On the evidence for and against palaeolakes in some Lake District valleys

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Introduction

For over 200 years the lakes (and tarns) of the Lake District have been the focus of a considerable amount of geological/palaeoenvironmental research. Early work was concerned with establishing lake depths and recording details of shoreline configurations (e.g. Mill, 1895a, b), while later studies aimed at determining the origin and significance of lakes with respect to former ice-sheet and valley glaciation, and post-glacial environmental changes. Included in this research are the lake sediments which have yielded valuable data concerning: 1) the presence and longevity of mountain ice-masses in the Lateglacial period (14.7-11.7 ka BP; e.g. Pennington, 1996; Avery et al., 2019); 2) natural and human-induced landscape changes during the Holocene (<11.7 ka BP; e.g. Clare, 1999; Grosvenor et al., 2017); and 3) records of flood events spanning the last 500-1500 years (e.g. Chiverrell et al., 2019; Schillereff et al., 2019). The results of these studies demonstrate the importance of the lakes in understanding how the landscape has responded to both long and short-term environmental perturbations, and how it may respond to current and future climate trends associated with a warming world.

In addition to these research issues, water bodies that no longer exist (i.e. palaeolakes) have also been subjected to various degrees of investigation, and it is with these features and their recognition and interpretation that this paper is concerned. Our reading of the literature relating to palaeolakes indicates that some of the associated landforms are in need of re-assessment regarding their mode of formation, while the significance of others has been underplayed in developing evolutionary models of post-glacial landscape change. We are also concerned that the existence of palaeolakes in some Lake District valleys is regarded as an undeniable truth, when in fact it appears that there is no substantive evidence for such lakes. Unfortunately, this has not stopped the myth being perpetuated in some 'popular' geological literature.

In this contribution we consider three themes relating to palaeolakes. We wish to emphasise that we have not undertaken any new fieldwork in relation to these themes. Rather, we base our comments on a combined total of ~100 years of field observations and discussion with other researchers. Some details accrue from basic map and field observations. Our intention is to highlight not only where we think additional work is needed but to encourage others to consider the implications of our comments and attempt to resolve the issues.

Ice-dammed lakes

During the last glaciation (~30-15 ka BP) the Lake District functioned as an independent centre of ice dispersal within the more extensive British-Irish Ice Sheet. Ice moving north and west from the Lake District met ice moving south from Scotland, both in the Solway Lowlands and in the coastal zone to the west of the fells. As deglaciation proceeded (after ~24 ka BP) downwasting and backwasting of the ice led to the decoupling of Lake District from Irish Sea/Scottish ice, leading to ice-free enclaves in which meltwater drainage was impounded. This resulted in the temporary creation of ice-dammed lakes of various extents and depths into which meltwater rivers delivered large amounts of sediment. As the ice wasted away these lakes drained, and evidence for their existence comes largely from the sedimentary record of their former locations. In addition, apparent shorelines were eroded around some of these lakes and these have been used to infer margins, extents and depths of the lakes.

An early account of ice-dammed lakes is found in Bernard Smith's work in the Black Combe area, southwest Lake District (Smith, 1912). Evidence for the existence of palaeolakes in the Whicham Valley (SD 155835) and Duddon Estuary, dammed by Irish Sea ice, was based on sediment characteristics, terrace-like features interpreted as former lake shorelines, and delta-like forms. However, of the detail provided there is little that unequivocally equates to a former lake. Sediment characteristics as described seem more akin to glacifluvial deposits, and the terrace-like features (at three different elevations between ~30 m and ~55 m above (present) mean sea level (amsl)) may represent kame terraces formed by meltwater flowing alongside a downwasting ice tongue. However, the delta-like forms may represent sediment deposition into standing water, but even so the receiving water body need not have been as extensive as inferred by the supposed shorelines.

Support for and details of an ice-dammed lake in the Duddon Estuary were outlined by Grace and Smith (1922). They identified 'fragmentary terraces composed of well worn gravel' at about 55 m amsl and 'deltaic deposits' where streams had entered the lakes. The 55 m lake was thought to have been 'quite small'. Following its partial drainage, the lake stabilised at ~30 m amsl, covered a greater surface area than at the earlier lake stage, and again deltas were identified at places of fluvial inputs. Overflow channels consistent

with both lake levels were recognised. Final drainage of the lake came with the retreat of Irish Sea ice.

In a later paper Bernard Smith (1932) presented evidence for 'glacier-lakes' in Eskdale, Miterdale and Wasdale, in the west of the Lake District. These lakes were thought to have existed in the earliest phase of deglaciation. The evidence used to identify these lakes was the recognition of overflow channels, deltas, beaches, and laminated sands and clays. The maximum elevation of Lake Miterdale was placed at ~150 m amsl and drainage was across the ridge of Muncaster Fell (SD 112983) into a lake impounded in lower Eskdale with surface elevation of ~125 m amsl.

Based on the recognition of channel systems at different elevations, Smith was able to reconstruct stages in the drainage of these lakes and also that of Lake Wasdale. The latter water body at ~120 m amsl extended over an area of 31km^2 and was said to have had a shoreline of sandy and gravelly beaches. Lake Wasdale subsumed Lake Miterdale and drained into Lake Eskdale. Over time as lake levels fell, new overflow channels were excavated and deltaic deposits laid down as water from Lake Wasdale entered Lake Eskdale. The finest of the delta deposits was said to be that on which Muncaster Castle is now located.

Later, during a readvance of Scottish ice along the Cumbrian coast, it was inferred by Smith that a Lake Wasdale was likely to have re-formed. Sediments in various locations were regarded as having lacustrine characteristics. Thus, a complex picture of lake formation and drainage was presented along this part of the western margin of the Lake District.

Further evidence for a lake in lower Wasdale was provided by Huddart & Tooley (1972) and Huddart (1991). A deltaic sediment sequence to the south of Gosforth, at 68 m amsl, with indicators of eastwards progradation was recorded. This was said to be the highest delta surface in lower Wasdale, thus representing the highest lake level, and considerably lower than proposed by Smith (1932).

In contrast to the picture of ice-dammed lakes portrayed by Bernard Smith (1932) a later study by Alan Smith (1967) argued that many of the channels in lower Eskdale and on the western flanks of Black Combe, around Bootle (SD 107883), that were previously thought to have functioned as lake drainage routes were more likely to be marginal and sub-marginal meltwater channels. This re-interpretation was based on channel gradients and plan-form morphologies which suggest that they were cut by meltwaters flowing alongside and beneath the margins of the ice sheet. Some of the channels were regarded as sub-glacial chutes because they descend at steep gradients and terminate suddenly or link to downslope channel systems.

Huddart (1967) also cast doubt on the existence of some ice-dammed lakes in the Ennerdale area that had been inferred by Eastwood et al. (1931). Once again supposed lake-overflow channels were re-interpreted as having been cut by subglacial meltwater. However, Huddart did concur with an earlier proposal by Dixon (1921) for 'a glacier-lake Ennerdale much larger than the present lake'. The evidence for this palaeolake, for which four levels between ~245 m and ~183 m amsl were identified, was based on the existence of perched, terraced deltas on the hillside to the north of the foot of the lake. These features have flat or very gently sloping upper surfaces and steep frontal slopes (Figure 1); they occur where sediment-charged streams entered the lake. Although these deltas can be used to define the level of the lake at different stages, the full extent of the lake is difficult to estimate, particularly its extent up-valley towards the retreating Ennerdale valley glacier and because of its time-transgressive nature.

Details of several ice-dammed lakes in the Cockermouth-Caldbeck area are given by Eastwood et al. (1968). One such lake was said to have occupied the lower Bassenthwaite and Embleton valleys and stood at an elevation of ~104 m amsl and later at ~91 m amsl, ~85 m amsl and ~70 m amsl as indicated by delta-top surfaces. Another such lake in the Caldew valley stood at ~171 m amsl and then at ~152 m amsl, ~134 m amsl and ~122 m amsl before final drainage.

In spite of contrasting views over the presence and



Figure 1. Palaeodeltas with gorse-covered frontal slopes on the hillside to the north of the foot of Ennerdale Water. The palaeodeltas formed when an ice-dammed lake existed in this area.

extents of ice-dammed lakes in the western and south-western Lake District, there is little doubt that lakes did exist for limited periods on the northern and north-western margins of the district (the Solway Lowlands). One former lake is represented by deltaic deposits at Holme St. Cuthbert (NY 105470; Huddart, 2002) and another, at Blackhall Wood (NY 386515), by laminated glaciolacustrine sediments interpreted as varves (Livingstone et al., 2010). At the latter site the varve count indicates that the lake existed for a minimum of 261 years, and borehole data from elsewhere in the Lowlands suggests the lake covered at least 140 km^2. Burial of the varves by subglacial tills places the lake in the period between initial deglaciation of the Lowlands and a readvance of the ice, which is not as yet chronologically constrained.

An ice-dammed lake, termed Newlands Lake, was considered by Raistrick (1925) to have existed in the Newlands valley at a time when ice in that valley had retreated but ice remained in the Bassenthwaite Lake valley. Overflow drainage from this lake was said to have excavated a channel at 150 m amsl on the northeast ridge of Barrow (NY 234229). A continuation of this channel at 110 m amsl separates Braithwaite How from Kinn 1 km to the northwest, and another channel a further 3 km northwest at 100 m amsl divides Powterhow Wood from Barf. Whether this sequence of falling channel elevations represents overflow drainage from the proposed Newlands Lake or a series of subglacial meltwater incisions requires detailed investigation in order to resolve the palaeolake issue.

The existence of an ice-dammed lake based on deltaic sediments at ~180 m amsl at Glenridding, in the eastern Lake District, was reported by Hay (1934, 1937). The delta was underlain and overlain by 'boulder clay' deposits and this tripartite sequence led Hay to argue that the lake was impounded because ice in the Glenridding valley had retreated but the Ullswater glacier was still present and acted as the dam. After the deltas had formed an advance of the valley glacier laid down the upper 'boulder clay'. About 2 km north of Glenridding, at Glencoyne, Hay (1937) also recognised an old shoreline at a similar elevation to the Glenridding deltas, and by implication an absence of a glacier in lower Glencoyne at that time. Delta and shoreline elevation indicate the ice-dammed lake(s) stood at ~25 m above the present day level of Ullswater. If such temporary lakes did exist in the Ullswater valley during deglaciation an implication might be that similar lakes existed in comparable situations in other valleys, but evidence for these does not seem to have yet been recorded.

Partially infilled lakes

The present day lakes and tarns are all ephemeral features of the landscape, progressively infilling with sediments. To varying degrees they also still show palaeo-features dating back to the time they were first formed, shortly after the disappearance of the ice cover. Some smaller basins have already infilled and no longer retain open water. The geomorphological processes involved in infilling are generally understood. Likewise, we can draw upon studies of current lake shore processes demonstrating patterns of erosion, transport and deposition of sediments in these relatively closed systems.

Lake basin infilling revolves around three groups of processes. First, and perhaps most important is the pattern of sediment input. This is manifest in particular, by the building of deltas at lake heads and by inputs of sediments from smaller valley side streams and from slope wash and related processes from lake shore margins. Many of the major lakes (notably Wast Water (Figure 2), Ennerdale Water, Derwent Water and Brothers Water for example) have classic lake-head deltas that have received some geomorphological attention or comment (Marr, 1916; Gresswell, 1952, 1962; Prosser, 2006; Smith, 2012, 2014). These deltas reflect the sudden dissipation of the river's power to transport sediment once open standing water is reached. They possess classic structures of foreset beds inclined down-current from the delta front, then near horizontal bottomset beds along the lake bottom. Surmounting these, horizontal topset deposits produce flat infill to the valley floors. Defining how far this 'topset plain' extends up-valley and represents infill into standing water, needs careful mapping. To date we have scarcely any sectional data on the calibre and disposition of these deposits. The palaeo-shorelines of the original lakes along the valley side slopes are usually still very clear, but the position where deltaic deposits on the valley floors merge with other up-valley fill can be difficult to determine. At Brothers Water for example, delta extension has already infilled around 900 m of the valley floor, about twice the length of the present lake. At the head of Derwent Water there is well over 1 km of infill, and well over that length above Wast Water. Similar infills at the heads of most of the other major lakes can be seen. The areal extent of all these delta accumulations could be measured with detailed mapping.

Secondly, sediment input is particularly related to the sizes and nature of the catchments. There is much variation to be observed. Grasmere, for example, is a small basin with a large catchment and exhibits high infilling rates. Thirlmere on the other hand is a larger



Figure 2. The modern delta building into the head of Wast Water seen from the summit of Yewbarrow. The main combined channel from Mosedale Beck and Lingmell Beck enters from the left. The smaller Lingmell Gill channel is at the top of the image.

basin with a relatively small catchment and hence little infill. There are many situations where two or even three lake basins exist in a catchment – Buttermere/Crummock Water, Grasmere/Rydal Water, Brothers Water/ Ullswater, or Thirlmere/Derwent Water/Bassenthwaite Lake. In these, the highest basin acts as a trap for much of the input. Bassenthwaite Lake, with actually the largest catchment area of all the major lakes, has two higher basins and thus does not infill at rates related to its catchment size. Delta growth is most conspicuous at present into the shallow, gently sloping basins. Rates in areal terms will obviously change as inputs into the deeper basins progresses (Millward & Robinson, 1970, 1972; Pearsall & Pennington, 1973).

All of this has to be put into a geological context. Most of the major lake basins receive inputs off the Borrowdale Volcanic Group rocks, input regimes from Skiddaw Group outcrops are clearly different - evidence from the present sediment infills at Bassenthwaite Lake and Crummock Water for example suggest higher rates.

Thirdly, timescale is also fundamental in our understanding of these processes. We have an approximate beginning point at the time of deglaciation, but rates of input clearly change. Broadly speaking rates of sediment movement down slope and into valley floors was probably higher in the early stages as slopes were less stable and unvegetated. Since then we also have to consider anthropogenic factors and climate change.

More work and detailed measurement of many of the factors alluded to here in relation to the existing lakes would provide a working background framework in which to investigate whether palaeolakes ever existed in many of the presently ‘lakeless valleys’ in Lakeland (Eskdale, Dunnerdale, Langdale and others).

Valley floor lake beds

The issue of lakes that previously existed in the ‘lakeless valleys’ of the Lake District is one that has occupied much space in the literature ever since Ward (1873, 1874, 1875, 1876) drew attention to this possibility. In addition to recognising that the contemporary lakes had been previously more extensive, Ward also believed that lakes had existed in valleys where no lakes currently exist, in particular upper Borrowdale and Great Langdale. This reasoning was based on: (1) the flatness of the valley floors (thought to represent lake infilling), (2) the presence in some locations of terminal moraines that were considered to have dammed the lakes and were later breached allowing the lakes to drain, and (3) the propensity for these valley floors to flood during periods of heavy precipitation and to temporarily resemble lakes. No consideration as to the nature of the sediments that underlie the valley floors was given.

This last point was recognised as a critical factor by Marr (1916) who suggested that flat valley floors could be composed of fluvial deposits rather than lacustrine sediments. He advocated the examination of valley floor materials before drawing conclusions on the matter. Unfortunately this did not stop Raistrick (1925) from claiming that three or four lakes had previously existed in upper Borrowdale. These were termed: (1) the Seathwaite Lake, occupying the valley floor between Seathwaite and Thornythwaite (Figure 3) and was dammed by a moraine at the latter location, (2) the Stonethwaite Lake, in the Stonethwaite branch of Borrowdale and impounded by the moraines at Rosthwaite, (3) the Rosthwaite Lake, sandwiched between the eponymous moraines and the valley constriction at the Jaws of Borrowdale, and (4) possibly a Borrowdale Lake situated between Thornythwaite and Rosthwaite.

These lakes were adopted by Millward & Robinson (1970, 1972) and Prosser (2006) and seem to have become a permanent fixture in much geological literature relating to the valley. Only one attempt to examine the sediments that underlie the floor of upper Borrowdale has been made (Riley, 1949). Several shallow (1-2 m depth) excavations were made into the former ‘lake beds’ but unequivocal lacustrine sediments were not found. Rather, beds of fine sands, water-worn gravels and boulder clay (glacial till) were reported. The sands and gravels are more likely to have been carried to the sites by rivers, and cannot be used to support a former lake hypothesis.



Figure 3. The Seathwaite branch of upper Borrowdale showing the flat valley floor extending north to Thornythwaite (T) and Rosthwaite (R). Former lake beds or sandar?

Moraine-dammed lakes were also claimed to have existed in the valley of Trout Beck, north of Windermere by Mitchell (1931). The same author also thought that a former lake had been present above Sadgill in upper Longsleddale but that the lower part of the valley did not contain lakes. In contrast, Prosser (2006) envisaged four former lakes in that valley impounded by rock bars or moraines, but again the argument for such lakes hinged on the flatness of the valley floor and its tendency to flood during heavy precipitation. Likewise, Great Langdale has been regarded as having held a lake (Gresswell, 1952; Millward & Robinson, 1972; Prosser, 2006).

An alternative explanation for some of the flat, lakeless valley floors is that they represent former outwash plains or sandar, created chiefly by braided meltwater rivers issuing from receding glaciers. Contemporary sandar (Figure 4) may have ephemeral ponds or lakes, so similar features cannot be excluded from having existed on Lake District valley floors throughout deglaciation. During the Holocene continued fluvial erosion and deposition, and the activities of generations of farmers have transformed the sandar into valuable valley floor pastures.

However, having cast doubt over the existence of palaeolakes in many Lake District valleys we recognise that lakes did previously exist in some locations and have been completely infilled. Raistrick (1925) recognised the sites of two such lakes in the Naddle valley (NY 295225) and St. John's in the Vale. He believed that these were ice-dammed for an unspecified time, and later, as the lakes drained, residual waters became impounded by previously submerged moraine barriers. A former lake in the Naddle valley was also recognised by Clare (1999), and the sediment sequence reported by Clare et al. (2002). Radiocarbon dates of 3890±70 BP and 3460±50 BP from wood fragments in separate cores were obtained, and the core stratigraphy from which the younger sample came indicated a transition from open water to mire at that time. These are the only ages that we are aware of relating to lake infills.

The sediments and pollen of a former lake at Witherslack (SD 439852) were described in detail by A.G. Smith (1958). This small lake (~1x0.2 km) with maximum sediment thickness of 9.25 m was dominated by silty clay and calcareous marl below 7 m depth and brown detritus muds with frequent wood fragments and tree trunks above. The start of the transition from shallow open water conditions to fen conditions was placed at ~4 m depth where marked changes occurred in the pollen record; aquatic species declined at the expense of ferns and sedges. Unfortunately this work was conducted before the widespread application of radiocarbon dating and numerical ages for the transition



Figure 4. The Rakaia River, South Island New Zealand – a very active braided river system. Some channels may become temporarily blocked as a consequence of sediment movement and form shallow ponds. Many of the 'lakeless valleys' of the Lake District probably looked similar to this during and immediately after deglaciation. (Photo courtesy of Professor D.J.A. Evans)

and near-surface buried wood have not been obtained. Nevertheless, the study demonstrates that some water bodies have disappeared from the landscape over the course of the Holocene.

Conclusions

Our consideration of the evidence for and against palaeolakes in some Lake District valleys indicates that more detailed investigations are needed in order to demonstrate that lakes did or did not exist in some of the locations referred to. There is both morphological and sedimentary evidence to support the former existence of ice-dammed lakes in certain areas, while in others the evidence presented can be interpreted in an alternative way. It is indisputable that the present-day lakes were previously of greater areal extent and have been reduced in size as a result of delta progradation. Interesting statistics would be gained through attempts to calculate these former lake areas. A programme of delta coring and radiocarbon dating of suitable materials would provide valuable data on rates of progradation. With respect to the 'lakeless valleys' of Lakeland, detailed investigations of valley floor sediments are needed in order to establish if these are lacustrine or fluvial (alluvial) in nature. Only then will it be possible to say whether or not lakes previously existed there.

Clearly, research concerning former lakes in the Lake District has only scratched at the surface, even though it is almost 150 years since Clifton Ward's maps showed the locations of some such lakes. A considerable amount of investigation is still needed if we are to understand how the lakes have changed and the significance and extent of palaeolakes. We believe it is time for new work to commence, to tackle and hopefully resolve the issues we have highlighted.

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