TUNNEL VALLEYS IN DENMARK AND NORTHERN GERMANY

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The theories of N. V. Ussing concerning the great valleys in Jylland being formed by erosion from subglacial rivers are critically analysed and found unrealistic. In some cases glacier erosion is a more probable explanation, in other cases new investigations are necessary.

In 1903, Ussing published a small paper entitled "On the outwash plains in Jutland and the theories on their development" in which he advocated that the outwash plains (sander) in Jutland are conical flats and that their sand has not been supplied by rivulets running down the surface of the ice, but was suspended in large meltwater rivers with outlets at the apices of these cones. Thus, the Karup plain should comprise three conical flats with apices: one at Dollerup at the western end of Hald Sø, one near Moselund, and one at Sebstrup.

In the second edition of "Geology of Denmark" from 1904 and in a paper from 1907 "On river valleys and terminal moraines in Jutland" Ussing discusses the large valley systems in Jutland and divides them into two groups: 1) the proper late-glacial outlet valleys carved by meltwater in front of the ice margin and 2) a second group which he calls "fjord valleys". According to Ussing the latter type should be older than the outlet valleys and has been eroded by sub-glacial water streams with outlet right at the apices of the cones. The floor of these fjord valleys lies considerably lower than the surface of the plains, and Ussing therefore advocated the theory that the subglacial streams must have been under pressure in the tunnels and thus been able to force their way uphill, and here the reason could also be found for the uneven profile of the fjord valleys with the many elongated lake basins and the shallow thresholds between them.

Ussing gives some examples of fjord valleys, fig. 1. Thus, there appears to be two valleys starting in the region around Mariager Fjord towards Viborg and further on to the apex at Dollerup. A third one stretches from Århus through the lakes Himmelbjerg-søerne and the Silkeborg region to the apices of the Moselund and Sebstrup cones. Later on, Madsen (1921) changed the

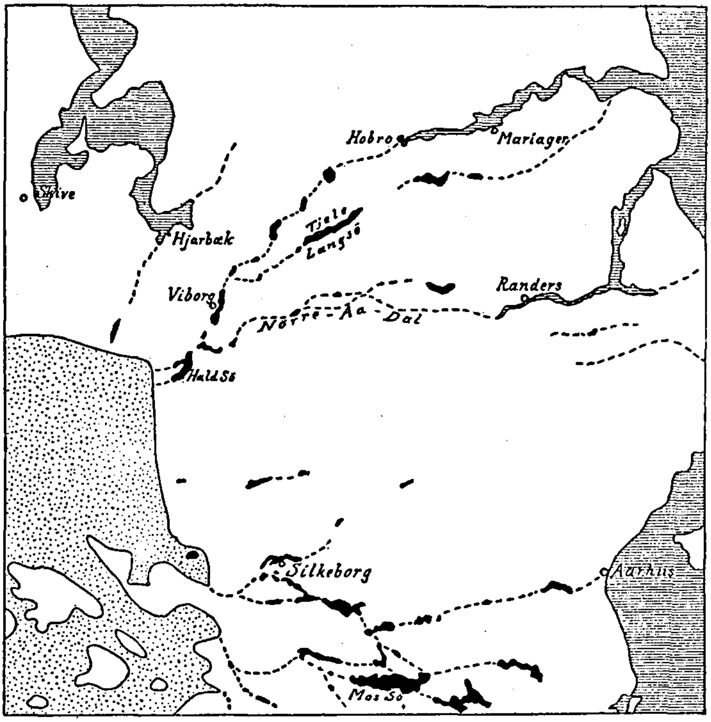

Fig. 1. Map showing the long lakes in Jylland and the continuation of the valleyes to the ice margin. After Ussing (1907).

name fjord valleys to tunnel valleys, and this has since been the generally accepted term for the large fjords in Eastern Jutland, but Ussing's description of the phenomenon has been repeated in all later works on the Quaternary geology of Denmark (Harder 1908, Andersen 1923, Madsen 1928, Rosenkrantz 1933, V. Milthers 1948, K. Hansen, Heller & Larsen 1960, S. Hansen 1965, Rasmussen 1966, Nielsen 1967). Only Nordmann (1958) expresses some doubts whether a valley as large and broad as the one containing Vejle Fjord with diverse branches could have been eroded as a large tunnel, and he suggests that the valley is more likely the result of several adjoining and perhaps anastomosing tunnels under the ice. Or, that falling ice masses from the ice-tunnel roof have forced the water stream now to one side and now to another side.

In Northern Germany, the problem concerning the development of the many lakes, especially the elongated lakes (Rinnenseen), has puzzled the geologists. Jentch (1884) suggested that these Rinnenseen were eroded by sub-glacial rivers that had run in the opposite direction of the ice to pass through the Baltic, the Belts and the Kattegat and out into the open sea.

Many other explanations have been suggested with regard to the origin of these Rinnenseen (Wahnschaffe, 1909), but after publication of Ussing's theories these gradually became generally accepted by the German geologists. In a number of publications Woldstedt (1913, 1923, 1926) tried to relate the outwash plains to elongated lakes and fjords made by erosion and deposition from sub-glacial streams along the marginal zone of the last glaciation, from Jels Søerne in Southern Jutland through South Slesvig, Holstein, Mecklenburg and Pommern in Germany.

Werth (1907, 1909) made an unsuccessful attempt to distinguish between fjords, Fjärde and Föhrden.

Fjords supposedly have been eroded by valley glaciers in mountainous countries like Norway, British Columbia, Alaska, Greenland and Spitzbergen. Fjärde should also have been eroded by valley glaciers, but in regions with a less elevated relief, as for example Sweden and Finland. Föhrden should only occur along the German Baltic coast and in the eastern part of Danmark and supposedly had been eroded by sub-glacial streams. This distinction between terms from different languages, which in reality have an identical meaning, was also accepted by Woldstedt and has passed on even up to modern handbooks (Embleton & King 1968). It should be stressed that

Fjord (Danish and Norwegian)
Fjärd (Swedish)
Föhrd (German)
Firth (Scottish)

all cover the same morphological element, namely a marine inlet which is longer than the width at the mouth regardless of the genetic origin; the contrast to it is the word bay (German: Bucht) which is a marine inlet with a very wide mouth in proportion to its length.

In support of his tunnel valley theories Ussing refers, like others, to observations from Greenland and from the Malaspina Glacier in Alaska. With regard to the latter it is stated that the meltwater rivers in front of the glacier margin are rushing so violently in an oblique, upward direction that their mudflow is lifted 4–5 m up into the air.

The Malaspina Glacier is formed by a confluence of several valley glaciers descending from the tall Saint Elias Mountains. The largest one is the Seward Glacier that comes out from the mountains at a height of 2500 feet (762 m) and here it expands and is now called the Malaspina Glacier. At the outer edge the surface of the glacier drops to 75 feet (22.86 m).

Near the outer edge is a rough, chaotic, debris-mantled topography characterizing stagnant ice. In an outermost marginal zone which averages 1 mile (1.6 km) in width, vegetation has taken root and a spruce forest with trees up to 100 years old grows on the glacier.

Russell (1891, 1893) states that the moraine-free part of the Malaspina Glacier is intersected by thousands of fissures through which meltwater rushes down and continues in tunnels within the ice. The meltwater is seen pouring out in many places along the coastal cliff, both somewhat higher up with water falling down in cascades and at the foot of it, in several places as limnocrenes where the water is under so high pressure that it bubbles and roars violently. On account of the pressure the water in some of the limnocrenes are pressed 4–5 m up into the air. It is quite evident that the different levels of these meltwater outlets and the glacier surface alone must provide a pressure in the streams. But nothing in Russell's statements justifies the ascertation that the meltwater tunnels should have reached down to the substratum and carved valleys into it, nor that the meltwater should have run uphill. Alone the fact that most of the meltwater streams have outlets some way up on the slope contradicts Ussing's theories.

Later investigations (Sharp, 1958) show that the Malaspina Glacier lies in a broad basin extending to at least 825 feet (ca. 250 m) below sea level. However, the margin of the glacier is everywhere a little above sea level. Surficially, the entire outer rim of the Malaspina basin consists of unconsolidated material with a thickness in excess of 500 feet (ca. 152 m). The ice from the lower Seeward Glacier therefore not only spreads out radially but also moves uphill for much, if not all of the 28 miles (ca. 45 km) from the debouchment in the mountains to the outer margin. Sharp also ascertained that none of the fissures in the surface of the Malaspina Glacier is deeper than 22 m, and that the glacier movements are brought about partly by basal slippage or boundary-layer flow and partly by internal flowage.

As the ice of the last glaciation, before reaching Denmark and Northern Germany, passed the broad and deep depressions of the Skagerrak, the Kattegat, and the Baltic Sea, it must have moved uphill as a compressive flow, consisting of a compact ice mass with shallow fissures in the surface. The later observations from the Malaspina Glacier, therefore, rather contradict Ussing's theory of sub-glacial rivers having cut deep valleys into the substratum.

Earlier German supporters of the tunnel valley theory also cite Nansen as to his observations from Greenland. Nansen (1890) advocated that at a depth of 3000 feet (950 m) the Greenland ice sheet is heated to the melting point by the terrestrial heat and that the thereby produced water must make its way towards the coast through channels under the ice. As it is running under high pressure he believed that it must have a significant erosive effect on the substratum. Similar sub-glacial rivers, Nansen believed, must have contributed to the erosion during the Ice Age, and he added that with his own eyes he had seen such rivers emerging from the ice margin during the winter as well as in the summer.

It is well-known that this assumption did not hold true against later investigations, and when Nansen stated that he had observed such sub-glacial rivers, this is not correct; admittedly, he has seen meltwater coming out at many places along the ice margin, but whether these ice caves are connected with ice tunnels up in the ice, or whether the meltwater has been pressed up from the substratum he could not know.

Furthermore, it is peculiar that also more comprehensive geological handbooks either do not mention tunnel valleys, or if they do, then with a certain amount of reservation as a special Danish phenomenon (Sauramo, 1931 and Flint, 1957).

More detailed studies of Ussing's works reveal clearly that these are to be considered preliminary studies with a sketchy statement of Ussing's theories on the location of the ice margin and the supply of meltwater; as Ussing died a few years after the publication of his last paper, he did not get to work out his investigations in greater details. It appears now that on many points Ussing's statements are not realistic.

Of the three outwash cones forming the Karup plain only the Dollerup cone is well developed and behind its apex it has a deep and broad valley, the Viborg-Hald Sø valley. The apices of the two southernmost cones are more difficult to locate because the elder diluvium (the Saale glaciation) lies so elevated that it emerges not only like islands above the surface of the "sander" but up to, and at some places even behind, the main stationary line stated by Ussing. Since both kinds of deposits consist of gravel and sand it is very difficult to decide what belong to the last (Weichsel) ice age and what to the previous (Saale). It is certain, however, that the place Ussing points out as the apex of the Sebstrup cone lies midway between the two large valleys, the Thorsø valley and the Salten valley, and the so-called Moselund cone seems to consist of several cone-shaped sections, all of which have apices without larger valleys behind. Nor the apex mentioned by Ussing NE of Moselund station has a large valley behind.

A closer study of the topography reveals that the slope of the Dollerup cone falls almost at right angles to the slope of the cone south of the Dollerup cone, and is more elevated (fig. 2). Apparently, the Dollerup cone has extended over the marginal zone of the large, flat cone, the apex of which must have been somewhere south of Torning. This suggests that the Dollerup cone represents a younger stage of the melting of the ice. K. Milthers (1935) was of the opinion that the ice margin during the last glaciation reached as far as Nedre Feldballe and Binderskov, and that the ice margin along the Dollerup cone indicates a withdrawal line. When Milthers suggests

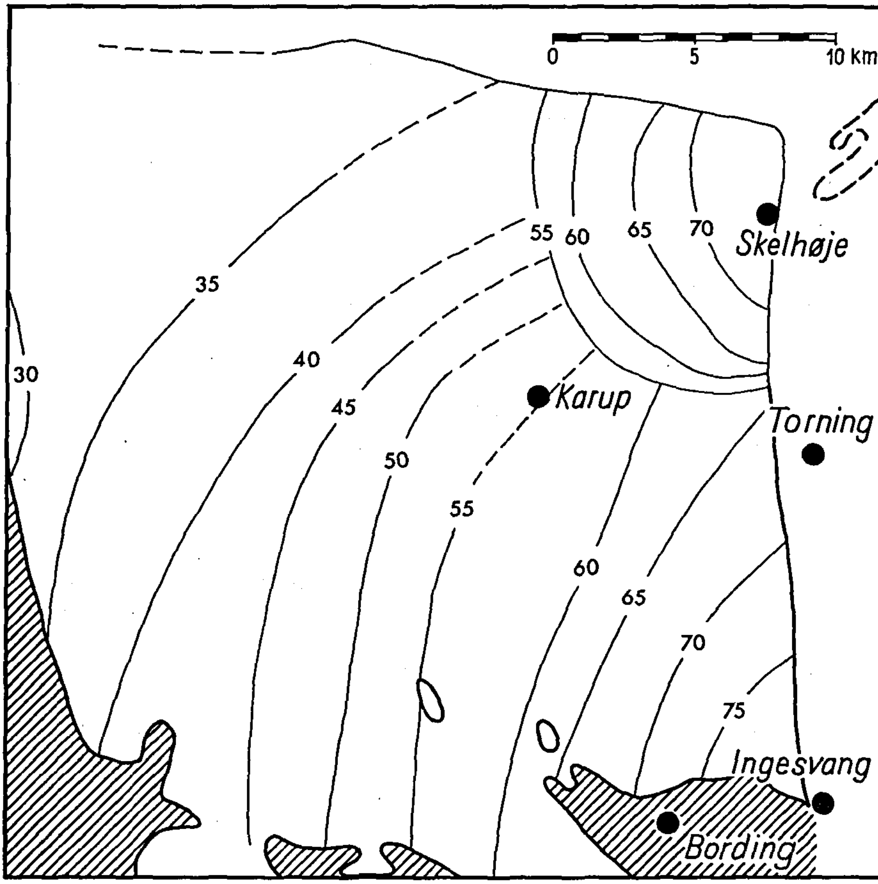

Fig. 2. The Dollerup cone. The slope is at right angles to the slope of the cone south of the Dollerup cone which extended over the northern marginal part of the large flat cone.

that the outer limit for the last glaciation went due south from Feldballe, this can only be an assumption and based on the same criteria the ice margin might just as well have had a south-east trend, as shown in fig. 3. S. Hansen (map II, 1940) placed the ice margin from Sønderhede directly towards Silkeborg, but his reasons to do so were not apparent.

The Dollerup cone has its apex at Skelhøje about 80 m above sea level. There is no doubt that here is the former site of a glacier cave with outpouring meltwater gradually forming the cone. However, it is very unlikely that the tunnel in the ice ran along the substratum, the enclosed meltwater excavating both the Viborg lakes and the basin of Hald Sø and, finally, at Skelhøje, being pressed upwards to the surface.

The surface of the lake of Hald Sø lies 8.85 m above sea level which

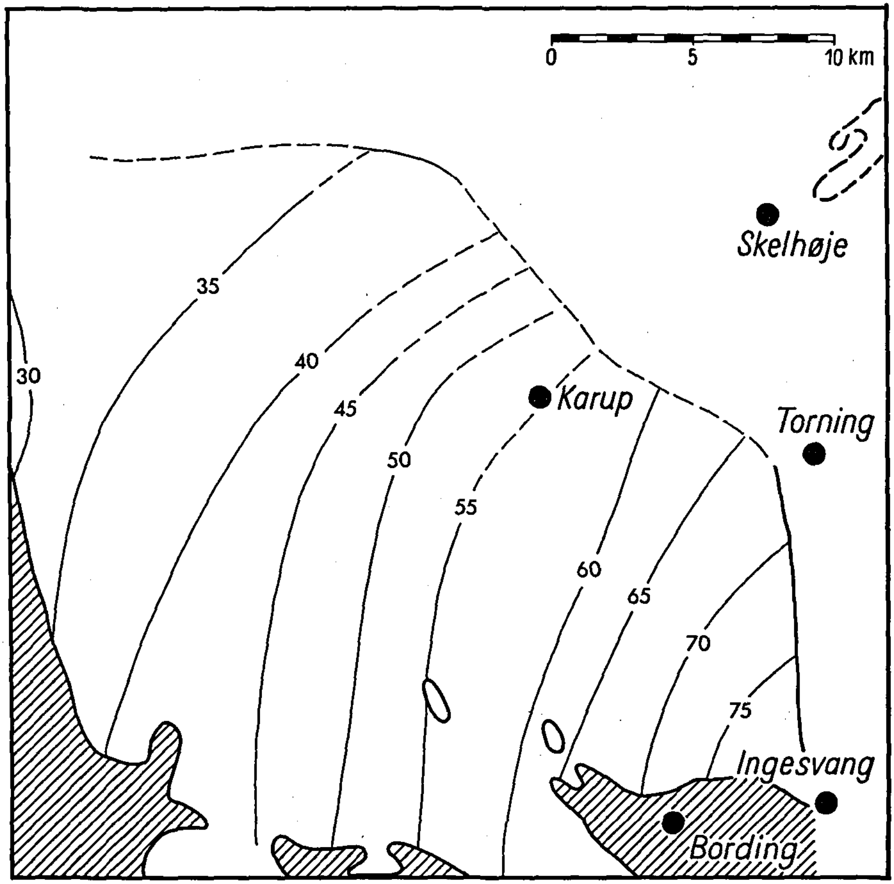

Fig. 3. The outer limit for the last glaciation on the Karup Sander.

is 71 m lower than the apex of the Dollerup cone. The lake is the second-deepest in Denmark with a water depth of 34 m at its western end. To this must be added the thickness of the lateglacial and post-glacial sediments. Observations in other lakes (K. Hansen, 1965 and 1968) show that the thickness hereof may be estimated to be about 8–10 m. The meltwater that built up the Dollerup cone should accordingly have been forced 113 m upwards with its content of gravel, sand, and clay. This seems very unlikely, especially in a receding ice margin with only a small gradient of the ice surface.

Also Woldstedt has reconsidered the theories and finds it unlikely that fjords and elongated lake basins should be explained as excavated by meltwater in ice tunnels, and he writes (Woldstedt, 1952 and 1961) that further studies have convinced him that lake basins and fjords are the result of glacial erosion, and that meltwater has contributed only to a limited extent. The longitudinal and the cross sections of these lakes and valleys with thresholds between their basins are typical of glaciated areas and have been formed by glacial erosion and not by meltwater. Furthermore, Woldstedt points out that the meltwater stream at a glacier cave is a confluence of innumerable streams inside the ice with the result that both run-off and the erosive force will reach a maximum just before the outlet. It is therefore to be expected that such tunnel valleys attained their greatest width at the outlet but in reality this is the most narrow passage.

Also Jaspersen and Weiss have objections against the tunnel valley theory. Jaspersen (1953) emphasizes that since the "sander" are also found at places where there are no outlets of tunnel valleys, these cannot be the prerequisite for the formation of "sander". However, more important are Jaspersen's hydrodynamic objections that a current velocity of 2 m/sec. is necessary for the transport of the sand and gravel deposited on the "sander". He has calculated that the water seeping through fissures at a height of 3000 m in the Scandinavian highlands cannot obtain a velocity higher than 0.57 m/sec. at the outlet because of the small gradient.

On the basis of sedimentological investigations Weiss (1958) finds that some layers have grain sizes, the transport of which required a current velocity of more than 2 m/sec., and that the average velocity in the marginal zone of the sander has been about 1 m/sec. The formation of the sanders has apparently taken place gradually, and as nothing indicates a sudden deposition of material outside the glacier cave, the process has rather been a washing out with residual sedimentation.

It must therefore be evident that sub-glacial streams cannot have formed the many tunnel valleys that Ussing and, especially, V. Milthers have shown on their maps. Tunnels in the ice cap must have existed, but they were confined to the upper part of the ice, only reaching and eroding the substratum where the ice covering was sufficiently thin. The eskers are the preserved evidence of such tunnels or channels in the ice, but it is easily inferred from the eskers on Fyn, with their lower strata pressed up from below and their cores of morainic clay, that the ice needs not be very thick before the weight of the surrounding ice masses will press the floor of the tunnel upwards.

A common argument from Ussing, Milthers and Woldstedt in support of their presumption that these large valleys are to be interpreted as tunnel valleys is that their length and width exclude excavation by the streams now flowing in them. However, it has been a neglected fact, that in late-glacial periods there was much more water in the soil, originating partly from the normal precipitation, and partly from the melting ice and the thawing permafrost in the decreasingly icefree soil. It is also characteristic that the two largest valleys in Jutland, the valley of Gudenå and that of Skalså, neither by Ussing nor Milthers were ever considered to have been subglacially excavated.

Hereafter, it is necessary to resume detailed investigations of each of the former, so-called tunnel valleys in an attempt to find another explanation for their origin.

To-day it can be generally accepted that the large fjord valleys must be presumed to have been excavated by glacier tongues. Harder (1908) believed that Vejle Fjord and Horsens Fjord and their depressions farther inland were old glacier beds. Gripp (1964) states that the ice margin would break into smaller tongues that scooped out troughs where the ice cap was forced to move uphill. Many valleys previously regarded as tunnel valleys must now be interpreted as narrow troughs. Thus the inner part of both Slien and Flensburg Fjord is considered created by these ice tongues by Gripp (1949).

When Woldstedt gave up the tunnel valley theory he referred, as Gripp did, to the conditions observed in the Alpine foreland, where glaciers branch out in narrow ice tongues. Also he believes that Åbenrå Fjord is a trough.

It will undoubtedly be more difficult to revise the new explanations of the formation of the long lake basins and some of the deep valleys of Jutland.

As to the lakes Hald Sø and Viborgsøerne it must be justified to believe that the landscape over which the last glaciation forced its way was not a flat plain, but a landscape of hills and valleys left by the foregoing Saale glaciation. Into the valleys stretching in the same direction as the ice movement, the advancing ice cap has extended glacier tongues which, especially in the marginal zone, had a higher erosive power than on the surrounding plateau where the ice movement had stagnated. That such individual ice streams can have their own movement independant of the surrounding ice is well-known from Greenland where several glaciers can be traced more than 100 km inland from the ice margin.

Undoubtedly, the valley of Salten Å was also excavated by an ice tongue. The western part of it, west of the Silkeborg-Bryrup highway, with its many hills displays the characteristic morphology of a terminal moraine landscape. Also the development south and west of the town Silkeborg suggests glacial erosion by tongues in the lake basins rather than excavation by meltwater in tunnel valleys.

Dansk sammendrag

N. V. Ussings teori, at de store jyske dalstrøg med deres rækker af langsøer skulle være udgravet af subglaciale vandløb, der stod under tryk, og som ved isranden pressedes op til overfladen og med deres indhold af opslemmet sand og grus opbyggede de store hedesletters keglefläder, har altid været betragtet som noget af det sikreste i dansk kvartærgeologi. Ussing kaldte disse dale for "Fjorddale". Senere ændrede Madsen (1921) navnet til "Tunneldale". (fig. 1).

I Nordtyskland, hvor man havde vanskeligheder med at forklare langsøernes opståen, sluttede man sig også til Ussings opfattelse, (Woldstedt 1913, 1923, 1926,) men i den engelsksprogede litteratur stillede man sig mere skeptisk til den.

Som støtte for tunneldalsteorien henviste Ussing til Russel's beskrivelse af Malaspinagletscheren i Alaska (Russel 1891, 1893), men en gennemgang af disse beretninger såvel som senere undersøgelser af denne gletscher (Sharp, 1958) viser, at der i virkeligheden ikke er iagttagelser, der støtter Ussings opfattelse. Malaspina-gletscheren udfylder et bassin, hvis bund ligger ca. 250 m under havniveau, men ingen gletscherspalter når længere ned end til 22 m under gletscherens overflade. Gletscherens nedre dele er en kompakt ismasse, der bevæger sig delvis ved glidning over bassinets bund, delvis ved intern flydning.

Den is, der under sidste nedisning har bevæget sig fra Skandinaviens fjeldområder ned over Danmark, har måttet passere de dybe og brede lavninger Skagerrak, Kattegat og Østersøen, og har derfor ind over Jylland bevæget sig opad bakke, presset fremad af trykket bagfra. Den har derfor næppe haft spalter ned til nogen større dybde.

En nøjere gennemgang af Ussings beskrivelser af forholdene i Jylland viser også, at disse på flere punkter ikke stemmer med virkeligheden. Af Karupfladens tre aflejringskegler er det kun Dollerup keglen der er veludviklet, og hvis toppunkt ligger i forlængelsen af et større dalstrøg, der rummer Viborg søerne og Hald Sø. Sebstrup keglens af Ussing angivne toppunkt ligger midt imellem to store dalstrøg, og den såkaldte Moselund kegle er sammensat af flere flade keglefläder. Dollerup keglens faldretning er nærmest vinkelret på den sydfor liggende flade, og synes at have bredt sig ud over denne, fig. 2. Den repræsenterer derfor et yngre afsnit af afsmeltningsperioden. Ydergrænsen for sidste nedisning har derfor sandsynligvis haft et forløb, som vist på fig. 3.

At der har stået en gletscherport ved Skelhøje er ganske sikkert. Derimod er det lidet sandsynligt, at det vand, der med sit indhold af sand og grus skulle komme helt fra bunden af den såkaldte tunneldal. Hald Søs overflade ligger 71 m lavere end Dollerup keglens toppunkt. Søen er i vestenden 34 m dyb, og hertil skal lægges mægtigheden af de sen- og postglaciale sedimenter, hvilket efter erfaringer fra andre søer kan sættes til ca. 8–10 m. Smeltevandet skulle således med sit indhold af opslemmet sand og grus være presset 113 m i vejret. Dette ville kræve en strømhastighed på ca. 2 m/sek., men tyske kvartærgeologer (Jaspersen 1953, Weiss 1958) har beregnet, at gennemsnitshastigheden i hedesletternes randzone ikke kan have oversteget 1 m/sek. og sandsynligvis har været ringere. Også Woldstedt har efterhånden fået betænkeligheder ved Ussings teori og har søgt andre forklaringer på langsøernes opståen (Woldsted 1952, 1961).

At der kan dannes tunneller i isen, og at disse kan nå ned til underlaget fremgår med tydelighed af åsenes dannelse, men de oppressede bundlag i de fynske åse viser også, at isdækket over sådanne tunneller ikke kan blive ret tykt, før tunnellens bund presses i vejret. De store fjorddale, og langsøernes tilblivelse må derfor i hvert enkelt tilfælde tages op til fornyet detailleret undersøgelse.

Fjorde som Horsens Fjord og Vejle Fjord og deres fortsættelse i de brede dale må sikkert være udgravede af gletschertunger, og det samme er sikkert tilfældet med

Åbenrå Fjord. Vanskeligere bliver det at finde forklaringer på dannelsen af langsøerne i nogle af de store dale i Midtjylland. Som allerede Madsen var inde på, må nogle af dem formodentlig være dannet allerede i næstsidste istid (Saale) og er så blevet yderligere udformet af istunger fra sidste nedisning.

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References

Andersen, S. A. 1923: *Det danske Landskabs Historie.* 275 pp. København: Levin og Munksgaard.

Embleton, C. & King, C. A. M. 1968: *Glacial and Periglacial Geomorphology.* 608 pp. London: Cunningham & Son.

Flint, R. F. 1957: *Glacial and Pleistocene Geology. 553 pp. New York:* Wiley & Sons.

Gripp, K. 1949: Die Entstehung der Föhrden. *Schr. d. naturviss. Ver. f. Schleswig-Holstein* **24** (1), 67–69.

Gripp. K. 1964: *Erdgeschichte von Schleswig: Holstein.* 441 pp. Neumünster: Vachholtz.

Hansen, K. 1965: The postglacial development of Grane Langsø. *Meddr dansk geol. Foren.* **15,** 446–458.

Hansen, K. 1968: En boring i Esrum sø. *Meddr dansk geol. Foren.* **18,** 244–246.

Hansen, K., Heller, E. & Larsen, G. 1960: Sedimentary and economic geology of Denmark. *Guide to excursions A. 47–48 and C 42–43. Intern. geol. Congr. XXI session, Norden.* 51 pp.

Hansen, S. 1940: Varvighed i danske og skånske senglaciale aflejringer. *Danm. geol. Unders.* række 2, **63,** 478 pp.

Hansen, S. 1965: The Quaternary of Denmark. In: Rankama, K.: *The Quaternary* **1.** 90 pp. New York, London: Interscience Publishers.

Harder, P. 1908: En østjysk israndslinie. *Danm. geol. Unders.* række 2, **19,** 259 pp.

Jaspersen, P. 1953: Sandurbildung durch subglazialer aufsteigende Schmelzwasser. *Eiszeitalter und Gegenwart* **3,** 129–135.

Madsen, V. 1921: Terrænformerne på Skovbjerg Bakkeø. *Danm. geol. Unders.* række 4, **1** (12), 24 pp.

Madsen, V. 1928: Third glacial period. In: Summary of the geology of Denmark. *Danm. geol. Unders.* række 5 (4), 107–119.

Milthers, K. 1935: Landskabets udformning mellem Alheden og Limfjorden. *Danm. geol. Unders.* række 2, **56,** 32 pp.

Milthers, V. 1948: Det danske istidslandskabs terrænformer og deres opståen. *Danm. geol. Unders.* række 3, **28,** 233 pp.

Nansen, F. 1890: Über meine Durchquerung Grönlands. *Verh. d. Ges. f. Erdkunde zu Berlin* **XVII,** 446–463.

Nielsen, A. V. 1967: Landskabets tilblivelse. I: *Danmarks Natur* **1,** 251–344. København: Politiken.

Nordmann, V. 1958: Beskrivelse til det geologiske kortblad Fredericia. *Danm. geol. Unders.* række 1, **22 a,** 125 pp.

Nye, J. F. 1952: The mechanics of glacier flow. *Journ. Glaciology* **2,** 52–53.

Rasmussen, H. W. 1966: *Danmarks Geologi.* 176 pp. København: Gjellerup.

Rosenkrantz, A. 1933: *Kortfattet oversigt over Danmarks geologi.* 144 p. København.
Russel, J. C. 1891: An exped. to Mount St. Elias, Alaska. *National Geogr. Mag.* **3.**
Russel, J. C. 1893: Second exped. to Mount St. Elias, Alaska. *U. S. geol. Surv. 13th ann. rep.*, **2** (1891–92).
Sauramo, M. 1931: De Kvartära bildningarna. I:: Ramsay, W.: *Geologiens Grunder,* **2,** Stockholm.
Schieferdecker, A. A. G. 1959: Geological nomenclature. *Gorinchem Nederland,* 523 pp.
Sharp, A. 1958: Malaspina glacier, Alaska. *Bull. geol. Soc. America* **69.**
Ussing, N. V. 1903: Om Jyllands hedesletter og teorierne for deres dannelse. *Overs. o. Det kgl. danske Vid. Selsk. Forh.* 1903, **2,** 99–152.
Ussing, N. V. 1904: Danmarks Geologi i almenfattelig omrids. *Danm. geol. Unders.* række 3, **2,** 358 pp.
Ussing, N. V. 1907: Om floddale og randmoræner i Jylland. *Overs. o. Det kgl. danske Vid Selsk. Forh.* 1907, **4,** 161–213.
Wahnschaffe, F. 1909: *Die Ursachen d. Oberflächengestaltung der norddeutsche Flachlandes.* 405 pp. Stuttgart: Engelhorn.
Weiss, E. M. 1958: Bau und Entstehung der Sander vor der Grenze der Würm. vereisung im Norden Schleswig-Holstein. *Meyniana* **7,** 5–60.
Werth, E. 1907: Studien zur glazialen Bodengestaltung in den skandinavischen Länder. *Zeitschr. Ges. f. Erdkunde zu Berlin,* 27–43; 87–101.
Werth, E. 1909: Fjorde, Fjaerde und Föhrden. *Zeitschr. f. Gletscherkunde* **3,** 346–358.
Woldstedt, P. 1913: Beiträge zur Morphologie von Nordschleswig. *Mitt. Geogr. Ges. u. d. naturh. Mus. in Lübeck,* **2** (26), 41–109.
Woldstedt, P. 1923: Studien an Rinnen und Sandurflächen in Norddeutschland. *Jahrb. preuss. geol. Landesanst. f. 1931,* **42,** 780–820.
Woldstedt, P. 1926: Probleme der Seenbildung in Norddeutschland. *Zeitschr. Ges. f. Erdkunde zu Berlin,* 103–124.
Woldstedt, P. 1952: Die Entstehung d. Seen in den ehemaligen vergletscherten Gebiete. *Eiszeitalter und Gegenwart* **2,** 146–153.
Woldstedt, P. 1961: *Das Eiszeitalter.* **I.** 374 pp. Stuttgart: F. Enke.