Tunnel valleys can be formed in one ice age by catastrophic flow

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Tunnel valleys or channels are large, elongated, over-deepened valleys cut into sediments or bedrock by subglacial meltwater during the Ice Age.[1] They frequently form sinuous, anastomosing networks oblique to the topographic gradient.[2] Tunnel valleys can reach more than 100 km long, 4 km wide, and up to 400 m deep. The bottom of a tunnel valley is sometimes flat, but the long dimension more commonly undulates, sometimes trending upslope and can have over-deepened areas with bedrock thresholds up to about 100 m. Some start and end abruptly.

Tunnel valleys are found over numerous glaciated areas, such as the outer continental shelf off Nova Scotia;[3] southern Ontario, Canada;[4] northern Alberta, Canada;[5] east-central Minnesota[6] and Wisconsin,[7] USA; north-west Europe[8]; and the central Barents Sea.[9] Figure 1 shows the ubiquitous tunnel valleys in north-west Europe.

Tunnel valleys have also been discovered offshore. Some of the largest and best documented occur in the North Sea, and are thought to have formed over multiple glaciations,[10] and then infilled by sediment from European rivers.

After a tunnel valley is first cut, it is usually (but not always) filled in. The Finger Lakes of New York are examples of tunnel valleys that were partially filled in with sediments.[1] The sediment fill is varied, and includes glacial till, glaciofluvial sands and gravels, sediment gravity flow deposits, and glaciolacustrine silts and clays. In tunnel valley fill, glacial till is uncommon and is found mainly along the edges of the valley or on top of other infill deposits (figure 2), indicating a meltwater origin with little subsequent modification by ice.[11]

Eskers, often on top of the tunnel valley fill and parallel to the valley, and drumlins in the vicinity of tunnel valleys sometimes also occur. The eskers sometimes end in an outwash fan at an ice-marginal position. The tunnel valleys sometimes cut through drumlins and moraines, indicating that they formed during deglaciation.

Over 20,000 km of buried valleys are found on the Canadian Prairie.[12] Most are pre-glacial valleys carved in poorly consolidated bedrock. In Alberta, these valleys occur between plateaus capped by consolidated-to-unconsolidated, rounded quartzite gravel, up to boulder size,[13] having come from areas of bedded quartzite in central Idaho and the Canadian Rockies. The preservation of these plateaus indicates that glacial erosion there was slight, which reinforces the idea of a single ice age in that region.[14] This geomorphology of Alberta indicates Flood sheet flow erosion transforming into channelized flow that cut the valleys and spread quartzite gravel over most of the area. The surface of the prairie was later eroded with the quartzite gravel mostly reworked during the Ice Age, forming tunnel valleys.

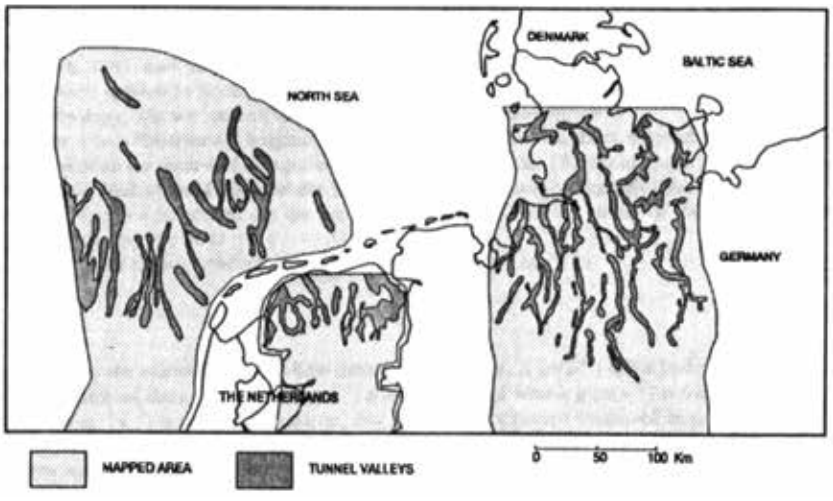

Figure 1. Tunnel valleys in north-western Europe (from Van Duke and Veldkamp[8])

Origin of tunnel valleys poorly understood

Russell and colleagues write: "Despite the ubiquity of tunnel channels and valleys within formerly glaciated areas, their origin remains enigmatic."[15] There is much controversy surrounding the origin and evolution of tunnel valleys.[16] It is accepted that tunnel valleys "were eroded by large, channelized subglacial meltwater flows that were driven by the hydrostatic gradient of the overlying ice sheet".[17] The hydrostatic gradient is related to both ice thickness and surface slope. The main controversy is whether the tunnel valleys formed at once or were shaped slowly by steadily but repeated meltwater discharges. The flows of water could be large catastrophic subglacial floods.

In areas with numerous tunnel valleys, such as the North Sea, researchers have claimed that they were eroded during seven glacial cycles between 500 and 40 ka.[18] Piotrowski claimed that the abundant tunnel valleys in north-west Germany date from the last three glaciations.[19]

New research shows tunnel valleys can form in one ice age

New research in north-eastern Alberta, Canada, indicates that one ice age could have produced numerous tunnel valleys[17] based on laterally extensive sheet-like sand and gravel bodies that extend beyond the margins of the tunnel valleys. These sediments indicate water flowed as a sheet under the ice before diminishing into shrinking channels. Glacial till interbeds (unusual for tunnel valleys) could have been formed by multiple subglacial floods of moderate intensity during one ice age:

> "However, in our reconstruction, we propose that rather than spanning multiple glaciations, tunnel valleys in northeast Alberta evolved due to a combination of steady-state subglacial drainage processes, punctuated by time-transgressive episodic jökulhlaups [glacial outburst floods, an Icelandic term] during a single cycle of Laurentide glaciation … . No evidence has been found in this study that supports near-synchronous erosion of tunnel valleys by catastrophic bankfull discharges. Rather, the valley fills described in this paper document jökulhlaups which were of low to moderate magnitude and/or high velocity, which at times reused existing valleys, while at others, eroded new valleys."[20]

Since these tunnel valleys are similar to those found elsewhere, I propose that all tunnel valleys formed during one ice age, during catastrophic glacial melting. This hypothesis contradicts those suggesting tunnel valleys formed during multiple glaciation events, particularly in the North Sea and northern Europe.

Regarding the tunnel valleys claimed to be from three ice ages in north-west Germany,[19] Ó Cofaigh says there is no basis for this designation:

> "His interpretation of both the genesis and age of these diamict units [within the tunnel valleys] is open to question, however, because 1) there are no detailed facies descriptions of the units he interprets as tills and he presents no firm sedimentological evidence to support this interpretation; and 2) the tills themselves are dated only indirectly according to their stratigraphy position and petrography."[21]

Tunnel valleys in the North Sea commonly cross-cut one another, which is probably why they are claimed to be from seven ice ages.[10,18,22] The researchers seem to be relying on the cross-cutting relationships between some of the tunnel valleys in the North Sea to place them in different ice ages, to fit the Milankovitch theory of the ice ages. In reality, these tunnel valleys cannot be dated: "The paucity of stratigraphic age data for the Pleistocene succession in the North Sea makes the absolute dating of the tunnel valleys problematic."[23] Multiple generations of tunnel valleys can be caused by multiple subglacial flood bursts. Some of these bursts could easily cross-cut previously formed tunnel valleys—all within a single glaciation. This level of activity should not be too difficult to conceive, since the central North Sea has unconsolidated Pleistocene sediments up to 1,000 m thick.[22] Wingfield even suggests that the tunnel valleys could be carved almost instantaneously if a 500-m-deep glacial lake suddenly burst, which would result in currents moving at 50 m/sec.[24]

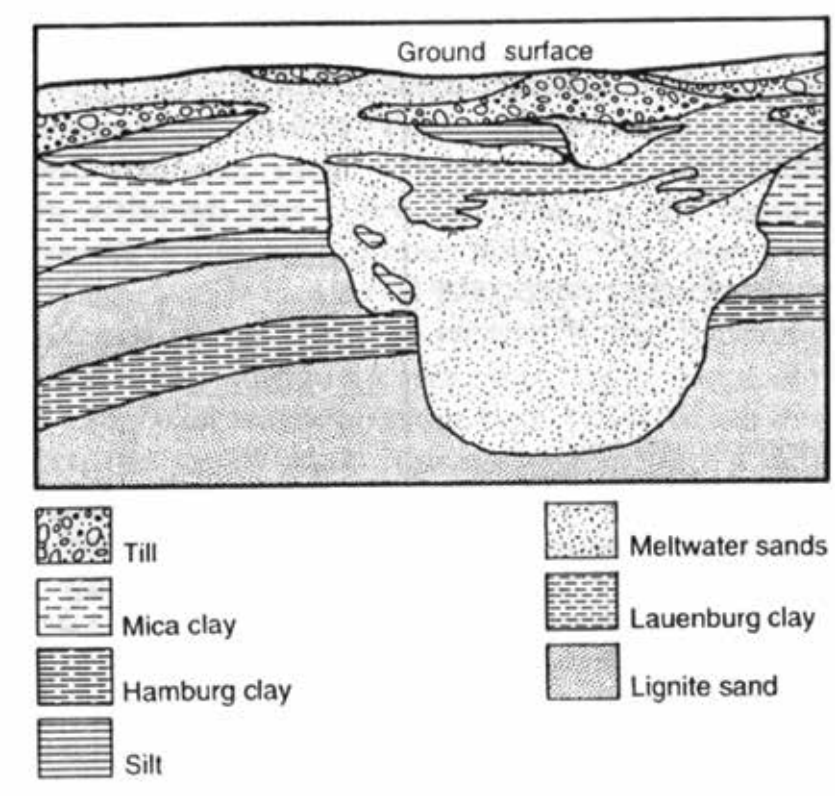

Figure 2. Typical tunnel valley fill (from Ó Cofaigh[1]). Note that glacial till, the deposits from the ice itself, are rare within the tunnel valley, indicating subglacial meltwater eroded them.

Can tunnel valleys form catastrophically?

There has been controversy over whether tunnel valleys were carved gradually by sporadic modest subglacial floods or cut quickly by large catastrophic floods, as envisioned by Wingfield and John Shaw and

colleagues.[4] The evidence for moderate to large catastrophic subglacial floods is substantial. The valley fill often includes boulders that would require strong flow to move.[19] Rocks up to 2 m have been observed in Wisconsin in an outwash fan at the base of a tunnel valley, suggesting a strong outburst flood from stored subglacial meltwater.[7] Percussion marks on some of the boulders support fast currents under high pressure.[1] In addition, the water sometimes flowed uphill; there are integrated, anastomosing channels; and channels show undulating bottoms with over-deepened basins. The size and number of steep channel walls also suggest catastrophic formation.[1,25] Curvilinear features observed in tunnel valleys in central Poland suggest high-energy flow vortices.[26]

Many researchers accept the catastrophic origin of tunnel valleys by high quantities of high-pressure subglacial flows,[27,28] but this causes difficulties in explaining the timing of the events in relation to the stratigraphic record.[1] High-pressure sheet flows can result from the depth of the ice sheet or from rapid glacial movement, such as surges. Kavanaugh and Clarke report that subglacial water-pressure records from a glacier in the Yukon Territory, Canada, indicated there was once much higher pressure than can be explained by the depth of the ice.[29] Laboratory experiments indicate that pressures up to 15 times the ice-overburden pressure can be generated by abrupt ice motion.

Formation of a tunnel channel was *observed* during the 1996 jökulhlaup from under a glacier in Iceland. The flood waters originated from a subglacial lake and had to ascend 300 m, indicating high-pressure flow. The bottom of one 160 m section of the tunnel channel rose 11.5 m. The flood first issued from the entire 23 km edge of the glacier as a sheet flow, before shrinking to several large channels. Peak discharge was about 50,000 m^3/sec through unconsolidated sediments, but estimated to be around 640 m^3/sec for tunnel channel formation.[15]

Shaw and colleagues have proposed very large subglacial floods, and tunnel valleys indicate that they are on the right track. It is still unknown just how catastrophic these floods were.

Summary

Tunnel valleys are common features associated with glaciated areas, but their origin is enigmatic. Since some channels exist in cross-cutting relationships, tunnel valleys are thought to have been cut in multiple ice ages. But if they formed rapidly by catastrophic flooding, it is not unreasonable to conclude that they formed during one ice age.

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