The British Geological Survey's Glaciological Expedition to Arctic Norway in 1865

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Abstract: During the two decades after 1841, the Glacial Theory was, at best, quiescent in Britain. The 1865 expedition arose from a progressive resurgence of interest in glacigenic sediments. The members were three young Geological Survey officers, Archibald and James Geikie and William Whitaker, all with recent drift mapping experience. Their objectives included making 'actualistic' observations of modern glaciers, comparing Norwegian and Scottish glacial features, and better comprehending glacial deposits, both ancient and modern. Field investigations were focused on two areas of Arctic Norway - Holandsfjord (Nordland) and Bergsfjord Peninsula (Tromsø-Finnmark). Their work produced the earliest known detailed glacial geological analysis (including accurate drawings, sketches, maps and cross sections) of any Scandinavian ice-marginal environments. These data permit a comparison of ice marginal and proglacial environmental changes between 1865 and the present day associated with the key Holandsfjord glaciers - Engabreen and Fondalsbreen. The characters of the ice margins in 1865 and 2005 are compared and, in conjunction with other observations, yield one of the most comprehensive records of Neoglaciation anywhere. In the Bergsfjord Peninsula, the 1865 details are more sparse, except for the Jøkulfjord regenerated glacier. The impact of the 1865 work on the Glacial Theory and subsequent careers of the participants was clearly significant.

In the summer of 1865, Archibald (Archie) Geikie (1835-1924) in the company of his brother James (Jamie) Murdoch Geikie (1839-1915), and William Whitaker (1836-1925), undertook a landmark glaciological expedition to northern Norway (Figs 1 and 2). All three were then junior serving officers of the Geological Survey of Great Britain. They appear to have had official encouragement to gain 'actualistic' field experience relating to 'the hot topic of the day' in Quaternary geology, namely the debate over the land-ice v marine-iceberg hypotheses in accounting for landforms and sediments associated with former glaciation in Britain and elsewhere.

The expedition formed a key stage in development of the Glacial Theory in Britain, and had a major impact on the participants' subsequent geological work, but it also provides an opportunity to compare the glaciers in 1865 with their equivalents of today.

The participants

Archie Geikie was born in Edinburgh in 1835, the same year that the Geological Survey of Great Britain was founded. Twenty years later in 1855, he joined the Survey after a classical high school education and uncompleted university studies. He progressed rapidly since, in the 1870s, he concurrently held the foundation Murchison Chair of Geology and Mineralogy at Edinburgh University and the Directorship of the Survey for Scotland. Ultimately, he rose to become Director General of the whole Survey and after retirement, President of the Royal Society, the only geologist ever to attain this prestigious position (Charles Lyell declined to be nominated in 1863). In the last year of his life he wrote an autobiography (Geikie 1924) the last achievement in an extremely prolific record of publication (Cutter,1974; Oldroyd,1990).

William Whitaker was born in Hatton Garden, City of London and read chemistry at University College London before graduating in 1855. After joining the Survey, his first Survey notebook shows that he commenced mapping work near Pangbourne, in the Goring Gap area of Berkshire in May 1857. Thereafter, for his entire career, he remained based in the southeast becoming a specialist in both Cretaceous and Tertiary sequences. He is best known for his seminal work on the geology of the London Basin and water supply issues (George 2004). During his career he mapped glacial deposits of varying ages in greater East Anglia, including some immediately prior to the expedition early in 1865.

Jamie Geikie was a younger brother of Archie and was born in 1839. He became an assistant geologist with the Survey in 1861 and commenced publishing during the year after returning from Norway. His epic book, *Great Ice Age*, was first published in 1874 and established him as a world authority on glacial geology. In 1882, he resigned from the Survey in order to succeed his elder brother in the Murchison Chair. This was not an easy decision for him and he would dearly have liked to have maintained a dual appointment like that of his elder brother but this was not approved by the civil service. He occupied his chair until retirement in 1910.

Glacial Theory before the expedition

Some of the earliest steps in the history of British glacial theory are recently reviewed in this journal, (Worsley 2006). One perplexing aftermath of Louis

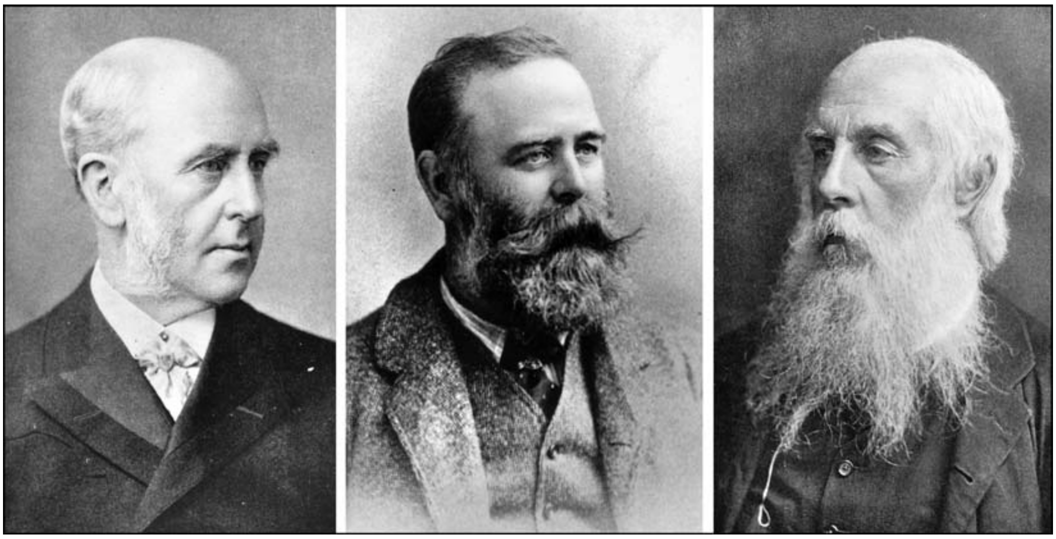

Figure 1. *The three expedition participants: left: Archibald Geikie, centre: James Geikie, right: William Whitaker*

Agassiz's famed visit in 1840, is that after a short euphoric phase, when senior geologists such as William Buckland and Charles Lyell declared their conversion to the land ice hypothesis, very serious doubts started to reassert themselves. An oft quoted sentence is that of Buckland in a letter to Agassiz (1885 p309) which reads *Lyell has adopted your theory in toto!! On my showing him a beautiful cluster of moraines within two miles of his father's house* [Kinnordy in the Vale of Strathmore], *he instantly accepted it, as solving a host of difficulties that have all his life embarrassed him*. Unfortunately, Lyell was soon to repudiate the land ice concept to again favour a marine iceberg theory and the British geological community at large remained highly sceptical. Buckland, finding himself almost totally isolated, tried in vain to adopt a conciliatory compromise position.

An American historian, Hansen (1970), asserted that before his study, no one had directly addressed the problem of explaining how or why the glacial theory was not accepted by the geological community in the 1840s. Lacking the advantage of direct experience of British superficial geology, it is understandable that he seemingly missed the principal point in comprehending this conundrum by not fully appreciating the influence of two key factors. First, the common occurrence of now isostatically raised *in situ* faunas in sediments originally deposited below sea level. Secondly, that glacially-derived marine faunas of existing species were often present in both till and outwash, on occasion at particularly high elevations (almost 400m) as at Moel Tryfan in north Wales (Thompson & Worsley 1966). The geologists of the day sought to interpret and reconcile the factual evidence afforded by these well-preserved faunas while not familiar with basic processes such as glacial ice rafting and glacio-isostatic loading.

In the introduction to his seminal book on palaeoglaciation, Ramsay (1860 p2) summed up the situation succinctly by stating *It is now 20 years since Agassiz and Buckland announced that valleys of the Highlands and of Wales had once been filled with glaciers. Few but geologists heard the announcement, and with rare exceptions, those who cared at all about it, met the glacial theory of the Drift in general, and that of extinct glaciers in particular, with incredulity, and sometimes with derision*. We should note that Charles Darwin was one of these exceptions since at Cwm Idwal he had identified supraglacial debris associated with cirque glaciation in north Wales (Darwin 1842, Worsley 2007). Later, Ramsay (1864 p106) observed *men sought to explain the phenomena of this universal glaciation by every method but the true one*. Indeed, Bailey (1952) notes the irony that in 1845 Ramsay attended a Geological Society of London meeting and afterwards wrote *Jolly night at the Geological. Buckland's glaciers smashed*. Apparently he converted to a marine version of the glacial theory in 1848 following a joint examination of the Llanberis Pass area of North Wales with Robert Chambers, a committed glacialist who wished to compare the Welsh with his native Scottish glacial evidence.

From 1845 onwards, Ramsay's sway on British geology grew, since in that year he became Local Director of the Survey for Great Britain, with responsibility for a field staff of six. His first public declaration of his belief in the former existence of glaciers in Wales came at a discourse held at the Royal Institution in 1850. He instigated a Survey mapping programme in Scotland in 1854 and this expansion of activities led to the appointment of Archie Geikie in the following year. In his 1860 book, Ramsay continued (p3) *it was necessary for competent observers to investigate the subject both of existing glaciers in other regions and of drift-ice in the northern and southern seas; and, accordingly, I have considered it needful for the thorough understanding of ancient British glaciers, that some of the phenomena now easily seen in Switzerland should in the first place be noticed*. Ramsay had twice visited Switzerland, in 1852 (on his honeymoon) and in 1858 in the company of John Tyndall who also published on Swiss glaciers in 1860. The first part of Ramsay's book (pp5-34) is mainly devoted to his observations of the Swiss Aar

Glacier. In the second part (pp35-116), he argues in favour of a phase of land ice glaciation in North Wales but also for a subsequent major marine submergence phase accompanied by ice bergs.

With Ramsay as his line manager, it is not surprising to find that Archie Geikie recalled (1924 p94) that in the following year *I deliberately set myself to undertake a serious study of them* [drifts], *with the view of trying to make out the history of the events of which they are the record. They were commonly regarded as various marine sediments, spread over the country when it was submerged under a sea on which icebergs and rafts of floating ice transported rock debris from northern lands*. He continued by saying that after field examination of the till and rock head surfaces beneath, *one became more convinced that the phenomena could not at all be accounted for by floating ice, but demanded the former existence of a great terrestrial ice sheet or sheets, as Agassiz had insisted, twenty years before*. He then devoted his 1862 summer holiday leave to making a traverse across southern Scotland specifically to obtain a better understanding of the glacial deposits and allied features. In the following year he accompanied Ramsay in making a transect along the East Coast from Berwick to the Humber, examining the glacial successions and making stone counts (clast lithological analysis in modern jargon!). As he comments in his autobiography *my mind was rather obsessed at this time with glacial questions* (Geikie, 1924 p99).

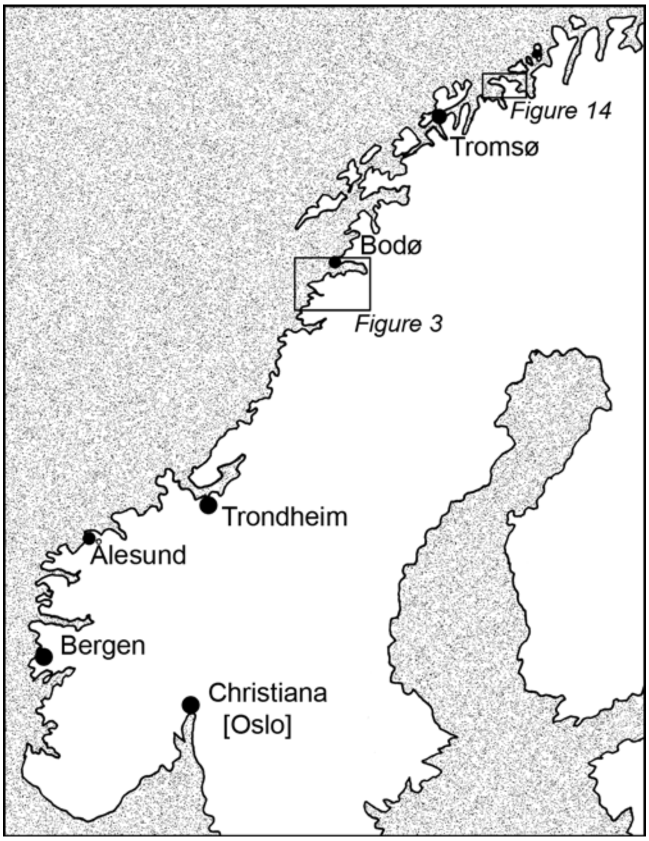

***Figure 2**. The two main study areas in Norway, within the counties (fylke) of Nordland and Troms/Finnmark.*

Archie Geikie's first major glacial paper (1863) was described as *The first attempt to present a connected view of the sequence of events in the history of Scotland during what is known as the Glacial Period or Ice Age*. This was a formidable achievement for someone working on a topic largely in their leisure hours. The paper is particularly illuminating since Geikie describes how his own interpretations switched from a drift ice standpoint to a perspective which accepted land ice as the main agency in the generation of glacial landforms and deposits. He did not, however, totally reject the marine submergence concept and came to adopt a compromise position whereby a main phase of land ice glaciation was followed by a submergence episode. Bailey (1952 p73), observed *Ramsay, Jamieson and* [A] *Geikie at this date* [1863] *retained a great deal more submergence in their philosophy than is commonly admitted today*. Indeed, Jamie Geikie (1881) later wrote *...German geologists continued to hold the opinion that all drift phenomena of the low ground were due to the action of icebergs and marine currents until 1875*. Even as late as 1916, J.E. Marr, one of the leading glacial geologists of the day, stated (p144) *the glacialists were divided in opinion as to the relative importance of land-ice and floating sea-ice as agents of glaciation, and for some areas in Britain the matter cannot be yet ultimately settled*.

Both Geikie and Ramsay were aware that ultimately they were subject to the approval of Sir Roderick Murchison, who at the relatively advanced age of 63, had become Director General of the Survey in 1855. Murchison's views were anti Darwin's evolutionary model and strongly critical of glacial theories. As Oldroyd (1990) succinctly put it, *Geikie was an uniformitarian (or quietist) while Murchison was a catastrophist (or convulsionist)*. Indeed, Murchison died in 1871 still an unrepentant neo-diluvialist. Hence, in the first edition of his North Wales memoir published in 1866, Ramsay was requested by his superior to be brief in his physiographic account that favoured glacial erosional processes in cirque genesis (Bailey, 1952).

Nevertheless, Ramsay must have given his backing to the proposed expedition since there was a very close relationship with both Geikie brothers. This is exemplified by the dedication of the first edition of Jamie Geikie's *Great Ice Age* to '*A.C. Ramsay dear friend and teacher*'. Additionally, after his death, Archie wrote a full sympathetic biography on Ramsay (Geikie, 1895), saying *He was almost my earliest geological friend, and for many years we were bound together by the closest ties of scientific work and of unbroken friendship*.

Archie, writing the preface to his just completed book *The Scenery of Scotland* immediately prior to departure on the 1865 expedition, noted that the principles of denudation were laid down long ago by Hutton and Playfair but that the question of the origin of valleys remained a controversial issue, and with

Murchison in mind, possibly disingenuously wrote *the views to which I have been led, run directly counter to what are still the prevailing impressions on the subject, and I am therefore prepared to find them disputed, or perhaps thrown aside as mere dreaming* (Geikie, 1865b p96). Later, in the preface to the second edition (Geikie, 1887), he recalled the controversy raging in 1865 and how William Whitaker's ideas on sub-aerial Wealden denudation had contributed support to his position.

Earlier glacier observations in Norway

Sensibly, some preparatory desk studies were undertaken prior to the 1865 expedition and these included the narrative of the Prussian savant Leopold von Buch (1774-1853), first published in 1810. In this von Buch described a prolonged journey during 1806-8 in which he followed a circular route extending from Christiania (Oslo) to the North Cape and back with the objectives of (i) investigating the geology, (ii) examining the role of latitude in determining the character of the natural vegetation and (iii) observing human land use *till at last, the noxious influence of snow and ice is destructive to everything which has life*. The translator of the English edition (von Buch, 1813) was John Black, and in a gloomy preface he anticipated *that country (Norway) will in all probability soon become the theatre of a bloody war, in which the British nation are pledged to co-operate*. Incidentally, Charles Darwin took a copy of von Buch's volume with him during his voyage on the Beagle, enabling him to appreciate how snow line elevations and calving tide water glaciers in the southern hemisphere lay at latitudes much closer to the equator than their equivalents in the European Arctic.

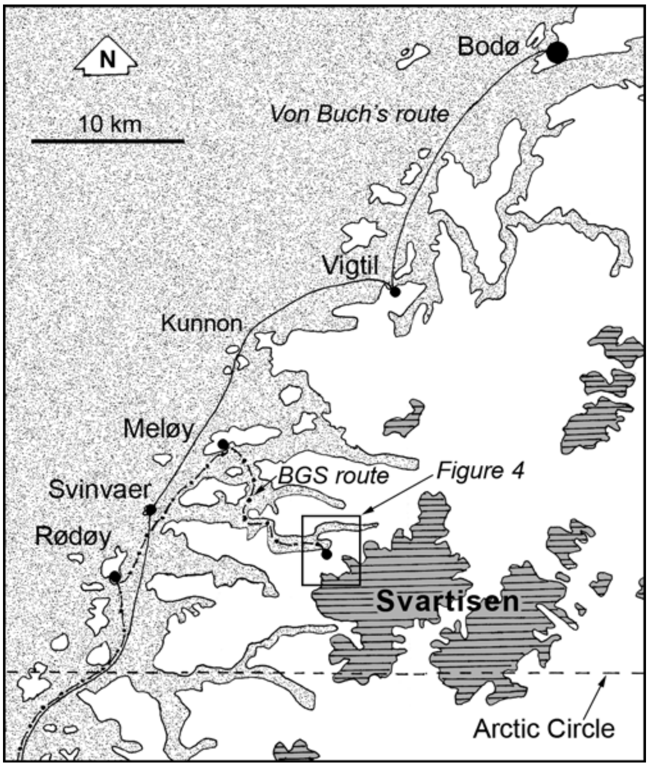

***Figure 3**. The Nordland coastal area between Rødøy and Bodø showing the location of places mentioned in the text.*

Two parts were relevant to the BGS expedition. Firstly, von Buch's account of the Arctic Circle coastal districts made during mid June in 1807 (Fig. 3). He commented *perpetual snow lies here and what is still more the snow has generated glaciers*. Between Lurøy and Bodø his precise route is unclear since the geographical names which he uses are no longer in current use. He reported *about 4 or 5 English miles south from the cape [Kunnon] opposite the trading station of Haasvär, a glacier descends from the height, and the ice comes into immediate contact with the sea, a circumstance perhaps peculiar to this glacier. Even then, the warmth of the summer had merely driven it a few steps from the shore, but it would probably regain its former space in a short time*. Here he was referring to the snout of Engabreen part of the Svartisen ice cap which, uniquely in Scandinavia for an outlet glacier, descended to sea level. The description of Haasvär as being opposite is misleading (probably an artefact of the translation) since it is a small uninhabited island just beyond Rødøy, over 30 km west of Engabreen.

Secondly, a description of the Bergsfjord Peninsula (halvøya) glaciers (these are 450 km northeast of Svartisen), as viewed from the east above Alteid. He remarked (p232) *They remain pendent in the middle above the steep and almost perpendicular rocks and in summer the great masses of ice are incessantly precipitated from above into the Fiord causing the sea level to rise by several feet for miles* (i.e. mini tsumanis). With the iceberg hypothesis being so favoured in 1865, the BGS expedition was naturally attracted to this iceberg-generating locality. Indeed, British trawlers operating out of the Humber ports utilised this free freshwater ice in packing their catches for many decades. Von Buch did not round the peninsula because of poor sea conditions (Fig. 14).

Another important source of guidance came from the pioneer Scottish glaciologist J.D.Forbes relating to a journey he made in 1853 (Forbes 1854). He had consulted widely with northern experts in Oslo before heading north. He included a map in the rear of his book showing his route and, rather crudely, the distribution of the main permanent snowfields. Curiously, he labelled the Svartisen ice caps collectively as Fondalen. The significance of this will be apparent later. After calling at Rødø [Rødøy] Forbes sailed non-stop to Bodø but wrote *on the right with more than common majesty; and over the snowy summits of Fondalen* [Svartisen] ..... *clearly distinguish true glaciers, descending from the hollows of the mountain towards the level of the sea*. He was understandably frustrated that the coastal configuration foiled his desire to see the glacier termini. He recalled that von Buch had stated that these glaciers of Fondal [Svartisen] fall *into the sea* (Forbes's italics). He also expressed scepticism that von Buch or any other *traveller who has published his observations* had visited the interior of these fjords. However, the insight shown by von Buch into the mechanism of annual frontal variations, whereby summer ablation exceeds forward movement resulting in frontal retreat, suggests that either he or an associate had first hand knowledge of the glacier. Archie Geikie made several pages of notes in his field note book from Forbes's account prior to departure for Norway.

Sources relating to the expedition

Archie Geikie's paper (1866) is a vivid account of their activities in Norway, and later a slightly revised version formed a chapter in his book *Geological Sketches at Home and Abroad* (1882a). A short socially oriented outline is included in his autobiography written almost 50 years later (Geikie 1924). His unpublished field note book, DD, gives both logistical and further valuable observational data and sketches (Geikie, 1865a). This is preserved in the archives of Haslemere Educational Museum, an institution that Archie encouraged in the last decade of his life while living in that town.

Unfortunately Jamie appears to have left little written material specifically relating to his expedition experiences. As his biographers wrote *Unfortunately only the barest notes of this visit remain ....and we do not know what impressions were obtained* (Newbigin & Flett, 1917). Nevertheless, they were able to fill in some details of the expedition which otherwise would not be known.

Sadly, no record has been identified concerning observations made by William Whitaker while in Norway, other than oblique comments. He appears not to have published anything specific arising directly from his experiences (see later). His official Geological Survey notebooks are in the BGS archive at Keyworth, but, alas, the volume covering the period October 1864 to August 1865 has a tantalising gap in his dated notes extending from June 19 to August 16. It is probable that he kept a separate field notebook (as did Archie) specifically devoted to the expedition, but its location is not known.

Expedition organisation and route

The expedition had originally been planned for the summer of 1863, consisting solely of Archie Geikie and his friend and colleague John Young (1835-1902). They had been school friends and sometimes Archie's junior brother Jamie was 'allowed' to accompany them on fossil hunting trips. Young first went into medicine but then decided that a geological career was preferable, so as Dr Young, he joined the Scottish branch of the Survey at the same time as Jamie Geikie in 1861. Unspecified, 'unforeseen circumstances' caused a year's postponement and during that time Young withdrew, with his place being filled by both Jamie and William Whitaker.

The principal objective was the examination of modern glacial environments as an aid to the interpretation of landforms and deposits in Scotland *where the ice still remains on the heights and creeps down the valleys in glaciers, some of which even descend to the edge of the sea, ...'there was every probability that ...light would be thrown on [the ice-age] in Scotland* (Geikie, 1924 pp106-7). Although access logistics played a role, Norway was selected primarily since its geological character was similar to western Scotland. It was known that some glacier margins were close to the sea, something which Ramsay knew that the Alps could not provide. The departure date, June 1865, was apparently determined by when Archie Geikie could finish correcting the proofs of his book *The Scenery of Scotland* (1865b). Just before their departure, Archie learned that he had been elected a Fellow of the Royal Society of London (later, the other two members were also elected FRS).

Archie Geikie was leader of the expedition and one wonders on how a small party consisting of two Scots brothers and a Londoner related to each other. Certainly in later years there were disputes between Geikie senior when he was Director General of the Geological Survey and William Whitaker over mapping policy. Furthermore, Jamie is said to have resented his brother's dictatorial style and reputedly did not inform him of his forthcoming book *The Great Ice Age* until it was published (Harry Wilson, 1985, pers. comm.) and this rumour gains support from a total absence of any mention of Archie in the preface. Similarly Archie makes no mention of Jamie in his magnum opus (A Geikie 1882b). Despite this, Archie did fairly acknowledge that his 1866 paper was the result of their conjoint observations, although joint authorship would probably have been more appropriate. The rear pages of Archie's field note book record the financial transactions during the expedition in great detail and there is little doubt that he also acted as treasurer (Geikie 1865a). Apparently there was a budget to finance the expedition in the field (possibly a subvention from the Survey), and his accounts separate personal items incurred by each participant from corporate expenses with William Whitaker being the most frugal personal spender.

Uncertainty surrounds the precise initial outward route. In his 1866 account, Archie mentions sailing from Bergen northwards along the coast, whereas in his autobiography (written 58 years after the event) he asserted that it was from Hull direct to Trondheim. In contrast, Newbigin (1917) reveals that Jamie's notes indicate a route from Newcastle to Ålesund and then up to Trondheim. All sources agree that in Trondheim they transferred to the daily north bound coastal steamer and disembarked at the island of Rodoy [Rödö]. The next leg was by a local ship to the island of Meløy [Melovær] about 30 km north of the Arctic Circle (Fig.3). There they overnighted at Melöegaard [farm] with a Mrs Hagen as host and she introduced the party to a range of Norwegian cheeses. Thereafter, it was a journey of at least 15 km by an open rowing/sailing boat with four oarsmen to their initial destination at the head of Holandsfjorden. There were other passengers on board, one a Lutheran pastor with whom Archie attempted a conversation. Use of successively English, French and German failed to solicit a response but was finally met with success when he spoke Latin. He commented that this was aided by him having been taught to speak Latin in Scottish High School tradition.

Close to the end of the fjord, on the crest of a morainic terrace on the southern flank, lay the farm of Fondal Gaard (Fig. 4). There Johan Peter Olsen was the host and his farm served as their base for the following week during which they investigated both Engabreen and Fondalsbreen glaciers and the immediate surroundings (Engabreen is locally known as Engenbreen). The two glaciers were of the outlet type and sourced by the same plateau icefield (Fig. 8). In 1865 Fondal Gaard consisted of a single farm building dating from c1670 and Knut Dahl, the grandson of Johan Peter, still lives (2005) in the original building (Fig. 5). An adjacent building (Hovedbygningen) dates from c1873, and after 1900 Knut's father, Adolf Dahl, used it solely to accommodate the many tourists who arrived by sea.

Concluding their work, the party returned to Meløy before embarking on a north bound steamer as far as Bodø. After a stay of four days, the party sailed further north, unfortunately in poor weather, via Lofotn and

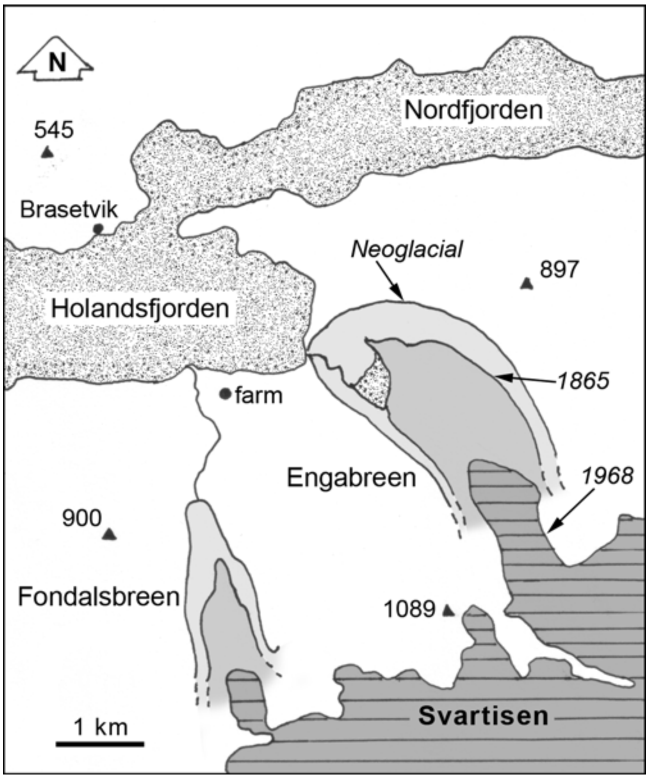

Figure 4. The inner Holandsfjorden region, showing the Engabre and Fondalsbre outlet glaciers at three stages – Neoglacial maximum, 1865 and 1968.

Figure 5. The original Fondal Gaard building dating from c1660 AD. and where the expedition stayed when based in Holandsfjord. The current owner, Knut Dahl, still lives there, and the white building behind is the Hovedbygningen.

Tromsø to the island of Skjaervö (Fig. 14). There they chartered a sailing boat for the not insignificant journey across Kvænangenfjord and on into its branch of Jökelfjorden, part of the Bergsfjord Peninsula. At the head of the inner part of this latter fjord (the appropriately named Isfjorden) they expected to find a calving glacier as reported by both von Buch and Forbes. This proved still to be the case, with the sea dotted by small icebergs. This glacier is technically a regenerated glacier being fed by snow and ice avalanching from a short lobe of the Øksfjordjøkel plateau icefield. After a night in a fisherman's hut, they could not move far because of an adverse wind. As a consequence, the following night was spent in the boat as it headed west back to Skjaervö. Two days were spent recovering before embarking again on a northbound coastal steamer to the next port of call at Loppen [Loppa]. From here, another boat was chartered for a journey initially south up Sørdre Bergsfjord, to the hamlet of Bergsfjord where they landed. They climbed up an adjacent valley in order to observe two outlet glaciers sourced by the Svartfjelljøkel ice cap. They then sailed northeast down Nordre Bergsfjord and subsequently eastwards as far as Nusfjorden where they again landed. After this they returned to Loppen to join another coastal steamer, which took them to the most northerly latitude they attained (over 70˚ N) at Hammerfest.

Here, they then turned south and returned direct by coastal steamer to Trondheim, staying at the Bellevue Hotel before continuing along the coast down to Bergen before crossing the North Sea to Grimsby in a Dutch steamer. It is most probable that William Whitaker took leave of his Scots companions in Grimsby and caught a direct Great Northern Railway train south to London since his Geological Survey field note book (p54) shows him mapping close to Canterbury on August 16. Certainly, the two brothers first travelled to Hull (via the Humber ferry from New Holland) and then onto York and finally Edinburgh. This inconvenient routing was taken, because the Keadby rail bridge over the River Trent was not completed until October, 1865.

Chronology of the modern glaciers

Current conventional wisdom accepts that during the Last Glacial Maximum (c20 ka BP), most, if not all of northern Norway, was buried beneath part of a single Fenno-Scandinavian ice sheet which extended towards the edge of the continental shelf. After this event, a phase of essentially continuous recession followed, resulting in many of the outer fjord and skerry areas being ice-free by c12 ka BP. Further retreat freed many of the fjords, but during the subsequent Younger Dryas climatic deterioration a widespread glacier resurgence was induced and some recently abandoned cirques were reoccupied. This is the same re-advance event which led to the construction of the Vassrygg end moraine in S W Norway (Worsley 2006).

This Younger Dryas readvance is often delineated by a chain of prominent moraine ridges, especially in the fjords, with Holandsfjord and the Bergsfjord Peninsula being no exceptions to this model. Also, relative sea level in the area lay at around 100 m higher today's. This correlates with a significant bench feature, the Main Shoreline, forming a prominent component of the modern landscape since it is often eroded into the bedrock, indicating particularly effective shoreline processes at that time. Many Younger Dryas glacier lobes ended in the sea, creating glacio-aquatic end moraines characterised by a crude deltaic structure. An excellent example is the terminal moraine ridge on which Fondal farm is located. In recent decades glacio-deltaic facies exposed below the farm in a large aggregate quarry have confirmed its sub marine origin. A coeval consanguineous feature at the mouth of the Enga valley is probably present, but here a combination of Holocene fluvial, glacier and marine erosional processes has resulted in the removal of the emerged (above sea level) component. Hence, there is a very marked contrast in the degree of post depositional modification by erosion between the relatively protected north-facing Fondalen and the exposed high energy environment at the mouth of the west-facing lower Enga valley at the head of the fjord.

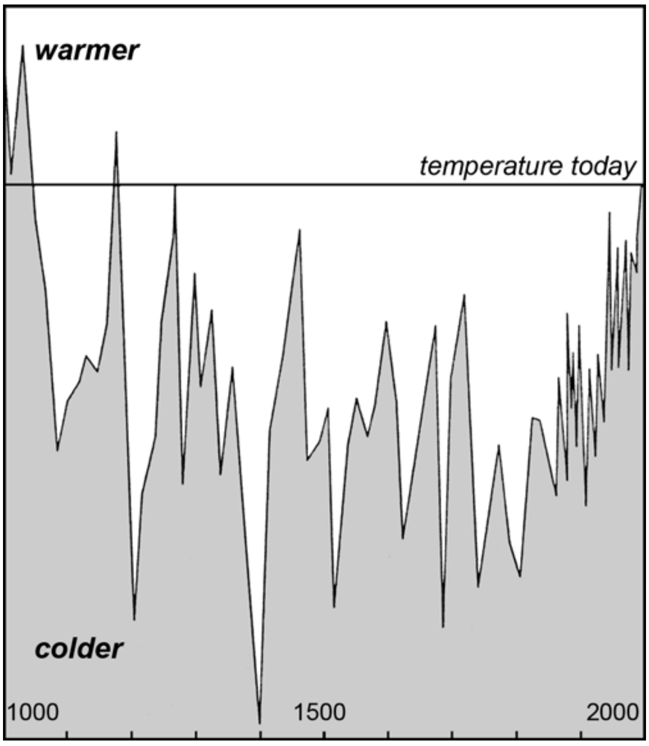

Figure 6. *The Little Ice Age as represented by the oxygen isotope signature from a central Greenland ice core in a record from 1000 to 2000 AD that indicates temperature variations relative to today's. Engabreen reached its maximum extent at c 1300, whereas Fondalsbreen was at its most extensive in the mid-18th century, as were virtually all the other Scandinavian glaciers.*

With the advent of rapidly rising temperatures heralding the Holocene Interglacial, ice recession recommenced and by the mid-Holocene little glacial ice, if any, remained, even in the mountains (Andersen, 2000). Following the climatic optimum, in the late Holocene there was renewed glacier growth heralding the start of the Neoglacial. Generally, in the eighteenth century, the Neoglacial maximum ice extent was attained, i.e. the culmination of the Little Ice Age (Fig. 6). No instance of Neoglacial ice extending beyond the Younger Dryas ice advance limits has been identified although the Engabreen Neoglacial limit is almost coincident with that of the Younger Dryas (see later). Generally, Little Ice Age maximum advance limits are expressed by a significant contrast in the vegetation on either side of an end/lateral moraine's trim-line system. In the rarer instances where this limit lies below tree line, as is the case in Holandsfjorden, its location within the present day forest is less obvious in the field. In 1865 there was, of course, no knowledge of this glacial chronology, although it was generally understood that there had been overall ice recession from an outer maximum off-shore to the modern glacier margins. Hence, there was the reasonable assumption, that any moraine ridges reflected either ice marginal oscillations or standstills during a single recession.

Neoglaciation at Engabreen and Fondalsbreen

With most glaciers, little is known about pre-eighteenth century glacier variations, and this is the case with Fondalsbreen. Uniquely for Scandinavia however, the ice advance maximum of Engabreen dates not from the classical Little Ice Age maximum of the eighteenth century but rather is significantly earlier, and probably dates from the early 13th century. This conclusion is supported by a range of evidence, including stratigraphy and spatial relationships of a buried soil, comparative development of surface soils on the crests of a series of moraine ridges, and sandur geomorphology. Since the lower part of the glacier lies below the regional tree line, the rates of weathering and pedogenesis in the deglacierised zone are enhanced relative to areas above it. A key factor in dating the glacial variations lies in an ability to unravel the chronosequence of soil development, specifically being able to confidently identify where the 1865 AD

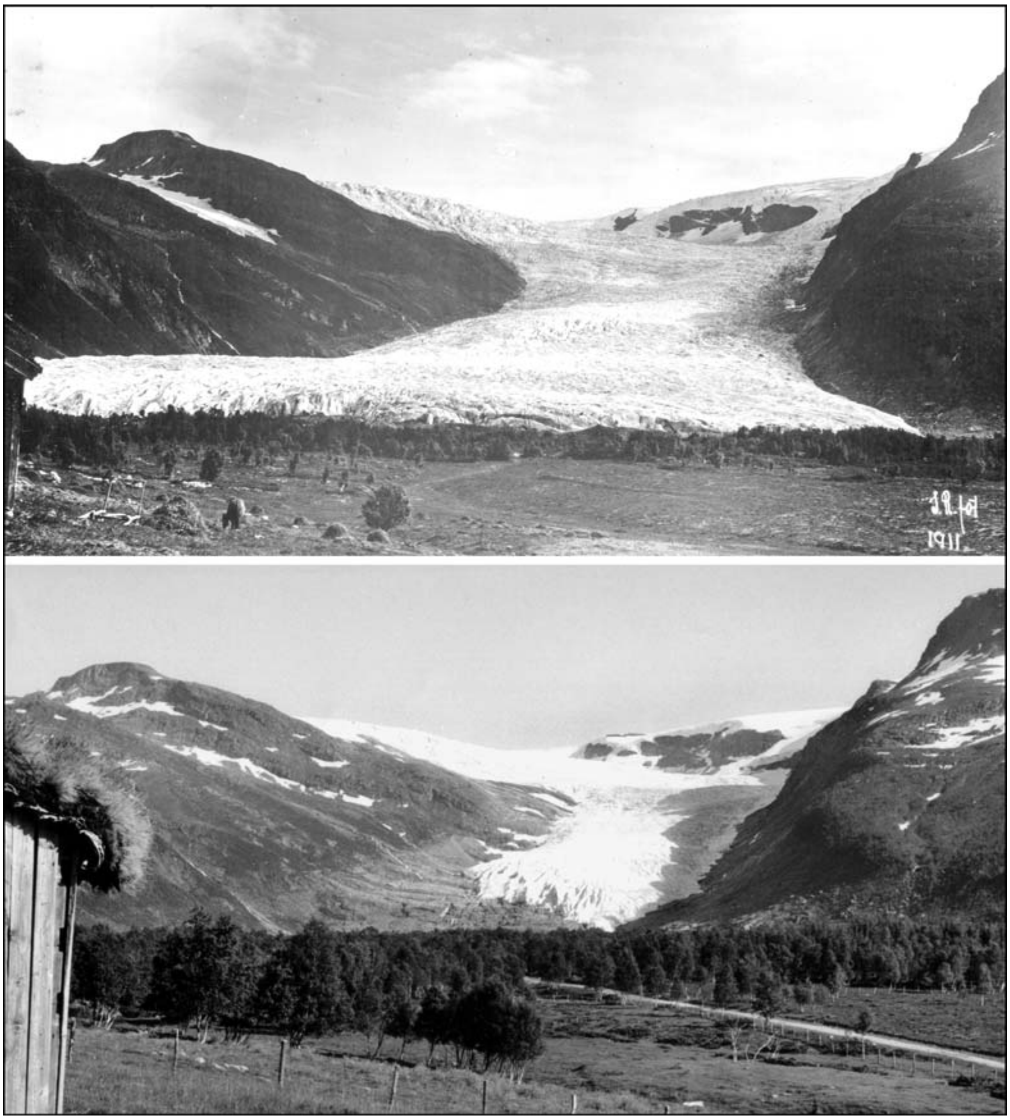

Figure 7. The glacier of Engabreen seen from the same location at the edge of the palaeosandur close to Steinar Johansen's Svartisen farm, showing the degree of ice recession through the 20th century – from 1909 (above) to 1976 (below). The wooden building has since collapsed under heavy snow and no longer exists.
(Photos: 1909 by J. Rekstad; 1976 by P. Worsley)

ice margin was situated. That this is possible is entirely due to the observations made by the 1865 expedition. Using this datum, Worsley and Alexander (1976), were able to map those parts of the distal sandur which antedate the classical Little Ice Age and identify the likely site of the farm Storsteinøren, which was so badly damaged by the eighteenth century ice advance that it was deleted from the tax roll.

In 1865 the snout of Engabreen displayed two distinctive types of ice margin. The more southerly was a proglacial lake into which the glacier was calving, yielding a scatter of icebergs. The lake was impounded by a series of moraine ridges, with a breach through them controlling the height of the lake. Through this cut a short river flowed directly into the fjord. This river still functions, with the controlling threshold height above sea level appearing to be unchanged. The feeding lake, Engabrevatn, is now vastly larger following glacial recession.

To the north of the lake, the ice margin was characterised by the glacier riding into and over glacial debris consisting of *a loose sandy clay or earth full of stones*. This debris contained a reworked fragmentary marine molluscan fauna derived from sediments beneath the glacier bed where the glacier was eroding pre-existing fjord deposits, possibly that part of the Younger Dryas end moraine which has survived below sea level. Archie's sketch sections (Fig. 8) show two profiles from the glacier across the proglacial area through the lake and land-based margins. About a decade after the expedition, the Norwegian geologist J Rekstad, commenced a long term programme of monitoring frontal variations in conjunction with photography. An early photograph (Fig. 9) was taken from below the icefall looking to the northwest and this shows that in 1891 the glacier margin had changed very little from that prevailing in 1865. It gives a good impression of the ice proximal terrain when the expedition was in the field.

From the mid 1880s onward there is a continuous annual record of the terminal position. A significant readvance culminated in 1911 but this did not attain the 1865 limits. Thereafter, for the next four decades, a progressive retreat followed and the marginal meltwater lake, Engabrevatn, expanded. Surprisingly, since c1960 the position of the glacier terminus has changed very little, and it has shunted by alternately advancing and retreating over short distances on the relatively steep bedrock floor above Engabrevatn. This departure from the global retreat norm is accounted for by an increase in snow accumulation on the ice cap which has counter balanced a rise in temperature. Since the completion of a hydroelectric power scheme in the 1990s, the main melt water streams have been tapped sub-glacially, resulting in a greatly reduced discharge into the lake. This will tend to favour slower wastage of the glacier tongue.

Fondalsbreen in recent decades has displayed readily observable frontal changes as the degree of connectivity of the ice cap margin and a lower regenerated glacier has varied. During some years there has been a direct link between the two producing what is technically an outlet glacier whereas during others this status has been lost leaving an entirely regenerated feature. Avalanching of ice blocks from the plateau ice cap margin down the steep bedrock backwalls above the regenerated glacier produces a granular ice mass with a texture not unlike a breccia. Again, sub-glacial tunnelling has intercepted the melt

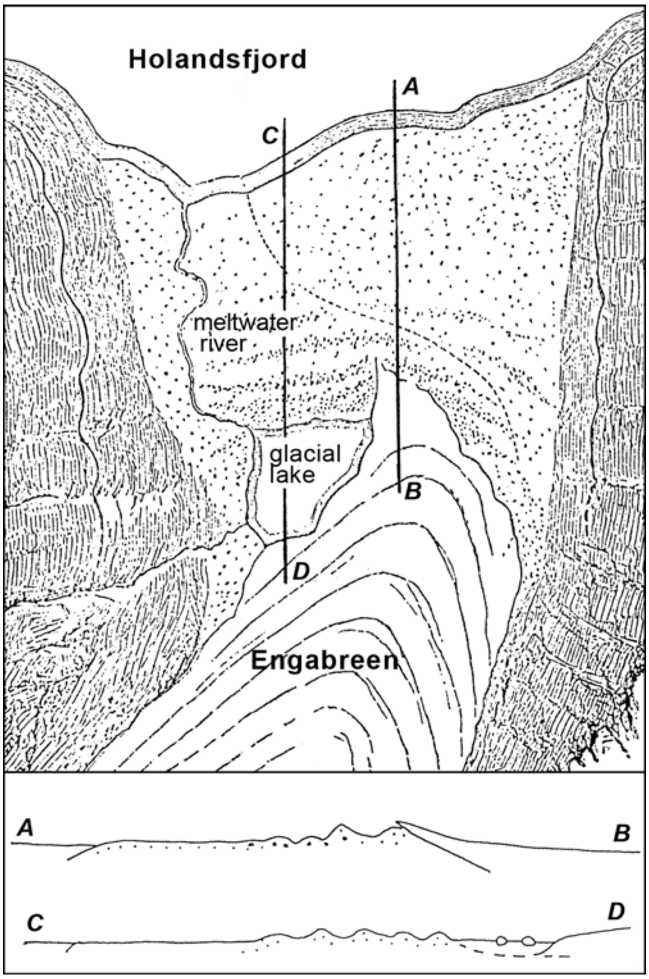

Figure 8. Map of the lower Enga valley as drawn by Archie Geikie, with the two long profiles through the ice margin. The ice proximal zone has a complex of end moraine ridges and a sandur extending to the fjord shore.

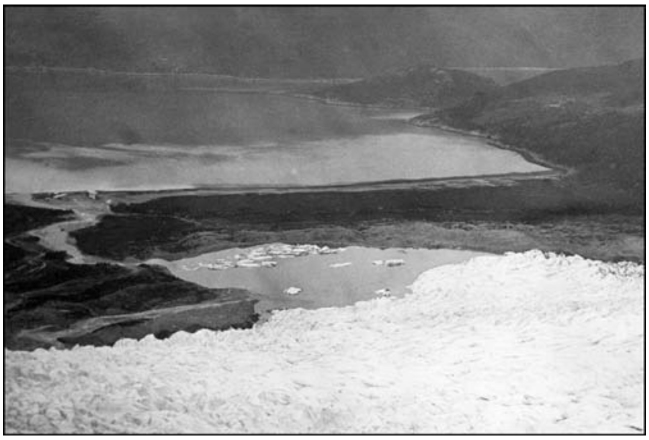

Figure 9*. Engabreen, in 1891, with a glacier marginal position and ice marginal lake very similar to those in 1865, when visited by the expedition. (Photo: J. Rekstad)*

water and drastically reduced the discharge at the snout. The contemporary glacier bears no similarity to that of 1865. In that year the snout of a classical outlet glacier lay just below an icefall over a bedrock step and was confined by the bedrock geometry. In sharp contrast with Engabreen, there was very little glacial debris at the glacier bed but the bedrock was heavily striated and smoothed. This is probably the spot where the expedition members were first able to crawl beneath an ice margin, being less than a half hour walk from Johan Peter Olsen's farm. Here Archie experienced *the revelation which the first sight of a glacier flashes upon the mind of a geologist* and *caught the ice, as it were, in the very act of doing the work of which I had hitherto only seen the ancient results* (Geikie, 1924 p108). Earlier he had recorded *I crept some yards under the ice, and found the floor of gneiss on which it rested smoothly polished and*

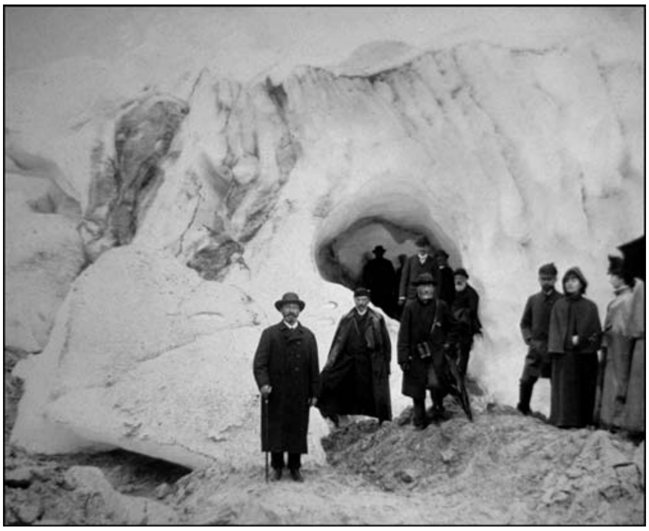

Figure 10*. A group of late-19th century investigators at the snout of Engabreen. Notable visitors at this time included the German Keiser Wilhelm II and the Prince of Monaco. Despite the remoteness of Holandsfjord, it was readily accessible by sea, and numerous cruise liners now visit the fjord in the summer months.*

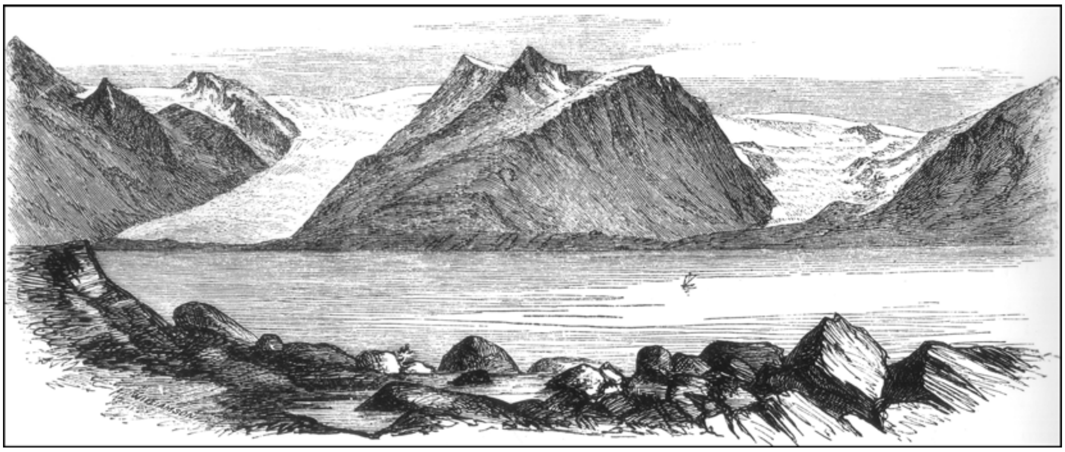

Figure 11. *Field sketch made by Archie Geikie at Brasetvik on the north shore of Holandsfjord (Fig. 4), showing both the Enga (left) and Fondal (right) outlet glaciers.*

covered in scorings of all sizes, exactly the same in every respect as those high on the sides of the valley, in the fjord below and away on the outer islands and skerries. Figure 12 is a facsimile sketch from Archie's notebook showing the form of the lower part of the glacier from a vantage point on the mountainside to the east. Today the Fondalsbreen outlet glacier depicted in the sketch has almost completely disappeared and the rim of the Vestisen (western half of Svartisen) plateau ice field occupies the left hand skyline above a steep rock wall. It is from this rim that ice avalanching feeds a small regenerated glacier at the base of the slope.

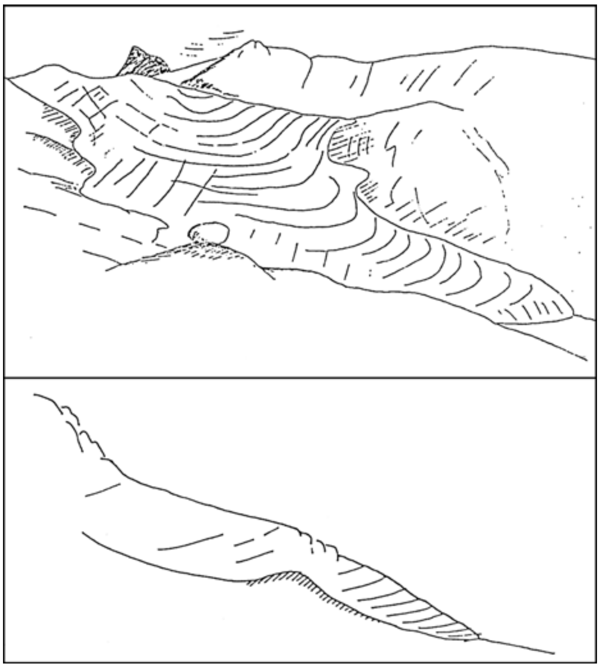

Figure 12. *Facsimile of the notebook sketches of Fondalsbreen drawn by Archie Geikie from a position on the steep eastern hillside below Midnatsoltind. In 1865 the glacier had the morphology of a typical outlet glacier, not unlike that of the modern Engabreen. The long-section anticipates the presence of a buried rock bar, and subsequent glacial retreat has shown this to be entirely correct. From this viewpoint, only the rim of the ice cap at the top left corner would now be visible.*

Neoglaciation in Isfjorden

Neoglaciation of the Bergsford Peninsula, is principally related to three plateau icefields (Fig. 14). These have been investigated by Gellatly *et al* (1989) in conjunction with an evaluation of the observations made by earlier investigators. A comparison of the reports by Hardy (1862) and A. Geikie (1866) suggested that the separation of the Jøkullsfjord regenerated glacier from the plateau ice sheet above may have occurred between 1859 and 1865. They indicate that the names *fall jøkull* and *Nedrebreen* (the lower glacier) have both been applied to the same glacier. With this exception, Gellatly *et al* (1989) make no other use of the expedition's observations in the peninsula, supporting the opinion expressed previously that the Bergsfjord data are generally ephemeral in contrast to those from Holandsfjord.

Thus, scientifically, the critical locality visited in 1865 was the head of Isfjorden. In the context of the time, when the drift ice hypothesis remained in the ascendancy in British glacial geology, it was important to examine a location where the presence of a calving

Figure 13. *Fondalsbreen in July 1980. The subglacial meltwater river discharges from beneath the ice cap on the right at the top of the rockwall and then disappears beneath the regenerated glacier below.*

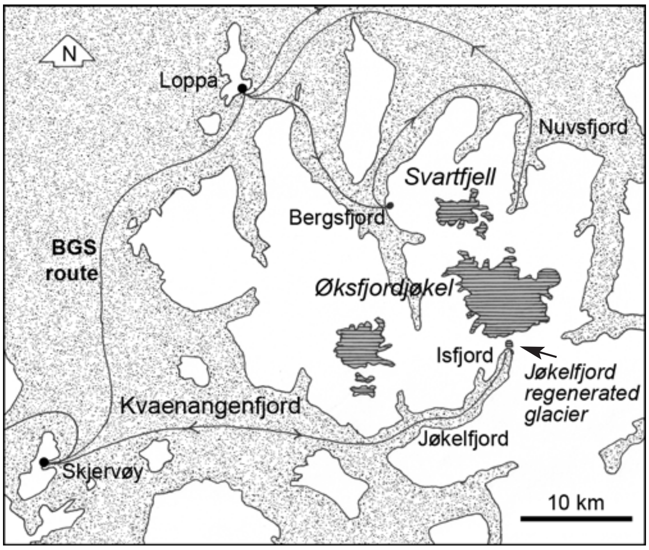

***Figure 14**. The Bergfjord Peninsula, showing the current plateau ice fields, the Jøkulfjord regenerated glacier and the route taken by the 1865 expedition.*

glacier had already been established by earlier workers. However, this calving glacier proved not to be of the normal kind where an outlet valley or ice shelf glacier directly entered the sea. Rather it was what Archie termed a *re-cemented glacier* [regenerated or reconstituted glacier].

He wrote a vivid description (1885) of its dynamics: *When making the sketch from which Fig. [15] was made, I observed that the ice from the edge of the snow-field above slipped off in occasional avalanches, which sent a roar as of thunder down the valley, while from the shattered ice, as it rushed down the precipices, clouds of white snow-dust rose into the air. The debris thus launched into the defile beneath accumulates there by mutual pressure into a tolerably solid mass, which moves downward as a glacier and actually reaches the sea-level - the only example, so far as I am aware, of a glacier on the continent of Europe which attains so low an altitude. As it descends it is crevassed, and when it comes to the edge of the fjord, slices from time to time slip off into the water, where they form fleets of miniature icebergs, with which the surface of the fjord (f in Fig 138) is covered*. This must be one of the first descriptions by a geologist of this particular glacial process.

The essence of this behaviour still prevailed in the early 1970s according to the North Scandinavian Glacier Atlas (Østrem *et al* 1973) which stated that calving was still ongoing. But this was different from the earlier behaviour (pre-1938), since rather than the regenerated glacier extending into the sea and releasing icebergs, some massive ice blocks were breaking away from the plateau ice cap margin with sufficient momentum to reach the sea and form bergs of non-brecciated ice (Brian Whalley, pers.com).

Outcomes from the expedition

Archie Geikie's accounts of 1866 and 1882 outline the main expedition discoveries. Paradoxically, neither of these sources appears to have been referred to in Jamie Geikie's subsequent extensive writings despite the obvious excitement of experiencing a modern glacial environment for the first time. To a much lesser degree this omission applies to the works of Archie. This is strange when it is realised that both brothers independently wrote several text books, some specifically for school audiences. Another curious finding is that in the context of Holandsfjord, no modern Nordic worker is known to have made reference to the Geikie papers (e.g. Gjelle *et al*, 1995), even though their importance has been highlighted by Worsley and Alexander (1975, 1976) and discussed by Worsley (1984). These latter authors have emphasised

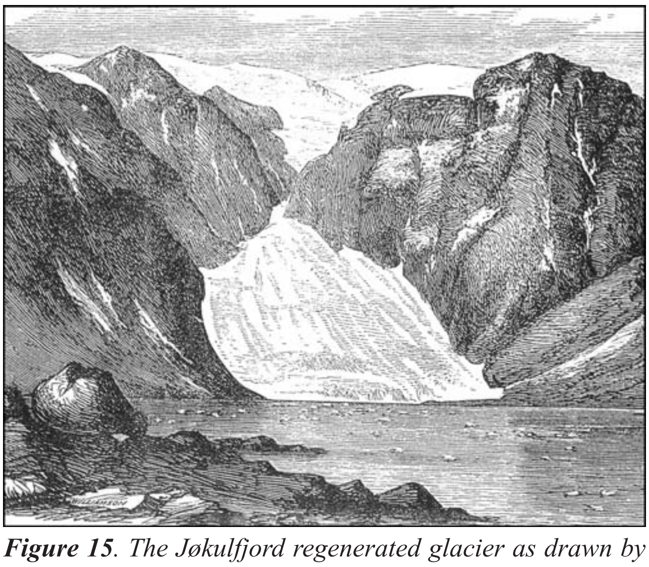

***Figure 15**. The Jøkulfjord regenerated glacier as drawn by Archie Geikie in 1865, with small ice bergs on the sea surface. Gellatly et al (1989) comment favourably on the accuracy of Archie's field observations.*

***Figure 16**. The Jøkulfjord glacier in 1986, showing the rim of the plateau ice cap, which is the source of the avalanche material forming the ice bergs. (Photo: Brian Whalley).*

the value of the maps and sketch sections made by Archie Geikie and that they antedate the earliest work undertaken by Scandinavia workers.

Jamie's momentous book, *The Great Ice Age*, was published nine years after the expedition (Geikie, J., 1874) with the declared objective of explaining the character of the drifts as a function of the efficiency of land ice. In his subsequent later editions, in *Prehistoric Europe* (1881), and in other of his books such as *Earth Sculpture* (1902), there are general descriptions of fjord scenery clearly based upon his Norwegian observations. However, he did not make any specific reference to his observations in 1865 and one wonders whether he was discouraged by the thought that to do this would require him crediting his elder brother.

Whitaker had an active interest in earth surface processes generally and shortly after his return from Norway he submitted a paper to the Geological Society of London in which he argued that the morphology of the chalk escarpments was not the product of marine erosion as had been argued by Charles Lyell, but rather the result of sub aerial denudation. He wrote how he slowly became convinced that *the irregularities of the earth's surface have chiefly been caused by subaërial actions, by rain, rivers, frost and springs, forces that can be seen in action every day* (1867 p451), with understandably no mention of glaciers *per se* on the North Downs. However, in arguing for a lesser role for marine erosion in landscape fashioning he drew attention to *the wonderfully intricate coastline of Norway .... well known to have been caused by the sinking of the land and not by the action of the sea .... so clearly seen to be submerged valleys*. He continued *moreover the sea would have little power to act in so narrow and sheltered place but would be harmless as in the Norwegian fjords where I have seen the old ice-scratches run down to (and perhaps below) high-water mark, unaffected by the waves* (pp 451-2).

Unfortunately this paper was officially considered to be *withdrawn by permission of the President*. This was a cosmetic device to cover the unfortunate fact that it had been rejected by the Geological Society establishment of the day and only an abstract (with an error in the title) was published under Society auspices. He then resubmitted his manuscript to the Geological Magazine, whose editor took a more enlightened view of its scientific credentials (Whitaker, 1867). The paper was published in two parts and significantly included a statement from Lyell in which he supported Whitaker's argument and in effect recanted his earlier views. It was later highly commended and praised by Charles Darwin, who was then living at Down House and fully familiar with the geomorphological character of the North Downs escarpment (Darwin, 1883). It was described by Archie Geikie as *the excellent paper* (A. Geikie, 1885 p434), and by another Director of the Geological Survey as *a masterly account of the position by that time reached* (Bailey, 1952 p70). Anomalously, despite these commendations, Chorley *et al* in the first volume of their magisterial history of geomorphology (1964, Part Three: Marine versus sub aerial erosionists 1846-1875) omit any mention of Whitaker's denudational papers. Yet three entries are included in their Part Three reference list, suggesting a serious oversight by the authors. His subsequent official survey work did involve the mapping of glacial deposits including Last Glaciation sequences in The Wash area and the heavily weathered and dissected Anglian glacigenic deposits of southern East Anglia and the lower Thames. Despite this, Whitaker's work is not normally associated with glacial geology *per se*.

Conclusion

Following c 1860, the pendulum of British opinion started to swing away from the drift ice hypothesis towards one in favour of terrestrial glaciation. Undoubtedly, the return of three enthusiastic young geologists fired by their first hand knowledge of modern glacial processes in the Norwegian Arctic, boosted the crusade initially launched by the visiting Louis Agassiz over two decades previously. The momentum behind verifying the land ice concept through actualistic field work in currently glaciated areas continued in the summer of 1868, when Archie Geikie, as the newly appointed Director of the Geological Survey for Scotland, took three of his staff (Ben Peach, John Horne, and brother Jamie) to Grindalwald in Switzerland for *a little bit of mountaineering* and a descent of the Unter Aar glacier. The constraints imposed by the aging Murchison's views were soon pushed aside as the books authored by both Geikie brothers, giving full accounts of basal terrestrial glacier processes, became standard texts during the following decade.

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Appendix

Currency units used by Archie Geikie in his accounts

The currency of 1865 is no longer used and most Nordics would not be familiar with it. The basic unit was the Thaler or Daler – a silver coin used throughout much of Europe for almost 400 years. The word dollar is derived from this root. The Daler was replaced by a Swedish krona (crown) and a Danish kroner in 1873. When Norway joined the Scandinavian Monetary Union in 1876, the new Norwegian kroner had parity with the Swedish and Danish kroner. Before 1813, 1 Riksdaler/Riksmynt = 4 ort or 6 mark or 96 skilling but after the transfer of Norway from Denmark to Sweden at the conclusion of the Napoleonic wars, in Norway from 1816 to 1875, 1 Speciedaler = 5 ort or 120 skilling. i.e. 1 ort = 24 skilling. Hence this was the currency used by the expedition (in 1876, 1 Speciedaler = 4 Nkr). Archie's accounts use the speciedaler, ort and skilling but unexpectedly also the mark. It is possible that the mark was being used by the Sami (Lapps) who were the indigenous people of North Norway since in the mid nineteenth century they were much more widespread in Nordland than is the case today. The Tsar approved the Grand Duchy of Finland using the Finnish Mark from 4th April 1860 with a rate of 0.25 marks to the rouble. It appears that the Sami in 1865 were using the recently introduced mark.