Jakobshavn Isbræ, West Greenland: the 2002–2003 collapse and nomination for the UNESCO World Heritage List

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Jakobshavn Isbræ (also known as Sermeq Kujalleq or Ilulissat Isbræ) is situated at about 69°10′N and 50°00′W in West Greenland. This major outlet from the Inland Ice has an extremely high rate of movement (nearly 1 m/hour) and thus a high production of icebergs, which via the icefjord float westwards through Disko Bugt to Davis Strait (Fig. 1). Estimates of the iceberg production are in the range of 35 ± 10 km^3 ice per year, more than 10% of the entire calf-ice production of the Inland Ice (e.g. Bauer 1968; Bindschadler 1984). The icefjord into which Sermeq Kujalleq calves is Kangia, best known in glaciological literature as Jakobshavn Isfjord. Spectacular changes of the glacier were observed during 2002 and 2003 at the same time as it was nominated for inclusion in the UNESCO World Heritage List under the name 'Ilulissat Icefjord'.

Nomination of 'Ilulissat Icefjord' and Sermeq Kujalleq

The Eskimo ruins and archaeological sites in the region around the modern Greenland township of Ilulissat include representatives of all the cultural phases since the first Eskimo settlement of Greenland. The association with Greenland's most productive glacier makes the 'Ilulissat Icefjord' area a strong candidate for inclusion in the UNESCO World Heritage List. In December 2000 the Government of Greenland decided to nominate 'Ilulissat Icefjord', and the Geological Survey of Denmark and Greenland (GEUS) was given the task of preparing the nomination document (Fig. 1; Mikkelsen & Ingerslev 2003). A decision as to whether 'Ilulissat Icefjord' will be awarded World Heritage List Status

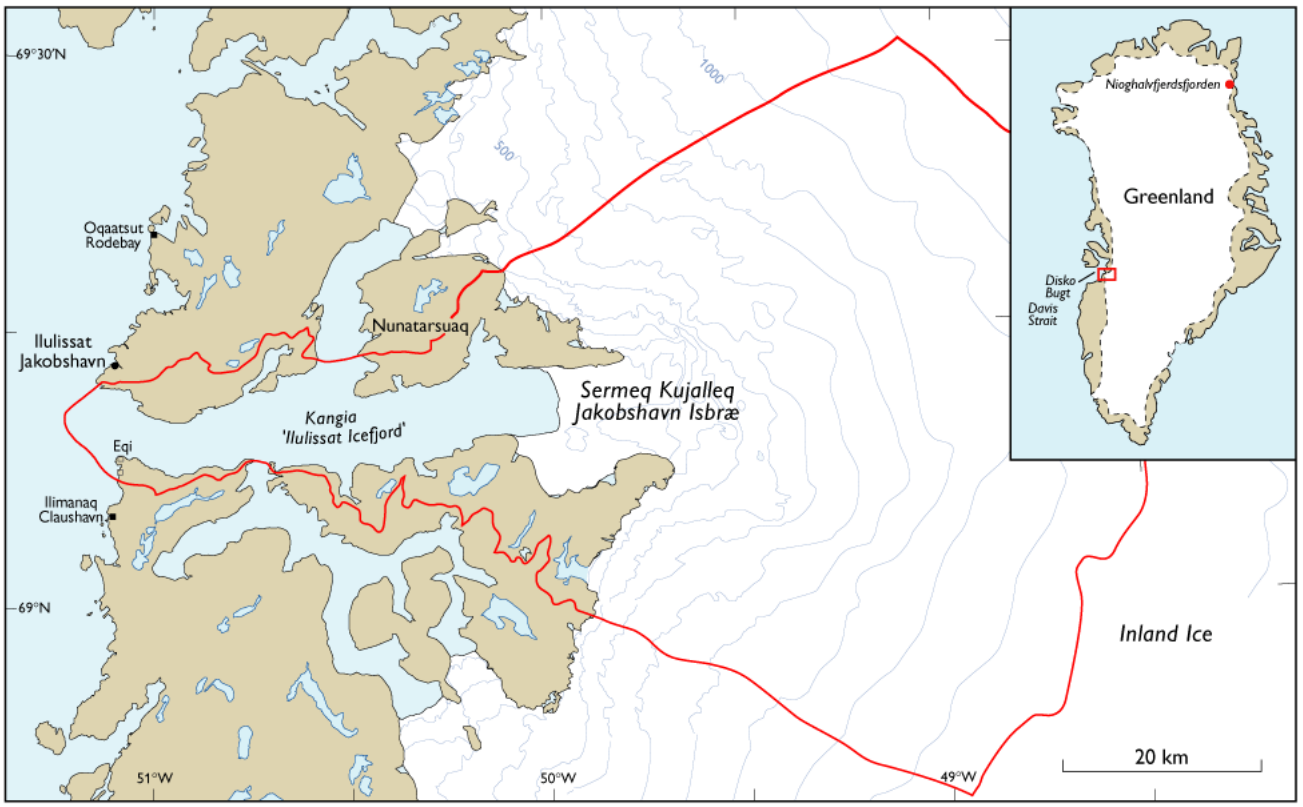

Fig. 1. Extent of the nominated area of 'Ilulissat Icefjord' (**red boundary lines**). The ablation area and front of the glacier Sermeq Kujalleq are included, together with the entire icefjord area. Modified from Mikkelsen & Ingerslev (2003).

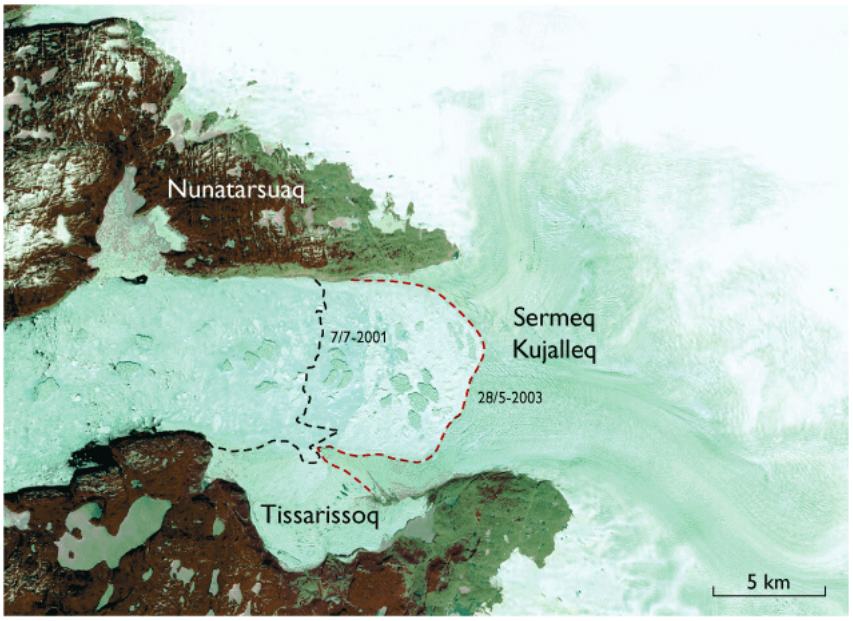

Fig. 2. Sermeq Kujalleq on 28 May 2003; glacierfront indicated by **dashed red line**. Satel-lite image by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radio-meter) installed in the Terra satellite, with the position of the glacier front on 7 July 2001 indicated by **dashed black line**. ASTER data are distributed by the Land Processes Distributed Active Archive Center (LPDAAC), located at the United States Geological Survey's EROS Data Center: http://lpdaac.usgs.gov

will be made at the annual meeting of UNESCO in June 2004.

The nomination document includes comprehensive documentation on observations and investigations of Sermeq Kujalleq. This major glacier, or 'ice stream', is situated in a subglacial trough that in its outer parts reaches depths of 1500 m below sea level (Iken *et al.* 1993; Clarke & Echelmeyer 1996), and it can be traced inland for about 100 km (Echelmeyer *et al.* 1991). General descriptions of the outer part of the glacier stress the quasistable conditions of the glacier front throughout the second half of the 20th century (Stove *et al.* 1983; Echelmeyer *et al.* 1991; Sohn *et al.* l997a, b). However, during an inspection visit to the nominated area in August 2003 radical changes in the situation of the glacier front were found to have occurred compared to the description set out in the nomination document (Fig. 2).

Prehistoric variations of Sermeq Kujalleq

At the beginning of postglacial time (*c.* 9500 B.P.) the front of Sermeq Kujalleq was situated at the mouth of the fjord, about 50 km west of the front position shown in Fig. 1, resting on a bank near Ilulissat at depths of 200–300 m below present sea level (Weidick 1994). Subsequently, the ice margin retreated some 65–70 km, and at the end of the climatic optimum *c.* 5000 years ago the glacier front was located about 20 km east of the ice margin position of 1964 (Weidick *et al.* 1990, fig. 4).

The following neoglacial readvance culminated during the Little Ice Age (A.D. 1500–1900), with the maximum position of the glacier front in 1851 (Fig. 3; cf. Bauer 1968). Since the postglacial climatic optimum the ice margin is presumed to have advanced in pulses, such as it has been documented for the ice margin 40 km north of Sermeq Kujalleq where the response of the ice-sheet margin has been calculated for the last 1400 years (Reeh 1983). There may have been two periods of advance: at A.D. 700–800 and during the Little Ice Age (A.D. 1500–1900).

Historical records of Sermeq Kujalleq

Historical records of the glacier fluctuations of Sermeq Kujalleq have been collected and described by Larsen & Meldgaard (1958) and Georgi (1960). The numerous observations since the beginning of the 1700s and up to 1851 suggest a gradual advance during this period.

Subsequent to 1851 observations and descriptions are more frequent and more detailed. The first mapping of the frontal position was by Rink in 1851 (Rink 1857), the first determination of the fast movement of the glacier front was made in 1875 (Helland 1876), and seasonal fluctuations of the glacier front position were recorded by investigations in 1879–80 (Hammer 1883). Regular meteorological observations were begun in the town of Ilulissat in 1873.

The quasistable period of Sermeq Kujalleq 1950–2002

Recessional positions of Sermeq Kujalleq are summarised in Fig. 3. The recent part of the curve is based on aerial photographs (from about 1950) and since 1962 also satellite information (Sohn *et al.* 1997a). This well-documented 50-

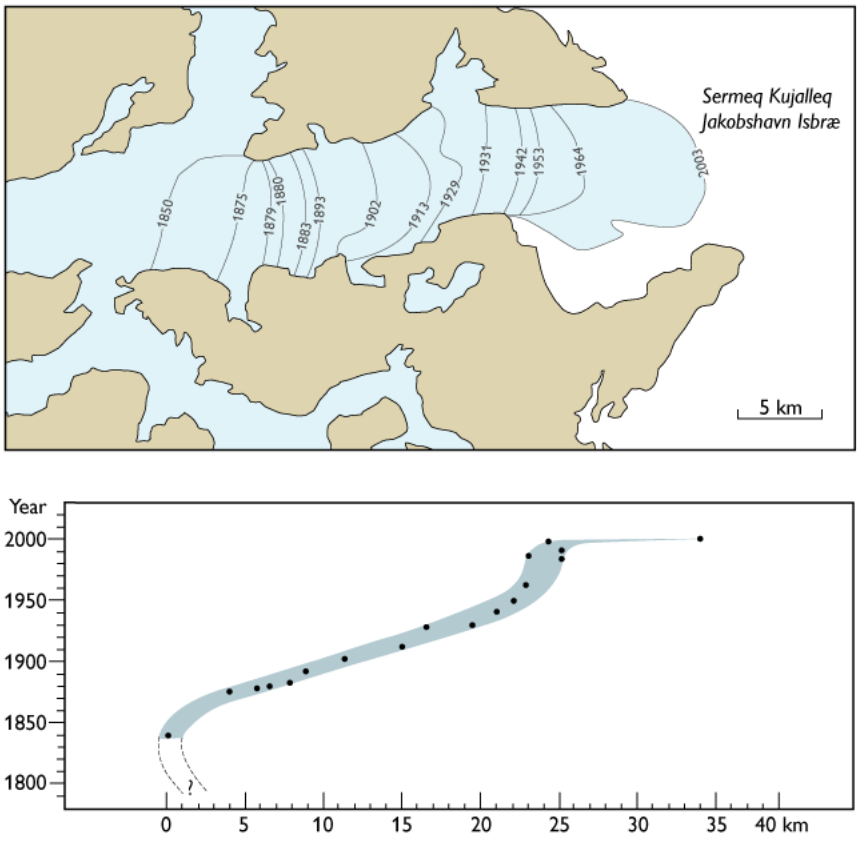

Fig. 3. **Top**: Approximate recessional positions of Sermeq Kujalleq. Modified from Bauer (1968). **Bottom**: Conceptual recessional curve of the Sermeq Kujalleq glacier front, based on the positions given by Bauer (1968) up to 1964. The younger parts of the curve are based on satellite information by Stove *et al.* (1983), Sohn *et al.* (1997a, b) and later Landsat and ASTER images. The width of the curve depicts range of seasonal variations in the position of the glacier front. Note the rapid break-up and retreat from 2002–2003. Bauer (1968) and Georgi (1960) give very advanced positions of the front in 1870 and 1880; both were considered uncertain by Engell (1904), and have therefore been omitted here.

year period coincides with a stable position of the glacier front at a broad part of the fjord. The quasistability of the glacier front position was probably influenced by subglacial topography (Echelmeyer *et al.* l991; Weidick 1992).

The thinning of the glacier during the recessional period *c.* 1850–1950 has been estimated at more than 200 m (Weidick 1992), while observations on subsequent changes in thickness of the glacier front are few and scattered. A lowering of the frontal surface may have occurred from the 1960s to the 1980s (Echelmeyer *et al.* 1991). Between 1993/94 and 1998/99 investigations of the glacier by laser altimetry showed Sermeq Kujalleq to be one of the few Greenland outlets showing signs of slight growth (Abdalati *et al.* 2001). However, since 1997 a sudden transition to a rapid thinning has occurred, starting in the lower reaches of the glacier and spreading gradually inland. By 2001 almost the entire glacier up to elevations of 2000 m exhibited thinning (Thomas *et al.* 2003). Substantial changes of the glacier front were therefore not entirely unexpected.

The break-up of the Sermeq Kujalleq front

The inhabitants of Ilulissat had observed an unusual amount of detached parts of the glacier front at the mouth of the icefjord in 2002, and observations during the 2003 visit showed that these parts are the result of a break-up of the floating glacier front.

To date more closely the time of glacier break-up and retreat of the front, studies were made of a series of Landsat images covering the years 2001 to early 2003. It was established that the last winter advance of the quasistable period took place in March 2002, and was followed by a period of continuous break-up and recession of the glacier front. By May 2003, the glacier front was situated *c.* 11 km east of the 'normal' winter position. Major parts of the floating glacier described by Echelmeyer *et al.* (199l) had disappeared.

Two stages in this break-up are illustrated in Fig. 2 (July 2001 and May 2003). The 'normal' retracted summer position of the quasistable stage (July 2001) was followed by the last winter advance of *c.* 3.5 km to March 2002. In May 2003, a major recession of the glacier front has occurred, and the glacier segment in Tissarissoq had become isolated and had partially disintegrated.

The frontal position after 7 July 2003 is currently uncertain, but recession seems to have continued and it is now approaching the retracted position of the climatic optimum 4000–5000 years ago. The occurrences of marine shells in the neoglacial moraines surrounding Tissarissoq demonstrate that the area was ice-free in the past, although the duration of this ice-free period is not known. A single radiocarbon dating

of a walrus tusk is currently available (4290 ± 100 B.P.; Weidick 1992). Local legends record that this area was formerly ice-free and used as a hunting locality (Hammer 1883, p. 5). If these legends record a real event, then the end of the open-water period and advance of the ice may be as recent as the Little Ice Age (A.D. 1500–1900). This can only be verified by extensive dating of the marine deposits, such as that carried out to determine the duration of open water in Nioghalvfjerdsfjorden in North-East Greenland (Bennike & Weidick 2001).

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References

Abdalati, W., Krabill, W., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R., Wright, W. & Yungel, J. 2001: Outlet glacier and marginal elevation changes: near-coastal thinning of the Greenland ice sheet. Journal of Geophysical Research **106**(D24), 33729–33741.

Bauer, A. 1968: Missions aériennes de reconnaissance au Groenland 1957–1958. Observations aériennes et terrestres, exploitation des photographies aériennes, détermination des vitesses des glaciers vêlants dans Disko Bugt et Umanak Fjord. By A. Bauer, in collaboration with M. Baussart, M. Carbonnell, P. Kasser, P. Perroud and A. Renaud. Meddelelser om Grønland **173**(3), 116 pp.

Bennike, O. & Weidick, A. 2001: Late Quaternary history around Nioghalvfjerdsfjorden and Jøkelbugten, North-East Greenland. Boreas **30**, 205–227.

Bindschadler, R.A. 1984: Jakobshavn Glacier drainage basin: a balance assessment. Journal of Geophysical Research **89**, 2066–2072.

Clarke, T.S. & Echelmeyer, K. 1996: Seismic-reflection evidence for a deep subglacial trough beneath Jakobshavns Isbræ, West Greenland. Journal of Glaciology **42(**141), 219–232.

Echelmeyer, K., Clarke, T.S. & Harrison, W.D. 1991: Surficial glaciology of Jakobshavns Isbræ, West Greenland. Part I: Surface morphology. Journal of Glaciology **37**(127), 368–382.

Engell, M.C. 1904: Undersøgelser og Opmaalinger ved Jakobshavns Isfjord og Orpigsuit i Sommeren 1902. Meddelelser om Grønland **26**(1), 70 pp.

Georgi, J. 1960: Otto Fabricius und andere über die Eisverhältnisse auf Grönland, mit einem Exkurs auf den Jakobshavner Gletscher. Polarforschung **4** (Jahrgang 28, 1958, Heft 1–2), 79–91.

Hammer, R.R.J. 1883: Undersøgelser ved Jakobshavns Isfjord og nærmeste Omegn i Vinteren 1879–1880. Meddelelser om Grønland **4**(1), 68 pp.

Helland, A. 1876: Om de isfyldte Fjorde og de glaciale Dannelser i Nordgrønland. Archiv for Matematik og Naturvidenskab **1**, 69 pp.

Iken, A., Echelmeyer, K. & Funk, M. 1993: Mechanism of fast flow in Jakobshavn Isbræ, West Greenland. Part I: Measurements of temperature and water level in deep bore holes. Journal of Glaciology **39**, 15–25.

Larsen, H. & Meldgaard, J. 1958: Paleo-Eskimo cultures in Disko Bugt, West Greenland. Meddelelser om Grønland **161**(2), 75 pp.

Mikkelsen, N. & Ingerslev, T. (eds) 2003: Nomination of the Ilulissat Icefjord for inclusion in the World Heritage List. Document prepared for UNESCO, 136 pp. Copenhagen: Geological Survey of Denmark and Greenland.

Reeh, N. 1983: Ikke-stationær beregningsmodel for Indlandsisens randzone. Gletscher-hydrologiske Meddelelser Grønlands Geologiske Undersøgelse **83/7**, 81 pp.

Rink, H. 1857: Grønland, geografisk og statistisk beskrevet. Vol. 1: Det nordre Inspektorat, 420 pp.; vol. 2: Det søndre Inspektorat, 588 pp. København: Andr. Fred. Høst.

Sohn, H.G., Jezek, K.C. & van der Veen, C.J. 1997a: Jakobshavn Glacier, West Greenland: 30 years of space-borne observations. Geophysical Research Letters **25**, 2699–2702.

Sohn, H.G., Jezek, K.C. & van der Veen, C.J. 1997b: Seasonal variations in terminus position of Jakobshavn Glacier, West Greenland. In: van der Veen, C.J. (ed.): Calving glaciers. Byrd Polar Research Center Report **15**, 137–140.

Stove, G.C., Green, K., Birnie, R.V., Davidson, G., Bagot, K., Palmer, M., Kearn, G., Ritchie, P.F.S. & Sugden, D.E. 1983: Monitoring iceberg production from West Greenland tidewater glaciers using Landsat data. Results of the AGRISPINE experiment for the Jakobshavn Isbræ, 32 pp. Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen, Scotland and the National Remote Sensing Centre, Farnborough, Hampshire, England.

Thomas, R.H., Abdalati, W., Frederick, E., Krabill, W., Manizade, S. & Steffen, K. 2003: Investigation of surface melting and dynamic thinning on Jakobshavn Isbræ, Greenland. Journal of Glaciology **49**(165), 231–239.

Weidick, A. 1992: Jakobshavn Isbræ area during the climatic optimum. Rapport Grønlands Geologiske Undersøgelse **155**, 66–72.

Weidick, A. 1994: Fluctuations of West Greenland calving glaciers. In: Reeh, N. (ed.): Workshop on the calving rate of West Greenland glaciers in response to climate change, 143–168. Copenhagen, Denmark: Danish Polar Center.

Weidick, A., Oerter, H., Reeh, N., Thomsen, H.H. & Thorning, L. 1990: The recession of the Inland Ice margin during the Holocene climatic optimum in the Jakobshavn Isfjord area of West Greenland. Palaeogeography, Palaeoclimatology, Palaeoecology **82**, 389–399.

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