4).

He previously had written of "*the universal breastwork of diluvium that envelops it [Berwyn Range]*" (Bowman, 1841a, p. 199). In fact, the rounded hills of the Berwyns (SW of Llangollen) are draped with drift and littered with erratics (which can be found up to 2500 ft) but in 1841 Bowman did not associate either with glaciation. In the valleys of the Dee and Ceiriog there are several moraines which are covered in vegetation and thus obscured. Arenig Fawr (854 m) has some larger cirques and its slopes are littered with angular blocks. However, in poor weather these are not always visible from the road. At 56 and within six months of his death he may well have not been fit enough to walk the required distance. However Bowman was a competent geologist, who started to look for evidence of glaciation in a part of North Wales where evidence is equivocal. He stopped at the striae sketched by Underwood below Dinas Mawr described above, but considered them as non-glacial as the only potential source of ice was the hill above to the north. As the direction of the striae was northwest he eliminated glacial action. He found but one example of a "*roche moutonée*" at Ogwen, but explained it by river action.

The most significant part of his paper is his description of the kames near Pentrefoelas. Of lateral moraines, Bowman recorded that "*no instance has fallen under my observation*" (Bowman, 1841b, p. 471). In this he was correct, but he was mystified by the 200 ft high kames near Pentrefoelas. He thought these had similarities to terminal moraines but, "*should anyone contend that they had originated in a glacier, it would be necessary to admit they must have been subsequently modified by water*" (Bowman, 1841b, p. 472).

Bowman suffered from a combination of unfortunate circumstances. He began in the Dee valley where glaciation presents an ambiguous picture without any of the dramatic features associated with Alpine-style glaciation. By remaining at low altitude on roads he would have missed much evidence. His observations were sound as he rightfully pointed out the apparent lack of glacial features from Llangollen to Pentrefoelas and alerted his readers to

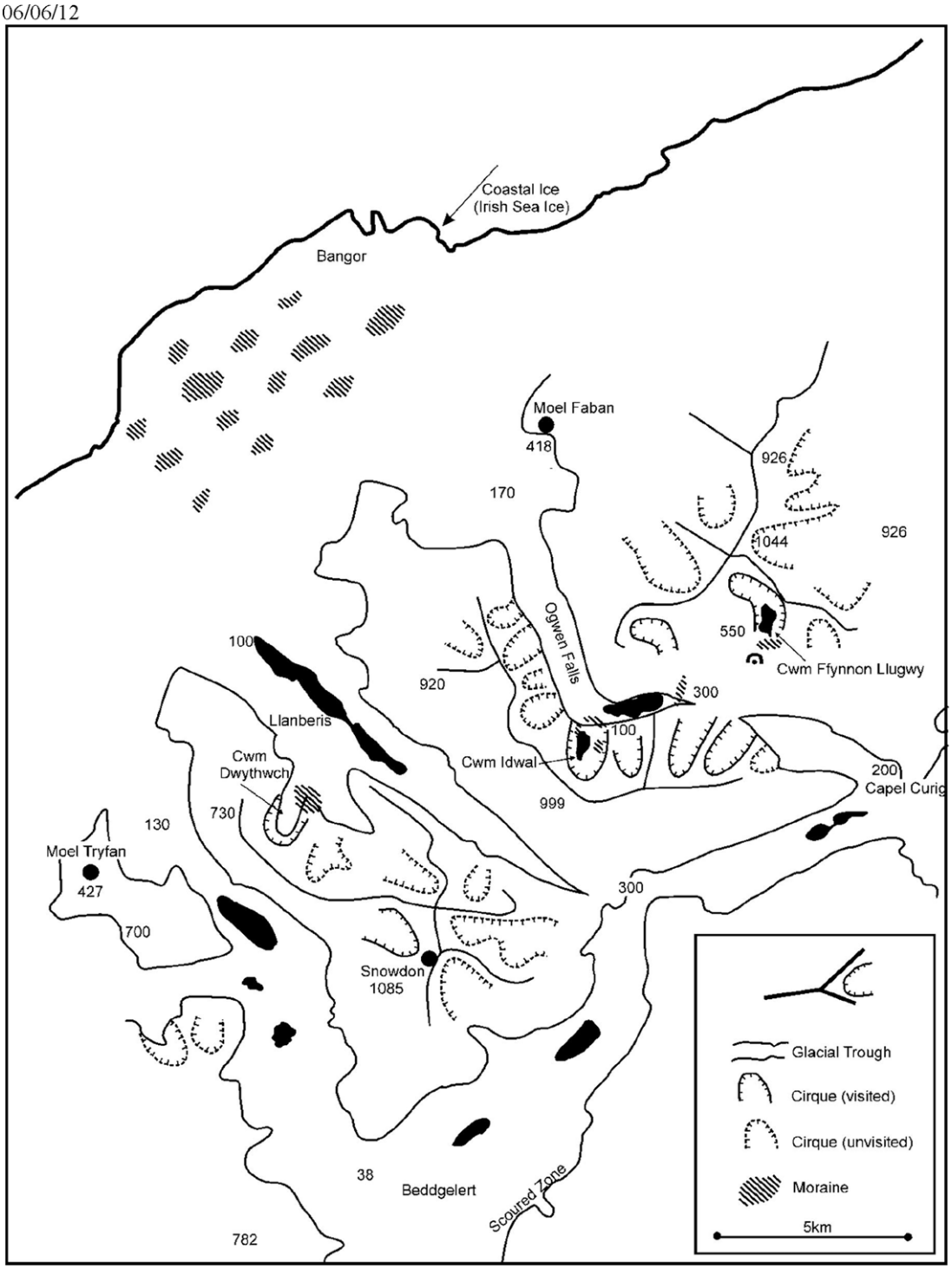

Fig. 5. Snowdonia Glaciation. This indicates the glacial troughs, cirques and moraines observed by Buckland and Darwin, and the coastal areas of Moel Faban and Moel Tryfan.

the unusual Kame structures near Pentrefoelas. The chief virtue of his paper was that he unwittingly killed the Terrestial or ''Alpine-valley'' understanding of glaciation, which had been fruitful in Scotland. Thus the following researchers knew that whatever glaciation there was in the rest of North Wales it was not simply alpine glaciation on a smaller scale.

3.2. Buckland in Snowdonia 1841

In October 1841 Buckland and Thomas Sopwith (1803–1879) a mining engineer and geologist from Newcastle and grandfather of maker of the Sopwith Camel (ODNB, vol. 51, pp. 641–642) visited Snowdonia. Buckland's field notes do not survive, but most of the localities visited can be ascertained from his paper published in the *Proceedings of the Geological Society*. Their route can be determined from Sopwith's journal, which was written up in December 1841 (Thomas Sopwith, Journal 1841, p. 417). Buckland met Sopwith at Chester on 11th October and then travelled to Ellesmere. From there they took a ''*car*'' and travelled to Chirk and then to Llangollen and Corwen and finally to Snowdonia. They more or less followed Bowman's route in appalling weather and then explored the main Snowdonia valleys. However, Buckland's paper and Sopwith's

diary possibly contradict each other on which glacial cirques they visited. Sopwith described a visit to the cirque at Cwm Idwal in purple prose but made no reference to other nearby cirques. Buckland made no reference to Cwm Idwal but described "*a vast morain or congeries of detritus and boulders*" (Buckland, 1842c, p. 581) at Ffynnon Llugwy. However Buckland identified the main glaciers and troughs and regarded the gravels at Moel Tryfan as the result of a diluvial wave. The lack of precision in his Geological Society paper may be due to heavy editing from London,[7] possibly with gentle encouragement from Muchison, resulting in a regrettable toning-down of his glacial observations. This seems to be an early example of peer-reviewing going awry. This can be seen in "Buckland's paper, where it says, "*If at any time, observes Dr Buckland, the mountains of Caernarvonshire were the sites of lasting snows and glaciers, each of the triple series of wild ampitheatres between the summit of the Glyder and the south margin of Llynn Ogwyn must have poured forth a stream of ice to unite with those descending from Llynn Ogwyn into the valley of Nant Francon. . ..*" It is difficult not to conclude that the editor thought Buckland was fantabulising, and attempted to thwart his ideas. He probably delayed a proper understanding of Ice Ages for many years.

At Ellesmere, they visited the various meres (kettleholes) and noted the gravels and the provenance of clasts from the Dee valley and Llanymynech to the South and West and others from the Lake District and Scotland to the North. Later Buckland concluded that the Dee and Severn glaciers met at Ellesmere and, "*From the transport of Cumberland rocks . . . such a current on arriving at Ellesmere impinged on the united glaciers of the Severn + Dee, it would have set them both afloat.*"[8]

Buckland's paper makes no mention of any field observations between Chirk and Pentrefoelas, but Sopwith described their search for glacial striae between Llangollen and Corwen. The first, several hundred yards upstream from the bridge at Llangollen, was also described as non-glacial by Bowman (1841b, p. 473). The second is east of Corwen. Sopwith wrote, "*On removing a portion of this [soil] Dr Buckland found the surface polished and scratched precisely after the fashion of the glacial scratches which Agassiz has so carefully investigated in Switzerland nor did the torrents of rain which fell with a pitiless pelting deter us from a leisurely examination of this first, and successful search for evidence of former glaciers. . .*(Sopwith, Journal 1841, p. 424). Buckland omitted these in his paper, despite discussing other striae. Probably when he gave his paper Buckland became less convinced that these were glacial striae. On the London-Holyhead Road below Bonwm Ichaf (GR 097434) is a cutting similar to that described by Sopwith in which there is a scour or stria about 6 in. wide running almost horizontally across the rounded slate face. The cutting was perhaps made during the building of the road in about 1805, but it needs careful observation to eliminate the possibility that they are glacial. (It is probable that the road has been widened since 1841 destroying the striae.) The pair also visited the kames at Pentrefoelas, which also baffled Darwin. He agreed with Bowman that if these were moraines they had been modified by water (Buckland, 1842c, p. 580). Darwin visited them on his return from Snowdonia the following June but omitted them from his paper. Thus all three geologists failed to understand these deposits later to be identified as kames as glacial in origin, but identification would have required a large conceptual leap.

The most important part of the Buckland-Sopwith fieldtrip was the three days spent in Snowdonia – 14th to 16th October. From Pentrefoelas they descended for the night to Llanrwst. On 14 October they travelled through Capel Curig to the Ogwen Falls and overnighted at Bangor. The following day they travelled over the Llanberis Pass, where there inspected "flutings" sketched by Underwood and recognised them as glacial. (See Fig. 3.)

They continued to the summit of the Llanberis Pass and descended Nant Gwynant to the Goat Hotel at Beddgelert, and returned to Bangor the next day via Llyn Cwellyn. On the shore of Llyn y Gader near Rhyd-Ddu (GR 573525) they noted "*a cluster of dome-shaped bosses*" (Buckland, 1842c, p. 582), i.e. a roche moutonnée, which Sopwith sketched[9] (Figs. 6 and 7).

On 17 October they left Bangor on the Holyhead–London Mail Coach. In the course of these three days they elucidated the essential pattern of alpine-style glaciation in Snowdonia and identified the main troughs and some of the cirques and moraines but without recognising the two phases of Dryas glaciation. Their speed and good judgement are remarkable.

The identification of Alpine Glaciation was the easier part of their work, as a direct comparison with the Bernese Oberland and Scotland provided the type features. Far more complex was the understanding of the "Glacial confluence and Piedmont land-system" running between Bangor and Caernarfon and beyond to the Southwest. Buckland had visited this in 1836 with Trimmer, when he also visited Dinas Dindlle "*a hill of diluvium*" to the southwest of Caernarfon. Buckland wrote that, "*The beds of gravel and clay . . . are strangely contorted*" and explained, "*that the curvatures are due to the lateral pressure of icebergs, after the manner suggested by Mr Lyell in a paper on the cliffs of the Norfolk coast*" (Buckland, 1842c, p. 584). This anticipates interpretations of glacio-tectonism.

Thus Buckland re-interpreted the "*diluvium*" from Caernarfon to the Vale of Clwyd and the Cheshire/Shropshire plain as being due to icebergs carried from the north on "*a great diluvial wave or marine current*". This is a marrying up of Agassiz's "dry" continental glaciation with Buckland's predilection for the Deluge, which Agassiz had hinted at to the British Association in 1840. Both were catastrophic in geological doctrine but show a remarkable consilience with the uniformitarian interpretation of Darwin in 1842.

Buckland had already begun to combine glaciation and the iceberg theory earlier in the year when he gave his anniversary address to the Geological Society on 19 February 1841 stating, "*A middle way between these two opinions will probably be found in the hypothesis, that large portions of the northern hemisphere . . . Have at no very distant time been so much colder than they are at present, that the mountains. . .. Were within the limits of perpetual snow accompanied by glaciers; and that the melting of this snow and ice was accompanied by great debacles and inundations which drifted the glaciers with the load of detritus into warmer regions,. . .. At vast distances from the rocks in which it had its origin*" (Buckland, 1842b, p. 516). These tentative ideas were developed after his visit to Snowdonia and in his paper on Welsh Glaciation.

However by the end of 1841 Buckland realised the problems over glacial theory and aired these in a letter to the Revd Henry Duncan (1774–1846), a former Moderator of the Church of Scotland, who, despite his diffidence, was a competent amateur geologist (ODNB, vol. 17, pp. 234–236). Buckland had come in contact with him in connection with Duncan's uncovering of fossil footprints (Tresise and Sarjeant, 1997). Duncan wrote to Buckland on 15 December 1841, asking for help for a lecture he was to give, "*. . . before a Society of young men in Glasgow on the agreement of geological discoveries with the Mosaic Record*".[10] Despite his wishing to marry up geology with the Mosaic Record, i.e. Genesis, there can be no doubt he accepted geological time along with almost all Presbyterian clergy of his era (Roberts, 2008, chap. 4, 2007, 2009).

[7] Peter Boylan, personal communication.
[8] Glaciation 14. Buckland Archive. Oxford University Museum of Natural History.
[9] Glaciation 15. Buckland Archive. Oxford University Museum of Natural History.
[10] Glaciation 2(ii). Buckland Archive. Oxford University Museum of Natural History.

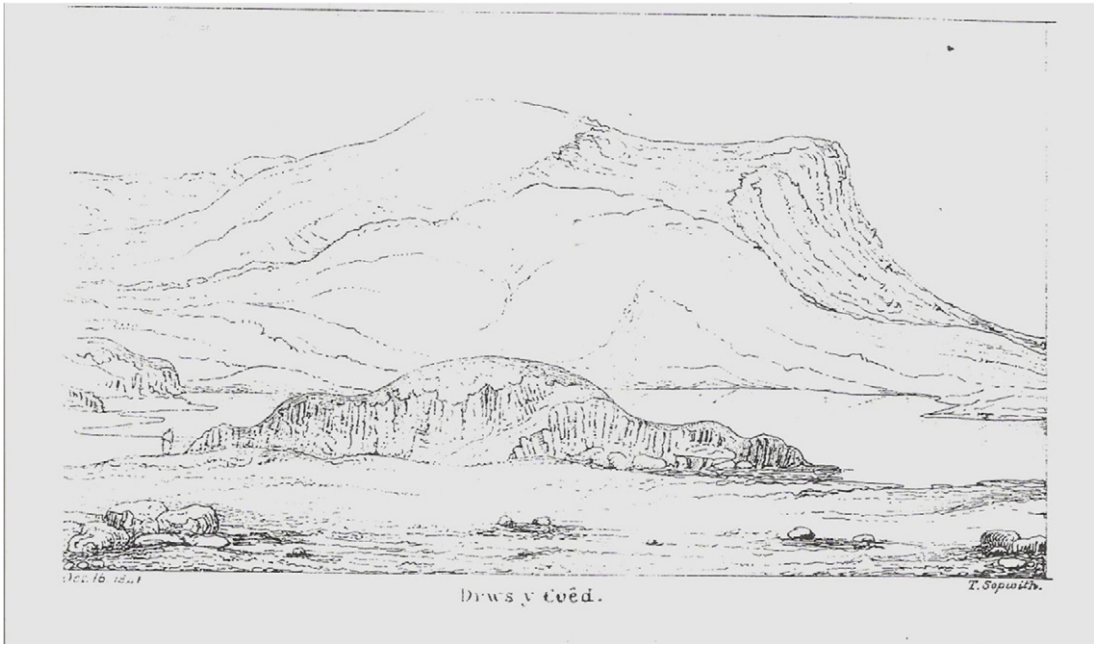

Fig. 6. Tom Sopwith's sketch of a *roche moutonee* at Lynn y Gader. One of "*a cluster of dome-shaped bosses*", i.e. a roche moutonnée, which Sopwith sketched below Drws y Coed, Rhyd Ddu. Glacial Theory File, Buckland Files, Oxford University Museum.

Fig. 7. A photograph of the *roche moutonee* sketched by Thomas Sopwith.

As he had referred to the Ice Ages, Buckland mentioned these in his reply, "*The glacial Theories of Agassiz are at present so much dispute + will probably require so much modification that it is at present hazardous to found any argument on this conjecture that a huge portion of the N. Hemisphere was for a long time enveloped in a <illeg> sheet of snow + ice. The laws of Physics seem opposed to such a hypothesis*,"[11] and later wrote in a draft article, "*It seems also that whatever may have been the extent of glaciers at any time…most observers are agreed that floating Icebergs have been drifted over large portions of Europe + N. America which are now dry land*."[11]

By now Buckland was far less "*frost-bitten*" than he was previously. His doubts are not manifest in the summary of his paper published the following year in the *Proceedings of the Geological Society* (Buckland, 1842c), in which he emphasised both "dry" Alpine glaciation and that due to Icebergs and "*diluvial waves*". Effectively leaving the synthesis to later workers, Buckland concluded his glacial researches with a fine preliminary paper acknowledging both alpine glaciers and icebergs and an admission of the complexity of the glacial question. His confidence in the triumphant glacial pilgrimage with Agassiz in 1840 had waned.

This was partly due to political manoeuvrings within the Geological Society of London, with censorship of the glacial theory by Murchison and his henchmen (Boylan, 1998, p. 156). In the second edition of the *Elements of Geology* (1841) Lyell rejected glaciation and reverted to the glacial submergence theory. With further opposition from the president of the Geological Society, Murchison, the glacial papers of Agassiz and Buckland given in 1840 were "referred" a second time and never published. Buckland then presented a further paper on Welsh Glaciation of which a summary was published in the *Proceedings*, which faced similar opposition. On 28 June 1842 Buckland wrote to Lonsdale, the Secretary, withdrawing all his papers. Yet on the day Buckland surrendered to the censorship of the Geological Society Darwin was about to leave Snowdonia after a 10 day field trip totally convinced of the fact of glaciation in North Wales.

3.3. Darwin in Snowdonia 1842

Darwin carried out no geological fieldwork from July 1838 until he visited Snowdonia in June 1842 to study glaciation. He wrote in

[11] Glaciation 2(iii). Buckland Archive. Oxford University Museum of Natural History.

his Autobiography, "*In the summer of 1842 I was stronger than I had been for some time and took a little tour by myself in N. Wales*" (Darwin and Huxley, 1983, p. 58). Since 1838 he was frequently ill and from December 1839 to February 1840 and from August to November 1840 while staying in Shrewsbury, he lost much time when he scarcely did any work and lagged behind in his correspondence (Colp, 2000, p. 223). He was also unable to carry out any geological fieldwork and the initiative had already passed from him. Agassiz had presented a paper to the Geological Society on 4 November and Buckland was to present one on 18 November. Darwin did nothing to extend his ideas of 1838.

During the early months of 1841 Darwin thought long and hard about glaciation and his letters to Lyell in February and March reveal his change of mind. In the first letter to Lyell, Darwin wrote, "*Are you* **sure** *there are perched rocks on* **Jura***? My impression . . . there are not – that the surface is rather uniform. – The perched blocks if on pinnacles would be to my mind fearful argument for Agassiz's sheet of ice*" (Burkhardt and Smith, 1986, p. 281). At this time he was reading *Etudes sur les glaciers* and was slowly convinced by Agassiz's arguments. On 1 March he wrote to Agassiz enclosing a copy of his *Journal* (C.R. Darwin, 1839), with a semblance of an apology for his comments in the appendix, "*. . . the only means I have of expressing the regret I feel at the manner in which I have alluded to . . . your most valuable labours on the action of glaciers*" (Burkhardt and Smith, 1986, p. 284). He wrote again to Lyell 10 days later and by now had accepted much of Agassiz's theory, "*What a capital book Agassiz's is – in all the early part I gave up entirely the Jura blocks & was heartily ashamed of my appendix (& am so still of the manner in which I presumptuously speak of Agassiz)*" (Burkhardt and Smith, 1986, p. 286). However his conversion was only partial and he continued, "*but it seems by his own confession that that ordinary glaciers could not have transported the blocks there and if an hypothesis is to be introduced, the sea is much simpler.*" Darwin continued by emphasing his belief in "**floating** *ice*". Thus a year before Darwin visited Snowdonia he was holding both to floating ice and to alpine glaciation, but still favoured icebergs as the means of transport for erratics (Darwin, 1841). Darwin's Chronology in his Journal records that in the late spring he was "*idle and unwell*" (Burkhardt and Smith, 1986, p. 434) and this may well explain why he carried out no field work that summer despite being in Shrewsbury and Maer from May to July. As a result another year's fieldwork was lost.

3.3.1. Darwin's visit to Snowdonia June 1842

Darwin was still dogged by illness in early 1842 and when he visited Shrewsbury in March he could walk only a flat 3 km to Shelton Rough. This he described to Emma as "*an immense walk for me*" and "*was rather too much for me*" (Burkhardt and Smith, 1986, p. 281). One may conclude that he did no fieldwork around Shrewsburyduring that visit. Darwin's visit to Snowdonia in June stands out against this inactivity. With his Glen Roy argument of submergence under severe challenge by Agassiz and Buckland, Darwin had considerable incentive to rise from his sickbed and prove them wrong, even though he had come to partially accept alpine-style glaciation. This is apparent in his paper on that tour which began "*Guided and taught by abstract of Dr Buckland's memoir. . .*" (Darwin, 1842). Darwin was long protective about his Glen Roy thesis and was "*made . . . horribly sick*" (Burkhardt and Smith, 1988, p. 74) in 1847 when Milne attacked his theory. When he wrote to Buckland in November 1840, he had perhaps sensed that Agassiz and Buckland would undermine both what he wrote in the appendix of his *Journal of Researches* and the "*long, gigantic blunder*" of his paper on Glen Roy. In the event he confirmed Buckland's demonstration of glaciation in Wales and retained his ideas of "elevation" by concluding that the sea reached up to 1200 ft at Moel Tryfan. As a result he could keep to his interpretation of the Parallel Roads for another two decades.

After a severe bout of illness Darwin went to Shrewsbury in June 1842 and from there went to Snowdonia for 11 days. Darwin wrote romantically of this trip in his *Autobiography*. This was probably the first geological fieldwork Darwin had carried out since 1838, as there appear to be no geological notes for this period in the Cambridge archives and his diary does not record any fieldwork. On 18 June 1842 Darwin left the Mount for Capel Curig in his gig for what was to be his last geological field trip (see Figs. 4 and 5). According to his journal, at that time he had written half of his 1842 sketch on *Natural Selection* (Burkhardt and Smith, 1986, p. 435). Darwin's route is shown in Figs. 4 and 5. Darwin spent five nights the Royal Hotel (now Plas y Brenin) at Capel Curig, where he had stayed previously (Roberts, 1998). He moved on to Bethesda for the night of Friday 24 and Caernarfon on Saturday 25. He spent Sunday at Moel Tryfan before moving on to the Victoria Hotel at Llanberis. On 28 or 29 June he returned home visiting the kames at Pentrefoelas en route along the London–Holyhead road. His notes recorded "*I believe a sec[ondary] deposit*" (CUL DAR 27, fol 20) and like Bowman and Buckland ended up in bafflement over their origin.

When one considers the aim of this visit, which was to see whether or not glaciation had occurred and whether there was evidence of massive "elevations" in Wales as Darwin had asserted for Glen Roy, Darwin walked just far enough to determine these two points to his own satisfaction. It seems that Darwin felt much better in June than he was in March when he previously visited the *Mount*, and thus thought a visit to Snowdonia was in order. It was almost a case of calculating beforehand from Buckland's paper the minimum amount of effort needed to prove his point and to retain the validity of his Glen Roy paper. He also had the advantage of knowing Snowdonia intimately and had probably climbed most of the peaks in the 1820s. In his Autobiography he incorrectly wrote, "*it was the last time I was ever strong enough to climb mountains. . .*" (Darwin and Huxley, 1983, p. 58), as he never walked more than a few miles. None of his day-trips exceeded 6 km and 300 m of climbing, which are not very onerous for a moderately fit man of 33. This was not the Darwin of 1831 in Wales, nor of the *Beagle* voyage, nor of 1838 in Glen Roy when 20 or 30 km was par for the course. This points to a dramatic decline in Darwin's physical capabilities from 1838 to 1842, and is most likely the reason why he made little further contribution to geology.

Darwin made 25 pages of notes (CUL DAR 27, fols 1–24), which means that sites and the dates can be identified with fair accuracy. He visited areas not visited by Buckland and spent much time at Cwm Idwal and above the Victoria Hotel in Llanberis and into the remote Cwm Dwythwch. His work is far more detailed than Buckland's and confirmed and extended his work. With both notes and paper available his research can be considered in greater detail. On his return to The Mount he revisited old sites near Shrewsbury interpreting the deposits as formed by "*coast ice*" (CUL DAR 27, unnumbered page before fol 1). After this fieldtrip Darwin was convinced of glaciation in Snowdonia – and of a former sea level at 1200 ft (400 m) at Moel Tryfan confirming to his mind the validity of his Glen Roy paper. He had combined both alpine glaciation and "uplift" of a style similar to Glen Roy. An infuriating aspect of both Darwin's notes and paper is that they both suffer from a tendency to invert compass bearings, making location difficult! Darwin also similarly inverted compass bearings in 1831 (Roberts, 1996, 1998).

Like Buckland, Darwin concentrated on geomorphological evidences of glaciation and looked especially for ice-smoothed rocks – *bossified* – in his terminology, moraines and boulders, rounded and angular. He spent two days on the slopes above Capel Curig, where he traced out the upper edge of the massive glacier which came down the trough (vallée) from Snowdon through Capel Curig to Betws y Coed and thence to Conwy. For Capel Curig

Fig. 8. Moraines at Cwm Idwal, probably the four parallel linear "mounds of rubbish".

Fig. 9. Darwin's boulders in Cwm Idwal. Twll Du in the background.

he wrote up, "*Almost every dome of rock south of the Inn is surmounted by one or more large angular masses of foreign rock*" (Darwin, 1842). Unfortunately few of these are now left.[12] After that he visited the Ogwen Falls and Cwm Idwal for a couple of days, presumably travelling there in his gig and leaving it at Idwal Cottage. The visit to Cwm Idwal was the centre-piece of his visit and is the only part mentioned in his *Autobiography* (and consequently the only place mentioned in biographies), where he mentions, "*the plainly scored rocks, the perched boulders, the lateral and terminal moraines*" which he and Sedgwick had failed to observe in 1831.

Darwin made several pages of notes and devoted much of his paper to glaciation near Llyn Ogwen. Both give a fine description of glacial features, though identification is problematical due to his tendency to invert compass directions. On the west side of Llyn Idwal he described four parallel linear "*mounds of rubbish*" (Fig. 7) which were considered to be lateral moraines, though he does not use the term, and which "*These lines mark where of glacier, in it[s] last stage _ <<illeg>> the glacier must have extended at far greater height*" (CUL DAR 27, fol 7). Thus Darwin gave a fine description of moraines in Cwm Idwal. Ken Addison has suggested convincingly that these are more probably terminal moraines from a glacier descending from Cwm Cneifion (Addison, 1997, p. 16).

In Cwm Idwal Darwin described a set of boulders near the lake's outlet (these are just visible in Fig. 8), which have been christened Darwin's boulders (Fig. 9). In his notes he locates them "*about eighty yards west of the spot where the river escapes from the lake* (Darwin, 1842), whereas they lie to the east. Darwin frequently inverted compass directions in his notes and did so at Llanymynech (Roberts, 1996) and in Nant Peris. The five boulders are in fact two with the larger less rounded one broken into four pieces, with one fragment lying on top of a more rounded boulder (on the right of the photograph – Fig. 9). Darwin regarded the four fragments as coming from one boulder "*falling through a crevice in the ice*" and that two fragments "*have partly fallen over a neighbouring boulder*". These are described and analysed by Worsley (2008) who stresses the angular nature of the four boulders (on the left of photograph – figure) and the more rounded nature of the fifth. Worsley points out that Darwin identified the four fragments as supraglacial erratic which later slid down a crevasse to the glacier bed. Worsely concludes by stating that 'Hence historically, the locality is an important landmark in the global development of Quaternary science and being adjacent to the main tourist access footpath into the Cwm, it merits greater public recognition.'

Darwin also made an extensive study of Ogwen Falls, which he delightfully called a *vomitory* (Fig. 10), i.e. the site of the former ice fall as the glacier descended, or was *vomited over* to the base of the

[12] During the course of fieldwork both in Snowdonia and Northeast Wales I have found that many erratics recorded by 19th century researchers have disappeared. Many have been moved by farmers, others were blown up by quarrymen in case they contained gold!

Fig. 10. The ice fall or *vomitory* at the Ogwen Falls. The location of the glacier by Llyn Bochlwyd is to the left of centre and Cwm Idwal is to the right of the photograph.

Nant Francon. These he considered to be "*the most striking examples of boss or dome-formed rocks... that they may have served as models for some of the plates in Agassiz's work on Glaciers*". He also noted glacial furrows on some rocks, along with perched boulders.

In his notes he gave acknowledgement to both Agassiz and Buckland.

A few days later Darwin made extensive studies of the south side of the glacial trough in Nant Peris south east of the Victoria Hotel, near the present terminus of the Snowdon Railway in Llanberis. A careful study of the area shows that Darwin climbed the broken crag at the northwesterly edge of Clogwyn Mawr and probably left the road at GR 592591. It was possible to identify

Fig. 11. Looking down Cwm Dwythwch. The valley in front of the slate quarry is Nant Peris.

each of the sites Darwin described. He particularly described what he considered to be the junction of the edge of the glacier in its trough and calculated the gradient of the glacier – "*at an angle of 18° with the horizon*" (Darwin, 1842). This is clearly seen from the junction of *bossified* and jagged rocks at about mid-height on the crag, which descends in altitude lower down the valley. (One can follow this junction for a considerable distance.) After ascending 300 m to the top he described glacial features of a rounded hill named Derlwyn (marked A and B on his sketch – http://darwin-online.org.uk/content/frameset?itemID=CUL-DAR27.1&viewtype=image&pageseq=1) on recent maps, but his notes have confused compass directions making identification difficult. Despite this directional confusion Darwin identified the main glacial trough and subsidiary glaciers which joined the main glacier at Llanberis and had descended from Cwm du'r Arrdu and Cwm Dwythwch (marked D in his sketch mentioned above. See Fig. 11.), where he identified lateral moraines (CUL DAR 27, fol 20). This sketch map in his notes demonstrated how he visualised the former glaciers near Llanberis, with the arrows in the centre marking the valley left by the glacier descending from Clogwyn dur Arddu, and further arrows for the former glacier descending Nant Peris.

In between his visits to Cwm Idwal and Nant Peris, Darwin spent several days studying the "piedmont" glaciation between Bethesda and Moel Tryfan. He noted that this was of a different character, particularly with the extensive gravel. At Moel Tryfan at a height of 400 m he noted 3–6 m of till and boulders, both rounded and angular His notes and paper do not record any fossils, such as *turritella*, which I found on one occasion. In his notes he concluded that the boulders were "*not brought by glaciers*" but "*by icebergs*" and in his article argued that this represented a former uplift of about 1300 ft (400 m). He stated that these, "*Were deposited when the summit of Moel Tryfan stood submerged beneath the surface of the sea*." and that "*we must suppose that the boulders were transported on floating ice*." He likened the deposits at Moel Faban and Moel Tryfan to those in Shropshire and Staffordshire. He suggested that where the glaciers reached the sea "*icebergs charged with fragments would occasionally be formed*." and that "*By this means we may suppose that the great angular blocks of Welch rocks, scattered over the central counties of England, were transported*" (Darwin, 1842). His notes refer to an angular block found at Ashley Heath, 20 km northeast of Shrewsbury, during a visit in 1837 (CUL DAR 5, fol 31). Buckland's suggestion of glaciers flowing down the Dee and Severn valleys and meeting at Ellesmere was closer to the mark. By arguing for uplift at Moel Tryfan and the transport of boulders by icebergs to Staffordshire and Wenlock Edge, Darwin was able to retain his hypothesis for Glen Roy even though Agassiz and Buckland had rejected it.

Darwin concluded that both terrestial glaciation and submergence with associated icebergs had occurred, and set the glacialogical agenda on a false trail for several decades.

4. Conclusion

Between them Buckland and Darwin had identified alpine-style glaciation in Wales and in their preliminary work identified the main glacial troughs, most glacial cirques, moraines, striae and other glacial features in Snowdonia. They also partly understood the "piedmont system" to the northwest of Snowdonia, which Buckland explained as caused by a diluvial wave carrying icebergs and Darwin by uplift of over 400 m, thus allowing marine deposition at that height. Both recognised that ice in some way had caused the features of the Cheshire and Shropshire plain. Again Buckland's Deluge came to the fore, while Darwin clearly understood it as "*coast ice*". The pair all but ignored the central area between Llangollen and Betws y Coed though they had visited the kames at Pentrefoelas. Bowman was almost correct to say he could find no glacial features in this area, as they are easily overlooked.

Both Darwin and Buckland unwittingly brought about Murchison's wish for a compromise between Agassiz and those "*of the floating icebergs*", just when Murchison rejected glacial theory. However neither made any reference of the central area between Betws y Coed and the Welsh Border, though Buckland referred to glaciers coming down the Dee and Severn valleys and meeting at Ellesmere in a manuscript article. Neither gave any indication of different phases of glaciation though Darwin was thinking along those lines.

Buckland and Darwin went to Snowdonia with different geological outlooks, the one a partly reconstructed Catastrophist and the other an extreme Uniformitarian, with a tendency to outlyell Lyell. Both were previously convinced on the likely existence of former glaciers in Snowdonia. Despite their differing philosophies they broadly agreed but diverged over the more coastal drift deposits of Moel Tryfan, though both concluded a partially marine origin. Buckland retained the Deluge as an after-effect of the Ice Age (as he did for Shropshire) whereas Darwin postulated changes in sea level similar to Glen Roy. This is, in a sense, no surprise as both Darwin and Buckland adopted a uniformitarian or actualist methodology, but only Darwin held to what Gould refers to a *substantive* uniformitarianism (Gould, 1988, p. 118f).

Yet, sometime before October 1842 Murchison visited North Wales and found no trace of glaciation, eliciting the comment from Darwin to Lyell, "*Murchison, who has been a flying visit into Wales & he can see no traces of glaciers. . .It is enough to make an extraneous man think geology from beginning to end a work of imagination & not founded on observation*" (Burkhardt and Smith, 1986, p. 336). Here was a Catastrophist who would not accept glaciation and used his power to thwart the glacial theory. And on the other hand Lyell, who was a convert to glacial theory during Agassiz's visit in 1840, rejected glacial theory in 1841. The conclusions over glaciation of these four geologists should warn against an over-simple identification of acceptance of the Ice Age with Catastrophism and hostility to it with Uniformitarianism. It may appeal to those, whom Gould engagingly criticises for reducing historical personages to *cardboard cut-outs*, who oversimplify scientific controversies, but Catastrophists and Uniformitarians cannot be thus caricatured as Hooykaas (1963) and Gould (1988) have long argued.

5. Aftermath

Glacial Theory was all the rage in the early 1840s and many scientists were, according to Coneybeare, "*severely frostbitten*". In 1842 each issue of the *Edinburgh New Philosophical Journal* contained many articles on glaciers including Darwin's paper in October. Interest in glaciation continued in the 1840s. However neither Buckland nor Darwin carried out further fieldwork on glaciation, because of ecclesiastical preferment and illness, respectively. Increasingly diluvium became glacial till. Darwin still retained ideas of uplift and deposition by icebergs.

Buckland attempted to write up his findings in a large work with the proposed title *Reliquiae Diluviales et Glaciales*, but only fragments survive. His confidence in his harmony of the Deluge and the Ice Age faltered at the end of 1841, and the interest was shelved. In 1845 Buckland succeeded his former pupil Bishop Samuel Wilberforce as Dean of Westminster and a few years later developed mental illness.

One subsequent researcher in Snowdonia, who also rejected any glaciation, was Angus Macintosh, who is not to be confused with Daniel Mackintosh, a later glaciologist. In 1845 he published a paper which was devoted to refuting Buckland on

"Rounded Surfaces, Striae, Polished Rocks and Moraines" (MacKintosh, 1845). His somewhat negative research was soon superseded by Ramsey who published several important papers and summarised his work in the *Ancient Glaciers of Wales* (Ramsey, 1860). Earlier Ramsay accepted glaciation but argued for submergence up to 2300 ft (700 m) on the northern flanks of Snowdonia (Ramsey, 1853).

During the next six years Darwin took great interest in glaciation with various correspondents, but carried out no further fieldwork. In September 1843 he wrote to W.D. Fox in connection with both his Welsh and Glen Roy work. Of the former he said, "*I feel certain about the glacier-effects in N. Wales*" and on the latter, "*My marine theory for these roads was for a time knocked on the head by Agassiz ice-work – but is now reviving again*" (Burkhardt and Smith, 1986, p. 387). For a time Darwin's ideas on Glen Roy were even rejected by Lyell as, "*even Lyell for a time became a Catastrophist*". The elevation theory came back into vogue and thus for two decades the drift which covers much of Central and Northern England and high level erratics were explained by submergence and floating icebergs. In 1848 Darwin argued for the latter in *On the Transport of Erratic Boulders from a Lower to a Higher Level* (Darwin, 1848). Darwin developed his ideas of a rising sea level at Glen Roy and Moel Tryfan and incorporated Hopkins' observations that boulders from 160 m in the Vale of Eden had been transported to 440 m at the pass of Stainmoor. Geologists working on the Lake District and environs from 1840 to 1860 adopted a "floating iceberg" interpretation or "marinism" as described by Oldroyd (1999). This interpretation was still accepted by Lyell in his *Antiquity of Man* (Lyell, 1863). In his publications on the erratic blocks of north east Wales D. MacKintosh argued that erratics up to an altitude of 575 m[13] were emplaced by floating icebergs rather than a solid ice-sheet (Mackintosh, 1874). MacKintosh carried out his work on the hills to the north and south of the Dee between Corwen and Llangollen and did not traverse the Berwyns, where there is a large erratic (5 m × 1.5 m × 1.5 m) close the summit of Cadair Bronwen (756 m) which would mean that the sea-level must have been about 3000 ft above the present level. However the viscitudes of glacial theory in the 1840s and 1850s and research on Welsh Glaciation are beyond the scope of this study.

As a matter of priority Buckland was the first to elucidate Welsh glaciation, but the credit usually goes to Darwin. Murchison obtained his compromise between those of glaciers and "us of the icebergs", which he then rejected, despite a quick tour of Snowdonia with Count Keyserling. However Darwin set the scene for two decades of glacial geology with his "elevation theory", first postulated for the Jura and Glen Roy and then applied to the area from Caernarfon to Staffordshire. This developed into the Marinism of MacKintosh, which was the conceptual framework for the Lake District glaciology of the 1850s and 1860s (Oldroyd, 1999) and Welsh glaciation in the 1870s. Perhaps Darwin was too influenced by his Patagonian researches and thus unwittingly influenced glaciology in Britain for many decades with it marinism.

The work of Buckland and Darwin on the glaciation of Snowdonia may be summed up in the words of Darwin from his *Autobiography* (Darwin and Huxley, 1983, p. 40), "*Yet these phenomena are so conspicuous, that as I declared in a paper in the Philosophical Magazine, a house burnt down by fire did not tell its story more plainly than did this valley. If it had still been filled by a glacier, the phenomena would have been less distinct than they are now.*"

[13] The author has found erratics at 784 m at the summit of Cadair Bronwen, south west of Llangollen.

Archives

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Darwin's 1842 glacial notes are CUL-DAR27.1.B1-B20, on line at http://darwin-online.org.uk/content/frameset?viewtype=image&itemID=CUL-DAR27.1.B1-B20&pageseq=1.

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