Age of a pre ‘Little Ice Age’ advance of Engabreen, Arctic Norway

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Abstract. Engabre is an outlet glacier which, unusually for Scandinavia, descends well below treeline and terminates only some 100 m above sea level. It has a rich record of glaciological and historical documentation. Some 2 km from the sea but just 10 m above sea level, a glacial advance was known to have invaded a boreal forest, but the direct dating of tree death caused by ice overriding had been elusive. New exposures revealing a prostrate tree buried by till and a new radiocarbon age estimate now demonstrate an unambiguous link. Ten radiocarbon assays obtained from *in situ* sub-fossil tree stumps and clastic logs are re-assessed. It is concluded that the ice advance into birch woodland was in progress c. AD 790 in the late first millennium and this may have attained the outermost end moraine in the 12th century AD.

Introduction

Just north of the arctic circle lies Engabreen (the ‘en’ at the end of Engabre is the definite article in Norwegian), an outlet glacier which flows north-westwards from Vestisen, the western plateau ice cap of Svartisen in Nordland fylke (county). Vestisen, covering 218 km², is the second largest Norwegian glacier (Andreassen and Winsvold, 2012) and Engabreen itself has an area of 36.02 km² (Fig. 1). From the perspective of the Scandinavian Neoglacial (late Holocene), Engabreen is arguably the most significant glacier because of its particularly diverse bio and lithostratigraphic record. Due to the proximity of its terminus to sea level at the head of Holandsfjord, the lower part of the glacier descends well below the local tree line lying at *c*. 500 m above sea level and given time the recently deglaciated area would become part of the regional forest (Fig. 2).

Figure 1. *Map of Vestisen, the westernmost ice cap of Svartisen, with the individually numbered glacier drainage basins. Engabreen is basin 1094 and its outlet tongue can be seen descending towards sea level in the northwest (after NVE: Noregs vassdrags-og energidirektotat, inventory 2012)*

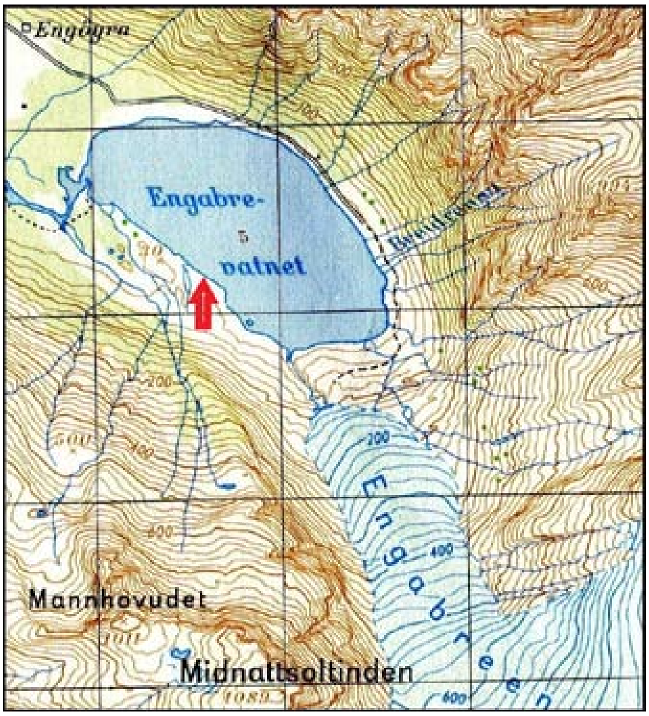


Figure 2. *A geographical map of the Engabreen study area (extract from map sheet 1928 II, Norges geografiske oppmåling). In 1968 the tongue of Engabreen extends down to c. 90 m above sea level. The meltwater river flows down a bedrock gorge for some 350 m to discharge into Engabrevatnet. The study site location has a red arrow. (20 m contour interval and 1 km grid squares)*

Despite a location in a remote area, its closeness to the sea has also meant that historically it was relatively accessible by boat to early travellers from more southerly European countries, as well as to Norwegians. As a result, there is extensive archive documentation going back to the late 17th century. In addition, land register returns for taxation purposes reveal that *c*. AD 1723, the farm called Storstenøren, was destroyed by extensive flooding associated with a major advance of the glacier such that the property was struck off. Storstenøren translates to ‘the big stone sandy flat’ and just outside the most distal end moraine one very large erratic block survives today. Particularly noteworthy is the report made by a three-man expedition from the

British Geological Survey (Geikie, 1866). This party, led by Archibald Geikie, spent a week examining the glacial geology of Engabreen and the adjacent Fonndalsbreen (Worsley, 2007; 2019).

Although it has a seemingly typical sequence of 'Little Ice Age' (LIA) landforms and sediments, the outermost end moraine limits of Engabreen are unusual in having a suite of 'older' moraine ridge fragments preserved beyond the classical 18th-century AD maximum advance position. These were investigated by Worsley and Alexander (1976), who identified an extensive aeolian coversand overlying a former land surface on which a distinctive soil had formed. This buried soil was present upon both the 'older' moraine ridges MR1 and MR2 and allied sandur deposits. Utilising both geomorphological and lithostratigraphic evidence in conjunction with the soil chronosequence, they argued that at a *minimum*, this ice advance could tentatively be ascribed to the early medieval warm period *prior to* AD 1450. Accordingly, the glacier had previously been slightly more extensive than that attained by the classical 18th-century advance maximum. Unfortunately, this reasoning has apparently been ignored by later workers who have persisted in asserting that the Engabreen outer limit dates from *c*. AD 1725. For example, Grove (1988, p 107) in her initial global synthesis asserted that 'No convincing evidence of expansion of Scandinavian glaciers before the seventeenth century has been found'. Later (Grove, 2004, p 430) failed to understand the study site stratigraphy (see below) and erroneously claimed that 'Engabreen advanced and retreated several times in this period to form a complex moraine'.

By good fortune, within the area of Neoglaciation at Engabreen, independent evidence supporting an ante classical LIA maximum advance had come from a locality some 2 km proximal to the end moraines (Fig. 3). Here in the early 1950s some 10–15 glacially overridden *in situ* sub-fossil tree stumps could be observed protruding through a thin cover of clast-rich till (University of Durham Exploration Society, 1951; Bergersen, 1953). This site had been deglaciated about AD 1940 (Figs. 4 & 5). A sample from one of the tree stumps (identified as birch and herein referred to as *Betula* A) collected by Alf Bergersen (University of Bergen) was ultimately subject to radiocarbon age estimation, but the result was mis-reported as 1600 AD (Liestøl, 1962). This error arose from muddling the AD and BP (before present) reference years; a clear case of 'the eye seeing what the mind was looking for'! Thus, the age in radiocarbon years should have been reported as 1600 ± 100 yrs BP (T-263) (Worsley, 1974). Assuming that the numerical age was meaningful, the stratigraphy had a much greater significance as nothing comparable was then known from any Scandinavian Neoglacial contexts. This prompted a detailed re-examination of the locality and the results of that exercise were reported in Worsley and Alexander (1975).

A conundrum emerging from the latter study was the lack of an unambiguous field relationship between ice overriding the site and the death of the trees, no matter how plausible that might be. If this were to be proven, then a radiocarbon age estimation from such a tree could theoretically define the ice advance chronology at the site with reasonable precision. There was no doubting the relationships seen in the early 1950s but, alas, all the formerly exposed sub-fossil tree stumps had been removed by the landowner (the late Knut Dahl) in the interests of conservation! Despite the subsequent acquisition of an additional five radiocarbon age estimates from buried tress, driftwood and palaeosol within a glacigenic fluvial facies, there remained a degree of uncertainty over the date of the ice advance. The purpose of this paper is to report the

Figure 3*. View over Engabrevatn from the summit of Midnatsoltindan (1089 m). Holandsfjorden and Nordfjorden can just be seen in upper left-hand corner and Engabreen is lower right. Study site has a red arrow.*

***Figure 4**. In situ tree stumps of* Alnus *and* Betula *inclined to the right as exposed on 1950, ice-axe for scale (University of Newcastle Exploration Society archive)*

discovery in a new exposure of an *in situ* sub-fossil birch tree (*Betula* B) which demonstrates 'beyond all reasonable doubt' a direct relationship between its death and burial from glacial overriding. A new radiocarbon age estimate from *Betula* B also permits a re-assessment of the earlier interpretation of the radiometric data from the locality, highlighting the pitfalls arising from over interpretation of radiometric datasets.

Study site

The site lies adjacent to the southern shore of Engabrevatn (Svartisvatn), a glacier meltwater lake where the adjacent terrain consists largely of lodgement till. Along the lake shore, exposures revealed the dramatic sight of tree trunks projecting out of the till (Fig. 6). This locality is of importance for the history of geology as it was here in the early 1930s, immediately beyond the retreating ice margin, that the first systematic investigation into the relationship between till macrofabrics and modern ice flow direction was made (Richter 1936). As a result of colonisation by birch woodland the surface till morphology is now becoming obscured.

Since the section was first fully exposed and logged in 1974 by Alexander and Worsley, degradation of the lake shore bluffs has taken place and the formerly exposed sections have been eroded back by about a metre on average. During clean-up in 1980, the hitherto unknown tree, the main focus of this discussion, was revealed and two years later another *in situ* stump. More

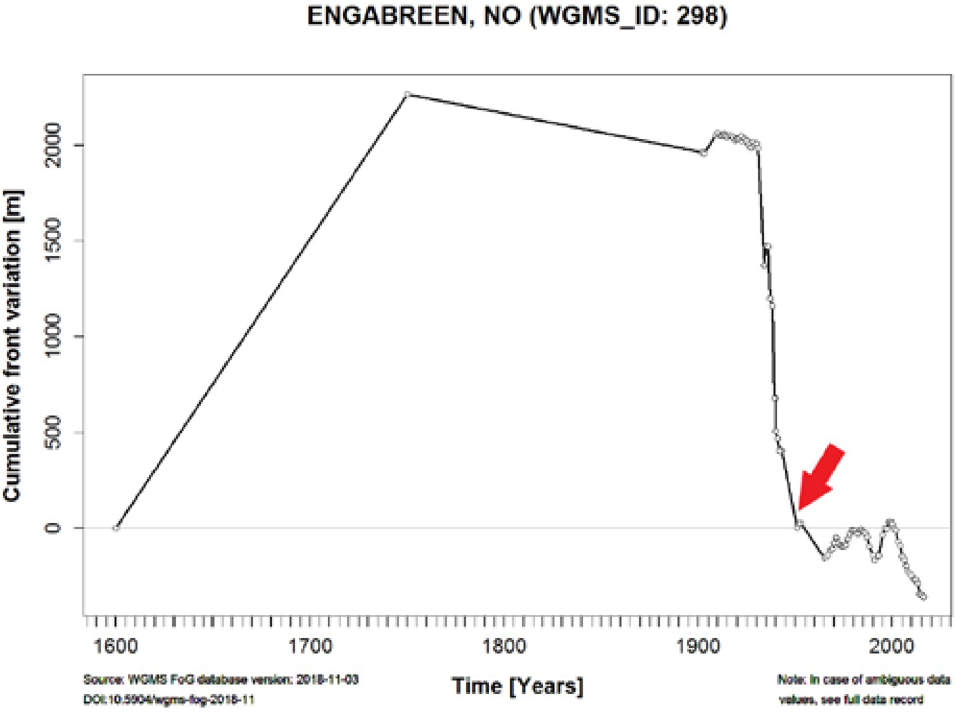


***Figure 5**. Engabreen frontal variations according to the World Glacier Monitoring Service. Note that (i) it assumes that the LIA advance maximum was c. AD 1750 and that (ii) the annual measurements commence in the late 1890s. The AD 1600 position is purely speculative. The 1940 position (when the sub-fossil trees became exposed) is arrowed. Immediately previous to this time, ice front was in the glacial lake and retreating rapidly.*

***Figure 6**. Shoreline exposure at the study site of the Svartis Gravel and Enga Till formations containing randomly distributed tree trunks in 1972.*

recently in 2005 it was found that only minor further recession of the bluff had occurred, but the slopes were so degraded that no organic material was exposed. This state is attributable to the cessation of wave washing of the site due to a reduction in lake level as a consequence of the Glomfjord-Svartisen Hydro Electric Power Scheme (opened in 1993). Assuming that a lower lake level is maintained, the site stratigraphy, including the prostrate *Betula* B trunk, ought to be conserved for the foreseeable future. If the lake shore erosion had continued at the pre-1990s rate much of the site would now have been destroyed.

The site stratigraphy consists of three basic lithological units, which in ascending order are: (a) Engavatn Gravel, (b) Helga Sand and (c) Enga Till (Worsley and Alexander, 1975). The former two units are interpreted as fluvial (outwash) facies, with the switch to sand sedimentation occurring after diversion of the meltwater away from the former main channel. Within the Helga Sand, an important marker horizon is a thin, very poorly developed palaeosol regarded as essentially an accumulation of detrital plant material in an almost abandoned channel. It was postulated that this channel had drained in a direction parallel to the modern lake shoreline and was probably separated from an ancestral lake by a linear moraine ridge. Some of the sub-fossil trees had colonised this low energy fluvial system. An erosive unconformity separates the sands from the overlying Enga Till. Since the top of the till also coincides with the modern land surface it constitutes the lithological record for a glacial advance over the site following the phase of fluvial sedimentation and tree growth.

***Figure 7**. View towards glacier showing the outcrop context, with the prostrate trunk of* Betula *B exposed in the centre of the section and the re-exposed in situ stump of* Alnus *(red arrow) on the right (scale Jim Rose)*

The sub-fossil trees

For reference purposes in the following description, the same horizontal reference scale of Worsley and Alexander (1975) will be used. The critical new section occurs between 24 and 30 m. Comparative drawn sections, corresponding to the lake shore bluff exposures in 1973 (upper) and 1980 (lower) are shown in Fig. 7. Large clasts littering the till surface in the cobble to boulder size range are omitted. In 1973 the *in situ Alnus* (at 27.5 m) was sited 1.3 m inland from the bluff on a surface littered by large clasts. In the drawing it appears as though the tree was rooted above the till, but this is misleading being due to the representation of a three-dimensional exposure in two dimensions. The base of the till sheet, an erosional unconformity, is irregular, and immediately to the right of the stump the till fails at one point so that the Helga Sand crops out at the surface. In contrast, by 1980 wave action had eroded back the plane of the section so that the *Alnus* stump cropped out in the bluff face. Hence, in the later section the base of the overlying till sheet can be seen to clearly overlie the Helga Sand.

The key exposure lay at between 24 and 25 m (Fig. 8). Here during section clean-up, a mass of woody material was revealed and progressively it became obvious that this corresponded to the roots of a near prostrate tree. Eventually the lower part of a tree trunk was exposed whose long axis lay at an angle of 45° to the alignment of the shore. The trunk still retained a complete cover of its characteristic *Betula* bark and was remarkably straight. Its basal diameter, just above what would have been the land surface at the time of death, was 0.15 m and when last seen in the excavated trench, at 1.7 m above the base, the diameter had reduced to 0.11 m. Beyond that point the tree trunk continued but was buried beneath a very large boulder and beyond this point the till thickness was such that further excavation was logistically impracticable. This tree will be referred to as *Betula* B.

In the root area, the former land surface corresponded to a partially preserved Ob horizon of a palaeosol and was traceable into that previously identified in 1973 around the *Alnus* stump only 3 m away. Although the two trees were directly related to the same land surface, a height difference of about 1 m over 3 m suggested either localised erosion of the Helga Sand or minor depositional relief, such as a shallow bar, prior to tree colonisation. Within the *Betula* B root zone the palaeosol and underlying gravels displayed a gentle fold, but the deformation had not severed any of the roots from the main trunk. This relationship is considered crucial since it indicates that the tree had not suddenly been blown over by strong winds. Rather, an internal force acting over a longer time period appears to have progressively pushed it over and at the same time the sediments within which the roots lay had also been subject to a sustained stress resulting in gentle deformation. A further pertinent relationship was that the main tree trunk was encased by the Enga till rather than being in contact with the surface of the Helga Sand as would have been the case with a wind induced fall (Fig. 9). The evidence, therefore, strongly indicates that the tree had been pushed over by an advance of Engabre. This conclusion is augmented by the observations at the site in the early 1950s which showed that all the exposed tree stumps were aligned parallel to the former glacier flow direction (University of Durham Exploration Society, 1951).

A new section excavated more distal to the glacier between 32 and 36 m revealed another *in situ* sub-fossil tree stump rooted in the Helga Sand along with the surrounding palaeosol. The contrast in exposure character was remarkable with the erosional unconformity at the base of the till showing a high degree of irregularity (Fig. 10). Unlike *Betula* B, the tree, another birch, hence *Betula* C, was not uprooted but an almost broken-off piece of trunk some 0.75 m long immediately above the stump, was leaning at a

***Figure 8**. Betula B (left of spade) and Alnus (right of spade) underlain by the Svartis Gravel and a thin Helga Sand with a thin palaeosol, overlain by the Enga Till.*

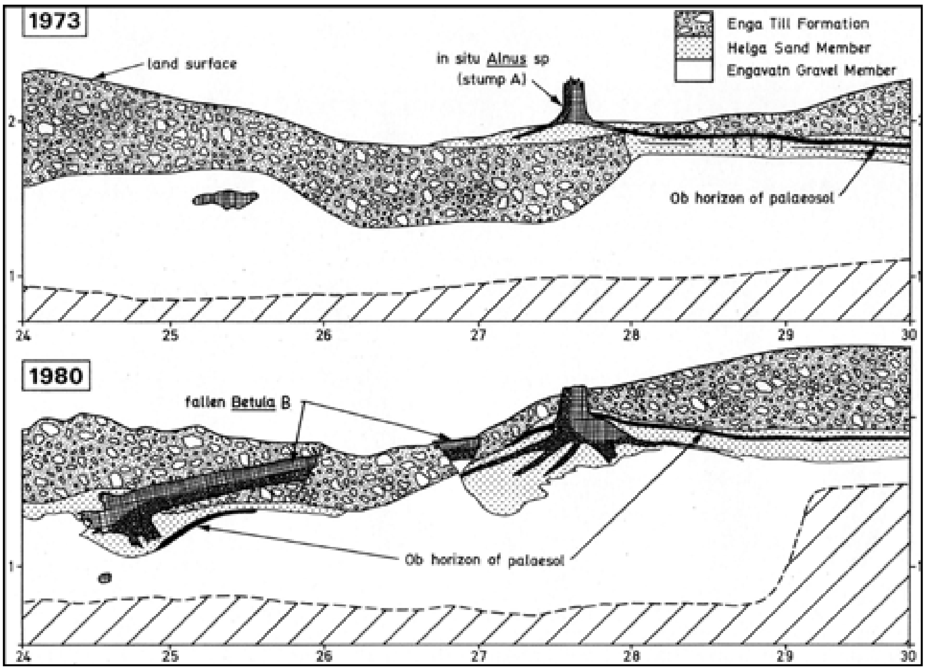


***Figure 9** (left). Drawn sections from 24–30 m to show how the exposures changed between 1973 and 1980. Note that the fallen tree (*Betula *B) was not evident in 1973 and that the trunk is orientated at 45° to the plane of the section.*

***Figure 10** (below). Drawn sections from 32–36 m in 1973 and 1980. The later exposure revealed another in situ tree stump –* Betula *C. Note the huge difference between the observational years, and that the clastic dyke was no longer visible in 1980.*

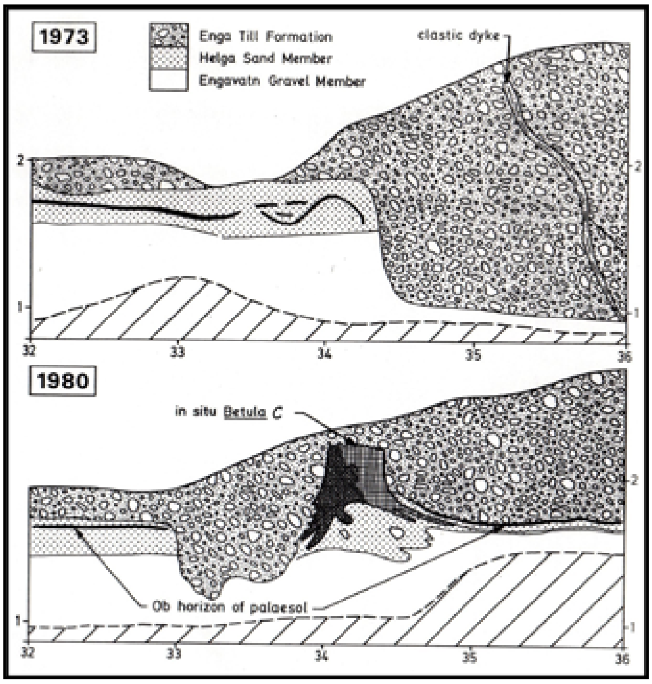
***Figure 11** (bottom). The wood fragment which is potentially a hand carved point was found on the top of the Helga Sand immediately to the right of the base of the tree stump* Betula *C. Scale length 0.1 m.*

45° angle towards 290°N. Again, the surviving trunk was totally encased in the till and once more the relationships strongly point towards a glacier advance being responsible for the death and subsequent burial of the tree shortly after passing over the previously described location.

A further point of interest at this site was the discovery of a pointed fragment of wood lying on the Helga Sand at the base of *Betula* C on the down glacier side. It has the attribute of having been sharpened by a knife to form a point and if this interpretation is correct, it is evidence of human presence in the period immediately before the glacier advanced over the tree (Fig. 11).

Radiocarbon age estimation

In an attempt to unambiguously establish the age of the glacial advance over the forest at this locality, a sample of the outer 10 rings of the fallen *Betula* B trunk was submitted for radiocarbon age estimation to the Trondheim Radiocarbon Laboratory, the same



laboratory which had undertaken the original *Betula* A assay. This yielded an age of 1390 ± 80 yrs BP (T-4019).

Through the kind co-operation of Stefan Winker (Winkler, 2001), the results of a further five assays (SWAN – 357/1032-35) on non *in-situ* Engabreen wood collected from very close proximity to the earlier material have been made available. The assays were undertaken by Quentin Dresser at the former Swansea Radiocarbon Dating Laboratory. The inclusion of these gives a data set of 12. A plot of **all** the known dates from the site are shown in Fig. 12. The age estimate for each sample is calibrated to near calendar age using the CalPal program of Cologne University. It should be noted that (i) the AD timescale is used rather than BP/b2k as the ages are all within historic time, and (ii) all have 95% confidence limits (± 2σ).

With the benefit of hindsight, it can now be seen that in the discussion of the first six age estimates by Worsley and Alexander (1975), too much emphasis was placed on trying to interpret each date in isolation, particularly those from the *in situ* material. The commentary was undoubtedly influenced by the prime objective of establishing a dated former position of the Engabre margin and hence the focus was on the *youngest* age beneath the Enga Till. Nevertheless, it was concluded 'it is doubtful on the present evidence if there is any direct relationship between the death of this particular alder tree and a glacial advance'. It was further stated 'even if the ice did not actually destroy the former woodland there was little time prior to inundation by ice' (Alexander and Worsley, 1975, p 61).

The interpretation of the radiometric results is now transformed by the knowledge that one sample comes from a context where it is highly plausible to assume that a growing birch tree was knocked over by an advancing glacier. The retention of all the bark on the trunk indicates that the tree was likely to have been alive when this happened. As a generalisation we can say that the date of 1390 ± 80 yrs BP (T-4019) from *Betula* B falls approximately in the middle of the time span defined by the other assays. This result was unexpected, as it was anticipated that the date would be the youngest in the dataset. In the earlier interpretation some concern had risen because the first date only just overlapped that of the *in situ Salix* and the youngest *in situ* date from the *Alnus* was almost 200 years adrift using the 2 σ criterion. The T-4019 estimate securely overlaps the first and the HAR-386 result but only just abuts with the *Alnus* date range. The latter had hitherto been regarded as having the closest relationship to the advance.

What is now clear is that in the early 1970s the sobering lesson which emerged from Barker's (1970) experiment was under appreciated. He revealed that 24 replicate measurements of the **same** sample yielded an age range of almost 1000 years when plotted at two standard deviations. This serves to emphasise the fundamentally **random** nature of radioactive decay (Fig. 13). Unfortunately, insufficient attention was given to this problem in the earlier published discussion and the dangers of making a too literal interpretation of the dates was overlooked. In partial mitigation it can be said that this issue was subsequently emphasised in an introductory account of radiocarbon dating aimed primarily at field geomorphologists (Worsley, 1981, fig. 5.1). Regrettably, when workers are obliged to justify radiometric dating in terms of cost rather than the science, it is not easy to accept that each relatively short-term measurement of the decay rate will register natural fluctuations which when converted to so called dates will throw up anomalies and inconsistencies in the apparent stratigraphic order. Thus, it now appears

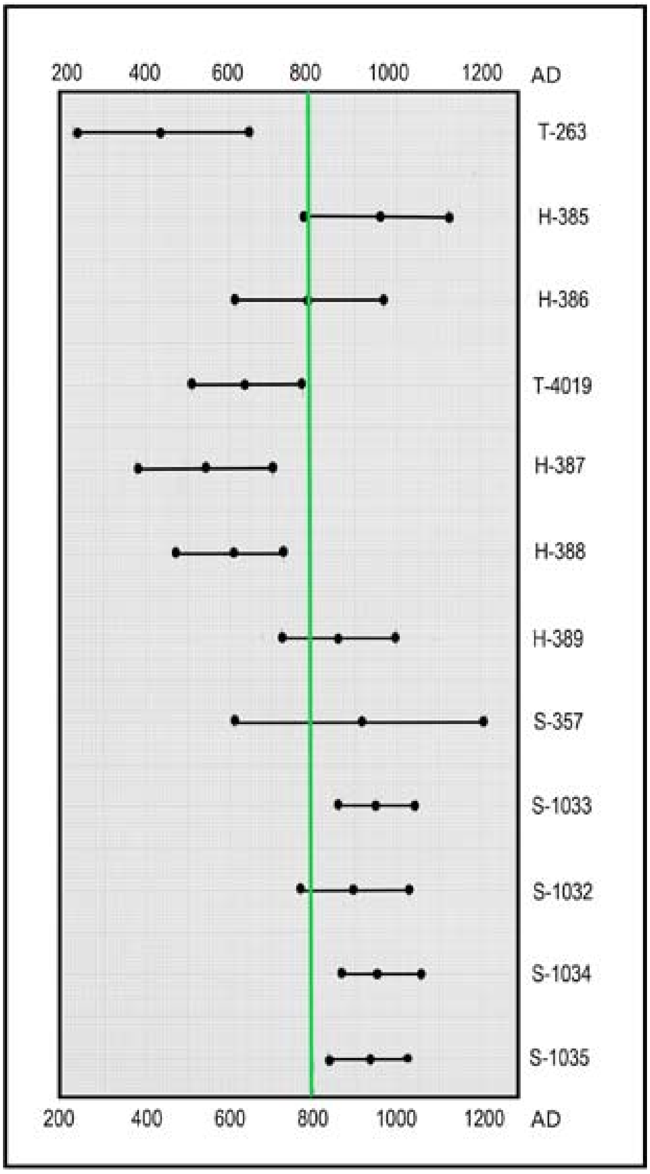


***Figure 12**. Unconventional plots of all calibrated radiocarbon ages (AD scale) at 2 σ from the study site. Note how the* Betula *B assay (T-4019) falls within the earlier in situ tree age ranges (T-263; H-385; H-385). The laboratory sample numbers are on the right; T = Trondheim, H = Harwell, S = Swansea. The green vertical line c. AD 790 is the average of the dataset mean.*

likely that all four of the dated *in situ* sub-fossil tree stumps were living at the same time and were killed by the advancing glacier within a period of no more than several years at the most. Yet despite this, the assays yield a spread of radiocarbon-based time as defined by the 2 σ plots (the most pessimistic viewpoint), ranging through almost 900 years. In the earlier study (Worsley and Alexander, 1975), it was tentatively concluded that the site was overridden approximately at the first-second millennium AD transition. In the light of the new data set this conclusion remains plausible although a century or so earlier appears likely.

Independent evidence for a significant ice advance in southern Nordland fylke in the first millennium AD using proxy data, has been assembled by a multidisciplinary team from the University of Bergen, working in the Okstindan mountains, 70 km SSE of Engabreen (Bakke *et al*, 2010). Mainly by analysing cores from lakes within the catchment of the outlet glacier Austre Okstindbreen, they have reconstructed what is claimed to be a complete record of glacier variability since total deglaciation of the area *c*. 9000 years ago. They hypothesise that the Neoglacial maximum glacial extent of the northern lobe occurred between 1350 and 1240 b2k (before 2000 AD), i.e. 650 and 760 AD.

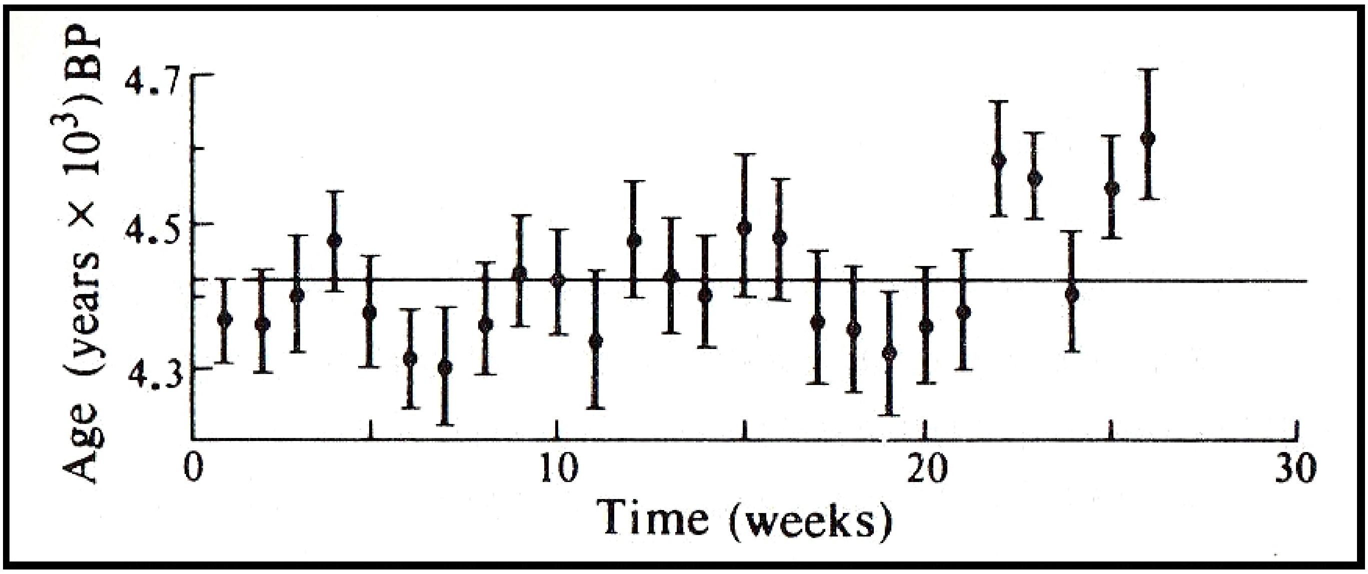
Discussion

A period characterised by a positive mass balance due to an increase in winter snow fall or lowered summer temperatures, or both, is likely to have induced the advance of Engabreen. That a forest was present in its path indicates that the advance was preceded by a period of reduced glacier size long enough for tree colonisation. If the last (LIA) deglaciation is a valid guide to colonisation rates at Engabreen, then a minimum of a century is required for a mature mixed alder-birch-willow forest to become established. The apparent lack of naturally regenerated *Picea* (spruce) within the contemporary ice-free Neoglacial area suggests that at least 300 years had intervened.

In a warming world, most glaciers are in retreat, and even for those which have had phases of advance, their paths have been over recently deglaciated terrain without a climax vegetation cover. Hence it is currently difficult to observe the process of ice–tree interaction. A well-documented historical example of a glacier advance into a forest relates to the Columbia Glacier margin in south-east Alaska (this is not to be confused with the Columbia Glacier in the Canadian Rocky Mountains). The Columbia Glacier (US) is a huge system covering some 1000 km^2 and its major outlet ice stream flows south and ends in tidewater north of Prince William Sound. It is notable for the calving of icebergs and dramatic retreat of 20 km over the last 40 years. At the turn of the 20th century the glacier terminus had an anchor point close to and on the north coast of Heather Island. For some 1–2 km the margin periodically encroached upon the shore zone where a mature spruce forest was established. Several American expeditions undertook investigations of the Alaskan coast, and Heather Island in particular was subject to detailed field investigations. Around 1910 the National Geographic Society funded several expeditions the results of which appeared as the classic book 'Alaskan Glacial Studies' (Tarr and Martin, 1914). For instance, Martin (p 271) reported that in 1909 'the ice was pushing in among the trees … overturning them by the thrust against their roots and killing them by burying their trunks beneath the rock and soil of the push material' (Fig. 14).

As noted above, the stratigraphy associated with the outermost (pre classical LIA advance limit) end moraines MR1 and MR2, implies an age at least twice that of the 18th-century advance termination. The radiocarbon data give a possible maximum age for

***Figure 13**. Conventional non-calibrated one σ plots of 26 replicate measurements of the same sample preparation made over a six-month period (Baker, 1970). The average age in this case is close to 4.42 k BP (AD 1950). This illustrates well the desirability of regarding radiocarbon results as estimates of true age.*



the earlier advance limit. This evidence now requires consideration within a broader palaeoclimatic context.

Lamb (1995, p 171) thought that by the end of the tenth to twelfth centuries AD, most of the world for which we have evidence seems to have been enjoying a renewal of warmth which at times may have approached the level of the warmest millennia of post-glacial times. Warmth reached its peak in Greenland in 12th century. However, after AD 1200 farmland in north Norway, which during the preceding century or two had been cleared, started to be abandoned. Lamb suggested that a strong thrust forward of the Arctic regime in longitudes of Greenland and Iceland distorted the pattern of the circumpolar vortex. This would most likely induce a deterioration in summer temperatures. Further south a colder more disturbed climate had set in already in the 1200s with advancing glaciers in the Alps between 1200 and 1350.

A major contribution to comprehending the abrupt transition from a relatively warm Medieval climate to a colder one promoting a major glacial advance was proposed by a team led by Giff Miller (Miller *et al*, 2012). They demonstrated a sudden cooling event between 1275 and 1300 AD and a subsequent one between 1430 and 1455 based on radiocarbon dating of rooted tundra vegetation recently exposed due to the retreat of small frozen-to-the-bed ice caps in Baffin Island, arctic Canada. They argued that the vegetation was killed by the onset of persistent snowline depression and subsequent ice cap growth. A supplementary investigation of lake varves from Hvitárvatn in Iceland, dated by tephra horizons, yielded a synchronous pattern of glacier growth reflected by an abrupt increase in varve thickness. This cooling, they argued, initiated the LIA. The abrupt cooling event 1275–1300 appears to coincide with four major volcanic eruptions in tropical latitudes and the latter were postulated as the key trigger event.

In a discussion of the term 'Little Ice Age', Jones and Bradley (1992) highlighted the problem of its lax definition. Whilst it is acknowledged that in modern usage it corresponds to the latest phase of the Neoglacial, there is no agreement as to the date of commencement. Some would argue for the end of the Middle Ages circa AD 1200 (e.g. Porter, 1986) and others AD 1550–1850 (e.g. Lamb, 1977; Fairbridge, 1987). Curiously, in her book 'The Little Ice Age', Grove (1988) did not explicitly define it although in practice she conforms with Lamb's usage. Equally important was the demonstration by Jones and Bradley (1992) that the last 500 years was not a uniform cold period but rather a period of complex climatic anomalies, with no evidence for a prolonged globally synchronous cold period. Accordingly, they urged caution in its usage.

Support for this viewpoint was forthcoming from Lockwood *et al* (2017), who asserted that the 'LIA' is a total misnomer as in their view, the LIA was just a very short-lived puny climate and social perturbation. Most recently, a subset of the 'Past Global Changes' team has concentrated on unravelling the paleoclimate of

***Figure 14**. The Colombia Glacier advancing into Sitka spruce forest – photograph taken by R. S. Tarr on 1909-08-23. Cornell University Library Collections.*

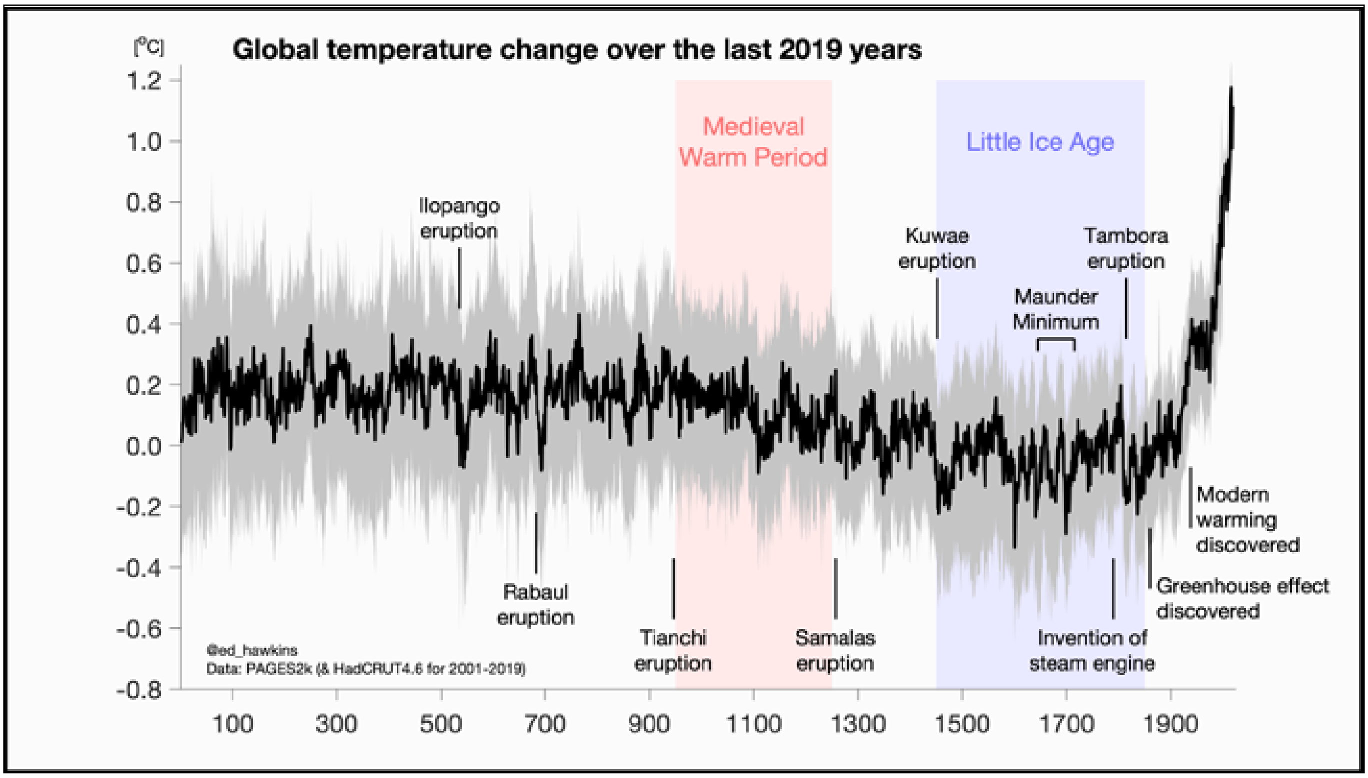


***Figure 15**. Global temperature change over the last 2019 years reconstructed from a wide proxy dataset including tree rings, corals, cave deposits, ice cores etc. The reference period is 1850–1900 which is often used as an approximation to the pre-industrial level, (after PAGES2k and Ed Hawkins Climate Lab Book blog). Note that AD 790 falls within the first millennium which was characterised by mildly fluctuating temperatures but does not correspond to a specific global climatological/vulcanological event. The scale of the current global warming episode far exceeds any earlier climatic amelioration.*

the last two thousand years. Their global temperature reconstructions (Fig. 15) have recently been published (PAGES 2k Consortium, 2019). These are consistent with the conclusions of Lockwood *et al*, but they also stress that a significant element of the pre-industrial era variability at multidecadal timescales is likely to be caused by forcing arising from volcanic aerosols as exemplified by the hypothesis of Miller *et al*. Nevertheless, the various LIA ice advances and subsequent retreats has made a major landscape impact even if considered by climatologists as 'puny' and certainly from a geological perspective the term is invaluable in analysing north European mountainous landscapes.

Summary

1. The field evidence demonstrates a direct relationship between the death of a birch tree and a glacial advance over the locality. Further, the broader relationships suggest that the ice advance was into a well-established forest.

2. The new radiocarbon age estimation (T-4019) from an *in situ* fallen tree lies within the envelope defined by earlier assays on *in situ* material.

3. Knowledge of the new date from a context which is confidently deciphered as defining the advancing ice margin, reveals that earlier attempts at interpreting radiocarbon data had been over influenced by the individual dates and too much meaning had been placed upon them. The new scenario acknowledges the random nature of radiocarbon decay and hence does not seek *precise* age relationships between samples. Nevertheless, the 12 assays have a mean value of AD 790.

4. Taking the radiocarbon data set as a whole, the age of the advance over the forest is taken as late first millennium AD. This well precedes the classical European LIA.

5. The post-formational time deduced from the soil chronostratigraphy associated with the outermost end moraine ridges at Engabreen, is consistent with the glacial advance chronology derived from the radiocarbon data at the study site. It is feasible that the ice advance at the study site eventually progressed to the outermost limit as defined by end moraine MR1.

6. The extreme rarity of outlet glaciers descending below tree line in northern Scandinavia accounts for the uniqueness of the Engabrevatn site.

Acknowledgements

The fieldwork was primarily funded by the University of Reading. *Betula* B was first revealed in 1980 by undergraduate Christine Cooper whilst re-exposing the 24–26 m part of the lakeside section during a Quaternary Studies field class. The late Knut Dahl of Fondalen Gaard gave permission for and encouraged the work on his land. Douglas Peacock, a member the 1950 Durham expedition, discussed the original discovery and Hal Lister located the photograph in the Newcastle University archives. Steinar Gulliksen and Reidar Nydal of the Trondheim Radiological Dating Laboratory (now NTNU University Museum) were most supportive. Help, discussions and/or reviews of the draft manuscript were contributed by Michael Alexander, Ed Hawkins, Peter Knight, John Matthews, Jim Rose (on site in 1980), and particularly Stefan Winkler. My wife Hilary gave invaluable assistance with manipulating the digital images.

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