Was Hardangerfjorden, western Norway, glaciated during the Younger Dryas?

JAN MANGERUD

Mangerud, J. Was Hardangerfjorden, western Norway, glaciated during the Younger Dryas? *Norsk Geologisk Tidsskrift*, Vol. 80, pp. 229–234. Oslo 2000. ISSN 0029-196X.

A new site with a shell-bearing till is described from the outer part of Hardangerfjorden. Two shell fragments from the till were dated to 10,870 ± 90 and 11,000 ± 40 radiocarbon years BP. These dates support the established hypothesis of a major glacial re-advance and an ice-filled Hardangerfjorden during the Younger Dryas. An opposite hypothesis, that Hardangerfjorden remained ice-free during the entire Younger Dryas, was proposed in a recent paper by Helle et al. (1997; *Norsk Geologisk Tidsskrift* 77, 101–117) and supported by several scientists during the Nordic Geological Winter Meeting in 2000. I argue in the present paper that the latter hypothesis is falsified, not only by the two new dates, but also by previously published dates from shell-bearing tills and sub-till sediments. In my opinion, the data presented by Helle et al. allow for alternative interpretations.

Jan Mangerud, University of Bergen, Department of Geology, Allégt. 41, N-5007 Bergen, Norway (e-mail: Jan.Mangerud@geol.uib.no)

Introduction

In a recent paper, Helle et al. (1997) concluded that Hardangerfjorden remained ice-free throughout the entire Younger Dryas. At the Nordic Geological Winter Meeting in Trondheim, January 2000, Helle et al. (2000) reinforced this interpretation and were supported by Bakke et al. (2000) and in the oral discussions also by Bjørn Follestad. Their hypothesis challenges the established view of a major Younger Dryas re-advance of the Scandinavian Ice Sheet across these parts of western Norway (Holtedahl 1967, 1975; Mangerud 1970, 1977, 1980; Follestad 1972; Aarseth & Mangerud 1974; Andersen et al. 1995b). However, Helle et al. (1997, 2000) did not really discuss published observations that contradict their own hypothesis.

In this paper I maintain that the two hypotheses are mutually exclusive. Therefore testing the alternatives, at least in theory, is simple. If it can be demonstrated that Hardangerfjorden remained ice-free during the Younger Dryas, as claimed by Helle et al. (1997, 2000) and Bakke et al. (2000), then the established hypothesis of a major Younger Dryas re-advance (e.g. Aarseth & Mangerud 1974; Holtedahl 1975; Andersen et al. 1995b) is wrong. If, on the other hand, the latter hypothesis can be shown to be true, then the hypothesis of Helle et al. (1997, 2000) is wrong – which is indeed the conclusion of this discussion paper.

The Younger Dryas re-advance

The reconstruction of a (or possibly two) major Younger Dryas re-advance(s) in this part of western Norway is to a large extent based on many radiocarbon dates of mollusc fragments incorporated into till, or molluscs in sediments overrun by glaciers (Figs. 1 and 2) (Holtedahl 1967, 1975; Mangerud 1970, 1977, 1980; Follestad 1972; Aarseth & Mangerud 1974; Andersen et al. 1995b). The dates yielded Allerød–Younger Dryas ages, showing that the re-advance took place during the Younger Dryas. Before the re-advance, the ice front had retreated at least as far east as the innermost dated site; i.e. in Hardangerfjorden at least inside Ølve (Fig. 1). The youngest dates yielded ages close to 10,000 ^{14}C years BP, indicating that the re-advance culminated close to the end of the Younger Dryas.

The Younger Dryas re-advance is best dated north of Hardangerfjorden, between Fensfjorden and Bjørnefjorden (Figs 1 and 2), where it terminated at the Herdla Moraine. However, from Os the Herdla Moraine is mapped continuously across the fjord to Vinnes, and further into the domain of the Hardangerfjorden glacier in the inner part of Bjørnefjorden (Fig. 1) (Aarseth & Mangerud 1974), as discussed below. This implies that Hardangerfjorden was glaciated when the ice front re-advanced to the Herdla Moraine (see reconstruction in Hamborg & Mangerud 1981). However, because Helle et al. (1997, 2000) avoid that discussion with the statement (Helle et al. 1997, p. 115): '... we propose that an open, ice-free corridor from the coast to the head of the Hardangerfjorden existed during Younger Dryas time', I will mainly restrict the discussion to observations along Hardangerfjorden.

The mapping and the correlation of the Younger Dryas (Herdla–Halsnøy) moraines are strongly supported by the consistent tilted shoreline levels along the moraine (Aarseth & Mangerud 1974; Anundsen 1985) and the distinct drop in level proximal to the moraine (Aa & Mangerud 1981; Hamborg 1983).

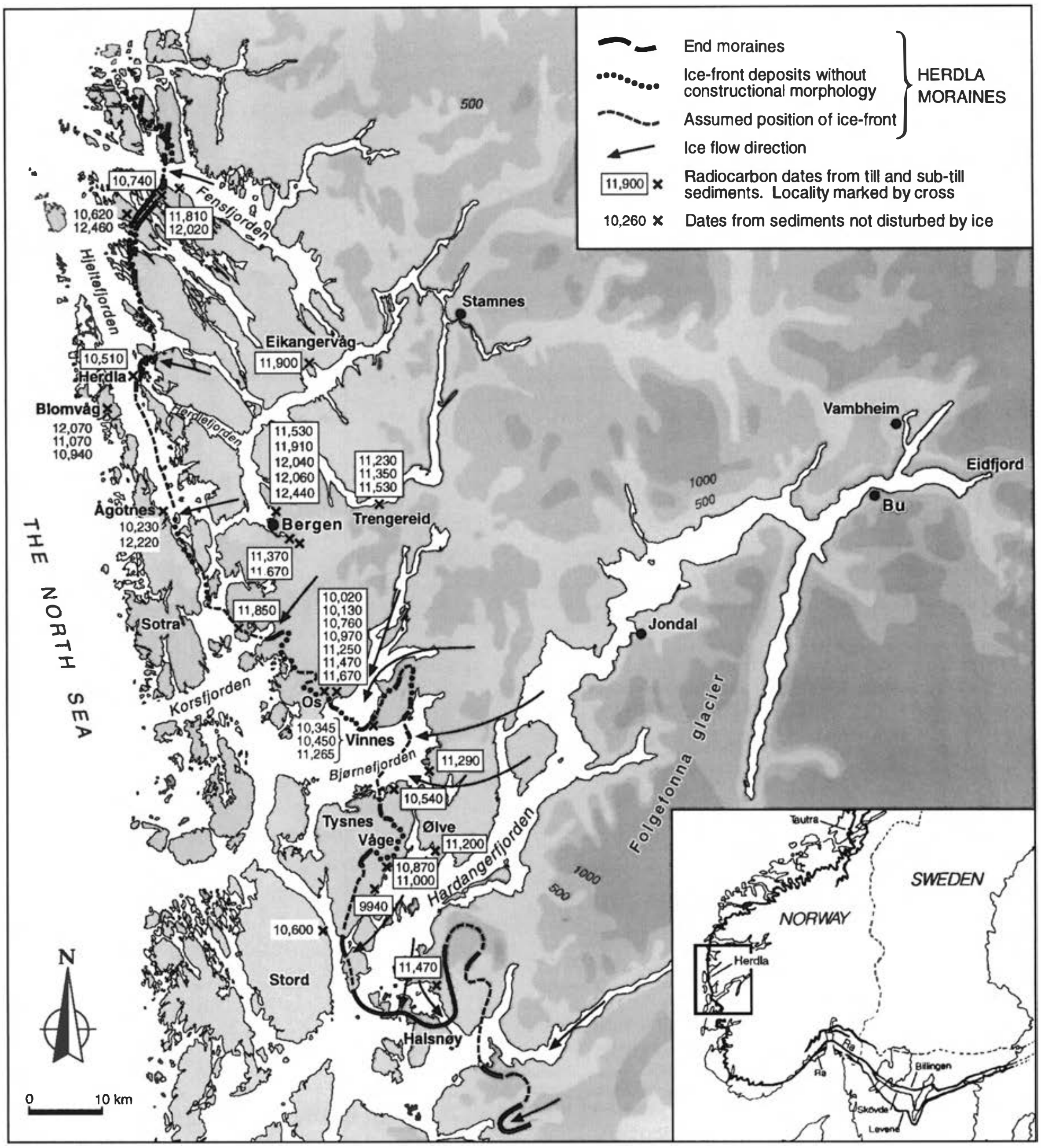

Fig. 1. Map of the Younger Dryas Halsnøy–Herdla moraines. Moraines around nunataks are omitted. Based on Anundsen (1972); Follestad (1972); Holtedahl (1975), Aarseth & Mangerud (1974); Aarseth et al. (1997) and Andersen et al. (1995b). The shaded altitude areas (500 and 1000 m) are approximate. Inset map shows the Younger Dryas moraines in southern Scandinavia, from Andersen et al. (1995a).

A new site

A small outcrop was exposed along the main road south of Vaage on Tysnes (UTM 135 537) (Fig. 1) the summer of 1999. At the base, the bedrock was polished by SW-oriented (240°) glacial striae, reflecting ice flow along the fjord. A 1.5 m thick diamicton, which, based on its strong compaction, is interpreted as a basal till, rests directly on the striated bedrock. The lower part of the till is bluish and contains shell fragments. Some could be identified as *Mya truncata, Hiatella arctica* and *Balanus* sp. Two shell fragments were dated (Table 1) yielding the ages $11{,}000 \pm 40$ and $10{,}870 \pm 90$, when corrected for a reservoir age of 440 years, which is the value used for all previously published dates referred to in this paper (Mangerud & Gulliksen 1975). A more precise value for the reservoir age is not yet available for the transition Allerød/Younger Dryas (Bondevik et al. 1999); for the later part of Younger Dryas 700–800 years is a more realistic value (Haflidason et al. 2000). The simple conclusion from these observations is that a major glacier filled Hardangerfjorden and advanced beyond Vaage after about 10,900 BP, i.e. during the Younger Dryas.

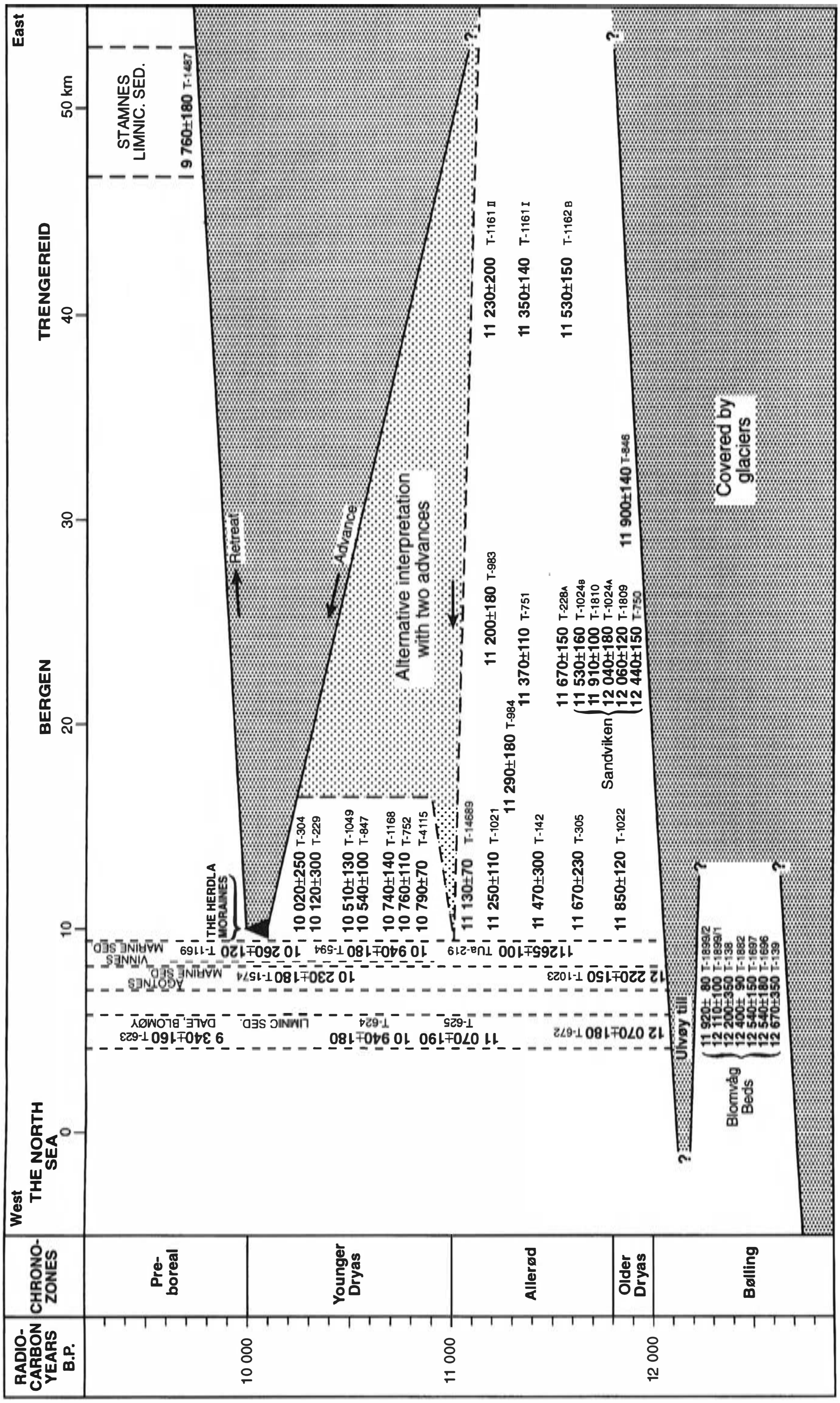

Fig. 2. Time-distance diagram of ice-front variations between Fensfjorden and Bjørnefjorden. From Andersen et al. (1997), with correction of a date and an additional date 11,130 ± 70 close to the Herdla moraine in Os. Included here is an alternative interpretation with two Younger Dryas advances that is considered less probable.

Table 1. AMS radiocarbon dates of single pieces of the mollusc *Mya truncata* from the shell-bearing till near Våge, Tysnes. The 'corrected age' is corrected for a marine reservoir age of 440 years (Mangerud & Gulliksen 1975).

Sample no.	Lab. ID	^{13}C	Conv. ^{14}C age	Corrected age
JM1999-2	Beta-131219	+2.2	11,440 ± 40	11,000 ± 40
JM1999-3	Beta-131220	+1.7	11,310 ± 90	10,870 ± 90

Earlier published sites

Molluscs from sites with shell-bearing tills along Hardangerfjorden have previously yielded Allerød–Younger Dryas ages (Fig. 1) (Holtedahl 1967, 1975; Follestad 1972; Aarseth & Mangerud 1974; Aarseth et al. 1997). These dates, in combination with the pattern of glacial striae, were used to reconstruct a re-advance of the Younger Dryas ice sheet across the dated sites to the Herdla–Halsnøy moraines (Hamborg & Mangerud 1981; Andersen et al. 1995b; Aarseth et al. 1997). However, Helle et al. (1997, p. 115) argued against this interpretation: 'The ice-overrun marine sediments of Allerød and Younger Dryas age from the outer Hardangerfjorden (Aarseth & Mangerud 1974; Holtedahl 1975) could have been influenced by a late Younger Dryas re-advance of ice located on coastal mountains possibly separated from the main Younger Dryas inland ice sheet'. However, neither in Helle et al. (1997, 2000) nor orally have they presented any new or previously published observations supporting their assumption. To my knowledge, no glacial features (e.g. glacial striae, local end moraines) indicate such local glaciers. Here, I discuss one area where the opposite can be demonstrated.

The peninsula between Hardangerfjorden and the head of Bjørnefjorden is hilly terrain, some 300–600 m a.s.l. The glacial striae show that the last ice flow was from Hardangerfjorden across the peninsula and into Bjørnefjorden (Fig. 1) (Aarseth & Mangerud 1974). This means that the Hardangerfjorden glacier must have had a surface altitude of at least some 600 m in this area in order to send an outlet glacier across to Bjørnefjorden (Hamborg & Mangerud 1981, Fig. 11). Within the area of this outlet glacier there are three sites where shell-bearing tills are dated. One site with extremely compacted sub-till silt along Hardangerfjorden yielded a date of 11,200 ± 180, and two at the head of Bjørnefjorden yielded dates of 11,290 ± 180 and 10,540 ± 100 (Fig. 1). If the shell-bearing tills are correctly interpreted, and to the best of my knowledge they have never been questioned, these observations represent unambiguous proof of a major glacial re-advance of a glacier entirely filling Hardangerfjorden. The re-advance must have post-dated the given dates, i.e. it is of Younger Dryas age.

This interpretation is supported by dates from the site at Vinnes on the shore of Bjørnefjorden (Fig. 1). Here there is a thick sequence of glacimarine silt deposited distally to an ice-front delta of the Herdla Moraine (Øvstedal & Aarseth 1975; Aarseth et al. 1997). AMS dates of *Portlandia arctica* from the ice-proximal silt yielded 10,450 ± 125 (Tua-74) and 10,345 ± 125 (Tua-75) when corrected for a reservoir age of 440 years. If corrected for a more realistic marine reservoir age for the Younger Dryas of 700–800 years (Haflidason et al. 2000), the cited dates would be very close to 10,000 ^{14}C years BP. The conclusion is that the Herdla Moraine at Vinnes dates from the very end of the Younger Dryas.

Sindre (1980) described shell-bearing diamictons that he interpreted as tills on the SE part of Stord, about 10 km distal to the Halsnøy moraine (Fig. 1). He concluded that the glacier briefly advanced to Stord, before it halted at Halsnøy. However, these diamictons were much less compacted (E. Sindre, oral communication 1975) than the very compacted shell-bearing tills studied by Mangerud (1970) and Aarseth & Mangerud (1974). I. Aarseth and J. Mangerud (oral communications 1975 and 2000) therefore considered that the diamictons on Stord were probably glacimarine sediments, possibly disturbed by icebergs. Whether the snout of the glacier reached Stord or not cannot be decided without new sections. For the theme discussed in this paper the solution is not important, except that Sindre's interpretation, if correct, would support the conclusions in the present paper. Conservatively, I have not plotted Sindres dates on Fig. 1.

Discussion of the evidence for Hardangerfjorden remaining ice-free

The evidences presented above demonstrate that Hardangerfjorden was glaciated during the Younger Dryas. Subsequently, the glacier calved and melted back very rapidly during the early Preboreal, so the head of the fjord (Eidfjord, Fig. 1) was ice-free about 9700 ^{14}C years BP. According to my interpretation, the moraines, terraces, etc., found along the fjord inside the Halsnøy moraine are therefore of Preboreal age. The implication is that also the low-lying local moraine described by Bakke et al. (2000) in Jondal (Fig. 1) was formed after the front of the fjord glacier withdrew inside that area. It is likely that the fast calving in the fjord left ice masses on the land areas that could be re-activated, or that form the nucleus for short-lived glacial advances.

Certainly the ice front could have started to withdraw from the Halsenøy moraine before the very end of the Younger Dryas, even though the moraine is of late Younger Dryas age. However, Helle et al. (1997) and Bakke et al. (2000) postulated that the fjord remained ice-free during the Younger Dryas, so this alternative does not solve the conflict. Also, the shoreline diagram of Hamborg (1983) indicates that Jondal became ice-free some 200–300 years after the ice front withdrew from Halsnøy, well after the fast Preboreal isostatic uplift had commenced.

Here I discuss the chronological arguments that Helle et al. (1997) present for an ice-free Hardangerfjorden during the Younger Dryas. These authors have studied three paleo-lake basins; Bu, Vambheim-119 and Vambheim-128

(Fig. 1), from which they present three datasets to argue for a Younger Dryas age of the sediments; radiocarbon dates, pollen diagrams and the Vedde Ash. They also use an interpreted transgression to argue for an Allerød–Younger Dryas age of the sediments.

Helle et al. (1997) obtained four radiocarbon dates from Bu. They emphasize a bulk gyttja date of 10,065 ± 125 BP and use it to argue for a Younger Dryas age of the underlying sediments. However, the age is on the ^{14}C plateau, and with the given standard deviation could be well into the Preboreal. Some 10 cm deeper they obtained an AMS date on plant fragments yielding 9550 ± 110 BP, which they rejected, and some few centimeters higher another bulk gyttja date yielding 9665 ± 125 BP. The fourth, and deepest, sample yielded the obviously erroneous date of 7595 ± 80 BP. In my opinion the three earlier dates indicate an Early Preboreal age, and certainly cannot be used as an argument for a Younger Dryas age. From Vambheim they have three dates from the same stratigraphical level in different cores, yielding 10,935 ± 135, 8400 ± 95 and 8300 ± 100. They rejected all three, a decision with which I agree. From Vambheim-128 they have two dates, the oldest yielding 8485 ± 120 BP. The conclusion is that not a single radiocarbon date indicates a Younger Dryas or Allerød age of the sediments at the three studied sites.

Pollen diagrams from Bu and Vambheim-119 are also presented. As emphasized by Helle et al., the pollen sums are extremely low, less than 50 grains per spectrum for most of the parts they interpret as Younger Dryas. For that reason the diagrams are not diagnostic for stratigraphic dating. However, most features in the diagrams are in my opinion more compatible with a Preboreal than a Younger Dryas age of the sediments. *Artemisia* is for example almost missing (at Bu totally missing), and many spectra have more than 50% *Betula.*

Lastly, Helle et al. use identified shards of the Vedde Ash (Mangerud et al. 1984) as an argument for a Younger Dryas age. However, the numbers are extremely low, maximum 30 shards per cm^3. I informed them before they published their paper that consideration had to be given to the fact that the Vedde Ash was spread out across the inland ice. During deglaciation the ash would be washed into glacilacustrine and glacimarine sediments. Such redeposition of the Vedde Ash stored in glacial ice is documented from a basin inside the Younger Dryas glacier further north in western Norway (Sønstegaard et al. 1999). These authors also propose a similar interpretation of the Vedde Ash particles described by Helle et al. (1997), an interpretation I support.

Helle et al. (1997) postulated a major marine transgression around the head of the fjord based on the occurrence of freshwater diatoms in sediments below marine diatom-bearing deposits in two of the basins. They correlated that transgression with the known Younger Dryas transgression along the outer coast (Anundsen 1978, 1985; Krzywinski et al. 1984). A transgression is certainly one possible interpretation of their data. However, it is far from a unique interpretation, and is therefore not an argument for the age. When arguing for a transgression Helle et al. (1997, Fig. 11) compared the diatom flora at their sites with the flora at sites along the open oceanic coast (Sotra). However, their sites are situated in a very different environment, at the head of a long narrow fjord. During the deglaciation, and even today, one should expect that freshwater diatoms were brought into the fjord with (meltwater) rivers and deposited in marine and glacimarine sediments. At Bu such an interpretation is even supported by the fact that the freshwater diatoms occur in sand beds. The water depths at their sites could never have exceeded 15 m. Their sites therefore record only the surface water layer. Jiang et al. (1998) found 60–88% freshwater diatoms in a sediment sequence covering several hundred years during the Younger Dryas in the much more open embayment of the Kattegat, between Sweden and Denmark. They interpreted the freshwater diatoms as a result of meltwater influx. A similar interpretation would be a simpler explanation for the freshwater diatoms found by Helle et al. (1997). During the Preboreal deglaciation there was certainly periodically a fresh surface water layer near the head of the narrow fjord due to meltwater input.

Helle et al. (1997, 2000) conclude that the Hardangerfjorden remained ice-free during the entire Younger Dryas, and that the Eidfjord moraines at the head of Hardangerfjorden represent the Younger Dryas moraines. These moraines constitute part of a moraine system mapped well inside the Herdla–Halsnøy moraines (Andersen 1980; Anundsen 1985, with further references). Based on radiocarbon dates their ages have been considered to be in the range 9500–9800 ^{14}C years BP. The implication of the reconstruction of Helle et al. (1997, 2000) is therefore that the Younger Dryas moraines are erroneously mapped and correlated along a considerable part of western Norway, well outside the Hardangerfjorden area.

Conclusions

1. The geographical distribution of radiocarbon-dated shell-bearing tills, related to the pattern of ice-flow directions, demonstrates that there has been a major Younger Dryas re-advance of the Scandinavian Ice Sheet in Hardangerfjorden and Fensfjorden and across the area between these fjords. This conclusion is supported by the shoreline pattern.

2. All observations given by Helle et al. (1997) as arguments supporting an ice-free Hardangerfjorden during the younger Dryas are compatible with a Preboreal age of the sediments; some of the observations positively indicate a Preboreal age, and none represents a strong argument for a Younger Dryas age. I consider their hypothesis to be erroneous.

Acknowledgements. – The work is a contribution to the Strategic University Program, 'Rapid sedimentation and high resolution stratigraphy: processes and application', funded by the Research Council of Norway. A slightly earlier version of this manuscript was given to all authors of papers discussed in this article, and also to other scientists who have worked in the area, requesting possible comments. I appreciate comments from Inge Aarseth, Jostein Bakke, Stein Bondevik, Svein Olaf Dahl, Stein Kjetil Helle, Hans Holtedahl, Øystein Lohne, Atle Nesje, Eivind Sindre and John Inge Svendsen. Michael R. Talbot corrected the English language. Eva Bjørseth drew the map. The journal's reviewers, Svante Björk, Harald Sveian and Eivind Sønstegaard, provided aditional useful comments. I thank them all for their help.

Manuscript received March 2000

References

Aa, A. R. & Mangerud, J. 1981: Glasialgeologi og vegetasjonsinnvandring i Indre Nordhordaland, Vest-Norge. *Norges Geologiske Undersøkelse 369,* 33–75.

Aarseth, I., Austbø, P. K. & Risnes, H. 1997: Seismic stratigraphy of Younger Dryas ice-marginal deposits in western Norwegian fjords. *Norsk Geologisk Tidsskrift 77,* 65–85.

Aarseth, I. & Mangerud, J. 1974: Younger Dryas end moraines between Hardangerfjorden and Sognefjorden, Western Norway. *Boreas 3,* 3–22.

Andersen, B. G. 1980: The deglaciation of Norway after 10,000 B.P. *Boreas 9,* 211–216.

Andersen, B. G., Lundquist, J. & Saarnisto, M. 1995a: The Younger Dryas margin of the Scandinavian Ice Sheet – an introduction. *Quaternary International 28,* 145–146.

Andersen, B. G., Mangerud, J., Sørensen, R., Reite, A., Sveian, H., Thoresen, M. & Bergstrøm, B. 1995b: Younger Dryas ice-marginal deposits in Norway. *Quaternary International 28,* 147–169.

Anundsen, K. 1972: Glacial chronology in parts of southwestern Norway. *Norges Geologiske Undersøkelse 280,* 1–24.

Anundsen, K. 1978: Marine transgression in Younger Dryas in Norway. *Boreas 7,* 49–60.

Anundsen, K. 1985: Changes in shore-level and ice-front position in Late Weichsel and Holocene, southern Norway. *Norsk Geografisk Tidsskrift 39,* 205–225.

Bakke, J., Dahl, S. O. & Nesje, A. 2000: Reconstruction of Younger Dryas and Holocene glacier fluctuations and paleoclimate at Folgefonna, southwestern Norway. *Geonytt, 1, 2000,* 36.

Bondevik, S., Birks, H. H., Gulliksen, S. & Mangerud, J. 1999: Late Weichselian marine ^{14}C reservoir ages at the western coast of Norway. *Quaternary Research 52,* 104–114.

Follestad, A. B. 1972: The deglaciation of the south-western part of the Folgefonn peninsula. *Norges Geologiske Undersøkelse 280,* 31–64.

Haflidason, H., Eiriksson, J. & Van Kreveld, S. 2000: The tephrochronology of Iceland and the North Atlantic region during the Middle and Late Quaternary: a review. *Journal of Quaternary Science 15,* 3–22.

Hamborg, M. 1983: Strandlinjer og isavsmeltning i midtre Hardanger, Vest-Norge. *Norges Geologiske Undersøkelse 387,* 39–70.

Hamborg, M. & Mangerud, J. 1981: En rekonstruksjon av isbevegelser under siste istid i Samnanger og Kvam, Hordaland, Vest-Norge. *Norges Geologiske Undersøkelse 369,* 77–98.

Helle, S. K., Anundsen, K., Aasheim, S. & Haflidason, H. 1997: Indications of a Younger Dryas marine transgression in inner Hardanger, West Norway. *Norsk Geologisk Tidsskrift 77,* 101–117.

Helle, S. K., Rye, N. & Stabell, B. 2000: Shoreline displacement and fault activity in the Hardangerfjord, western Norway, after deglaciation. *Geonytt, 1, 2000,* 82.

Holtedahl, H. 1967: Notes on the formation of fjords and fjord-valleys. *Geografiska Annaler 49A,* 188–203.

Holtedahl, H. 1975: The geology of Hardangerfjord, West Norway. *Norges Geologiske Undersøkelse 323,* 1–87.

Jiang, H., Svensson, N.- O. & Björck, S. 1998: Meltwater discharge to the Skagerrak–Kattegat from the Baltic Ice Lake during the Younger Dryas interval. *Quaternary Research 49,* 264–270.

Krzywinski, K. & Stabell, B. 1984: Late Weichselian sea level changes at Sotra, Hordaland, western Norway. *Boreas 13,* 159–202.

Mangerud, J. 1970: Late Weichselian vegetation and ice-front oscillations in the Bergen district, western Norway. *Norsk Geografisk Tidsskrift 24,* 121–148.

Mangerud, J. 1977: Late Weichselian marine sediments containing shells, foraminifera, and pollen, at Ågotnes, western Norway. *Norsk Geologisk Tidsskrift 57,* 23–54.

Mangerud, J. 1980: Ice-front variations of different parts of the Scandinavian Ice Sheet, 13,000–10,000 years BP. *In* Lowe, J. J., Gray, J. M. & Robinson, J. E. (eds.): *Studies in the Late-Glacial of North-West Europe,* pp. 23–30. Pergamon Press, Oxford.

Mangerud, J. & Gulliksen, S. 1975: Apparent radiocarbon ages of recent marine shells from Norway, Spitsbergen, and Arctic Canada. *Quaternary Research 5,* 263–273.

Mangerud, J., Lie, S. E., Furnes, H., Kristiansen, I. L. & Lømo, L. 1984: A Younger Dryas ash bed in Western Norway, and its possible correlations with tephra in cores from the Norwegian Sea and the North Atlantic. *Quaternary Research 21,* 85–104.

Øvstedal, D. O. & Aarseth, I. 1975: Bryophytes from Late Weichselian sediments at Vinnes, Western Norway. *Lindbergia 3,* 61–68.

Sindre, E. 1980: Late Weichselian ice-front oscillations in the Hardanger–Sunnhordland district, West Norway. *Continental Shelf Institute 102,* 1–16.

Sønstegaard, E., Aa, A. R. & Klagegg, O. 1999: Younger Dryas glaciation in the Ålfoten area, western Norway; evidence from lake sediments and margoinal moraines. *Norsk Geologisk Tidsskrift 79,* 33–45.