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A tale of two moraines and the discovery of Ice Ages

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Abstract

The discovery of Ice Ages is one of the most revolutionary advances ever made in the Earth sciences. In Norway this discovery was made by Danish-Norwegian geoscientist Jens Esmark and his young student Niels Otto Tank, who on a mountain traverse in early september 1823 observed a number of geomorphological features produced by an extant glacier, and compared these to similar features they had previously noted where glaciers today are absent. Seing a recent moraine pushed up by an extant glacier they suddenly realized that a big ridge of gravel they had earlier seen at sea level in Southern Norway had to be an ancient moraine, deposited by a big glacier at a time when the climate was substantially colder than today. The brevity of Esmark's account made the precise location of the site of enlightenment remained a mystery for almost two hundred years until it was rediscovered by the author in 2008. This paper describes the crucial site and its lessons.

The present is the key to the past

The discovery of former Ice Ages took place in two countries with extant glaciers – Norway and Switzerland. This is no accident. By observing up close what glaciers do to the landscape scientists were able to recognize similar glacier effects in places were currently no glaciers exist, and thus trace the former much greater extent of former glaciers in Northern Europe, the Alps and North America (Rudwick 2008; Krüger 2013; Hestmark 2017, 2018). The encounter with an extant glacier also proved decisive in 1823 when Jens Esmark (1762-1839) reached the conclusion that large glaciers once had covered Norway down to sea level, carving out valleys and fjords. The significance of this glacier location for the history of geoscience and, more broadly, our understanding of climate change, strongly suggests that it should be designated as an IUGS Geological Heritage Site site by the International Commission on Geoheritage (ICG) of the International Union of Geological Sciences (IUGS).

Esmark was already a fairly old man of 60 when this early morning in September 1823 he rose from his bed at the summer farm, where he and his two accompanying students Niels Otto Tank (1800-1864) and Jan Theodor Kielland (1803-1844) had spent the night. Up to this point his career had been respectable, but not illustrious as a mining administrator at Kongsberg and professor of mining sciences at the young university in Christiania (now Oslo) (Hestmark 2017). Within the next 36 hours Esmark would make an ardous traverse over the central mountain chain of Norway from west to east, and stumble upon the discovery that forever would ingrain his name in the history of science.

Almost three months had passed since they left Christiania in mid-June, sailing along the south and west coast of Norway to evaluate some abandoned copper works at Forsand close to the town of Stavanger (Fig. 1, locality 3) . Not far from the copper works, almost at sea level, they had stumbled upon a big, long ridge of gravel. Stretching straight across a valley the ridge dammed a small lake called Haukalivatn. The ridge consisted of an unsorted mixture of big boulders, smaller rocks, pebbles and sand (Fig. 2). They wondered: What kind of natural process can produce such a distinct landscape feature? (Esmark 1824, 1826). They had no immediate answer.

Sailing up the Norwegian west coast to inspect another abandoned copper mine (Fig. 1, locality 5) they wondered about the many polished, smooth cliff surfaces along the sea (Fig. 1, locality 4). What was the polishing agent? The sea itself? (Esmark 1824, 1826).

By late August they had reached far up the west coast, and Esmark made the decision to go inland and cross over the mountains rather than return home by sail along the coast. A mountain crossing to reach the coach service in the valley Gudbrandsdalen would speed up their return to Christiania. It was an improvised decision, and it proved fateful. They sailed east in the Nordfjord to Stryn, and from here walked up to Oppstryn, and up the valley Sunndalen where many of the Stryn farms have summer farms and pastures for goats, sheep and cows, producing butter and cheese through the light Nordic summerdays (Hestmark 2018). The summer farms at Sunndalsseter are clustered at the threeline, 460 m above sea level.

From here a very steep track leads up a barren mountain side to a pass called Kamperhamrane at approximately 1300 m above sea level. Situated at a breaking point between western and eastern weather systems, the pass is usually enshrouded in thick fog, and snow can fall any time of year. The track is an established old route between west and east, clearly marked by big cairns, where farmers brought cattle, horses and handicraft items to be sold at markets on either side of the mountain (Standal 1995).

When reaching the pass after the steep climb, Esmark must have been quite exhausted. And in front of him the route was apparently blocked: A big glacier tongue called Rauddalsbreen reached over the track, from the south side of a valley to its north. It is the northernmost tip of continental Europe's largest extant glacier, the mighty Jostedalsbreen glacier (Fig. 1, locality 6).

Glacier action up close

Today this glacier tongue has almost completely melted away, leaving a large, exposed foreland called Merradalsbotn. During the so-called 'Little Ice Age' (LIA) Norwegian glaciers expanded substantially, reaching their maximum extension at around 1750 (Fægri 1934; Hoel and Werenskiold 1962). Rauddalsbreen glacier then crossed the valley transversally from south to north, reaching roughly a hundred meters up on the north side. By 1823 the glacier probably had receded some 150-200 m from the LIA maximum, as suggested from other dated moraine sequences in the area (Winkler et al. 2013), leaving a rim of recently exposed areas, exhibiting many of the phenomena associated with glacial action. Esmark had read about such phenomena (cf. Hestmark 2017); now he could observe and experience them up close, indeed the terrain is a lesson in glaciology:

Most prominently was the sharp border of the foreland itself, between vegetated and unvegetated land. They stepped from grass to gravel, from green to grey in a single step. This highlighted the glacier as a dynamic body of ice, advancing and retreating.

At this western border of the foreland several large rounded single boulders rest directly on clean-swept rock surfaces. They look remarkably detached, like the big boulders (erratics) scattered all over Northern Europe. By 1823 the problem of the transport of erratic boulders was heavily debated among European geoscientists, and a number of moving agents had been proposed, such as strong floods, ice floes or volcanic eruptions (Rudwick 2008; Krüger 2013). To Esmark, upon seeing these boulders scattered in the foreland in front of the glacier it was immediately clear to him that the moving agent was ice.

Polished cliff surfaces emerged everywhere from the gravel and boulder fields, swept free of debris, with sculpted surface forms unrelated to the structure and veins in the (gneiss) bedrock. The polishing agent was obviously the glacier, with its rock debris included to abrade the surface. Erratic boulders and polished cliffs would both be noted as evidence of former glaciation in presently non-glaciated areas in Esmark's Ice Age paper (Esmark 1824, 1826).

Their track now continued over the flat glacier itself. They stepped onto the ice and walked eastwards a little more than a kilometre to the other side. Stepping down into the small foreland on the eastern side they hit upon a large ridge of gravel and boulders parallel to the glacier front — an end moraine (Fig.3). With the glacier front just some 150 m behind it, the ridge was obviously pushed in place by the glacier. Deposited at LIA maximum around 1750 it had an uncanny resemblance to the big ridge deposit they had seen close to sea level at Forsand, although scaled down to 25% size – it is 4-5 m high rather than 20-30 m. Like the ridge at Forsand it stretched across the valley runs and consisted of an unsorted mixture of boulders, pebbles, sand and clay — a diamicton. Furthermore, in front of the moraine there is a glacial outwash plain, a sandur, similar to a plain in front of the ridge at Forsand. And it is at this stage, at this site, 1040 m above sea level, they suddenly realize what they had seen down at Forsand:

> 'The resemblance is so striking, that anyone who has an opportunity of making this comparison, must form the same ideas. I must put forward as proof of this, that Mr. *O. Tank*, a skilful young mineralogist, who with me observed the here described rampart [at Forsand] and afterwards travelled [with me] to the glaciers mentioned, immediately exclaimed to me, without me giving him any pretext, that that rampart by Stavanger had to be a glacier rampart.' (Esmark 1824: p. 45, transl).

And the implication? Enormous glaciers must previously have covered Norway and reached down to sea level at Stavanger, implying a climate significantly colder than the present. Here a scientific revolution took place with a completely new way of reading the landscape.

Given Otto Tank's exclamation, I have found it appropriate to name this moraine at Rauddalsbreen Otto Tank's Moraine in honor and memory of Esmark's enthusiastic young student (Hestmark 2017, 2018). The big gravel ridge at Forsand has been known informally as the Esmark Moraine for many years, and is now considered to have been deposited by an enormous valley glacier tounge at the end of the cold Younger Dryas, ca.

11 500 years ago, at the end of the last Ice Age (Weichselian) (Andersen 1954, 1992; Worsley 2006; Briner et al. 2014).

Having passed over the mountain range, Esmark and his students proceded down to Gudbrandsdalen valley and by coach along the main road south to Oslo. On the east side of lake Mjøsa they observed large erratic boulders in the middle of spruce forest quite similar to boulders they had seen in front of the Rauddalsbreen glacier (Fig.1, locality 7). They realized that big glaciers had once covered the eastern parts of Norway also (Esmark 1824, 1826).

Esmark spent the winter of 1823-24 working out the implications (Hestmark 2017), and in his paper published late April 1824 stated that there now was indisputable evidence that Norway and Northern Europe had formerly been covered by great glaciers, carving out valleys and fjords, depositing moraines and erratic boulders (Esmark 1824, 1826). To explain the former cold climate he proposed that the eccentricity of the Earth's orbit had been changing.

Not quite out of the blue

Although Esmark's Ice Age paper has often been seen as coming right out of the blue, recent studies documented that his discovery happened on a prepared background: 1) he had a deep and life-long interest in climate and for meteorological measurements, and in effect was the first Norwegian state meteorologist (Hestmark & Nordli 2016); 2) inspired by the 'physiographic' alpine researches of de Saussure, de Luc, Ramond and von Humboldt, Esmark from 1798 and onward made altitude measurements of treelines, snowlines and several of the highest peaks in Norway (Hestmark 2009)(Fig. 1, letters A, B, C, D); 3) Esmark supplied encouragement and instruments, notably barometres for altitude measurements, to numerous explorers of Scandinavian glaciers before 1823 (Hestmark 2017).

Esmark's main achievement was one of *synthesis*: Several of the geomorphological phenomena he realized to be caused by a single agent – former enormous glaciers – were well recognized and studied separately before 1823-24 (Rudwick 2008). He brought them together in one unified story. The very same landscape features – erratic boulders, moraines, polished rock surfaces – were also the main clues to the former extent of Alpine glaciers noted by Swiss savants Ignaz Venetz, Jean de Charpentier and eventually Louis Agassiz and his German friend Karl Schimper a few years later (Krüger 2013). The complex reception history of Jens Esmark's Ice Age paper in the national and international scientific community is detailed in Hestmark (2017).

Otto Tank's Moraine is situated on public land, protected in Breheimen National Park. It can be accessed by a days mountain walk along marked tracks from main roads in the east or the west. Its state of preservation is pristine condition. The Esmark Moraine is situated on private land, but is accessible to the public by a short walk on a track from public road. Its state of preservation is good, but part of the moraine was planted with pine trees after World War II. The significance of both these moraines for one of the greatest discoveries in geoscience strongly suggests that they should both be designated IUGS Geoheritage sites and put on the UNESCO World Heritage List.

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Figure Captions

Fig. 1. Map of southern Norway, with white dotted line showing Jens Esmark's voyage from June to September 1823. 1 = Christiania (Oslo); 2 = Rød, the home of Otto Tank; 3 = Enighed Copper Works and the site of the Esmark Moraine close to sea level; 4 = Steinsund, with polished Devonian conglomerate at sea level, Sula Islands; 5 = Grimeli Copper Works; 6 = Northern tip of Jostedalsbreen glacier, Rauddalsbreen with Otto Tank's Moraine; 7 = Mjøsa boulder terrain. The letters refer to high peaks ascended and measured by Esmark between 1800 and 1810: A = Tronfjell 1800; B = Rondane 1800; C = Snøhetta 1801; and D = Gausta 1810.

Fig. 2. The Esmark Moraine and the sandur plain in front before the moraine was planted with pine and the plain in front completely cultivated, Norway, Rogaland county, Sandnes municipality (58º54'14''N, 8º08'14''E). Deposited ca. 11500 years ago, 30-50 m above sea level. Lake Haukalivatn in the background now cover the valley where once the big glacier pushing up the moraine was situated. Old arial photograph from the early 1940s. Locality 3 in Fig. 1.

Fig. 3. The Esmark Moraine today, overgrown by pine forest planted after WWII. Locality 3 in Fig. 1.

Fig. 4. The Rauddalsbreen glacier foreland. White line indicates approximate position of glacier in 1823, and arrow points to the distinct LIA maximum extent. White arrows show the probable track of Esmark and his companions over the glacier. To the right arrows point to Otto Tank's Moraine, and the sandur plain with braided glacial rivers running towards lake Ytste Leirvatnet in the upper right corner. Remnant of glacier at bottom of page, northernmost tip of Jostedalsbreen. Base photograph Google 2013. Image CNES/Spot Image 2014. Site 6 in Fig. 1.

Fig. 5. A. Otto Tanks' Moraine at c. 1040 m above sea level, seen from the east towards west. The locality is situated in Breheimen national park, Skjåk municipality, Innlandet County (61º43'26'' N, 7º26'43'' E). The moraine was deposited around 1750, at the glacial culmination of the 'Little Ice Age'. B. The sandur east of Otto Tank's Moraine (moraine indicated by arrow). The northernmost tip of the Jostedalsbreen glacier can be seen in the background. Figure modified from Hestmark (2018). Site 6 in Fig.1.

Fig. 6. Portrait of Jens Esmark.

Fig. 7. Portrait of Otto Tank, ca. 1825 by unknown painter. Courtecy of the Wisconsin Historical Society.

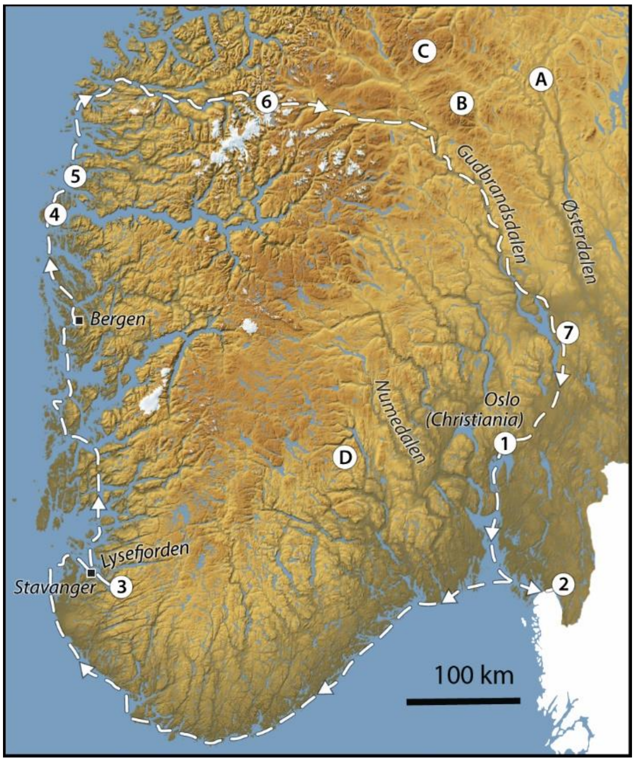
C
A
6
B
5
4
Gudbrandsdalen
Østerdalen
Bergen
7
Numedalen
Oslo
(Christiania)
1
D
Lysefjorden
Stavanger
3
2
100 km

Figure 1

Figure 2

Figure 3

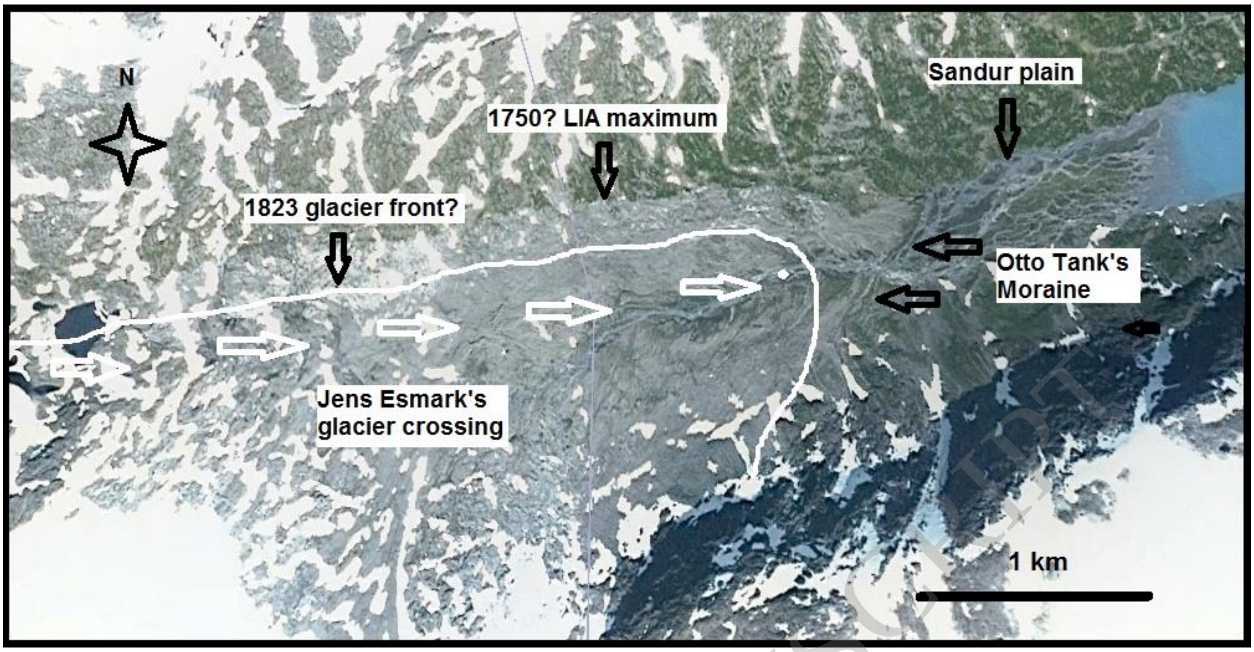
N
Sandur plain
1750? LIA maximum
1823 glacier front?
Otto Tank's
Moraine
Jens Esmark's
glacier crossing
1 km

Figure 4

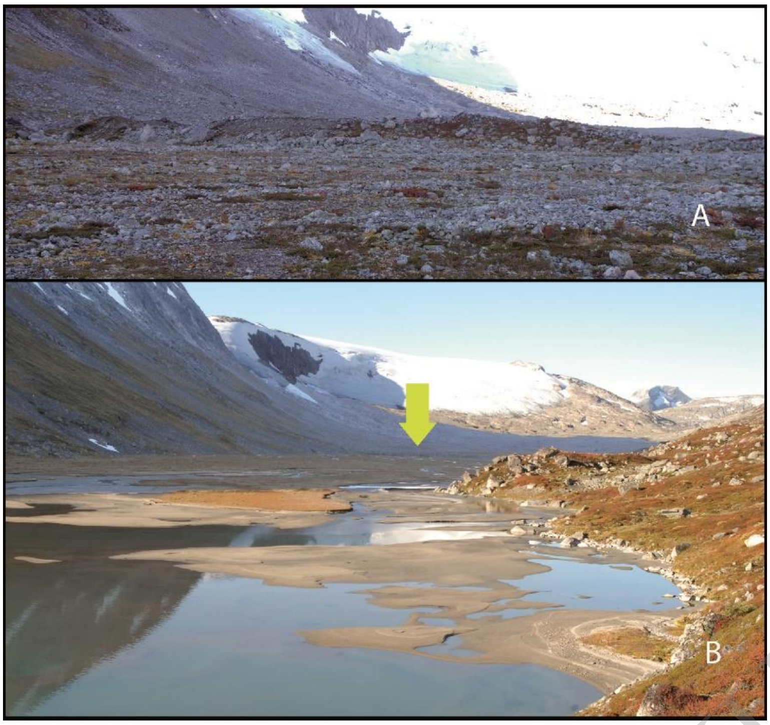

Figure 5

Figure 6

Figure 7